

# GAME PROGRAMMING FOR THE PROPELLER POWERED HYDRA

A Guide to Developing Games, Graphics, and Media Applications for the HYDRA Game System

*By ANDRE' LAMOTHE*



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### **Version 1.0, 2<sup>nd</sup> Printing**

### **ISBN 1-928982-40-9**

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### **Supported Hardware, Firmware and Software**

This manual is valid with the following hardware, software, and firmware versions:

HYDRA Board	Propeller Chip	Software	Firmware
Rev A	P8X32A-D40	Propeller IDE v1.0	P8X32A v1.0

## Dedication

I dedicate this book to Fox Mulder and Dana Scully. Without the X-Files to look forward to each night at 3:00 a.m. I would have surely gone insane!

## Acknowledgements

Writing a book is a tremendous amount of work for the author, but there is a small army of people that support him and do a lot of work behind the scenes, especially since this book is really part of a larger product, the "HYDRA Game Console Kit." I would like to thank the following people for their support and contribution to this project. First, Chip and Ken Gracey of Parallax for collaborating on a project of this scale. Hopefully, this is the first in a long series of collaborations.

Next, all the support staff at Parallax including Stephanie Lindsay who created the look and feel, edited and laid out the book, and Rich Allred who transcribed my artwork into final renderings for the book and read my cryptic writing! Also, thanks to Jen Jacobs for the artwork and packaging of the book and kit (and making it "edgy" enough). Next to Aristides Alvarez for managing the final manufacturing, assembly, and production of the HYDRA itself along with Mac Ma in China for manufacturing support. Additionally, Lauren Bares in marketing, Lynette Cepeda in purchasing, Jim Carey in sales, Jeff Martin in software engineering, and last, but not least Jim Ewald that made sure my email got through!

I would also like to thank all the vendors, companies, and friends that helped the HYDRA project and this book in one way or another (in no particular order); Iain Cliffe of Labcenter Electronics ([www.labcenter.co.uk](http://www.labcenter.co.uk)) for the use of Proteus to design the HYDRA, Sellam Ismail of Vintage Tech ([www.vintage.org](http://www.vintage.org)) for always getting me those hard to find retro items, Ari Feldman for the use of SpriteLib (<http://www.flyingyogi.com/fun/spritelib.html>). And Mike Perone of Barracuda Networks ([www.barracudanetworks.com](http://www.barracudanetworks.com)) for hosting and spam firewalls. To Steve Wozniak and Depech Mode, thanks for the concert! And David Perry of Shiny Entertainment and Game Consultants ([www.gameconsultants.com](http://www.gameconsultants.com)) for helping get the word out about the XGS and HYDRA. To Steve Russell for writing the foreword, I really appreciate it.

The next group of people I would like to thank are the demo coders that created many of the cutting edge demos for the HYDRA (found in Chapter 25). The demo coders are: Rémi Veilleux, Colin Phillips, Robert Woodring, Jay T. Cook, Nick Sabalausky, Rainer Blessing, Matthew Kanwisher and Michael Thompson. Also, special thanks to Lorenzo Phillips ([www.ldp-solutions.com](http://www.ldp-solutions.com)) that managed the software development and asset organization as well as Terry Smith for webmastering ([www.ternaryworks.net](http://www.ternaryworks.net)).

Finally, to my mom, dad, and beautiful girlfriend Ines – they all put up with me once again through my 7 day a week, 100+ hour schedule from hell.

## **Author Bio**

André LaMothe holds degrees in Mathematics, Computer Science and Electrical Engineering. He has been programming since 1977 when he started writing games on the TRS-80 at the local Radio Shack. He has worked in many fields of Computer Science and engineering. Highlights include the head of Graphics R&D at Software Publishing Corporation by 19, a NASA Artificial Intelligence research associate at 20, and the creator of one of the first super computer, networked Virtual Reality games at 24. He is the founder of Xtreme Games LLC, the Xtreme Games Developers Conference, as well as Nurve Networks LLC. Additionally, Mr. LaMothe is a best-selling author with numerous titles on game development, graphics, and DirectX programming. He is a native Californian and lives in sunny Silicon Valley. You can reach him at [ceo@nurve.net](mailto:ceo@nurve.net).

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## Foreword by Steve Russel

Over 45 years ago, a new PDP-1 computer arrived near my office with a display system that could do more than anything I had seen before. There was just one demonstration program, but it didn't use all the power of the display.

I thought that I could make a better demonstration program, and after discussion with my friends, I started writing code. That program developed into "Spacewar!" – one of the first computer games to use a display and the distant ancestor of Atari Asteroids. I learned that playing computer games was fun, but writing them was even more fun!

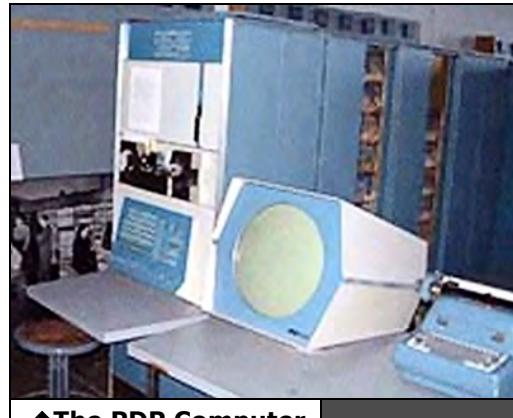
One of the great things about writing a game is finding solutions to the puzzle of trying to get the most fun into the game while getting it to work well. Unlike most computer programming assignments, with a game you can adjust the problem to fit the available solution.

The development of SpaceWar! was a collaboration, for example Dan Edwards looked at my version of Spacewar! and decided it needed a sun and gravity to better show the problems of getting a spaceship into orbit. Even after he developed a run-time code generator that wrote

a custom program to drive the display at its maximum speed, there still was only time to compute the gravity effect on 2 spaceships!

We left the torpedoes untouched by gravity, and decided that they were "photon torpedoes" that were unaffected by gravity since they are pure energy (a game developer's prerogative). The game still played fast enough, and the spaceship orbits added a great deal to the fun.

At one point, I decided that the torpedoes would be more "realistic" if they had a little random error, just like real torpedoes. I added this but everyone else complained loudly, so I took it out in the next version.



▲The PDP Computer  
and Display

Figure F:1



▲Screen Shot of  
SpaceWar!

Figure F:2

## Front Matter

A few years later I had a different, much better display system arrive. I was able to write a very primitive flight simulator for it, but the pace was so slow that it was no fun. I learned that just having 3 dimensions doesn't necessarily make a game better.

You have much better hardware, software and examples to start with, so I hope you will learn how much fun game programming is with less pain and more fun than I did nearly half a century ago!

It turned out that I never got a new version of Spacewar! working well until some time between midnight and 6 AM.

**Steve Russell**

Co-creator of SpaceWar!  
San Jose, California  
July 2006

## Chapter 0: Introduction and a Little History about Game Development

Welcome to ***Game Programming for the Propeller Powered HYDRA***. This is a no-holds-barred development manual about creating basic games and graphics applications on the Propeller powered HYDRA game console. As you might know, game development is the most complex field of computer science in the world and takes years to master. A video game is unlike any other program you can write for a computer; games must be fast, fun, graphically intensive, real-time, support multiple players, run on minimal hardware, and perform complex and/or seemingly impossible mathematical calculations at a rate fast enough to update the screen at 30-60 frames per second or more!

Additionally, games pull from advanced research in artificial intelligence, optimization theory, multiprocessing, compiler design, memory management, data structures, physics modeling, networking, compression, search algorithms, and much more. And if that wasn't enough, there are all the graphic, audio, and artistic media assets needed for a game. Some games literally are built upon tens to hundreds of terabytes of data and take hundreds of man-years to develop! Thus, video games are the ultimate fusion of science and art, together creating a real-time experience that billions of people have enjoyed since the late 50's.



▲**Halo II** Running  
on the XBOX

Figure 0:1

Today games such as Halo II shown in Figure 0:1 amaze and delight millions. With the new next-generation systems available such as the XBOX 360 and the Playstation III (shown in Figure 0:2) the future is almost frightening to think of what will come next. The sheer computational power of these systems is staggering – each system is capable of an excess of 1.5 trillion floating-point operations per second! Both with multiple computational elements, especially the PS3 which contains the most advanced processor in the world – the "**Cell**" processor, a multibillion-dollar joint venture among Sony, IBM, and Toshiba.



▲The XBOX 360 (left) and Playstation III (right)

Figure 0:2

Everyone knows that game development is serious business. With a gross revenue in excess of \$30B, the game industry is larger than the movie industry, so getting into game development is one of the most desired job positions now and in the future for many engineers, programmers, and artists. Never has there been more freedom technically and artistically than there is today for game development. For fun, let's take a stroll down memory lane of some of the highlights in the game development and computer industry. This list is by no means complete. In fact, I highly recommend that you read some good books on the history of the video game industry and the computer industry, it's fascinating stuff.

 **TIP**

I highly recommend the following texts if you're interested in learning more about the foundations of the video game and computer industries and the amazing personality and technical challenges therein:

- *Hackers: Heroes of the Computer Revolution* by Steven Levy
- *The Ultimate History of Video Games* by Steven Kent
- *Supercade: A Visual History of the Video Game Age* by Van Burnham
- *Masters of DOOM: How Two Guys Created an Empire and Transformed Pop Culture* by David Kushner
- *Opening the XBOX: Inside Microsoft's Plan to Unleash an Entertainment Revolution*

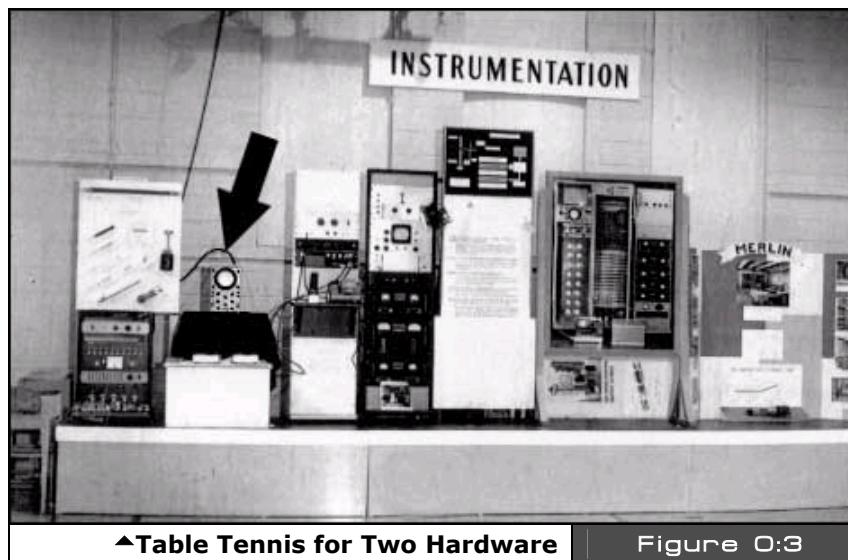
Finally, watch the DVDs *Pirates of Silicon Valley* and *Nerds 1.0*, both fascinating introspections into the genius and innovation the early years of computing generated.

## 0.1 A Brief History of Games 1958 - 1993

Ironically, game development is a very complex field. Most would think games are toys and simple, but many game developers have been programming 10-25+ years and are experts in numerous fields of computer science; moreover, the field is extremely competitive and changes on a day-to-day basis. Nonetheless, developing games and graphics applications are some of the most rewarding things to do with a computer; there is nothing like playing your own games, or watching others have fun with what you have made! As an artist it's the ultimate form of what I call "liquid art." Additionally, learning to develop games makes you a much better programmer; you will no longer be limited by memory, processor speeds, or the need for high-level languages; a game developer can literally make impossible things happen with a computer.

### 0.1.1 Table Tennis for Two (1958)

History is replete with examples that literally changed the world. With that in mind let's take a look at few key events in the development of the video game industry.



Let's begin by setting the record straight. Many people think that **Nolan Bushnell** created the first video game with "**PONG**," then others think that technically it was **Ralph Baer** with the "**Brown Box**" and the Magnavox **Odyssey** game console, still others think it's "**Space War!**" developed by **Stephen "Slug" Russell**, but they are all wrong – in fact, it

## Introduction and a Little History

was a physicist – **William Higinbotham** in 1958 at the Brookhaven National Laboratory developed a game called "**Table Tennis for Two**" for an open house to show their new analog computer. Figure 0:3 shows a picture of the hardware that "Table Tennis for Two" ran on with an arrow pointing to the output device. Also, check out the link below to see the game in action (Real Player format):

<http://real.bnl.gov/ramgen/bnl/PONG.rm>

The game was developed completely in hardware by means of an analog computer. The lab wanted to show off something interesting other than weapons design research, so Willy took the manual that came with the analog computer and read about examples of drawing trajectories and curves on the oscilloscope. He took this information, and with the addition of some hardware he and a colleague cobbled together the VERY first video game in history.

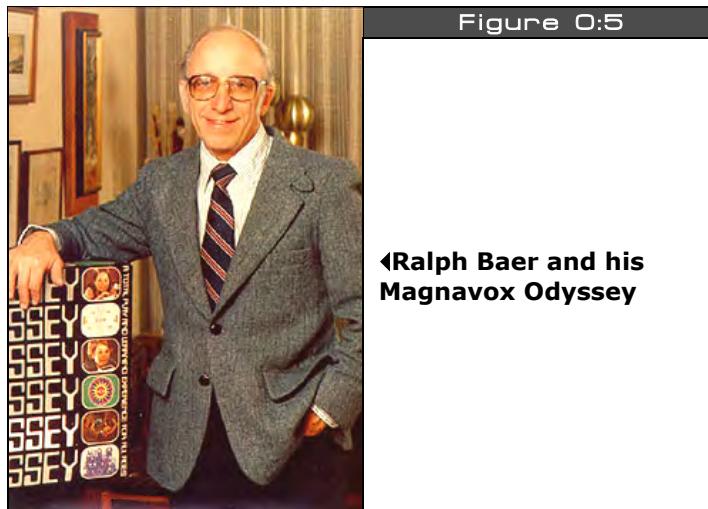
### 0.1.2 Space War! (1962)

Next up was the creation of "**Space War!**" by Stephen "Slug" Russell at MIT. Other major contributors include Peter Samson, Martin Graetz, Wayne Witanen, Alan Kotok and Dan Edwards. The game was written on a DEC PDP-1 in pure assembly language in 1962. Steve "Slug" was nick-named "Slug" since like all software engineers, he took forever to finish anything! Figure 0.4 shows a screen shot of the original Space War! hardware, quite a difference from your laptop. You can actually play a remake of Space War! by following this URL:

<http://lcs.www.media.mit.edu/groups/el/projects/spacewar/>



### 0.1.3 Ralph Baer, the Brown Box, and the Maganvox Odyessy (1966)



Ralph H. Baer was a TV engineer who had an interest in interactive TV. He was the first person to ever have the notion of moving objects around on a TV screen, and quite frankly his associates and boss at Sander and Associates told him to forget about it and focus on making better TV sets. Nonetheless, Ralph kept working away on his "**Brown Box**" and in 1968 had a working prototype of a hard-wired game system capable of moving simple dots around on the screen.

Figure 0:5 shows Ralph and the Magnavox **Odyssey** system. The rendering ability (if you can call it that) of the Odyssey was non-existent, so in a brilliant stroke of "engineering ingenuity" Ralph thought "Why not add transparent backgrounds as overlays on the TV set itself?" So, that's what they did; the games that ran on the Odyssey all were nothing more than dots moving around, but when you put a nice background on the TV set screen itself of a tennis court, baseball diamond, or haunted house, it was like nothing anyone had seen. The Odyssey sold about 100-150,000 units depending on where you get your information. Interestingly though, it came out in 1972 officially, which was the same time that Atari PONG came out.

### 0.1.4      Atari PONG (1972)

Next, the most important commercial game was "**PONG**" developed by **Nolan Bushnell** and **Al Alcorn** of newly formed **Atari** in 1972. This game was responsible for putting games on the map and was the genesis of the entire video game industry as we know it. It all happened at Andy Capp's Tavern in Sunnyvale, CA. Nolan Bushnell, with his newly founded company Atari, decided to test a prototype of new game that his new engineer Al Alcorn developed called PONG in local neighborhood Andy Capp's Tavern as an experiment.



Figure 0:6 shows one of the hand-made early prototypes. To their surprise, one week after the game was deployed there was a line around the corner to play, and the coin mech (a coffee can) was jammed since the machine was completely full of quarters! This moment in time launched the \$30B video game industry, and Atari, one of the icons of American business and innovation, was created.

Atari was the fastest growing company in history at the time! And Bushnell, when he sold the company for \$24M+ and change, was the "rock star" of Silicon Valley. Atari PONG more or less put the Odyssey out of business when Atari came out with a home version of PONG – remember it? The Atari version of PONG and the system it ran on (PONG on a chip) was light-years ahead of the Odyssey. The reason why is that the Odyssey technology was really early 60's technology and it took Ralph Baer such a long time to get the suits to listen, by the time they did, Nolan Bushnell was able to create the 2nd generation of games with PONG and capture the consumer market. But, we should acknowledge that technically the first game console was the brain-child of Ralph Baer, thus the designation of "**Father of the Video Games**" goes to Nolan Bushnell, while the "**Grandfather of Video Games**" goes to Ralph Baer! Interestingly, the first big patent infringement goes to Nolan Bushnell and PONG: Magnavox, on their knees, financially sued Atari as a last-ditch effort saying that PONG was a copy of games on the Odyssey. Atari did settle, but patenting dots running around on the screen – you've got to be kidding!

### 0.1.5 The Apple Computer (1977)

The personal computer industry was also a result of video games. **Steve Jobs** (co-founder of Apple) worked at Atari, and he and **Steve "The WOZ" Wozniak** were both interested in developing their own computer and game system to play games on and hack. Steve Jobs actually worked at Atari – Nolan Bushnell requested him to create a prototype of a new game called "**Breakout**" and Jobs accepted the challenge, enlisting electronics guru Steve Wozniak to do the design.

Together after a 4 day straight engineering/programming tribute to sleep deprivation, the result was a completed game in a ridiculously low number of chips with NO microprocessor! In fact, the design was so clever, so optimized, that Atari engineers couldn't understand it! However, the knowledge that Steve Wozniak learned and experimented with over those 4 days helped him develop both the Apple I and II computers, and the beginning of the personal computer era began in 1977.

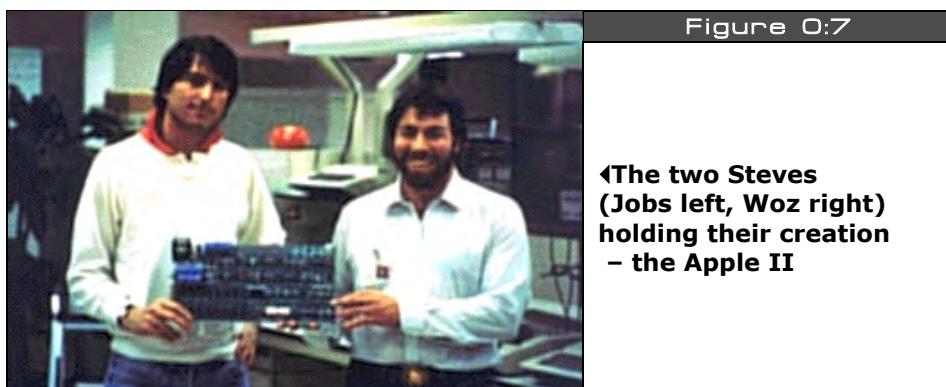
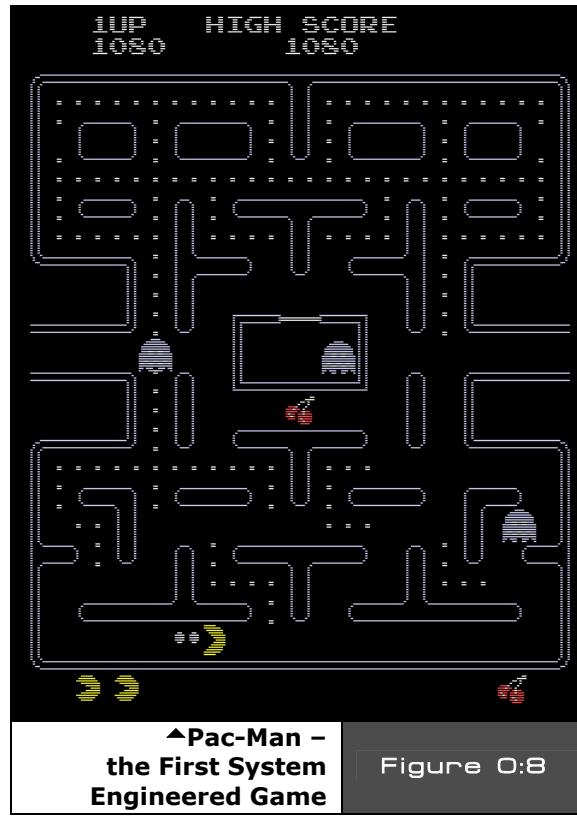


Figure 0:7 shows the two Steves working on the original Apple I personal computer; this was of course followed by the Apple II which made Apple computer the fastest growing company in American history and the largest IPO (initial public offering) in history – I still am mad at my dad for not believing me in the late 70's when I told him to buy Apple stock!

### 0.1.6 Pac-Man (1980)

So, now we have the creation of the video game industry and the personal computer industry, the 80's are upon us, and things are getting serious and competitive. With the USA taking the lead position in the industry, the Japanese weren't far behind with their own blockbuster game and their contribution to changing the world of games. **Toru Iwatani**, a 24 year old programmer, was in Tokyo and decided to sit down with some friends and have some pizza at the American franchise Shakey's Pizza. While ordering pizza, someone took a single piece of the cheese pizza and that image of a yellow circle with a piece removed was the inspiration for "Pac-Man," quite arguably one of the most successful games in history. Toru and his colleagues worked for 18 months on the game with a team of hardware and software engineers to develop Pac-Man. It was the largest game ever developed and the largest team ever to develop a game, but it paid off.



Pac-Man as shown in Figure 0:8 was an instant hit in America and all over the world where the machines were sent. The characters of Pac-Man also become overnight stars and everything from sequels to cartoons to breakfast cereals had a Pac-Man logo on it. The age of engineered games and product marketing was born. People realized this was serious business, and there were billions to be made...



INFO

Pac-Man was originally called "PUC-MAN", but when shipped to America, kids used to erase part of the "P" and the resulting name was less than desired by Namco. Thus, they change it to "Pac-Man" so at worst the game would read "Fac-Man"!

### 0.1.7 Wolfenstein 3D and the Era of First Person Shooters (1992)



Certainly, there are dozens of games worth mentioning that were eventful in the industry, but we don't have time to really cover them in the depth that they deserve. Games like Space Invaders, Asteroids, Computer Space, and more all made a difference in the early 60's, 70's and 80's, but it wasn't until the 90's that games got scary – enter ***id Software*** the creators of ***Wolfenstein 3D*** as shown in Figure 0:9. Another Cinderella story, **John Carmack** and **John Romero** both were Apple II fanatics, both loners, and both interested in making games and world domination. John Romero, a little older than Carmack, had been bouncing around

working at various places on game projects; at some point he met up with John Carmack and the results were similar to Bill Gates and Paul Allen getting together. John and John literally changed the world with their games. Soon after their initial meeting they were working at a company called ***Softdisk Publishing***, and to make a long and interesting story short, they were making a game a month for Softdisk to place on a floppy with a magazine! This is a feat to say the least, but during this time they got really good at making games, and did what most game programmers take years to do in months. Thus they honed their skills to a white-hot blaze ready to cut the fabric of space-time.

Ready to take on the world and report to no one, they started id Software. Their first game of note was "***Commander Keen***" (1990), a side scrolling tour de force thought to be impossible to achieve on the IBM PC, but they were just warming up. Carmack, turning into the technical guru of the group, had been experimenting with "ray casting" technology, a simplified version of "ray tracing" used to create photo real imagery in CG movies. However, ray casting allows 3D rendering to be achieved at blazing speeds due to simplified geometrical assumptions and a lot of tricks. The results of this ray casting technology was "*Wolfenstein 3D*" released in 1992, a 3D remake of the popular Apple II game "*Castle Wolfenstein*", but *Wolfenstein 3D* was 3D, and immersed the users in a fluid world running at blistering speeds. Figure 0:9 shows a screen shot.

*Wolfenstein 3D* was not only a technical marvel and for the billionth time made all the doubters realize that game developers are sorcerers and capable of magic, but *Wolfenstein* was highly controversial – its depiction of Nazis', blood and gore got the whole world up in a roar, but it was the first real-time cinematic experience on a personal computer. And like it or not, the world wanted more...and more they got...

### 0.1.8 DOOM (late 1993)

DOOM shown in Figure 0:10 speaks for itself; there are few people that do not know what DOOM is or who haven't played it.



DOOM by far was the most impressive technical achievement on a PC the world had ever seen. Released in 1993, DOOM was based on a technology called "*Binary Space Partition*" or BSP trees, a technique discovered in the 60's to bisect space into half spaces for easier computation in a recursive algorithm.

Technical details aside, the results of the algorithm coupled with a game developer's clever programming was the most incredible experience ever on a PC: DOOM. Millions of people were stunned by the technology, and numerous industries including military, medical, and architectural, were affected. Not to mention the game spawned (no pun intended) the entire 3D accelerator market.



If you are interested in DOOM technology and how BSP trees work and how to implement them, you will be pleased to know that *The Black Art of 3D Game Programming* by yours truly is in electronic form included with the CD of this book. It came out in 1994/1995, and within it I showed the world how DOOM worked among other things.

## 0.2 Origins of the HYDRA

A few other hits have come out since including Quake, Half Life and of course Halo, but none with the impact of awe of these early games. The technology of game development is now being disseminated at an exponential rate; books, courses, and entire degrees in game development technology are now available. Alas, we won't be changing the world here, but I can't think of a more engaging way to have fun with the new Propeller chip than to make games on it! The Propeller chip has something near and dear to my heart and that's **multiprocessing**. I simply love multiprocessing; if I could I would multiprocess in my sleep – I would! Game developers for years, including myself, have had to fake multiprocessing and/or use pseudo-multiprocessing with Pentium or PowerPC chips via "**multiple execution units**" which isn't the same. The Propeller chip is a true multiprocessing processor and definitely a very interesting chip to develop games on. Therefore, I thought "What better application than a game console around it, and to make some games on to get people interested in the processor and of course interested in games!"

When I developed the HYDRA, I wanted to keep the system open, simple, and more or less just a Propeller chip without adding a lot of ancillary hardware, thus the HYDRA has no extra computing augmentation and is more or less completely powered for the most part by the Propeller chip itself. The HYDRA is a good example of what you can do with just a Propeller chip; if you were to add extra SRAM or other hardware then the Propeller can be used to create all kinds of embedded applications. Additionally, the HYDRA was developed to simply experiment with the Propeller chip; the HYDRA has an expansion port, mouse and keyboard ports, game ports, dual 3.3 V / 5.0 V supplies, VGA and NTSC/PAL out, networking (RJ-11 based) and much more – I had a lot of fun designing it, and hopefully you have a lot of fun learning the Propeller chip and game development with it!

## 0.3 What to Expect

There is so much to cover in game development, a complete treatise on the subject usually takes about 1000-2000 pages to even scratch the surface. Alas rather than go nuts like I usually do, I decided to take a more beginners' approach with this book since unlike my other game development books where I assume we are all programming on a PC with DirectX, this is not the case. In this case, we have new hardware, a new chip, a new language, and you might be learning game development for the first time, not to mention being only a beginning programmer as well. Thus, I decided rather than engaging the transwarp drive like I usually do, let's keep this at impulse speed for most of the time with a romp here and there to warp speed!

With that in mind, I assume that you are a programmer; this book will not teach you programming. However, I don't assume you have done any game or graphics programming, so that part we will explore together, but you should be familiar with one or more of the

following languages: BASIC, C/C++, JAVA, ASM, PASCAL, DELPHI, etc. I will discuss the language constructs of the Propeller chip's native language "Spin", but I will not teach programming concepts. Additionally, there is a large part of the book on the Propeller chip itself and a lot of Assembly language material; if you are new to Assembly language, I suggest you read a good book on 6502, or ARM, or even 8086 and write some programs to get the hang of the language. Specifics aside, I will always try my best to teach where possible, so those of you that get bored, simply skip past anything that is old news to you. Now, let's take a look at the three main sections that make up the book:

- ▶ **The HYDRA Hardware** - This is a fast and furious circuit description of the HYDRA Game Console's implementation around the Propeller chip. Not meant to be complete, it simply gives you a frame of reference as programmers, so you know what hardware does what along with some technical detail here and there. Each chapter tends to focus on a specific aspect of the HYDRA, thus some chapters are short; others are longer.
- ▶ **Propeller Chip Architecture and Programming** – This is the nitty-gritty of the Propeller chip and has examples of programming graphics, sound, joysticks, I/O, networking, and explains both the ASM and high-level language (Spin) supported by the Propeller chip as well as the technical description of the Propeller chip itself. This part of the book is hands-on and you will get to run a number of demos and see what they do. Also, we will focus on using Parallax general-purpose objects rather than high performance gaming code, so we can keep a black box approach.
- ▶ **Game Programming on the HYDRA** – This is the fun part. Once we have all the fundamentals down and you know what the HYDRA does and how the Propeller chip works and is programmed, then we can sit down and start learning about game development and graphics.

### 0.4 Target Audience

Typically game development is all about software; however, if you have purchased a HYDRA then you probably are interested in embedded systems, hardware, and may even be a full-fledged Electrical Engineer. On the other hand, you might be a programmer that is interested in getting into embedded systems, and what better way than with games? Trying to cater to everyone is nearly impossible, so this book is going to be more of a software guide rather than a hardware guide in as much as we are going to spend 90% of our time programming, rather than doing circuit analysis. That is, when I show a circuit to you, I am going to assume that you understand electronics, rather than explain the nitty-gritty. If you don't know anything about electronics, the explanation will be more than enough for programming purposes. So this book is about writing games, graphics, and media applications on the HYDRA and learning the Propeller chip, it's not about designing game consoles or the hardware therein. Considering that, we are still going to cover every single

piece of hardware in the HYDRA in the first part of this book before getting into software. This way, even software guys will have some idea of what does what, and hardware guys will have a good reference for each sub-system to know what's doing what, or can make changes if they wish.

## 0.5 Conventions Used in this Book

The book's text is more or less straightforward: what you see is what you get. Typically, I will highlight important terms in the text the first time I introduce them, secondly, code listings will always be set off in a fixed point font and in a slightly smaller font pitch than the general text so more code can fit per page. Also, from time to time you will see special sidebars, like Notes, Warnings, etc. Lastly, when discussing key presses and menu item selection sequences I will always place angled brackets around the key or menu selection sequence, for example, if I wanted to tell you to press the control key and J at the same time, you will see "<CTRL + J>", similarly if I want you to go to the main menu, then select the sub-menu tools, then from there select configuration, I will write it something like this **<Main Menu → Tools → Configuration>**. And I may italicize the sequence and or highlight it to bring your attention to it and separate it from the text. Also, in the text, to set off code variables, I will simply italicize them. For example, if I wanted to talk about a "for loop", I would say something like, "referring to the *FOR* statement on line 10...", as you can see the "*FOR*" element is italicized.

## 0.6 Requirements

The main part of working with the HYDRA or the Propeller chip is using the Propeller Tool IDE. Currently, it only supports Windows XP, 2000, 2003. There are no Windows 95/98/ME tools or Linux. In the near future, I suspect there will be, so stayed tuned. But, most everyone with a PC has a copy of Windows XP/200X on it, so you should be fine. Other than that you should have at least one USB port free, and a standard multimedia type PC. Since the only thing you will use the PC for is compiling programs, you don't need a lot of horsepower, so a Pentium II or greater (or AMD equivalent) is more than enough.

Additionally, you will need a NTSC/PAL compatible TV to connect to the output of the HYDRA since it generates standard composite video. Also, if you want to experiment with the HYDRA's VGA output abilities you will need a VGA monitor or a simple KVM to switch your PC with the HYDRA. The HYDRA kit comes with everything else you need, so turn the page and let's start experimenting!



Last, but not least, skim entire book ***BEFORE*** doing anything! There are a few items that are embedded in the middle or end that will help you understand things, so best to read the whole thing first ***THEN*** go ahead and start playing with the hardware and programming.



## PART I:THE HYDRA HARDWARE

**Chapter 1: HYDRA System Overview and Quick Start, p. 27**

**Chapter 2: 5V & 3.3V Power Supplies, p. 77.**

**Chapter 3: Reset Circuit, p. 81.**

**Chapter 4: USB-Serial Programming Port, p. 83.**

**Chapter 5: Debug Indicator Hardware, p. 91.**

**Chapter 6: Game Controller Hardware, p. 95.**

**Chapter 7: Composite NTSC / PAL Video Hardware, p. 103.**

**Chapter 8: VGA Hardware, p. 115.**

**Chapter 9: Audio Hardware, p. 125.**

**Chapter 10: Keyboard & Mouse Hardware, p. 141.**

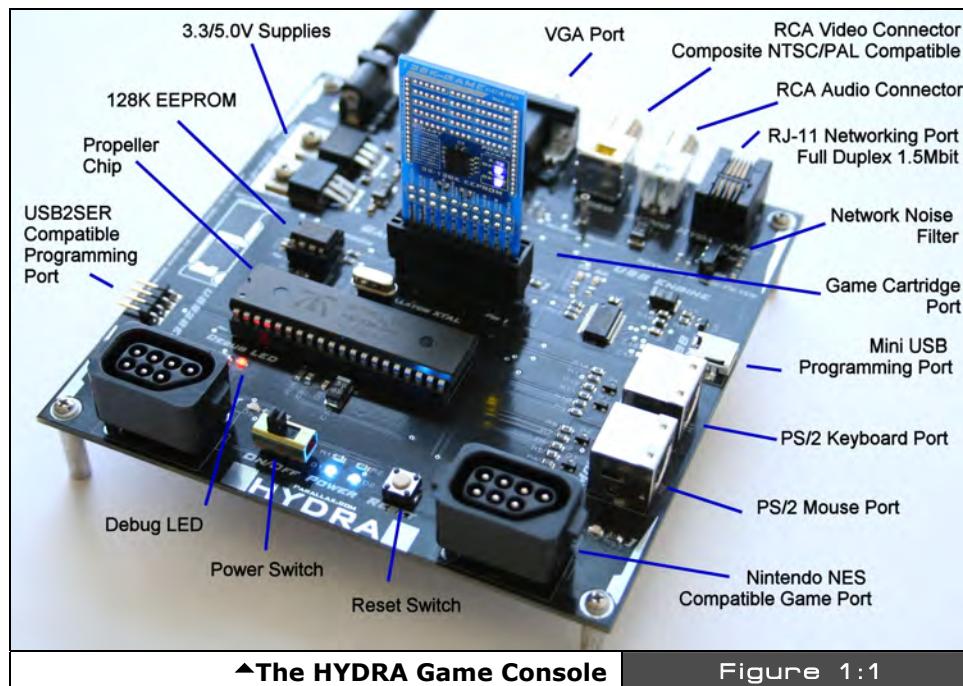
**Chapter 11: Game Cartridge, EEPROM & Expansion Port Hardware, p. 159.**

**Chapter 12: HYDRA-NET Network Interface Port, p. 167.**

## Chapter 1: HYDRA System Overview and Quick Start

In this chapter, we are going to get acquainted with the HYDRA game console and the Propeller Chip, as well as the Propeller Tool IDE itself. Of course, we are going to have some fun and try some games, load some programs, and in general get comfortable with the HYDRA system and everything that comes with it. Here's a general outline of what we are going to do:

- ▶ Take inventory of the HYDRA game console kit
- ▶ Experiment with the "Quick Start" demos
- ▶ Learn a little about the HYDRA and Propeller chip
- ▶ Install the USB drivers for the Propeller Tool
- ▶ Install the Propeller Tool and learn about the IDE

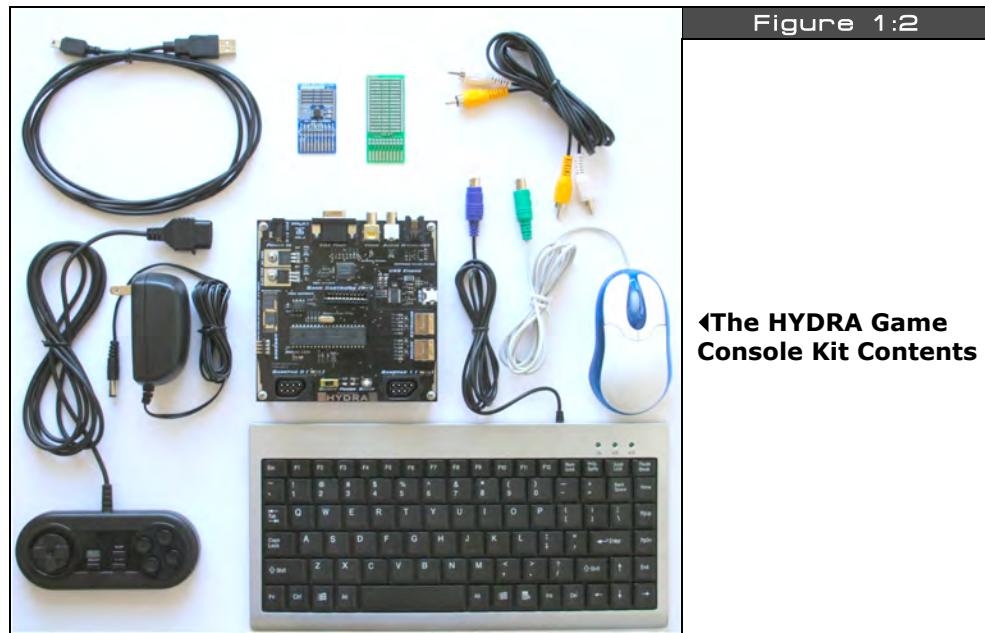


The **HYDRA Game Console** (HGC) is developed around the Parallax **Propeller chip**. Figure 1:1 shows an image of the HYDRA with all the various functional units labeled. The HYDRA has the following hardware:

- ▶ 40-Pin DIP Package of the Propeller chip, as DIP makes future upgrades and change outs easy; runs 80 MHz.
- ▶ RCA Video and Audio Out Ports.
- ▶ HD15 Standard VGA Out Port.
- ▶ PS/2 Mouse and Keyboard Support.
- ▶ Two Nintendo NES/Famicom compatible gamepad ports.
- ▶ RJ-11 (phone jack), Peer to Peer networking port, supports full-duplex serial at up to 2.56 Mb at 100 meters with simple coding.
- ▶ Single 9 VDC power in with regulated output of 5.0 V @ 500 mA and 3.3 V @ 500 mA on board to support external peripherals and components (Note: the Propeller chip is a 3.3 V device).
- ▶ Removable passive XTAL to support faster speeds and experimenting with various reference clocks.
- ▶ Debugging LED output.
- ▶ On-Board 128 KB Serial EEPROM used to hold program memory when power shuts down. The Propeller chip uses 32 KB currently only.
- ▶ Cartridge/Game/Expansion Port that exposes I/O, power, networking, USB, etc.
- ▶ Onboard Mini-B USB interface/programming port based on the FTDI USB chip.
- ▶ Backup external 4-Pin programming port compatible with Parallax "USB2SER" hardware/tools.

The HYDRA is more or less a minimal part count gaming platform to show off the capabilities of the Propeller chip. The hardware around the Propeller chip enhances functionality and interfacing, but doesn't add computational elements, thus all work performed by the HYDRA is solely the responsibility of the Propeller chip.

## 1.1 HYDRA Kit Package Contents



You should have the following items in your HYDRA kit, referring to Figure 1:2 (which shows most of the kit). So, take inventory and make sure you have everything you should have with the kit, and once you have confirmed everything and are ready to have some fun, read on.

- (1) HYDRA Game Console
- (1) PS/2 Mouse
- (1) PS/2 Keyboard
- (1) 128 KB Game Cartridge Pre-Loaded with “Ball Buster” demo game
- (1) Blank experiment card to build your own HYDRA projects on
- (1) Mini-USB programming cable to connect from your PC to the HYDRA
- (1) 9 V 500 mA, DC unregulated wall adapter with 2.1 mm plug and tip (+) positive, ring (-) negative
- (1) RCA A/V cable
- (1) Nintendo-compatible controller
- (1) CD ROM with all the software, demos, tools, and IDE

## 1.2 HYDRA "Quick Start" Demos

Your HYDRA is pre-loaded with a simple "**Asteroids**" clone demo programmed into the on-board serial EEPROM at **U4** (top left of the Propeller chip), a screen shot is shown in Figure 1:3. We will use this to test your system out.

The following are a series of steps to try the demo out and make sure your hardware is working and a stray high energy neutron didn't damage your EEPROM!

**Step 1:** Place your HYDRA on a flat surface, no carpet! Static electricity!

**Step 2:** Make sure the power switch at the front is in the **OFF** position, this is to the **RIGHT**.

**Step 3:** Plug your wall adapter in and plug the 2.1 mm power connector into the female port located at the top-left corner of the HYDRA.

**Step 4:** Make sure the XTAL marked 10 MHz is inserted into the XTAL port, top-center above the Propeller chip at J13. It's possible that during transport the XTAL came loose and isn't inserted all the way and/or is loose in the packaging, so make sure the XTAL is inserted.

**Step 5:** If you have plugged the cartridge into the system, then UNPLUG it – we want to run the code off the serial 128K EEPROM memory which is on-board (located top-left above the Propeller chip).

**Step 6:** Insert the A/V cable into the yellow (video) and white (audio) port of the HYDRA located top-right of the board, insert them into your NTSC/Multi-System TV's A/V port, and then switch your TV set to "Video Input" mode.

**Step 7:** Plug the mouse into the PS/2 mouse port (it's labeled "Mouse"), make sure to hold the port socket as you insert and be careful not to "force" the male into the female, ease it in and take your time. If it won't go in, try pulling it out and then putting it back in a couple times to loosen up the connection. You don't want to break the port off the PCB, as these boards can be cracked and some of the parts are a little tight in some cases.

**Step 8:** Turn the power ON by sliding the ON/OFF switch to the **RIGHT**.

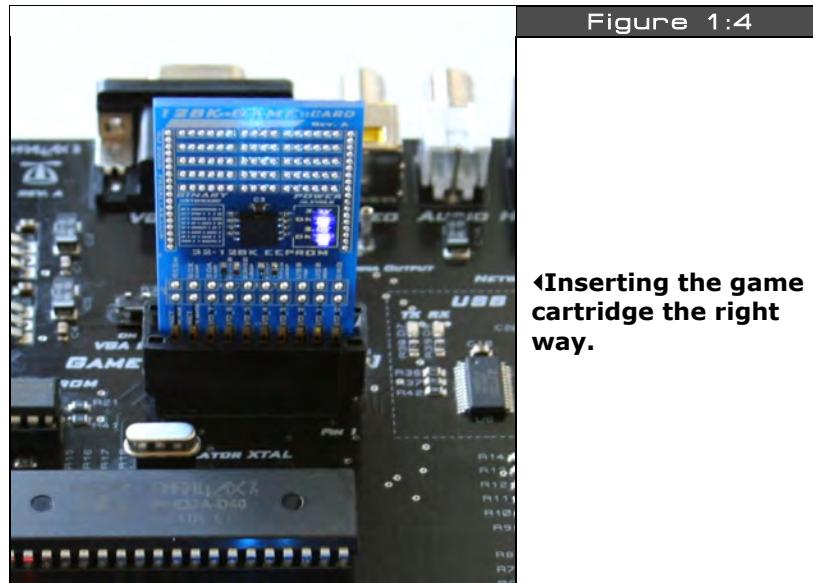
**Step 9:** You will see the logo/splash screen. Use the left mouse button to start the game and fire, right mouse button to thrust, left/right to rotate!



You should see something like that shown in Figure 1:3. The actual program that is loaded into the Propeller chip is located on your CD here:

**CD\_ROOT:\HYDRA\SOURCES\ASTEROIDS\_DEMO\_013.SPIN**

Next, let's have some fun, let's "hot-plug" another game in! Simply take your game cartridge and while the HYDRA is ON and running **Parallaxaroids**, plug the game cart into the system with its orientation such that the text and serial EEPROM chip are **facing you**. This is shown in Figure 1:4.



If all goes well, nothing will happen, but you will see the LED to the right of the cartridge port turn **ON**, and the power LEDs on the cartridge itself will illuminate; this indicates a cartridge is in the system.

Now, press the **RESET** button located next to the power switch and the HYDRA will re-boot from the **CARTRIDGE** rather than the on-board serial EEPROM (the cartridge always has priority). The cartridge basically overrides the onboard serial EEPROM and electrically disconnects it, so that the system feeds from the cartridge if it's inserted. Additionally, if you were to download a program to the HYDRA with the cartridge in, the cartridge would be programmed with the new program not the base board EEPROM. In any event, with the new cartridge in you should see a "Breakout/Arkanoid" like game running on screen named "Ball Buster". Now, plug in your mouse and/or gamepad (left port) and both input devices will move the paddle. The controls are listed in Table 1:1 on the next page.

Table 1:1			Ball Buster Demo Controls for Each Input Device▼	
Device	Action	Control		
Mouse	Launch Ball	Left Button		
	Move Left	Motion Left		
	Move Right	Motion Right		
Gamepad	Launch Ball	A/B		
	Rotate Left	Dpad Left		
	Rotate Right	Dpad Right		

Feel free to hot pull the cartridge out as well, just hit the **Reset** button again and the HYDRA will boot the Parallaxaroids game once again – cool huh! This concludes our little demo of a couple games, powering the unit, resetting the unit, and inserting a cartridge.

The actual top level file for the “Ball Buster” demo is located on the CD here:

**CD\_ROOT:\HYDRA\SOURCES\JTC\_B\_Buster\_005.spin**

### 1.3 The Propeller Chip

The **Propeller chip** comes in 40 pin **DIP** (dual inline package) or a 44 pin **LQFP** (low quad flat pack) as well as a 44-pin **QFN** (quad flat no lead) type package. Figure 1:6 shows the packaging and pinout of the chip. The Propeller chip was designed by **Chip Gracey** of Parallax Inc. as a low cost, high performance microcontroller with multiprocessing capabilities.

The Propeller chip has 8 cores and is, simply put, a symmetrical multiprocessing microcontroller supporting a "**round robin**" non-pre-emptive shared memory access scheme; however, all cores, called "**cogs**" run simultaneously and independently when not accessing main memory.

Figure 1:5 shows the Propeller chip architecture in block diagram form, and Table 1:2 lists the pins and their function for the Propeller chip.

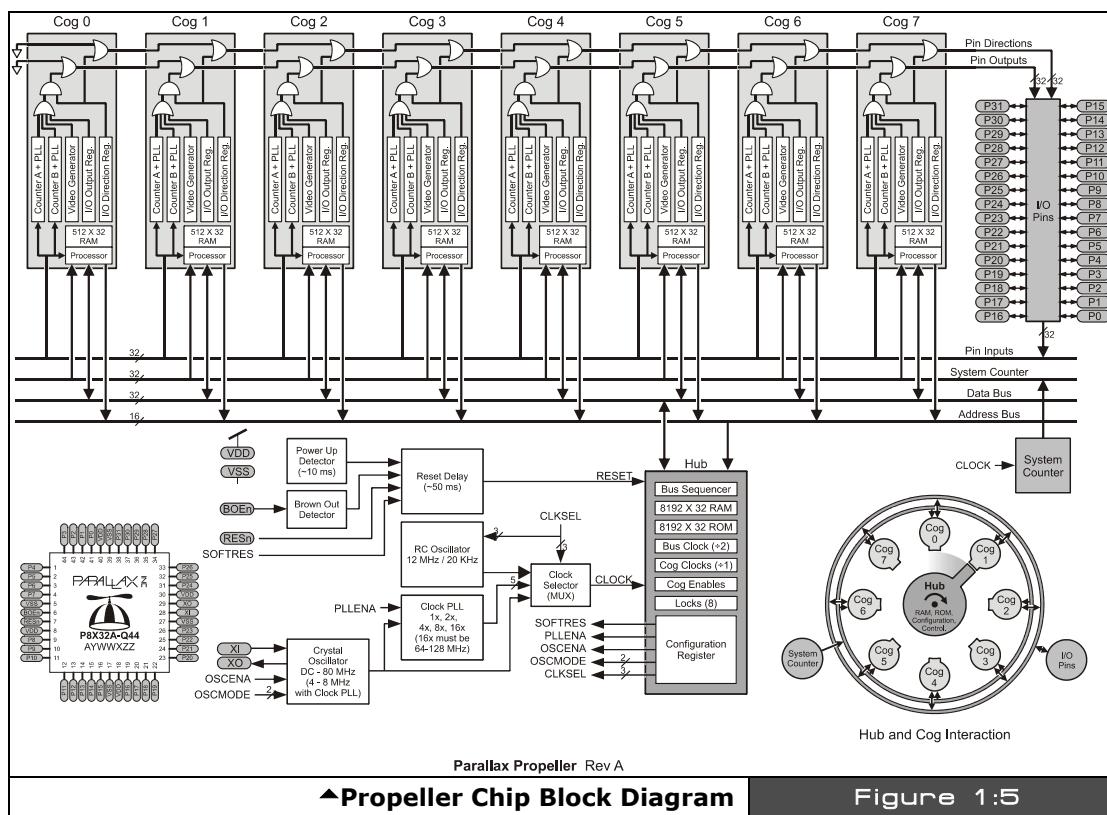


Image from Propeller Manual v1.0 courtesy of Parallax Inc.

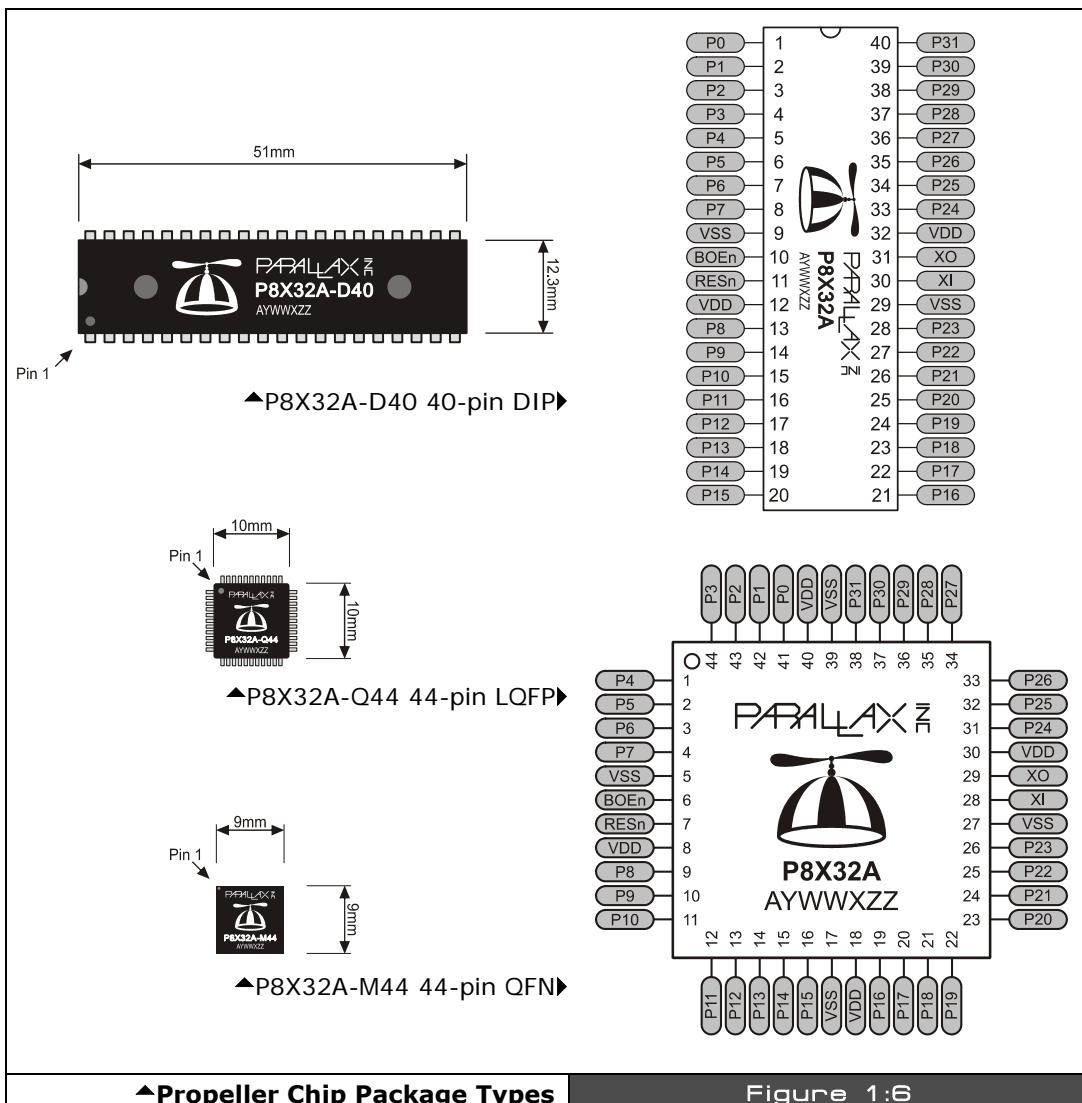
**▲Propeller Chip Package Types****Figure 1:6**

Image from Propeller Manual v1.0 courtesy of Parallax Inc.

<b>Table 1:2</b>			<b>Propeller Chip Pin Names and Functions▼</b>
<b>Pin Name</b>	<b>Direction</b>	<b>Description</b>	
P0 – P27	I/O	General purpose I/O. Can source/sink 30 mA each at 3.3 vdc. Do not exceed 100 mA source/sink total across any group of I/O pins at once.	
P28	I/O	$\text{I}^2\text{C}$ SCL connection to external EEPROM (General purpose I/O after boot up).	
P29	I/O	$\text{I}^2\text{C}$ SDA connection to external EEPROM (General purpose I/O after boot up).	
P30	O, I/O	Tx to host (General Purpose I/O after boot up/download).	
P31	I, I/O	Rx from host (General Purpose I/O after boot up/download sequence, if not connected to host).	
VDD	---	3.3 v power (2.7 – 3.3 vdc).	
VSS	---	Ground (0 vdc).	
BOEn	I	Brown Out Enable (active low). Must be connected to either VDD or VSS. If low, RESn becomes a weak output (delivering VDD through 5 KΩ) for monitoring purposes but can still be driven low to cause reset. If high, RESn is CMOS input with Schmitt Trigger.	
RESn	I/O	Reset (active low). When low, resets the Propeller chip: all cogs disabled and I/O pins floating. Propeller restarts 50 ms after RESn transitions from low to high.	
XI	I	Crystal Input. Can be connected to output of crystal/oscillator pack (with XO left disconnected), or to one leg of crystal (with XO connected to other leg of crystal or resonator) depending on CLK Register settings. No external resistors or capacitors are required.	
XO	O	Crystal Output. Provides feedback for an external crystal, or may be left disconnected depending on CLK Register settings. No external resistors or capacitors are required.	

The Propeller chip is a 32-bit RISC-like architecture (without pipelining) chip with a **fixed** instruction size of **32 bits**. The on chip memory is **64 Kbytes** and is organized as two **32 Kbyte** (8192 LONGs) banks as shown in Figure 1:7.

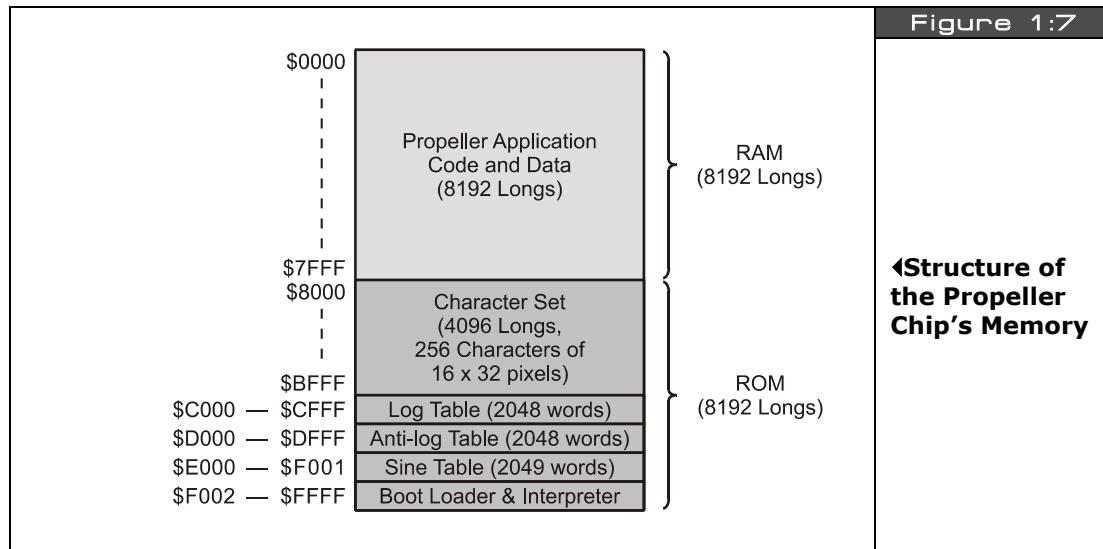


Image from Propeller Manual v1.0 courtesy of Parallax Inc.

Figure 1:7

#### Structure of the Propeller Chip's Memory

The first **32K** from **[0x0000 - 0x7FFF]** is **RAM**, the second **32K** from **[0x8000 - 0xFFFF]** is **ROM**. These memories are physically different, but logically addressed with a simple 0-64K address. The ROM contains the interpreter, data tables (sine, log, character data etc.) and other run-time objects needed for the Propeller chip's operation. The RAM is used for program memory, data, and video memory and is shared among all cogs. The Propeller chip doesn't differentiate between RAM and ROM, it is simply an address space from **[0x0000 - 0xFFFF]**. Additionally, there is no dedicated external memory interface integrated into the Propeller chip's architecture, therefore, memory is at a premium when programming, so care must be taken to conserve memory (especially when doing graphics since you must use a portion of the internal 32K for video buffers). The Propeller chip is programmed using either Assembly Language (which you will find reminiscent of a fusion of ARM/SX/PIC/6502 assembly code) or a high-level language called "**Spin.**"

A snippet of ASM is shown next:

```

' Plot pixel at px,py
plotd    mov px,dx      'set px,py to dx,dy
          mov py,dy

plotp    tjnz pwidth,#wplot   'if width > 0, do wide plot

          mov t1,px      'compute pixel mask
          shl t1,#1
          mov mask0,#%11
          shl mask0,t1
          shr t1,#5

          cmp t1,xlongs wc 'if x or y out of bounds, exit
if_c    cmp py,ylongs wc
if_nc   jmp #plotp_ret

          mov bits0,pcolor  'compute pixel bits
          and bits0,mask0

          shl t1,#1      'get address of pixel long
          add t1,basesptr
          mov t2,py
          rdword t1,t1
          shl t2,#2
          add t1,t2

          rdlong t2,t1     'write pixel
          andnt2,mask0
          or t2,bits0
          wrlong t2,t1
plotp_ret
plotd_ret  ret

```

The above ASM snippet is an excerpt from the graphics driver and is the plot pixel function. Additionally, the High-Level Interpreted Language (HLL) used to program the Propeller is called ***Spin*** (which is reminiscent of Pascal\BASIC), a snippet is shown below:

```

' move asteroids
gr.colorwidth(1,0)
repeat i from 0 to NUM_ASTEROIDS-1
  base := i*ASTEROIDS_DS_LONG_SIZE
  x := asteroids[base+ASTEROID_DS_X_INDEX] += asteroids[base+ASTEROID_DS_DX_INDEX]
  y := asteroids[base+ASTEROID_DS_Y_INDEX] += asteroids[base+ASTEROID_DS_DY_INDEX]

  ' test for screen boundaries
  if (x > SCREEN_WIDTH/2 )

```

```

asteroids[i*ASTEROIDS_DS_LONG_SIZE + ASTEROID_DS_X_INDEX] := - SCREEN_WIDTH/2
elseif (x < -SCREEN_WIDTH/2 )
  asteroids[i*ASTEROIDS_DS_LONG_SIZE + ASTEROID_DS_X_INDEX] := SCREEN_WIDTH/2

if (y > SCREEN_HEIGHT/2 )
  asteroids[i*ASTEROIDS_DS_LONG_SIZE + ASTEROID_DS_Y_INDEX] := - SCREEN_HEIGHT/2
elseif (y < -SCREEN_HEIGHT/2 )
  asteroids[i*ASTEROIDS_DS_LONG_SIZE + ASTEROID_DS_Y_INDEX] := SCREEN_HEIGHT/2

```

This snippet is from the “Parallaxaroids” demo game and shows a loop construct along with some assignments, array access, and conditional code, notice there is **no** begin/end construct, thus the loop block/nesting level is defined by **indentation**, this is definitely an area that can cause problems (so the Propeller Tool IDE has special align and display modes to help you with this), but keep it in mind that a single space can change the nesting level! When we discuss the Spin language we will cover this quirk in more detail.

The Propeller chip’s native Assembly Language is the best way to get performance and save memory; however, if you are not concerned with speed or need ultra high performance then the Spin HLL is the way to go. Now, a caveat – Spin HLL code must reside in main memory, while memory containing assembly code may be used for other purposes after the cog running that code has been launched. This extra memory consumption may become important when video buffers are used as well.

So for very large programs where speed is critical Assembly is a better choice, or you could write a FORTH or other HLL interpreter and run it then feed it from the EEPROM using a caching scheme. Of course, these limitations are consistent with most microcontrollers.



**NOTE**

There is currently no debugger built into the IDE. However, it's possible to access the USB TX/RX lines after boot etc. and a packet protocol to send back debug information like “printf’s” etc. could be developed on the PC side to send information. Additionally, a simple RS232 interface can be made that hooks to the PC as well with the same idea in mind. Therefore, the trick is to use Spin/ASM with a graphics driver and then send it debug information from your application through a shared memory and let it print on the screen or simply to print debug information on the screen for your graphic applications. So “old school” debugging is what has to be used here. For example, when we start developing applications and games, I will show you how to connect a VT100 terminal program and then send debugger information to it in real-time from the HYDRA.

### 1.3.1 System Startup and Reset Details

Although it's early in our discussion to get too technical, you might want to know what exactly happens with the HYDRA/Propeller chip is booted. On startup/reset the Propeller chip looks at the **TX (P31) / RX (P30)** lines connected from the PC host, these serial lines are interfaced via the USB connection and from the Propeller chip's point of view are standard

serial connections and from the PCs point of view are a standard serial port COMx (implemented as a VCP or “Virtual COM Port” in Windows-speak).

In any event, if there is activity on these lines, the Propeller chip will try to negotiate a link with the PC host using a very complex serial communication scheme that guarantees the PC is trying to talk and there isn't noise on the lines (a pattern-matching protocol is used). If the PC host is present then the Propeller chip will load the 32 Kbyte program image from the host and either copy it directly into RAM or the Propeller chip's firmware will copy the program into the EEPROM connected on lines P28 (Serial Clock SCK) and P29 (Serial Data SDA) respectively and then reset the chip which then pulls the program from the EEPROM and execute. Its important to realize that the **“binary image”** created on the PC by the Propeller compiler is 32 Kbytes and it is exactly copied into the RAM of the Propeller chip 1:1, this is a nice feature since you know that everything is always contained in this exact 32 Kbyte image no matter what the size is of the actual program/data (as long as its less than or equal to 32K), that is, if you have a small or large program the IDE will always create a 32 Kbyte image for the Propeller chip.

Once the program is download the Propeller chip launches Cog 0, runs the internal interpreter on it, and starts executing code at the very first PUB, that is, “public” Spin statement, more on this later.

## 1.4 Installing the Software

The Propeller Tool IDE used to develop all programs for the Propeller chip is shown in Figure 1:8 on the next page, it's a Delphi based application that you will use to develop applications for the Propeller chip/HYDRA. The Propeller tool only supports Windows XP, 2000, and 2003. It should work on Windows XP/64-bit versions as well. If you are a Windows 95/98 or NT user you will have to install one of these new variants of Windows over your old OS or as a dual boot setup if you want to use the Propeller IDE.

The Propeller Tool is the primary programming tool for the Propeller chip/HYDRA and allows editing and viewing of the various files and statistics as builds are performed. Propeller chip programs can be composed of both ASM and Spin code both with the extension **“.spin”** and are compiled and assembled into their final form by the tool as a **“binary”** image that is composed of a single **32 Kbyte image**. However, you can code completely in Spin if you wish, ASM is not necessary. But, you will find that 90% of all the drivers we have written for the HYDRA/Propeller chip use ASM. Moving on, the tool has a number of standard Windows IDE features, so the best thing to do is play with it as well as read the online Help.

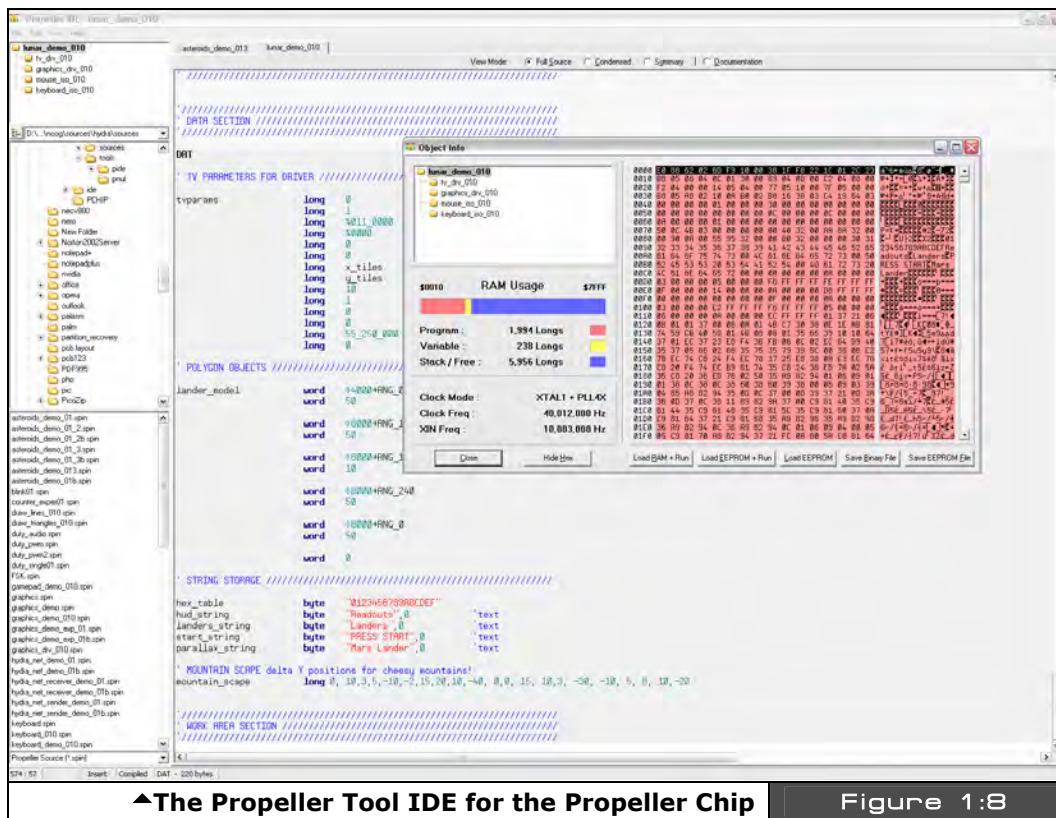


Figure 1:8

Also of note, there is a syntax highlighting technology that you may like or dislike, but it can be disabled and customized via the menu options. The idea of the syntax highlighting is to change the color of both the foreground and the background of your code to signify various code blocks.

As noted, with this tool you can write programs in both Spin and ASM; however, when doing so extra care must be taken when creating blocks or nesting levels since the HLL uses white space to define "blocks".

You can program the Propeller chip in a mixture of both HLL and Assembly, but *only* ASM or HLL can run on a core at a time. However, the interesting thing is that all your code for your final application is coalesced into a **SINGLE 32 Kbyte** binary image object that is loaded directly into the Propeller chip's RAM or onto an EEPROM for permanent storage when power goes down. In the next section, we will install the software tool itself and cover the use of

the Propeller IDE is some detail, so you know your way around the menus and functionality of the tool.

#### **1.4.1      Installing the Propeller Tool and all the Software**

Before we can do anything with the HYDRA we have to install all the sources for the HYDRA along with the Propeller Tool software. First, you need to have all the sources on your system, so step one is to simply copy the entire source tree from the CD to your PC. Insert the "**"HYDRA Software and Tools"** CD that came with your HYDRA into your CD ROM drive, there is no Autoplay, so use Explorer or My Computer to access your CD ROM and open up the CD drive. Inside you will find the following directory structure (more or less):

**CD\_ROOT:\**

```

└HYDRA\
  └SOURCES\
  └DESIGNS\
  └DRIVERS\
  └DEMOS\
  └TOOLS\
  └MEDIA\
  └DOCS\
  └EBOOKS\
  └GOODIES\
  └README.TXT

```

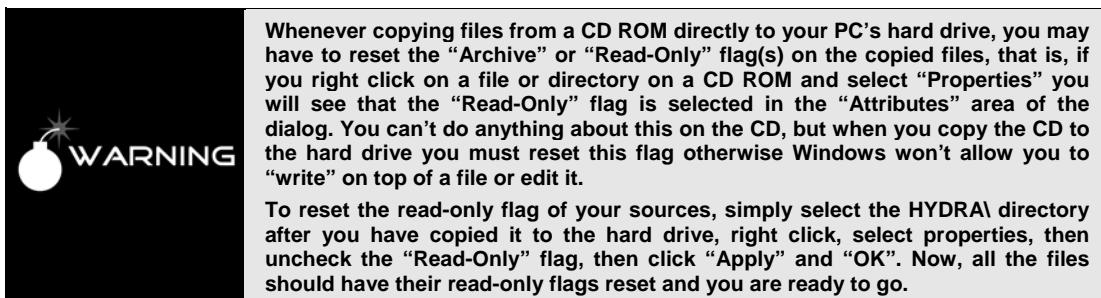
The contents of each of the directories is are follows:

- HYDRA\**      This is the main root directory of the entire CD, everything is within this directory, thus to copy the entire CD, simply right click on this directory, "copy" and then you can paste it anywhere you like on your hard drive, I suggest placing it at the root of C:\ so the paths are short to the files within.
- DESIGNS\**      This directory contains electronic design schematics.
- SOURCES\**      This directory is the source directory that contains the entire source for the book.
- DRIVERS\**      This directory contains any 3rd party drivers for the HYDRA and/or Propeller chip.
- DEMOS\**      This directory contains copies all the HYDRA demos as well as any other demos from the book. Some of this data is copied from the SOURCES\ directory, but is copied here to find more directly if you want to play with demos.

- MEDIA\** This directory contains stock media and assets you can use for your game and graphics development. All the media is royalty free and can be used for anything you wish, even in commercial applications. However, you can not license, sell, or otherwise transfer the files in the MEDIA\ directory as a product.
- DOCS\** This directory contains documents, tutorials, articles all relating the HYDRA, Propeller chip, and game development.
- EBOOKS\** In this directory you will find complete eBooks. Included specifically with the HYDRA is "***The Black Art of 3D Game Programming***" which can be used as a companion guide to this book for more advanced DOS game programming techniques and PC development that are similar to working with the HYDRA – a \$60 value!
- GOODIES\** This directory contains all kinds of cool little extras, so check it out and see what made it on the CD!
- README.TXT** This is the README.TXT file for the CD, please read it carefully it has many last minute changes, errata, and anything else you need to know.

### Copying the Files to your Hard Drive

The best way to "install" all the HYDRA book materials is to simply drag and drop the entire CD to your hard drive. There are a number of ways to do this: you can right click the HYDRA\ directory on the CD and select "Copy" then paste it into your hard drive at the desired location, or you can "drag" the HYDRA\ directory to the desired location on your hard drive and select "Copy Here." However you do it, I suggest that you copy the files somewhere "close" to the root of your hard drive, C:\, D:\, etc. so that if you do have to type in command line instructions or file names they will be short. I suggest dragging HYDRA\ right onto the root of your main drive, "C:\" for example, then you can work within the HYDRA\ directory directly.



### 1.4.2 Installing the FTDI USB Drivers

The first thing you need to do is make sure you have the latest copy of the FTDI drivers available on your PC. You can find the latest drivers for your particular Windows OS at:

<http://www.ftdichip.com/Drivers/VCP.htm>

The USB chip used on the HYDRA is the FT232RL model, so download the VCP (virtual COM port) drivers for this particular chip and save them to a location on your hard drive. To keep things organized, you might want to download the driver files into the CD\_ROOT:\HYDRA\DRIVERS\ directory on your hard drive and decompress them into directories within to keep things organized.

Additionally, you will find that I have already provided you with the latest drivers at the time this book was printed. They are located in the directory:

**CD\_ROOT:\HYDRA\DRIVERS\FTDI\**



Note that in general throughout the book, I will refer to file paths with the CD\_ROOT:\HYDRA\... notation, this simply means the HYDRA\ directory on your CD-ROM or hard drive, wherever it is, that's the one I want!

Within the **FTDI\** sub-directory you will find two more directories:

**WINDOWS\**  
**WINDOWS64\**

The **WINDOWS\** directory has the FTDI drivers for Windows XP, 2000, and 2003 while the **WINDOWS64\** directory has the drivers for the Windows XP 64-bit Edition (if you're lucky enough to have a computer this powerful). In any event, please read the release info.doc file as well as any readme files within these directories, it will save you headaches if something goes awry.

Now, here's the tricky part. Depending on your PC, your OS, and your luck, you may or may not have to do anything to install the drivers. In the best case, Windows will install the hardware for you and you won't have to do a thing, in the worst case you may have to install the drivers, two times over in some cases. So, let's hope for the best. The basic plan is that we will power up the HYDRA, then insert the USB cable from the PC into the mini-B port on the HYDRA (right side, top, above the PS/2 ports), when we do this Windows will detect the hardware and "hopefully" have drivers for it already, if not, Windows will ask to install the drivers and the usual dialogs will come up. Here are the steps to install the drivers, of course, your particular PC/Windows setup might display varying dialogs, but this should give you a good idea of what to expect.

### FTDI Driver Installation Steps

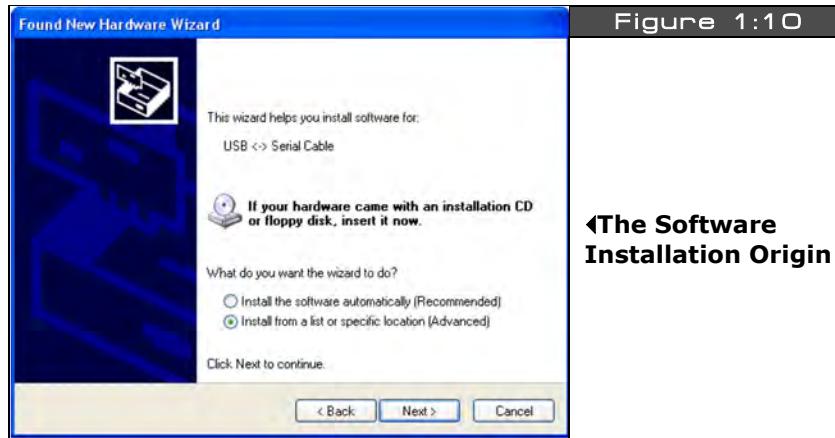
**Step 1:** I suggest shutting down all programs, performing a restart on your PC to make sure that any pending software updates are complete and any lost resources or crashed programs are reset, this way we have a fresh PC to work with.

**Step 2:** Power up the HYDRA and insert the black USB cable that came with the HYDRA kit into a free USB port on your PC, then insert the other end of the USB cable into the mini-B port on the HYDRA. The PC should detect the USB connection. If it doesn't make sure the HYDRA is powered, if you still have problems chances are you have a bad or unconnected USB port on your PC, move the cable to another USB port on the PC.

**Step 3:** In the system tray to the bottom right of the Windows desktop, you should see a "new hardware found" alert and Windows will either install the drivers automatically, or it will launch the Hardware Installation Wizards beginning with the "Found New Hardware Wizard" as shown in Figure 1:9, select the "No, not at this time" search option and click <Next>.



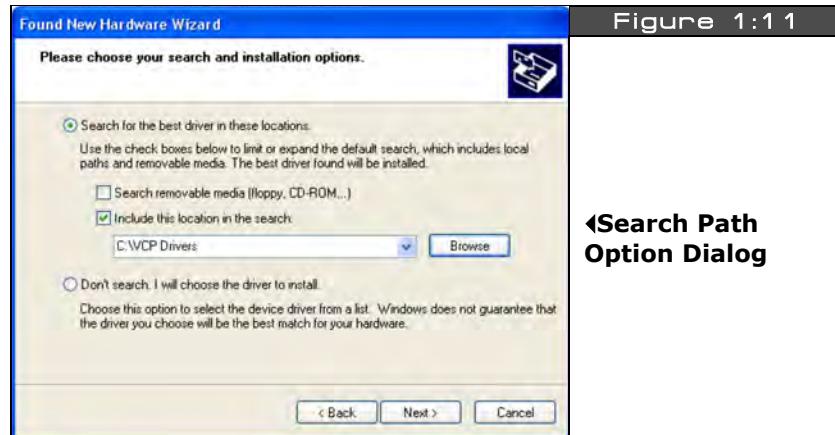
**Step 4:** The next wizard asks you if you want to install the software automatically or from a specific location. This is shown in Figure 1:10. Select the option "Install from a list of specific location (Advanced)" option and click <Next>.



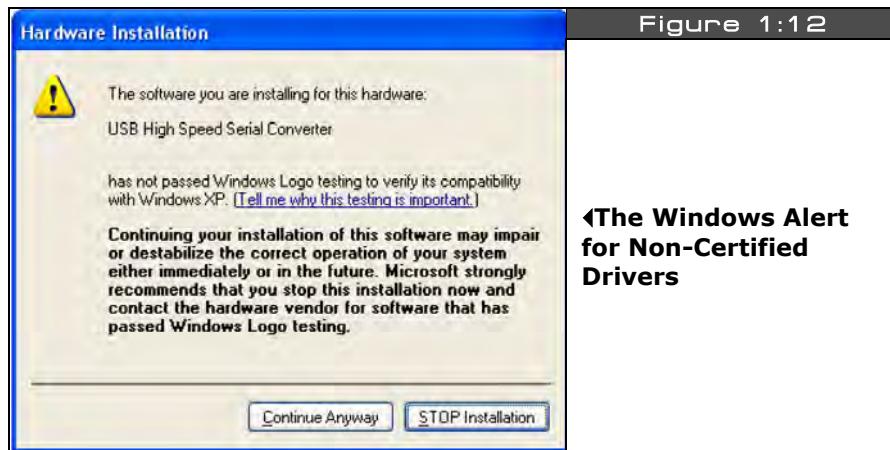
**Step 5:** The next dialog that comes up is the search path selection dialog as shown in Figure 1:11, select the top option “Search for the best driver in these locations.”, and only check the “Include this location in the search” checkbox, then navigate with the <Browse> button to find the location of the FTDI drivers as installed on your drive. They should be in this directory:

**CD\_ROOT:\HYDRA\DRIVERS\FTDI\WINDOWSxx**

...where “xx” denotes either the WINDOWS\ or WINDOWS64\ directory. Simply, select one of these directories (or the directory of the freshly downloaded drivers if you downloaded them from FTDI’s site) and hit <Next>.



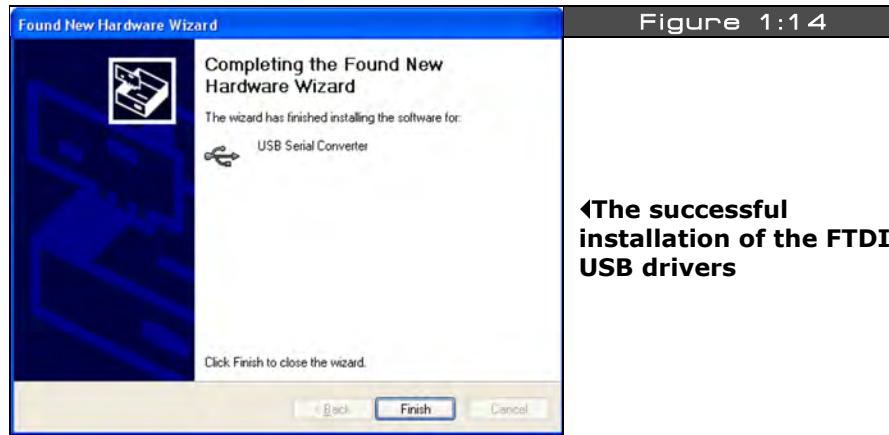
**Step 6:** The FTDI drivers may or may not have been Windows Logo certified yet, thus, if you see the alert box shown in Figure 1:12, simply click “Continue Anyway”. The FTDI drivers are under constant updates, so typically they are updated so frequently that they are never stable enough to Windows Logo test.



**Step 7:** If everything went right then you should see the file installation process start as shown in Figure 1:13, nothing to do here, but cross your fingers and follow the white rabbit.



**Step 8:** If everything installed properly, you will see the hardware installation completed dialog as shown in Figure 1:14, simple click <Finish> and you are done (hopefully).



**Step 9:** Give the PC a moment, you *may* see it discover yet more USB hardware, if you do then simply follow steps 1-8 again, and that should do it. When complete, give your PC a restart to make sure everything took and then you are ready to go!

#### 1.4.3 Installing the Propeller Tool IDE

The Propeller Tool installer/Setup program is named PROPELLER\_SETUP.EXE and is located on the CD-ROM within the directory:

**CD\_ROOT:\HYDRA\TOOLS\PROPELLER\PROPELLER\_SETUP.EXE**

Either navigate to the CD-ROM or your local copy on your hard drive and launch the installer.

When you launch the installer, you should see an installation splash logo and welcome screen something like that shown in Figure 1:15. Simply click <Next> and continue. During the installation, you will be prompted where to install the Propeller Tool, I suggest you install it near the root of your drive preferably where you copied all the source files from the book.

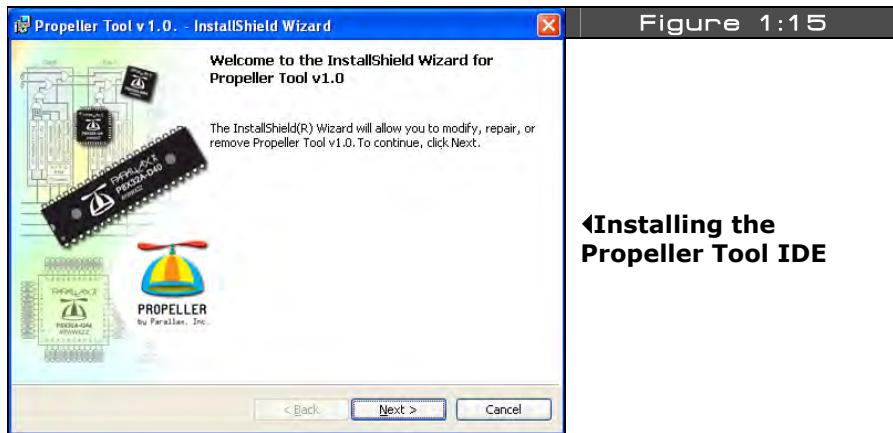


Figure 1:15

#### ◀Installing the Propeller Tool IDE

Of course, you can always install it in the \Program Files directory, but many times your main C:\ drive gets so full of application files that performance slows down quite a bit, so I prefer to install applications on a drive other than my OS drive to optimize performance.

When the installer is complete you will be shown a standard finished alert, simply click <OK>, <Done> and exit.

#### 1.4.4 Testing the Propeller Tool IDE

Before we get into any discussions of the tool itself, let's confirm that everything is working. On the Windows desktop, you should see an icon to launch the Propeller Tool, as shown in Figure 1:16.

Double-click the icon and the Propeller Tool should launch. If you do not see an icon, then click <Start Menu → All Programs → Parallax Inc → Propeller Tool v1.0> to launch the program. When the program launches, if it gives any warnings or alerts just click <OK> or <Next> and ignore them. You should then see the main IDE interface shown in Figure 1:8 without any files open of course.



Figure 1:16

#### ◀The Propeller Tool Icon

## Loading a Program in the HYDRA

Now, for the fun part, let's try and load something into the HYDRA. Make sure the HYDRA is powered up and the USB cable is plugged into the HYDRA itself from your PC. Plug your game controller into the left port. And of course have your HYDRA's A/V cables plugged into your TV set and the input on your TV set to "Video Input." Also, you might want to take out the game cartridge if you have it plugged in, doesn't matter, but let's all stay on the same page.

Now, we are going to load a game into the HYDRA. Here's the steps:

**Step 1:** From the main menu go to <File → Open> and browse your hard drive or CD-ROM for the HYDRA sources, they are located in CD\_ROOT:\HYDRA\SOURCES\\*.\*.

**Step 2:** Locate the file **REM\_ALIENINVADER\_013.SPIN** and open it. The program should load into the editor and you will see the source. The game is composed of a number of objects.

**Step 3:** Press <F10> on the keyboard, this will compile all the files (you will see it happen), then the Propeller Tool will search through all the COM ports and see if it can find the HYDRA/Propeller chip connected to it, once it does it will start a RAM only download, that is the program will be programmed into the Propeller chip RAM, but not the EEPROM.



**Step 4:** If everything went well, the HYDRA will reboot, then you will see the game start running and something like that shown in Figure 1.12 will display on your TV set.

Try the game out for a moment, then hit the RESET button on the HYDRA, notice that Parallaxaroids reloads? This is because it's still on the onboard EEPROM. If you wanted to overwrite the EEPROM then you could have pressed <F11>.

Now that you have successfully installed the IDE and loaded a program and ran it, it's time to learn a little bit more about the Propeller Tool itself.

If you had trouble then look below for some trouble shooting tips based on messages from the IDE and what you see on the screen:

### Trouble Shooting Tips

**IDE Message - "Propeller Chip Not Found"** – This means either you have the power off on the HYDRA, the USB cable is not plugged in, or you didn't install the USB driver.

**No Video** – If the program downloaded fine, then make sure you have the video output and audio output from the HYDRA plugged into the correct ports on the TV's video input, also, make sure you have the TV set for external video input mode.

**No Audio** – Good! There is none, this demo is so big, we couldn't fit sound in!

## 1.5 Propeller Tool IDE Primer

In this section we are going to briefly discuss the Propeller IDE and its functionality. This is by no means a complete treatise on the Propeller tool and is not an introduction to programming, but simply to familiarize you with the use of the tool and its various functions, menus, and short cuts. For a more information please read the Propeller tool's online help.

*Editor's Note: You may also refer to the [Propeller Manual v1.0](#), which is the source of the information in this section. It is available for purchase or free PDF download from [www.parallax.com/propeller](http://www.parallax.com/propeller).*

### 1.5.1 Propeller Tool Interface Overview

Referring to Figure 1.13, the IDE is composed of a number of panes. Panes 1, 2, and 3 are all part of the "Integrated Explorer". The Integrated Explorer is the region to the left of the main text Editor pane (pane 4) that provides views of the project you're working on as lists of the folders and files on disk.

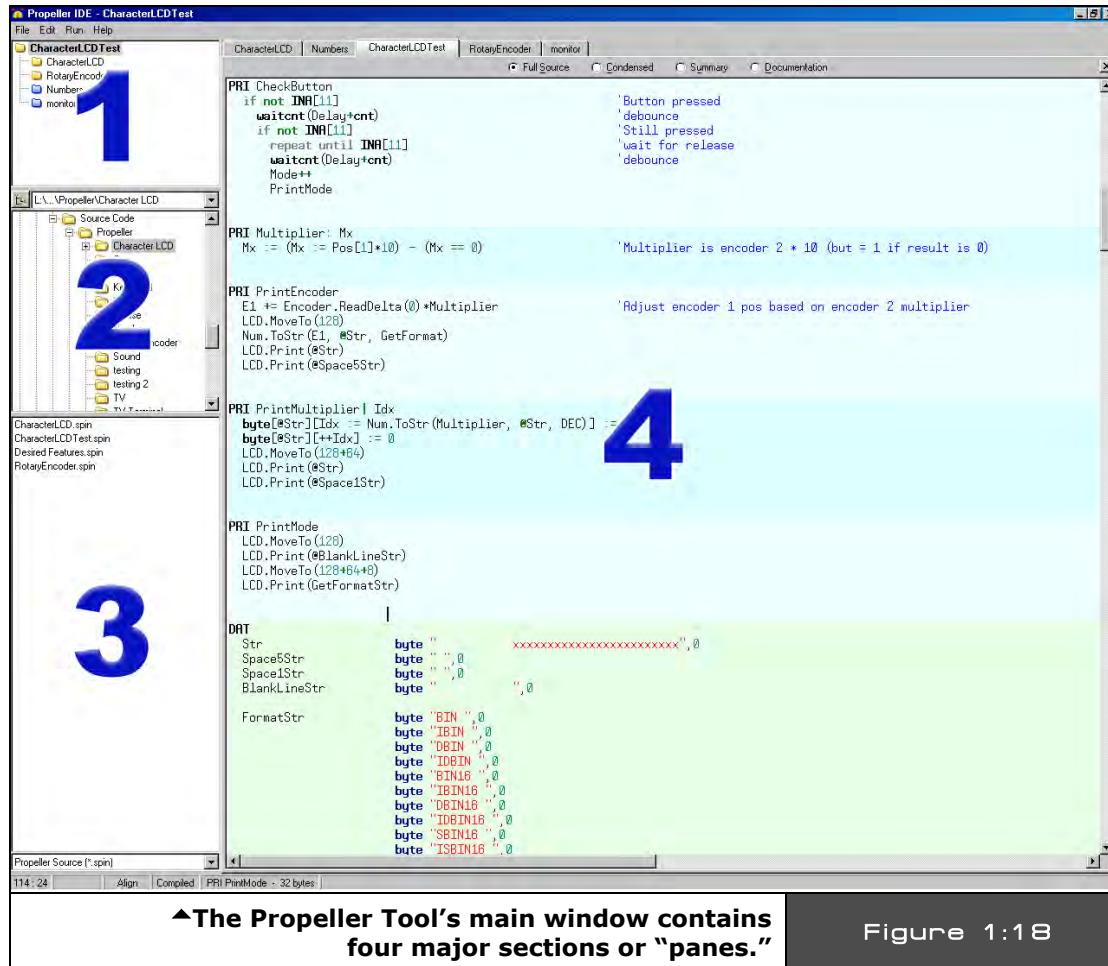


Figure 1:18

Image from Propeller Manual v1.0 courtesy of Parallax Inc.

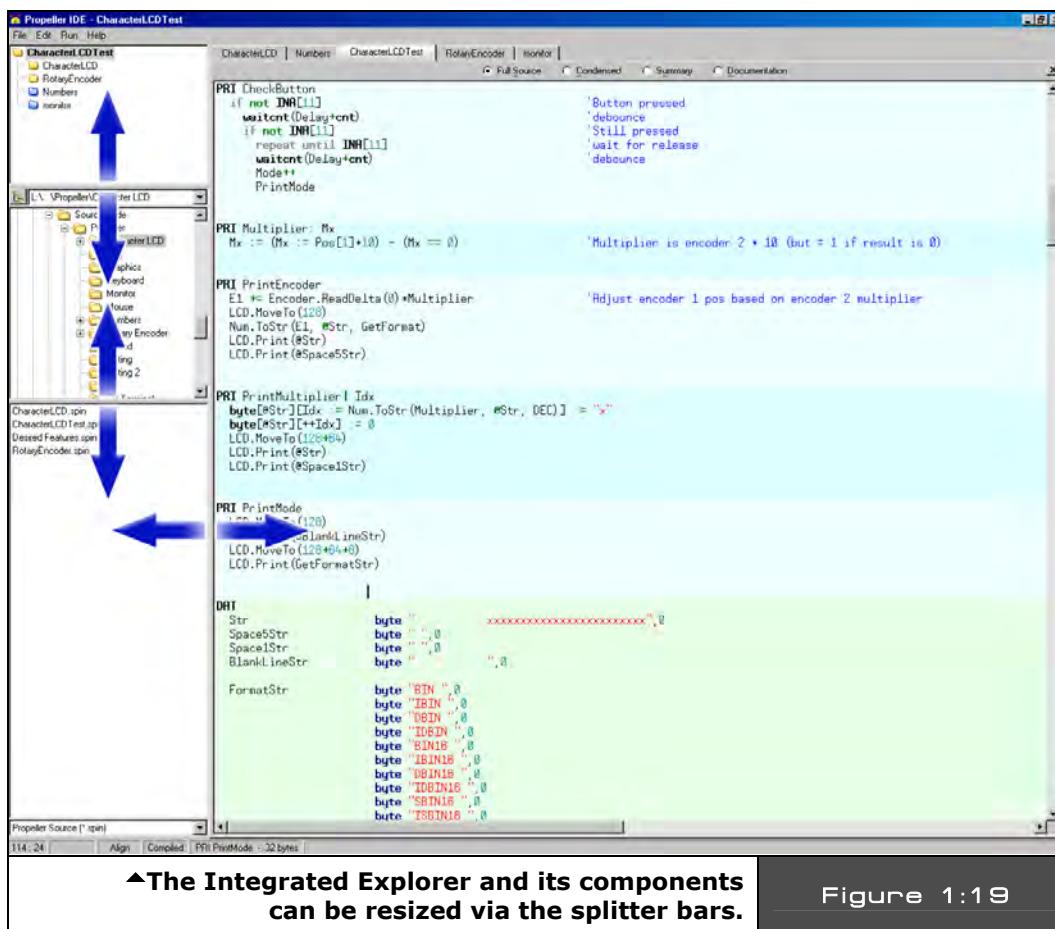
We'll take a look at each of the four panes in turn in a moment:

**Pane 1:** Object View Pane

**Pane 2:** Recent Folders Field and Folder List

**Pane 3:** File List and Filter Field

**Pane 4:** Editor Pane



▲The Integrated Explorer and its components  
can be resized via the splitter bars.

Figure 1:19

Image from Propeller Manual v1.0 courtesy of Parallax Inc.

The Integrated Explorer is separated from the Editor pane by a tall, vertical splitter bar that can be resized with the mouse at any time by simply dragging. The Integrated Explorer can even be hidden by resizing it down to nothing (left click and drag its vertical splitter bar), by selecting <File → Hide Explorer> from the main menu bar, or by using the keyboard shortcut <CTRL + E>. The menu and shortcut options toggle the Integrated Explorer between the following modes:

1. Visible (set to its last known size)
2. Invisible (completely collapsed into the left edge of the Propeller Tool)

### Pane 1: Object View Pane

Pane 1 is the Object View pane. Spin, the Propeller chip's native language is a loosely "object-based" language, where objects are external files that contain executable source code and even other objects. Thus, a Propeller Project can be made up of multiple objects or in other words multiple source files, the concept is similar to including source files in C/C++ with the pre-processor. The Object View displays the hierarchical view of the most recently compiled project providing visual feedback on the structure of your project. Using the Object View, you can determine what objects are included in your project, how they fit together with other objects, their physical location on disk (working folder, library folder or editor only), and potential circular references.

### Pane 2: Recent Folders Field and Folder List

Pane 2 contains two components:

1. The Recent Folders field
2. The Folder List

These two components work together to provide navigational access to the disk drives available on your PC. The Folder List displays a hierarchical view of folders within each disk drive and can be manipulated in a similar fashion as the left pane of the Windows Explorer. The Recent Folders field (above the Folder List) provides a drop-down list of the most recent folders you've loaded files from. Selecting a folder from the Recent Folders field causes the Folder List to immediately navigate to that folder. In addition, if you select a folder in the Folder List which exists in the Recent Folders list, the Recent Folder field will automatically update itself to display that item.

### Pane 3: File List and Filter Field

Pane 3 contains two components:

1. The File List
2. The Filter field (bottom)

The File List displays all the files contained in the folder selected from the Folder List which match the filter criteria of the Filter field. The File List can be used in a similar fashion as the right pane of Windows Explorer.

The Filter field (below the File List) provides a drop-down list of file extensions or filters to apply to files in the File List. Typically it will be set to show Spin files only (those with ".spin" file extensions) but can also be set to show text files (.txt) or all files (\*.\*). If you navigate to a folder and don't see the files you expect to see, make sure that the current filter in the Filter field is set appropriately.

Files in the Files List can be opened and viewed in the editor by double clicking on the file, dragging it into the Editor pane itself, or right clicking and selecting Open from the shortcut menu.

#### Pane 4: Editor Pane

Pane 4 is the Editor pane. The Editor pane provides a view of the open Spin source code files and is the general work area where you can review and edit all the source code objects for your project. Each file (source code object) you open is organized within the Editor pane as an individual tab named after the file it contains. The currently active editor tab is highlighted differently than the rest (bolded). You can have as many files open at once as you wish, limited only by memory. As the number of files increases and the tab control runs out of screen space, scroll arrows will appear on the right hand side of the tab control allowing you to navigate through the off-screen files.

You can switch between open tabs by:

1. Clicking on the desired tab with the mouse.
2. Pressing <ALT + Left Arrow> or <ALT + Right Arrow>
3. Pressing <CTRL+TAB> or <CTRL+SHIFT+TAB>



If you hover the mouse pointer over a tab long enough it will display a hint message with the full path and filename of the file it represents as shown in Figure 1:20.

The source code inside each file being edited is automatically syntax highlighted. Both, the foreground and background colors are highlighted to help distinguish block types, element types, comments vs. executable code, and so forth. You can turn this off if you wish by selecting the Tools/Option menu item from the main menu and altering the editor syntax highlighting settings.

Each file opened in an edit tab can display source code in one of four views:

1. Full Source view
2. Condensed view
3. Summary view
4. Documentation view

The view mode can be changed individually for each file edit tab by either:

1. Selecting the respective radio button with the mouse (located in a row under the tab control).
2. Pressing <Alt + Up Arrow> or <Alt + Down Arrow>.
3. Pressing <Alt+ [letter]> where [letter] is the underlined hot key of the desired view.
4. Pressing <Alt> and rotating the mouse wheel (if you have one) up or down.

**NOTE**

The Documentation view can not be entered if the object can not be fully compiled at that moment.

Since a project can consist of many objects, developing a project can be awkward unless you can see both the object you're working on and the object you're interfacing to at the same time. The Editor pane helps here by allowing its edit tabs to be dragged and dropped to different locations as shown in Figure 1:21. For example, once multiple objects are open, you can use the left mouse button to select and drag the tab of an object down towards the bottom half of the Editor pane and simply drop it there. The display changes to show you a new tab region where you just dropped that edit tab. You can continue to drag and drop edit tabs to this new region if you wish.

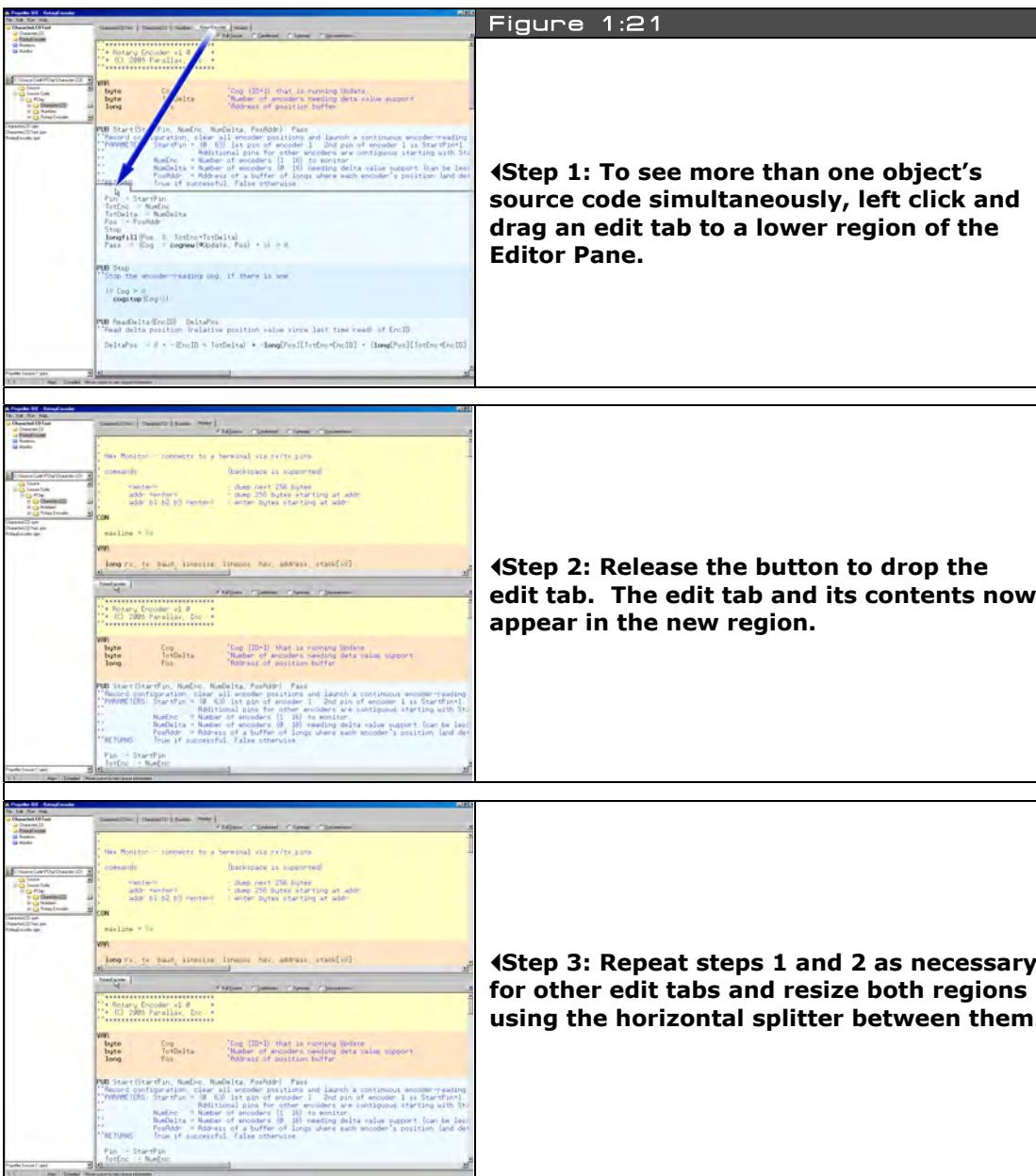


Image from Propeller Manual v1.0 courtesy of Parallax Inc.

The vertical size of each of the edit regions can be changed by dragging the horizontal splitter separating them. Of course, the objects you're interfacing to can be viewed in whatever mode is convenient at the moment (Full Source, Condensed, Summary, or Documentation) while the object you're developing remains in the Full Source view (the only editable view).

The Editor pane also allows undocking its tabs and for them to be dragged and dropped completely outside of the Propeller Tool as shown in Figure 1:22. When an edit tab is undocked, the new tabs occupy a new window that can be manipulated independently of the main Propeller Tool application window. This is particularly useful for development on multi-monitor systems.

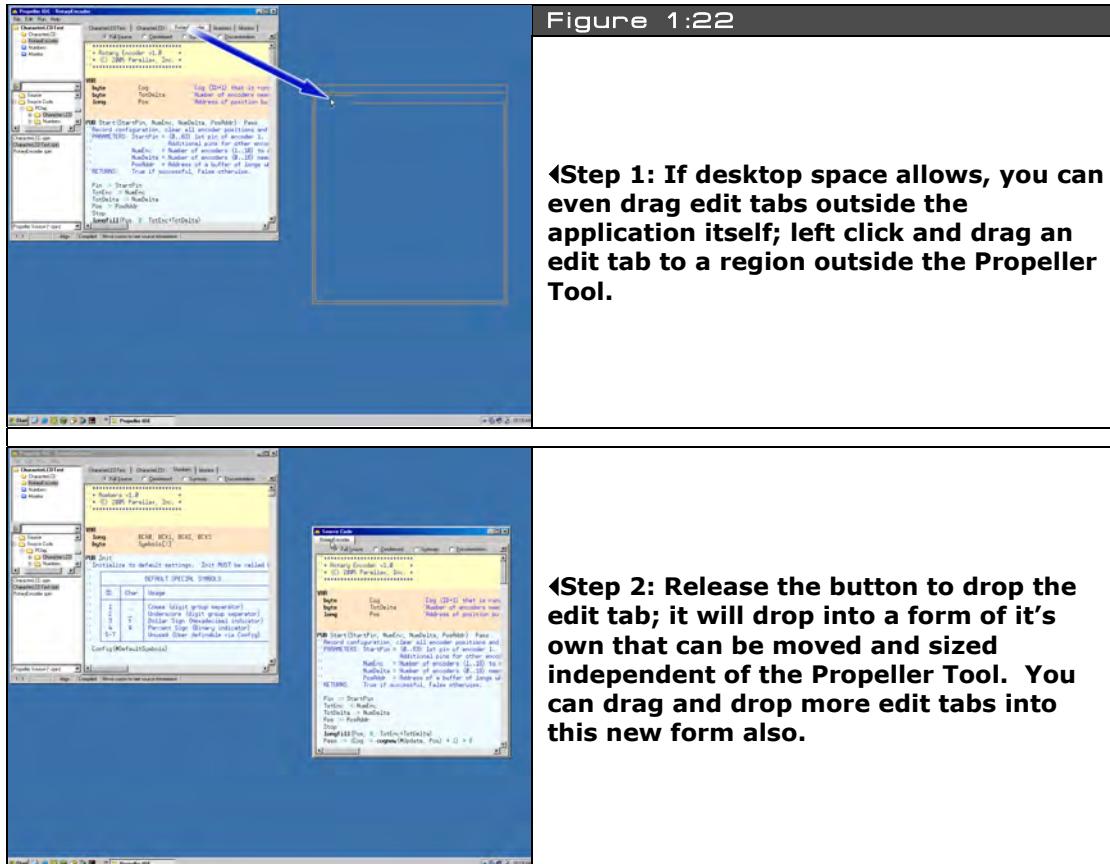
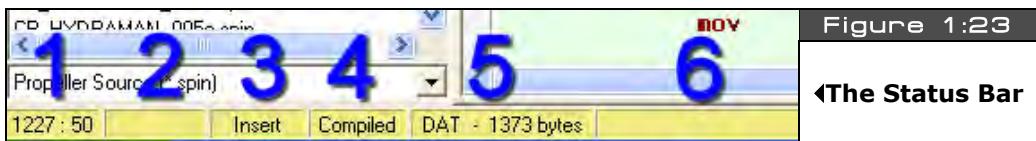


Image from Propeller Manual v1.0 courtesy of Parallax Inc.



The Status Bar at the bottom of the Propeller Tool is separated into six panels as shown in Figure 1:23. Each panel displays useful information at various stages of the development process.

**Panel 1** – Displays the row and column position of the editor's caret in the currently active edit tab.

**Panel 2** – Displays the “modified” status of the current edit tab; if it’s blank then the current line hasn’t been modified, if the panel reads “modified” then the current line has been modified, lastly the panel can indicate “read-only.”

**Panel 3** – Display the current edit mode:

1. Insert (default)
2. Align (available for “.spin” files only)
3. Overwrite mode

The edit modes can be toggled through by pressing the Insert key.

**Panel 4** – Displays the compilation status of the current edit tab; blank, meaning uncompiled or “Compiled” meaning the source has recently been compiled. This panel indicates whether or not the current source code is still in the form it was in when it was last compiled. If the code has not been changed since the last compile operation, this panel will say “Compiled.”

**Panel 5** – Displays context sensitive information about the current edit tab’s source code if that code has not been changed since the last compile operation. Move the edit tab’s cursor to various regions in the source such as CON, DAT, or PUB/PRI blocks to see information relating to that block.

**Panel 6** – Displays temporary messages about the most recent operation(s). This is the area of the Status Bar where error messages, if any, from the last compile operation are displayed until another message overwrites it. This area also indicates successful compilations, font size changes, and other status information.



#### NOTE

The entire Status Bar displays hints describing the function of each menu item on the menu bar as well as various other items when you let the mouse pointer hover over those items.

### 1.5.2 Propeller Tool Menu Items

The following lists outline the various menu items and options controlled via the application menu items.

#### File Menu

<b>New</b>	Create a new edit tab with a blank page. Any existing edit tabs are unaffected.
<b>Open...</b>	Open a file in a new edit tab with the Open file dialog.
<b>Open From...</b>	Open a file in a new edit tab from a recently accessed folder using the Open file dialog.
<b>Save</b>	Save current edit tab's contents to disk using the existing file name, if applicable.
<b>Save As...</b>	Save current edit tab's contents to disk with a new file name using the Save As dialog.
<b>Save To...</b>	Save current edit tab's contents to disk in a recently accessed folder using the Save As dialog.
<b>Save All</b>	Save all unsaved edit tab's contents to disk using their existing names, if applicable.
<b>Close</b>	Close current edit tab (will prompt if file is unsaved).
<b>Close All</b>	Close all edit tabs (will prompt for any files unsaved).
<b>Select Top Object File...</b>	Select the top object file of current project. This setting is used for all of the Compile Top... operations and remains until changed.
<b>Archive</b>	
→ <b>Project...</b>	Collect all objects and data files for the project shown in Object View and store them in a compressed (.zip) file along with a "readme" file containing archive and structure information. The compressed file is named after the project's top file with "Archive" plus the date/time stamp appended and is stored in the top file's work directory.
→ <b>Project + Propeller Tool</b>	Perform the same task as above but add the entire Propeller Tool executable to the compressed file.

<b>Hide/Show Explorer</b>	Hide or show the Integrated Explorer panels (left side of the application window).
<b>Print Preview...</b>	View a sample of the output before printing.
<b>Print...</b>	Print the current edit tab's contents.
<b>&lt;recent files&gt;</b>	The menu area between the Print... and Exit items displays the most recently accessed files, up to ten. Selecting one of these items opens that file. Point the mouse at a recent file menu item to see the full path and file name in the status bar.
<b>Exit</b>	Close the Propeller Tool.

### Edit Menu

<b>Undo</b>	Undo the last edit action on the current edit page. Each edit page retains its own undo history buffer until closed. Multiple undo actions are allowed, limited only by memory.
<b>Redo</b>	Redo the last undone action on the current edit page. Each edit page retains its own redo history buffer until closed. Multiple redo actions are allowed, limited only by memory.
<b>Cut</b>	Delete the selected text from the current edit page and copy it to the Windows clipboard.
<b>Copy</b>	Copy the selected text from the current edit page to the Windows clipboard.
<b>Paste</b>	Paste text from the Windows clipboard to the current edit page at the current caret position.
<b>Select All</b>	Select all text in the current edit page.
<b>Find / Replace...</b>	Open the Find/Replace dialog; see Find/Replace Dialog on page 49 for details.
<b>Find Next</b>	Find the next occurrence of the last search string entered into the Find/Replace dialog.
<b>Replace</b>	Replace the current selection with the string entered into the Replace field of the Find/Replace dialog.
<b>Go To Bookmark</b>	Go to bookmark 1, 2, 3... (visible only when bookmarks are shown).

<b>Text Bigger</b>	Increase the font size in every edit page.
<b>Text Smaller</b>	Decrease the font size in every edit page.
<b>Preferences...</b>	Open the Preferences window. Users can customize many settings within the Propeller Tool using this feature.
<b><u>Run Menu</u></b>	
<b>Compile Current</b>	
→ <b>View Info...</b>	Compile source code in current edit tab and, if successful, display Object Info form with the results. The Object Info form displays many details about the resulting object including object structure, code size, variable space, free space and redundancy optimizations.
→ <b>Update Status</b>	Compile source code in current edit tab and, if successful, update the status info on the Status Bar for every object in the project.
→ <b>Load RAM</b>	Compile source code in current edit tab and, if successful, download the resulting application into Propeller chip's RAM and run it.
→ <b>Load EEPROM</b>	Compile source code in current edit tab and, if successful, download the resulting application into Propeller chip's EEPROM (and RAM) and run it.
<b>Compile Top</b>	
→ <b>View Info...</b>	Same as Compile Current → View Info except compilation is started from the file designated as the "Top Object File."
→ <b>Update Status</b>	Same as Compile Current → Update Status except compilation is started from the file designated as the "Top Object File."
→ <b>Load RAM</b>	Same as Compile Current → Load RAM + Run except compilation is started from the file designated as the "Top Object File."
→ <b>Load EEPROM</b>	Same as Compile Current → Load EEPROM + Run except the compilation is started from the file designated as the "Top Object File."

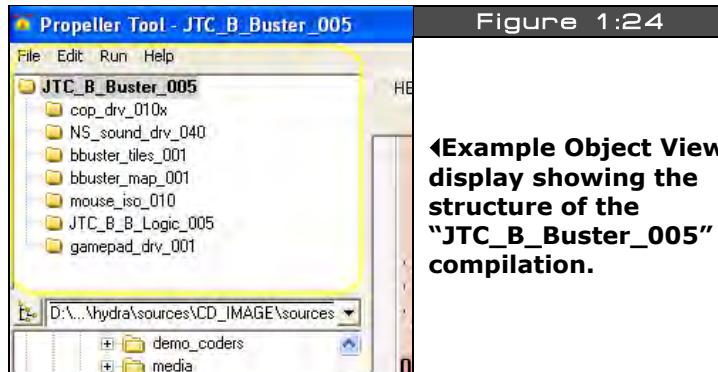
<b>Identify Hardware...</b>	Scan available ports for the Propeller chip and, if found, display the port it is connected to and the hardware version number.
<b><u>Help Menu</u></b>	
<b>Propeller Tool...</b>	Display on-line help about the Propeller Tool.
<b>Spin Language...</b>	Display on-line help about the Spin language.
<b>Assembly Language...</b>	Display on-line help about the Propeller Assembly language.
<b>Example Projects...</b>	Display on-line help containing example Propeller Projects.
<b>View Character Chart...</b>	Display the interactive Parallax Character Chart. This character chart shows the Parallax font's character set in three possible views: Standard Order, ROM Bitmap and Symbolic Order.
<b>View Parallax Website...</b>	Open up the Parallax website using the computer's default web browser.
<b>E-mail Parallax Support...</b>	Open up the computer's default email software and start a new message to Parallax support.
<b>About...</b>	Displays the About window with details about the Propeller Tool.

### 1.5.3 Object View Pane Details

The Object View displays a hierarchical view of the project you most recently compiled successfully. There are two Object Views in the Propeller Tool:

1. The Object View at the top of the Integrated Explorer in the main application's window
2. The Object Info View in the upper left of the Object Info form.

Both of these Object Views function in a similar fashion. The Object View provides visual feedback on the structure of the most recent compilation as well as information for each object within the compiled project.



Referring to Figure 1:19, the Object View indicates the structure of the "JTC\_B\_Buster\_005" game application. In this example, the "JTC\_B\_Buster\_005" object is the top object file and it includes a number of sub-objects including; "cop\_drv\_010x", "NS\_sound\_drv\_040", "bbuster\_tiles\_001", etc. Notice that the file names of the top level object and sub-objects do not include the file extension, its assumed to be ".spin" unless they are data files.

The icons to the left of each object name indicate the folder that the object exists in. There are the four color coded possibilities:

- Yellow** Object is within the Work Folder.
- Blue** Object is within the Library Folder.
- Stripe** Object is in Work Folder, but another object with the same name is also being used from the Library Folder.
- Hollow** Object is not in any folder because it has never been saved.

The following paragraphs describe the folder types.

### Work Folder

The Work Folder (yellow) is the folder where the top object file exists. Every project has one, and only one, work folder.

### Library Folder

The Library Folder (blue) is where the Propeller Tool's library objects exist, such as those that came with the Propeller Tool software. The Library Folder is always the folder that the Propeller Tool executable started from, and every object (file with .spin extension) within it is considered to be a library object.

### Striped Folders

Objects with striped icons indicate that an object from the work folder and an object from the library folder each refer to a sub-object of the same name and that sub object happens to exist in both the work and library folders. This same-named object may be:

1. An exact copy of the same object,
2. Two versions of the same object, or
3. Two completely different objects that just happen to have the same name.

Regardless of the situation, it is recommended that you resolve this potential problem as soon as possible since it may lead to problems later on, such as not being able to use the Archive feature.

### Hollow Folders

Objects with hollow icons indicate that the object was created in the editor and has never been saved to any folder on the hard drive. This situation, like the one mentioned above, is not an immediate problem but can lead to future problems if it is not addressed soon.

Using the mouse to point at and select objects can provide additional information as well. Clicking on an object within the Object View opens that object into the Editor pane. Left clicking opens that object in Full Source view, right clicking opens it in Documentation view and double clicking opens it, and all its sub-objects, in Full Source view. If the object was already open, the Editor pane simply makes the related edit tab active and switches to the appropriate view; Full Source for a left click or double click, or Documentation for a right click.

#### 1.5.4 Info Object View (F8)

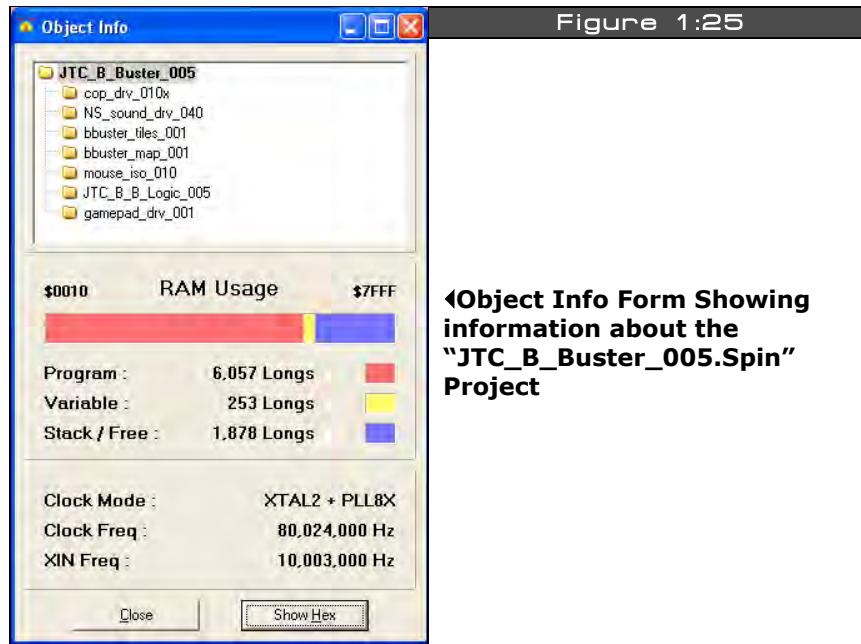
The Info Object View shown in Figure 1:25 works exactly like the Object View with a few exceptions:

1. Clicking on an object within the Info Object View updates the Object Info display with information pertaining to that object.
2. Double-clicking on an object within the Info Object View opens that object in the Edit pane.
3. Data files are not selectable in the Info Object View.

### RAM Usage Panel

The RAM Usage panel displays statistics about RAM allocation of the object currently selected in the Info Object View. The horizontal bar gives a summary view of the entire RAM with a

color legend and numerical details below it. For example, Figure 1:25 shows that the “JTC\_B\_Buster\_005” object consumes 6057 LONGs (24228 bytes) for program space and 253 LONGs (1012 BYTES) for variable space, leaving only 1878 LONGs (7512 BYTES) free.

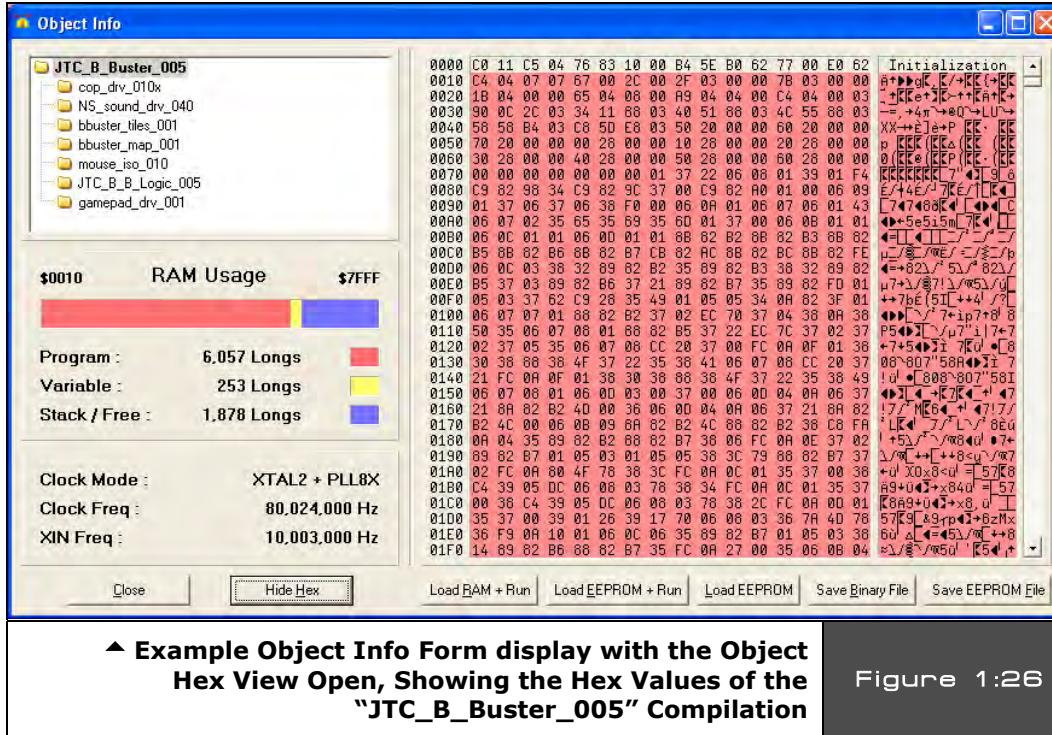


### Clock Panel

The clock panel, under the RAM Usage panel, displays the clock/oscillator settings of the object currently selected in the Info Object View. For example, Figure 1.20 shows that the “JTC\_B\_Buster\_005” object configured the clock for XTAL2 + PLL8 mode, at 80,024,000 Hz and an XIN frequency of 10,003,000 Hz.

## Hex View

The Show/Hide Hex button shows or hides the detailed object hex view, as shown below in Figure 1:26. The hex view shows the actual compiled object data, in hexadecimal, that are loaded into the Propeller's RAM/EEPROM upon download.



The buttons under the hex display allow for downloading and saving of the currently displayed hex data. The first three buttons, <Load RAM + Run>, <Load EEPROM + Run>, and <Load EEPROM>, perform the same function as the similarly named menu items under the <Run → Compile Current> main menu item. It's important to note that they use the current object (the one selected in the Info Object View) as the source to download. In other words, you can actually select a sub-object from the project and download just that; a practical procedure only if that object were designed to run completely on its own.

The last two buttons, <Save Binary File>, and <Save EEPROM File>, each save the hex data from the currently selected object to a file on disk. <Save Binary File> saves only the portion actually used by the object; the program data, but not variable or stack/free space.

<Save EEPROM File> saves the entire EEPROM image, including variable and stack/free space. Use <Save EEPROM File> if you wish to have a file that you can load into an EEPROM programmer for production purposes.

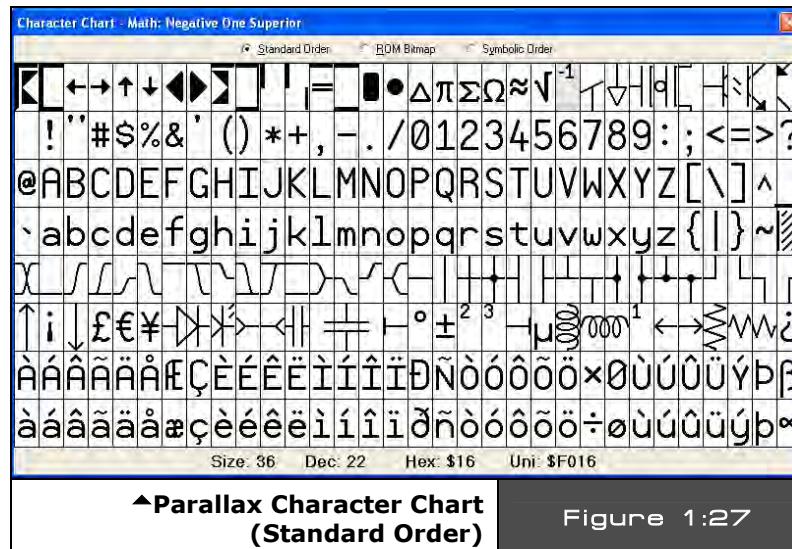
### 1.5.5 The Character Chart

The Character Chart window is available from the <Help → View Character Chart...> menu item. It shows the entire character set for the Parallax Font that is used by the Propeller Tool and is also built into the ROM of the Propeller chip. There are three views in the Character Chart: Standard Order, ROM Bitmap, and Symbolic Order.

In each of the three views, the mouse, left mouse button, cursor keys and enter button can be used to highlight and select a character. If clicked (or enter pressed), the highlighted character will be entered into the current edit tab at the current cursor location. As a new character is highlighted, the title bar and info bar of the window updates to show the name, size and address information for that character. Moving the mouse wheel up or down changes the font size displayed in this window.

#### Standard Order

Figure 1:27 displays the characters in the standard ANSI numerical order. The exponent (^1) in the first row of the display is selected in this example (light grey highlight).



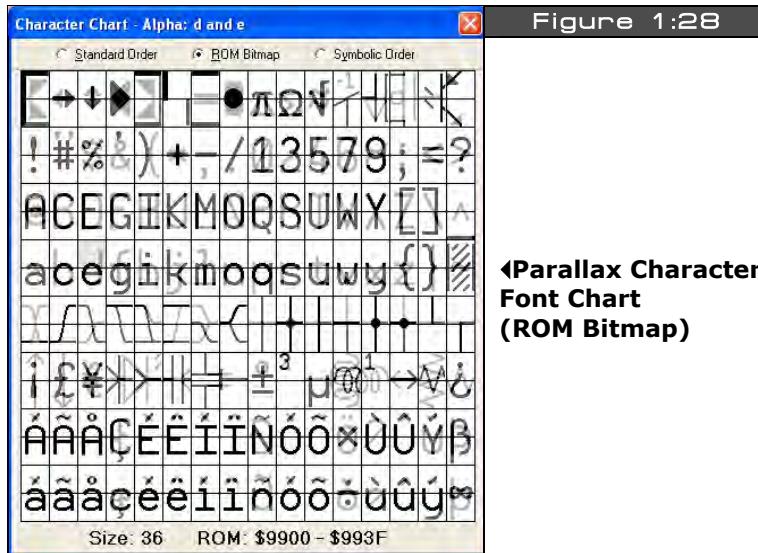
The information at the bottom of the window shows the font size, in points, and the character's location in the character set in decimal, hexadecimal, and Unicode.

**NOTE**

The Unicode value is the address of the character in the True Type® Font file that is used by the Propeller Tool. The decimal and hexadecimal values are the logical addresses of the character in the character set within the Propeller chip and correspond to that location in the ANSI character set used by most computers.

**ROM bitmap**

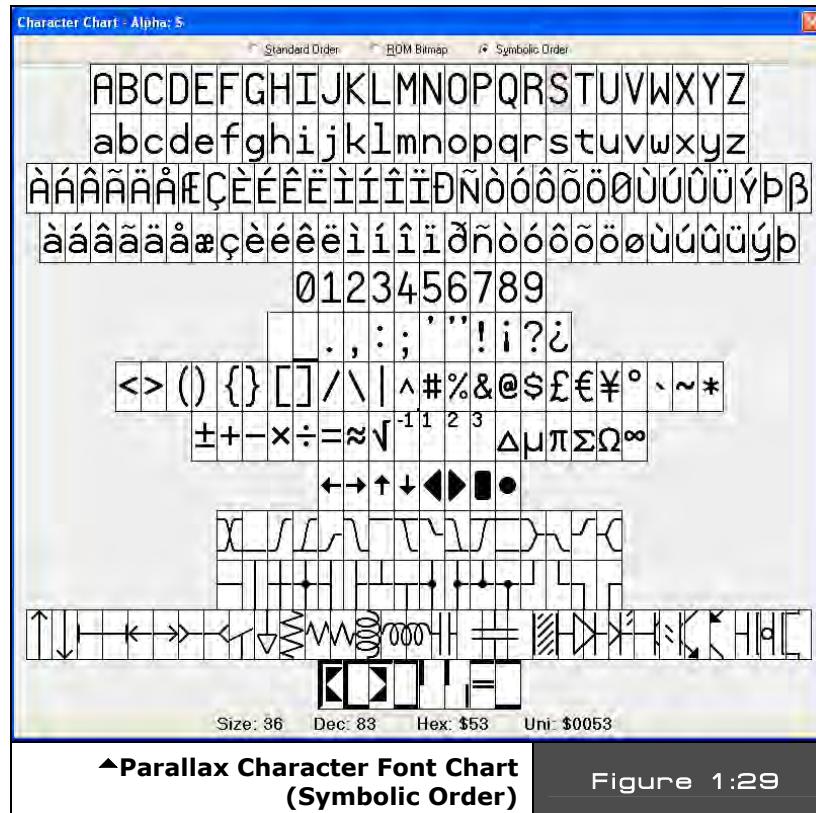
ROM Bitmap, Figure 1.23 shows the characters in a way representative of how they are stored in the Propeller's ROM.



This view uses four colors, white, light gray, dark gray, and black, to represent the bit pattern of each font character. Each character, in the Propeller's ROM, is defined with two bits of color (four colors per row in each character cell). The rows of each pair of adjacent characters are overlapped in memory for the purpose of creating the run-time characters used to draw 3D buttons with hot key and focus indicators. The information at the bottom of the window shows the font size, in points, and the selected character's pixel data address range in the Propeller's ROM.

## **Symbolic Order**

Symbolic Order orders the characters arranged categorically as shown in Figure 1.24. This is useful for finding the special characters in the Parallax font for depicting timing diagrams, lines, arrows, and schematics.



### 1.5.6 View Modes, Bookmarks and Line Numbers

While developing objects, or conversing about them with other users, it may sometimes be difficult to quickly navigate to certain regions of code simply because of the size of the file itself or because large sections of code and comments obscure the desired section. There are a number of features built into the Propeller Tool to assist with this problem, including different View Modes, Bookmarks and Line Numbers.

#### View Modes

Each edit tab can display an object's source in one of four view modes:

1. Full Source mode
2. Condensed mode
3. Summary mode
4. Documentation mode

**Full Source** view displays every line of source code within the object and is the only view that supports editing.

**Condensed** view hides every line that contains only a code comment as well as contiguous lines that are blank, showing only compilable lines of code.

**Summary** view displays only the block heading lines (CON, VAR, OBJ, PUB, PRI, and DAT); a convenient way to see the entire object's structure at a glance.

**Documentation** view displays the object's documentation generated by the compiler from the source code's doc comments.

By briefly switching to another view you may be able to locate the routine or region of code desired. For example, Figure 1:30 (top) shows the Graphics object open in an edit page. If you were having trouble finding the "plot" routine within the source code, you could switch to the Summary view (middle) locate the "plot" routine's header line and click the mouse on that line to place the cursor there, then switch back to Full Source view (bottom). Keep your eye on the line with the cursor because the code will expand to full view above and below the line where the cursor is. The view mode can be changed a number of ways.

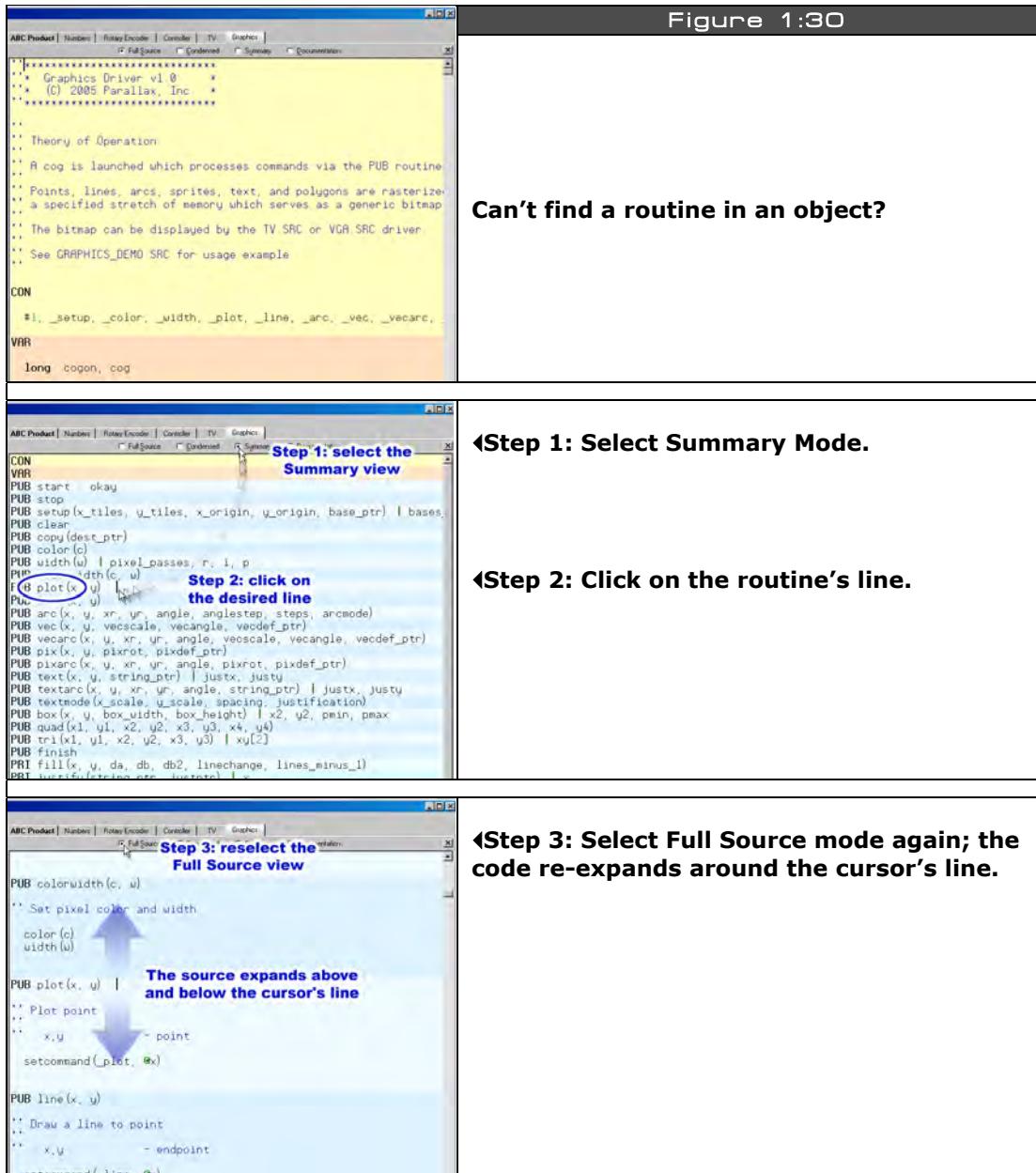
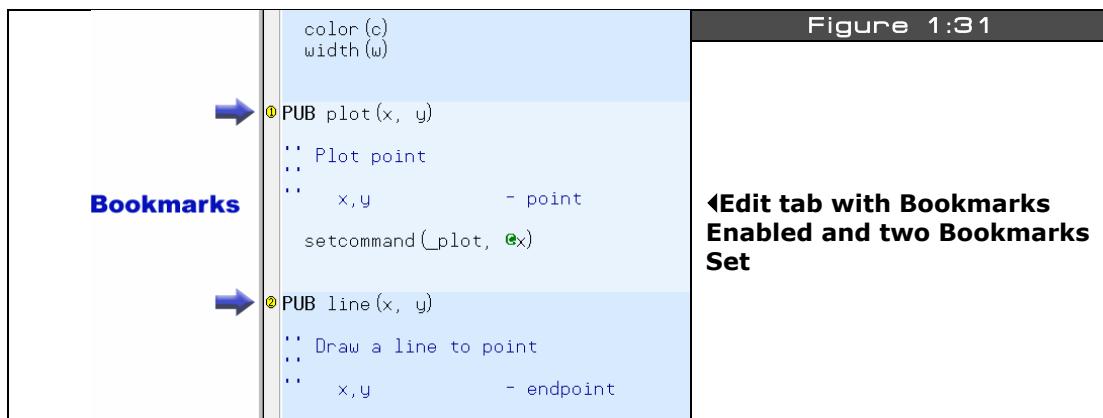


Image from Propeller Manual v1.0 courtesy of Parallax Inc.

## Bookmarks

You can also set bookmarks on various lines of each edit page's source code to quickly jump to desired locations. Figure 1:31 shows an example of two bookmarks set in the Graphics object's edit tab. To enable bookmarks, press **<Ctrl+Shift+B>** to make the Bookmark Gutter visible; a blank area to the left of the edit page. Then click the mouse in the Bookmark Gutter next to each line you want to be able to navigate to quickly. Finally, from anywhere in the page, press **<Ctrl+#>** where # is the bookmark number that you want to go to; the cursor will instantly jump to that location. Up to 9 bookmarks (1 – 9) can be set in each edit tab. The bookmarks are not saved in the source code; however, the bookmark settings of the last 10 files accessed are remembered by the Propeller Tool and restored upon reopening those files.



The screenshot shows the Propeller Tool's edit tab with the following code:

```

color(c)
width(w)

141
142 color(c)
143 width(w)
144
145
146 PUB plot(x, y)
147    '' Plot point
148    ..
149    ..      x,y           - point
150    setcommand(_plot, ex)
151
152
153
154
155 PUB line(x, y)
156
157    '' Draw a line to point
158    ..
159    ..      x,y           - endpoint
160

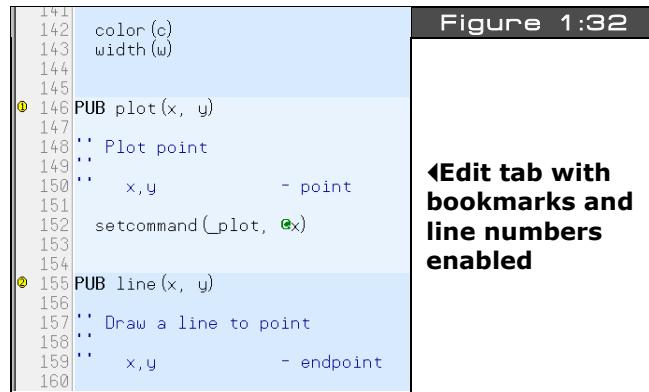
```

Two blue arrows point to the numbers 146 and 155 in the gutter, indicating they are bookmarked. The title bar of the window says "Figure 1:31". A caption on the right side of the window reads "Edit tab with Bookmarks Enabled and two Bookmarks Set".

Images on this page from Propeller Manual v1.0 courtesy of Parallax Inc.

## Line Numbers

At any time, you can enable or disable line numbers in the edit tab. Line Numbers show up in the Line Number Gutter, next to the Bookmark Gutter as shown in Figure 1:32. Lines are automatically numbered as they are created; they are a visual item only and are not stored in the source code. Line Numbers and Bookmarks are independent of each other and can be enabled or disabled individually.



The screenshot shows the Propeller Tool's edit tab with the following code:

```

141
142 color(c)
143 width(w)
144
145
146 PUB plot(x, y)
147    '' Plot point
148    ..
149    ..      x,y           - point
150    setcommand(_plot, ex)
151
152
153
154
155 PUB line(x, y)
156
157    '' Draw a line to point
158    ..
159    ..      x,y           - endpoint
160

```

Both the line numbers (141, 142, etc.) and the bookmarks (146 and 155) are visible in the gutter. The title bar of the window says "Figure 1:32". A caption on the right side of the window reads "Edit tab with bookmarks and line numbers enabled".

## Edit Modes

There are three edit modes provided by the Editor pane:

1. Insert (default)
2. Align (available for ".spin" objects only)
3. Overwrite

You can switch between each mode by using the <Insert> key. The current mode is reflected by both the caret/cursor shape and panel 3 of the lower status bar.

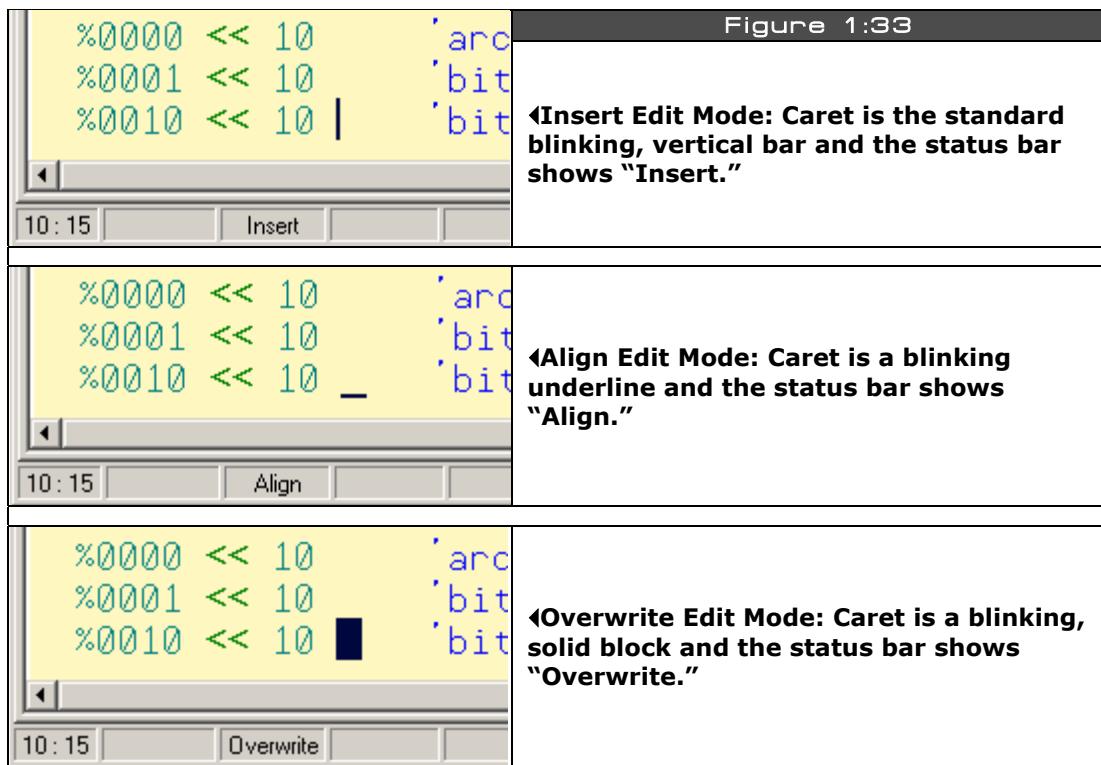


Image from Propeller Manual v1.0 courtesy of Parallax Inc.

## Insert and Overwrite Modes

The Insert and Overwrite modes are similar to that of many other text editors. These are the only two modes available to edit tabs containing files other than Propeller ".spin" objects, such as ".txt" files.

### Align Mode

The Align mode is a special version of the Insert mode designed specifically for maintaining source code. To understand Align mode, we first need to consider common programming techniques. There are two very common practices used when writing modern source code: indentation of code and alignment of comments to the right of code. It is also common for source code to be viewed and edited using more than one editor application. Historically, programmers have used either tabs or spaces for indentation and alignment purposes, both of which prove problematic. Tab characters cause alignment issues because some editors use different sized tab settings than others. Both tab and space characters cause alignment issues because future edits cause right-side comments to shift out of alignment.

For Spin code, the Propeller Tool solves this problem first by disallowing tab characters (Tab key presses emit the proper number of space characters), and second by providing the Align edit mode. While in the Align mode, characters inserted into a line affect neighboring characters but not characters separated by more than one space. The result is that comments and other items separated by more than one space maintain their intended alignment for as long as possible.

Since the Align mode maintains existing alignments as much as possible, much less time is wasted realigning elements due to future edits by the programmer. Additionally, since spaces are used instead of tab characters, the code maintains the same look and feel in any editor that displays it with a mono-spaced font.

The Align mode isn't perfect for all situations, however. We recommend you use Insert mode for most code writing and briefly switch to Align mode to maintain existing code where alignment is a concern. The Insert key rotates the mode through Insert → Align → Overwrite and back to Insert again. The Ctrl+Insert key shortcut toggles only between Insert and Align modes. A little practice with the Align and Insert modes will help you program more time-efficiently.

Note that non-Spin source (without a .spin extension) does not allow the Align mode. This is because, for non-Spin source, the Propeller Tool is designed to maintain any existing tab characters and to insert tab characters when the Tab key is pressed in order to maintain the original intent of the file, which may be a tab-delimited data source for a Spin program or other use where tab characters are desired.

## Block Selections

In addition to normal text selections made with the mouse, the Propeller Tool allows block selections (rectangular regions of text). To make a block selection, first press and hold the Alt key, then left-click and drag the mouse to select the text region. After the selection is made, cut and copy operations behave as they do with other selections. Figure 1:34 demonstrates block selection and movement of the text block with the mouse.

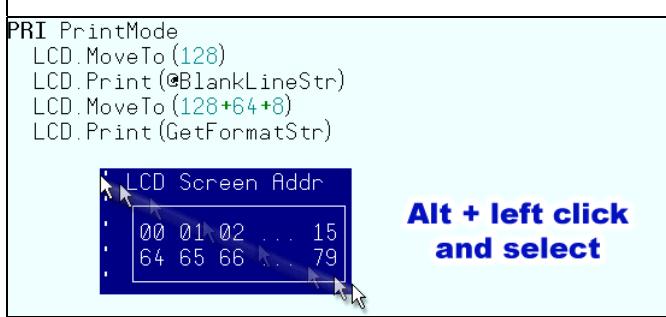
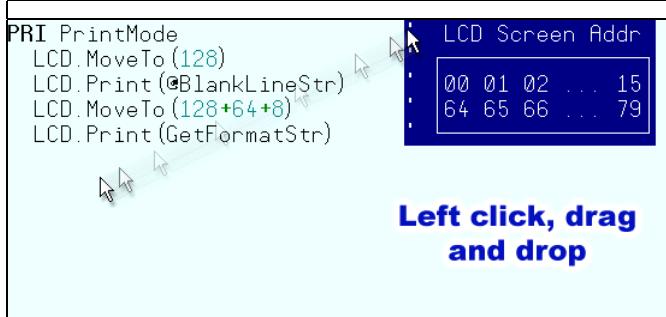
<pre>PRI PrintMode LCD.MoveTo(128) LCD.Print(@BlankLineStr) LCD.MoveTo(128+64+8) LCD.Print(GetFormatStr)  ' LCD Screen Addr ' 00 01 02 ... 15 ' 64 65 66 ... 79</pre>	<p><b>Figure 1:34</b></p> <p>◀Original code. We'd like to move the "LCD Screen Addr" comments to the right of the PrintMode routine.</p>
 <p><b>Alt + left click and select</b></p>	<p>◀First press and hold the Alt key. Next left-click and drag the mouse to make the selection.</p>
 <p><b>Left click, drag and drop</b></p>	<p>◀Finally, click and drag (from anywhere in the selected block) and drop the selection in the desired location.</p>

Image from Propeller Manual v1.0 courtesy of Parallax Inc.

### **1.5.7 Keyboard Shortcuts and Propeller Quick Reference Guide**

There are many keyboard shortcuts built into the Propeller Tool. Complete shortcuts lists in two formats, one categorically organized and one listed by key, are available through the Propeller Tool's Help menu.

Also available through the Help file is a 4-page condensed guide to the Spin and Propeller Assembly programming languages organized in table format for quick reference.

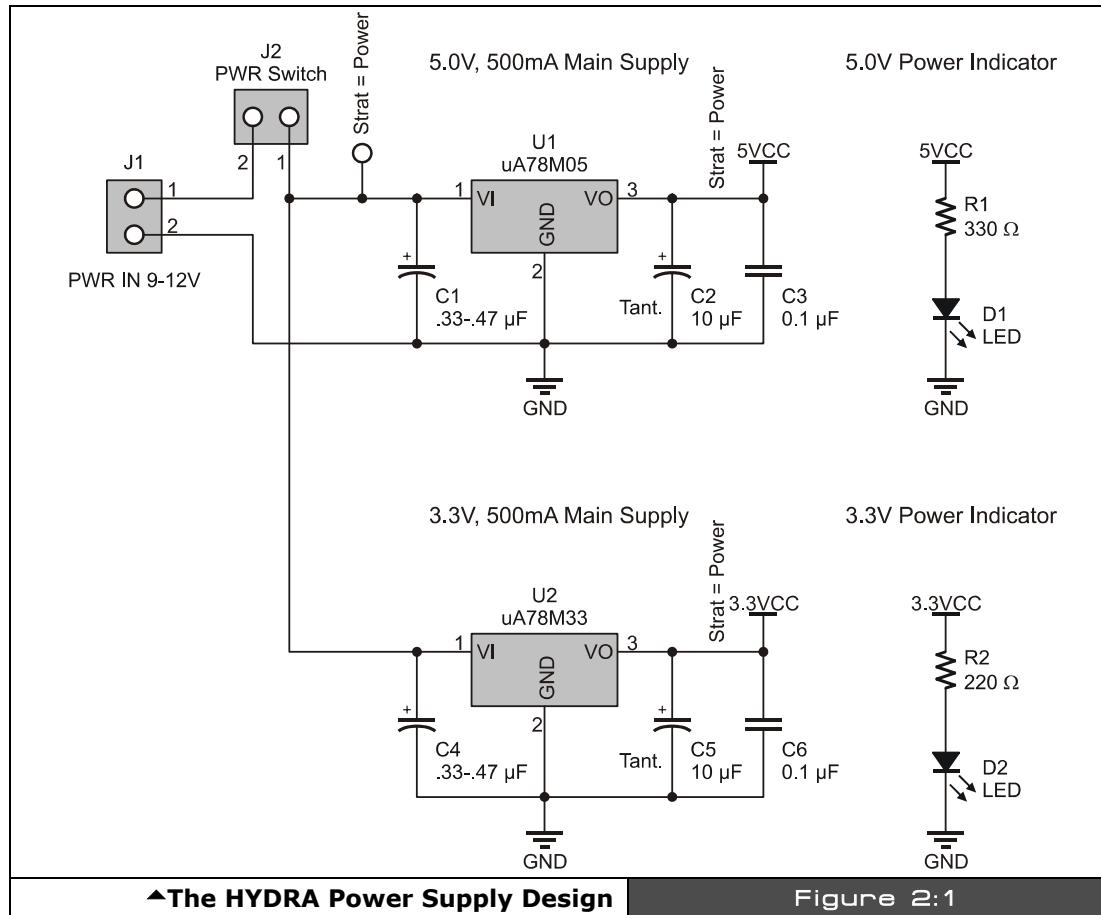
## **1.6 Summary**

In this chapter we inventoried the HYDRA, tried some games and demos, got the software and drivers loaded onto your PC and took a look at the Propeller Tool IDE. In the next chapter and the chapters to follow we are going to take a look at each of the hardware sub-systems of the HYDRA, so you can at least have a general idea of how they work and how to make modifications and hacks to them if you want to void your warranty! See you in Chapter 2.

## Chapter 2: 5V & 3.3V Power Supplies

The HYDRA, like any embedded system, needs power, so what better place to start discussing the hardware than with the power supply design? In this chapter, we are going to cover the following topics:

- ▶ The 3.3V power supply.
- ▶ The 5.0V power supply.



Game Programming for the Propeller Powered HYDRA ▶ Page 77

## 2.1 General Power Supply Overview

The HYDRA game console has a dual 3.3 V/ 5.0 V power supply system that is fed by a single 9 VDC unregulated input from a wall adapter. The supply designs are shown in Figure 2:1 for reference.

The HYDRA is a mixed voltage system since the Propeller uses 3.3 V, but the keyboard and mouse need 5.0 V, as do potential future peripherals; thus both supplies are available and can each supply up to 500 mA for all your needs. Additionally, the power supplies are exported to the 20-pin expansion port for plug-in cartridges. Initially, the power is fed in from a 2.1 mm female power jack at J1, the voltage should be from 9-12 VDC, but does NOT need regulation, unregulated DC is fine and hopefully there is a fat 2,000 – 20,000  $\mu$ F filter cap on the output to smooth the DC.

The wall adapter that comes with the HYDRA is something like that shown in Figure 2:2, it's a standard 300-500 mA 9 V DC adapter you can find almost anywhere, the only important detail is that the **TIP** is **positive** and the **RING** must be **negative**. If you are having trouble seeing the schematic of the power supplies, you can find an electronic version of it in higher resolution here (as well as all the other circuits discussed in the upcoming chapters):

**CD\_ROOT:\HYDRA\DESIGNS\hydra\_power\_01.gif**



Figure 2:2

◀The 9 VDC wall adapter that comes with the HYDRA kit

## 2.2 The 3.3 V Power Supply

The 9 V raw power is fed through the power jack at J1 and into the power switch at J2 then into the regulation circuit based on a standard UA78M33 linear regulator. The UA78M33 is a very hearty regulator with built-in protection so we don't have to add diodes and other assorted protection components to it. Referring back to Figure 2:1, the capacitors C1, C2, and C3 provide filtering on the input and output. The large 10  $\mu$ F tantalum on the output helps provide large currents on demand. When powering the HYDRA up, R1 and D1 provide a "power good" indicator, and you should see the LED illuminate to indicate the supply is working. Of course, there is no substitute for a voltmeter if you really want to check the voltage and be sure if you are having power problems.

The Propeller chip is a 3.3 V device, so this supply is the main supply of the system that powers the Propeller; however, add-in cards plugged into the expansion slot might want to use a lot of current, thus a regulator that can provide at least 500 mA of current is desired just in case.

## 2.3 The 5.0 V Power Supply

Many people supply the 3.3 V supply from the 5 V supply; this is a mistake. Any power supply designer will tell you that, not only do you cut your output load of your 5 V supply down since it's constantly working to supply your 3.3 V supply, you add the entire path of the 5 V supply into your 3.3 V system's final output since whenever the 3.3 V supply pulls, it pulls through the 5.0 V which can lead to pulling your 5.0 V supply down many hundreds of millivolts. Moreover, if you want to rate your 3.3 V at 500 mA and your 5.0 V at 500 mA, you can't! You need to rate your 5.0 V at 1 A(!) since it is responsible for supplying both front ends to the power. Finally, if the 5 V goes bad, then they both go bad, with two separate paths; if one supply goes bad, you still have the other and many vital systems may still operate.

With that in mind, the 5.0 V supply is identical to the 3.3 V supply, but instead of a 3.3 V linear regulator, the 5.0 V supply uses a 5.0 V regulator, the UA75M05. Again, this is a very robust regulator with built-in protection, so we can save parts. Also, the input and output filtering is very forgiving and as long as you have 0.1  $\mu$ F – 1.0  $\mu$ F on both the input and output, the regulator will work great, but I like to throw a nice 10  $\mu$ F tantalum on all my power supplies' outputs for a low-impedance path for current sourcing.

Lastly, the 5.0 V supply has a "power good" indicator constructed of R2 and D2 that provides some indication the supply is working. Both power indicators are of course up front on the HYDRA by the power switch.

## 2.4 Summary

The power supplies for the HYDRA are rather simplistic; all the work is done by the regulators. Also, you might wonder "Can the HYDRA can be powered from battery?" Absolutely, a 9 V transistor battery "will" work, for a while, but I suggest getting a series 6-AA cell battery pack to create a total of 9 V ( $6 \times 1.5\text{ V}$ ), and then connect a 2.1 mm power connect into the end of the cable and connect it to your pack (most battery packs like this have a 9 V transistor battery clip, so I usually just solder on a cable to my 2.1 mm jack). I have found that using standard rechargeable batteries, I can run the HYDRA for hours in this configuration. Figure 2:3 shows a picture of my little battery pack I use for the HYDRA.



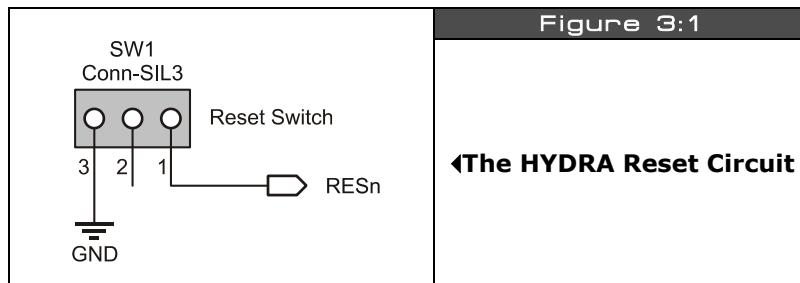
Figure 2:3

◀ An ad-hoc HYDRA battery pack

## Chapter 3: Reset Circuit

In this incredibly short chapter we are going to discuss the HYDRA's reset circuitry including:

- ▶ Reset circuit design
- ▶ Resetting the HYDRA manually
- ▶ Resetting the HYDRA via the USB/USB2SER interfaces



### 3.1 Reset Circuit Design

The Propeller chip can be reset externally via the USB hardware (via the DTR line) or by pressing the Reset button located at the **front** of the HYDRA. The reset circuitry on the Propeller chip doesn't require much conditioning, thus the manual reset circuit is nothing more than a switch (as shown in Figure 3:1) that pulls the **RESn** line to ground when depressed. If you do want to reset the Propeller chip with some external hardware then you call pull **LOW** on the **RESn** line; however, make sure that you place a weak **HIGH** on the line with a 2.2-100 KΩ resistor on your circuit, so there is a **HIGH** on the line if your device is not actively pulling the **RESn** low.



#### NOTE

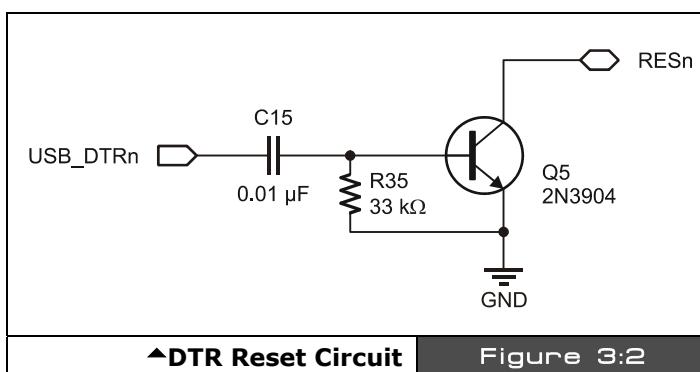
The Propeller chip keeps a weak HIGH on the **RESn** line itself via a 5 KΩ pull-up resistor, thus you technically do NOT need to pull up the reset circuit, but it won't hurt if you wish to. Additionally, the brown-out circuit will pull **RESn** low if a brown-out condition occurs.

### 3.2 Manual Reset of the HYDRA

To reset the HYDRA manually, simply press the momentary Reset switch located in the front of the HYDRA and the system will reset. During reset, the Propeller chip will look for communication from the PC host, and if there is none, the Propeller will then commence to load from an external EEPROM. If there is no EEPROM, the Propeller chip will go into a low power shutdown state until reset again. If an external EEPROM is found (which is always the case on the HYDRA), the first 32 KB of the EEPROM are loaded in the SRAM of the Propeller, then the Spin interpreter is launched and the code is executed. More details on this process later in Part II.

### 3.3 Reset Via DTR

Historically, the DTR or ***data terminal ready*** line on the serial interface was commonly used to initiate a reset on serial controlled hardware (modems etc.). The HYDRA is designed so that if DTR is pulled HIGH or asserted then RESn will be pulled LOW on the Propeller chip and the entire HYDRA will reset. Referring to the circuit in Figure 3:2, Q5 is normally OFF, thus no current flows in the collector-emitter circuit. However, when the signal USB\_DTRn is driven HIGH with a pulse, Q5 conducts and pulls RESn LOW, therefore resetting the system.



### 3.4 Summary

This was a pretty straightforward chapter; the HYDRA is reset either manually with the Reset switch or electronically via the DTR line or via the RESn line coming in from the secondary backup USB2SER programming port. The one thing to remember is that the RESn line on the Propeller is internally pulled HIGH by a 5 KΩ resistor to 3.3 V, so technically you do not need a pull-up on it, but if you want a really robust design, it can't hurt!

## Chapter 4: USB-Serial Programming Port

In this chapter, we are going to discuss the USB to serial hardware. The HYDRA ultimately uses a simple serial protocol to communicate with the PC, but due to the lack of old style 9-pin serial ports, the HYDRA has both a built-in USB interface as well as a port that supports the Parallax USB2SER device in case you only have a single USB port and you want to program both the HYDRA and other serial devices on your workbench. In any event, here's what we are going to cover:

- ▶ General USB serial overview
- ▶ Parallax USB2SER USB serial interface
- ▶ Onboard USB interface
- ▶ Communicating with the serial interface

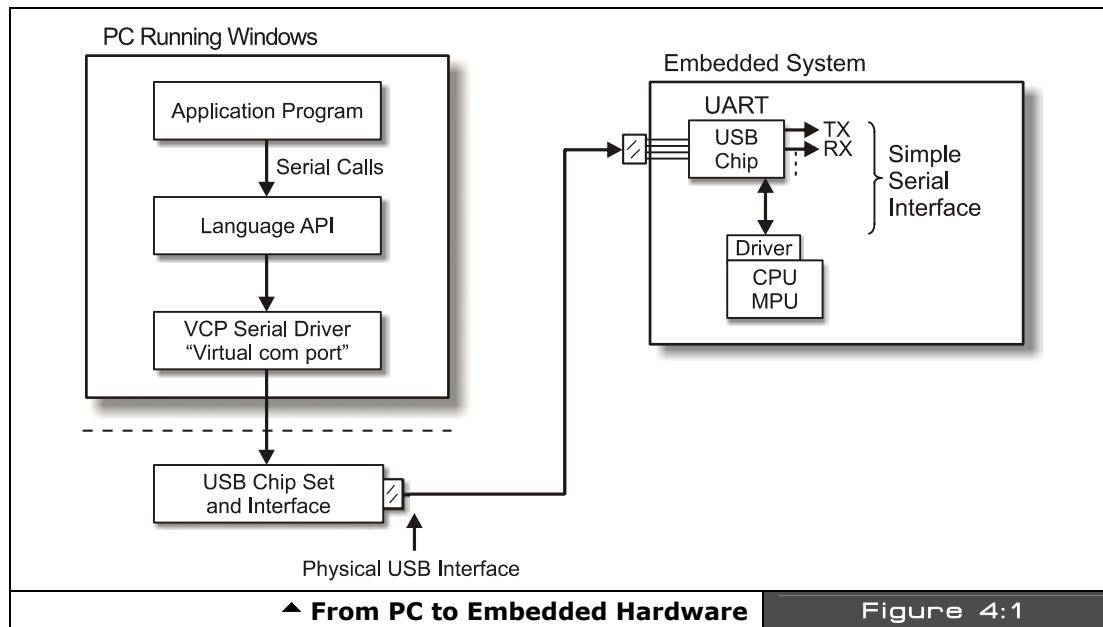
### 4.1 General USB Serial Overview

If you are at all a hardware hacker then you are more than familiar with the tried-and-true RS-232 serial standard. RS-232 is both an electrical as well as protocol standard that has been around for a long time. In the 70', 80's and even 90's every single computer on the planet had a standard DB9 serial port on it and most PCs had two. From a standpoint of interfacing, RS-232 is nearly the simplest of all standards to get up and running, based on a ±12V system to transmit data/receive data a minimal system can operate on a subset of the specification with only the TX (transmit), RX (receive) and GND (ground) lines.

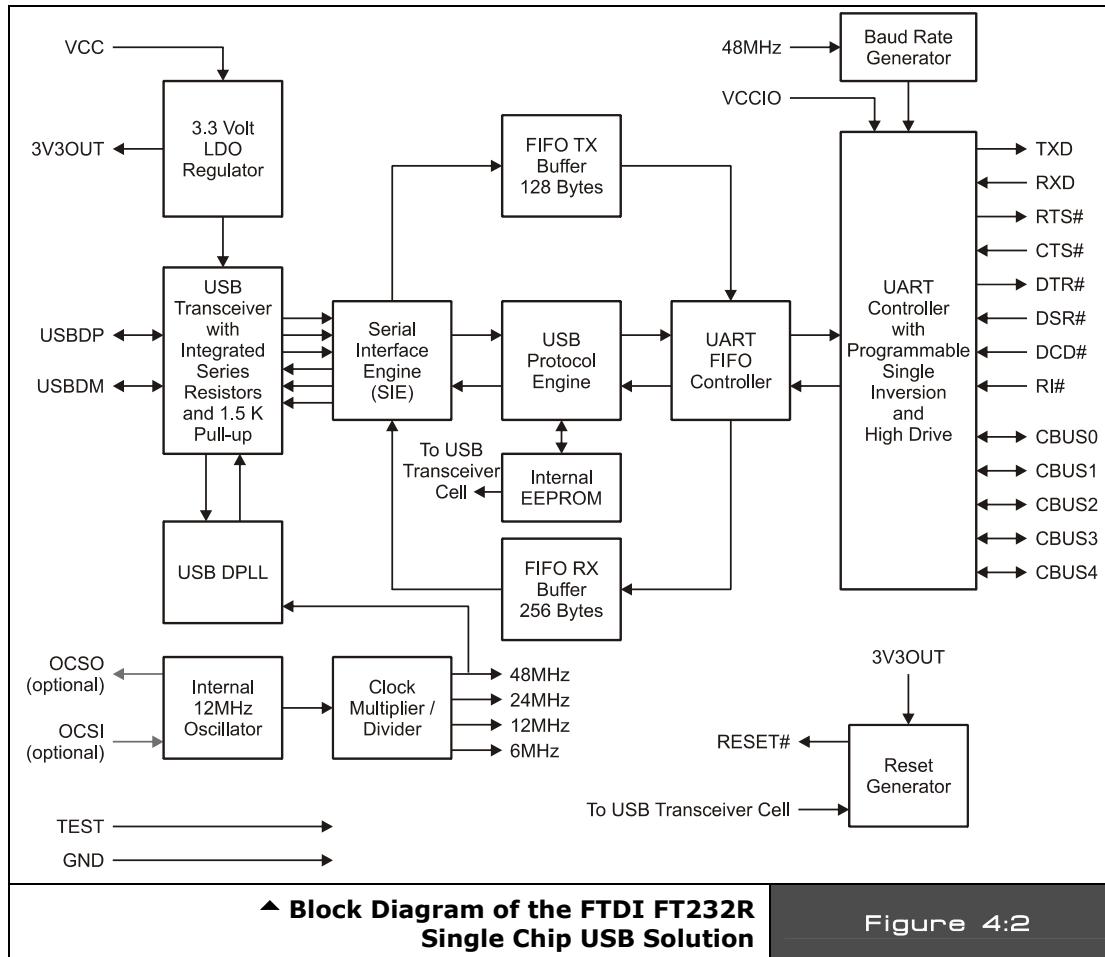
However, since the proliferation of the USB interface, standard serial interfaces have disappeared; in fact, many new PCs do NOT have a single DB9 serial port! This is really bad news for hardware hackers and embedded system enthusiasts, since interfacing to USB is NOT trivial; moreover, the protocol for USB is just as complex as Ethernet! Sure, there are chips that do it, but what used to take a DB9 and a couple resistors now takes a chip, a driver on the PC side, and a lot of trial and error. Nevertheless, we are stuck with USB interfaces, so we have to deal with it.

However, some manufacturers have acknowledged the need for "simple" serial interfaces through USB and designed a number of chips that facilitate this transparent to the user. That is, you use the chip in your design, load the manufacturer's driver into the PC, and then either through an API or virtual COM port, you can communicate to your hardware via the

USB interface as if the hardware were a simple serial interface. On your hardware itself, the chip does the entire protocol interface for USB, and at the end of the day when you send a BYTE to your hardware, the chip sends out on the USB to serial interface coming from the chip the data on the TX line. So in most cases, these special USB-to-serial chips have a "serial" like modem interface on them that you use on your design as if it came from a standard old style RS-232 interface. Figure 4:1 shows the entire data flow from the PC to the embedded hardware, so you can get an idea of everything in between.



So the point is that even if you only have a new USB port, you can still write old-style serial code that talks to COMx on the PC and with one of these USB-to-serial chips, the chip plus driver from manufacturer will make it all work for you. Of course, you still have to design the chip into your system and this can be hard or easy depending on the chip you select. In the case of the HYDRA I opted to use the new FTDI FT232R shown in Figure 4:2.



The FT232R is a pretty slick little chip, and with nothing more than a few resistors, caps, and the physical interface for the USB connector, you have a complete USB solution that outputs a standard serial interface. Referring to Figure 4:2, this is a block diagram of the chip; as you can see at the end of the day, there is a UART-like interface on the top right hand side of the design and this is what you connect to your serial interface on your hardware after you have the chip all hooked up.

Momentarily, we will discuss the hardware around the FT232R chip in the HYDRA itself, but if you want to take a look at the datasheet and a reference design for the chip, I have included them on the CD here:

**CD\_ROOT:\HYDRA\DOCS\DS\_FT232R\_v104.pdf**  
**CD\_ROOT:\HYDRA\DOCS\USB232R.pdf**

Summing up, the HYDRA uses a USB interface physically, but through the use of the FT232R USB to serial interface chip and their associate virtual COM port driver, from the PC's point of view (and the Propeller IDE) the HYDRA interface is a standard serial port. Moreover, from the point of view of the Propeller chip on the HYDRA, the USB port is a simple RS-232 style interface, so everyone is happy and we can use simple serial communications protocols, etc. riding inside of complex USB protocols!

## 4.2 Parallax USB2SER USB Serial Interface

The HYDRA has a onboard USB chip as noted, so you simply connect your PC to the HYDRA and you are off and running; however, as I was working with the design of the HYDRA and experimenting myself, I started with the Parallax USB2SER device to get my first Propeller designs up and running then I embedded the USB solution into the HYDRA itself. Nonetheless, when I finished the HYDRA, I was about to remove the 4-pin USB2SER interface header (1 penny worth of hardware) when I realized that I want to keep it. The reason why is simple: in many cases, you might only have a single USB port for hardware hacking, if you're a Parallax customer then you might already have a USB2SER device that you like to use to connect your other hardware to your PC, then when you want to play with the HYDRA, you would have to unplug the USB cable and plug the HYDRA into the USB port. So for the small percentage of users that have only a single USB port and use the USB2SER device already on their workbench, leaving the little USB2SER header is a good thing, so I did it. Thus, let's start briefly by talking about this interface to the HYDRA.

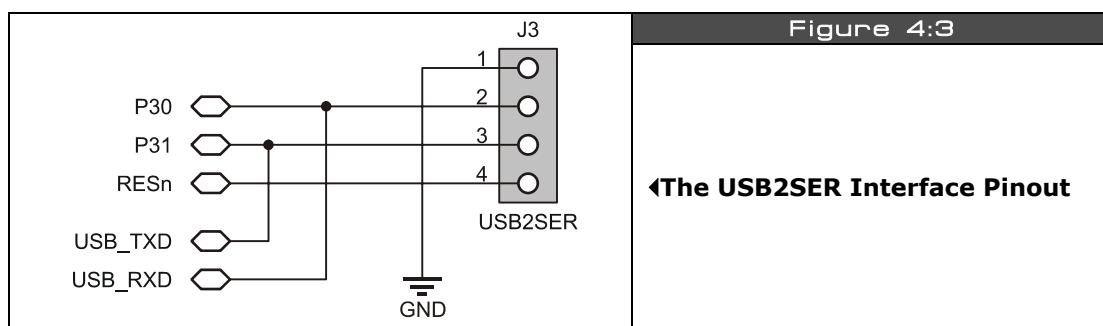


Figure 4:3 shows the hardware pinout and design of the USB2SER interface on the HYDRA. One end of the USB2SER connects to the PC via a **USB mini-B cable**, the other plug or header has 4 signals on it as shown in Table 4:1.

Table 4:1		The USB2SER Header Pinout▼	
USB2SER Pin #	Description	Propeller Chip Connection	
1	GND	GND	
2	RX	P30	
3	TX	P31	
4	Reset	RESn	

The USB2SER header interface is simply connected to the appropriate lines on the Propeller chip and HYDRA and the communications are handled transparently during programming etc. Additionally, once the Propeller chip is programmed and running, the TX/RX lines connected to the USB port at pins P30/P31 respectively can be used to communicate with the PC via the USB connection, thus one can use these to do upstream communication and/or talk with third-party tools you create.

For example, say the HYDRA is connected via the USB2SER to the PC host, and the Propeller IDE is not running, and the HYDRA boots with some onboard program on the EEPROM or cart. There could potentially be an app listening on the PC to the USB (serial port COMx) and with software you write you could download assets from the PC, or whatever. So the important point is that the USB serial connection to the host is freely available **after** programming is done, and the IDE has released the serial port resource connected to the USB port.

### 4.3 Onboard USB Interface

Refer to Figure 4:4; this is the complete design for the onboard USB interface. As you can see, the center of the design is of course the FTDI FT232R chip. The design is more or less based on their reference design along with consideration for some Propeller-specific issues. Of course there are transmit and receive LEDs for example! Anyway, let's briefly discuss some of the issues when interfacing with USB. First, the USB lines are "transmission lines" and thus they must be damped by a terminating network on the receiver end otherwise you will get ringing and reflections. Normally, this means either a serial or parallel termination network; USB specs usually call for a simple  $33\ \Omega$  in series with each of the data lines D- and D+. However, the FTDI chip comes with series terminating resistors, so you don't need them. Secondly, the USB interface starts up in either slow or fast mode; this is controlled by a pull-up resistor connected to the D+ or D- line. To initiate high speed mode, a pull-up from the D+ line should be made through a  $1.5\ k\Omega$  resistor to 3.3 V; similarly for low speed mode a  $1.5\ k\Omega$  pull-up should be connected to the D- line 3.3 V. The FTDI chip handles this for us as well and starts out in high speed mode.

**NOTE**

USB is a differential signaling standard; that is, the difference in voltage is the code, rather than the absolute value. This helps cancel out noise since:

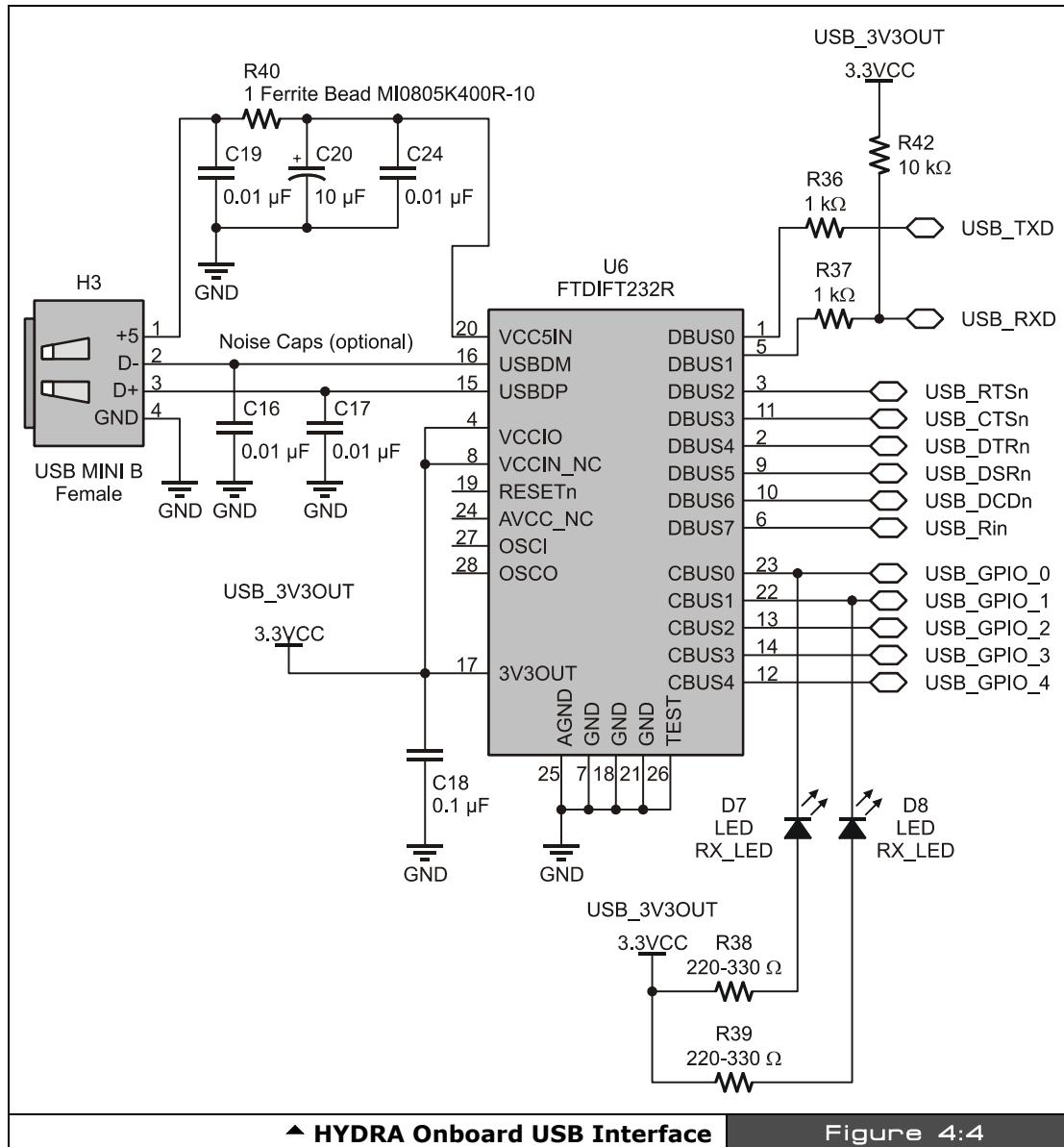
$$[(D+) + \text{noise}] - [(D-) + \text{noise}] = (D+ - D-)$$

That is, the noise cancels out.

Alas, there isn't much for an EE to do with the FTDI chip, it does everything for us. About the only thing you should add to the design are the filtering caps to the interface and power and that's about it. As far as the HYDRA is concerned, the DBUSxx I/O lines on the FTDI chip are all that we are concerned with. In fact, we only need the TX, RX, and DTR line for the HYDRA; however, the rest of the lines are there if you were to ever need them, but they are not exported to the expansion port, so you would have to piggy-back on them if you wanted access.

**WARNING**

Do not connect both the USB2SER interface and the onboard USB cable at the same time. Although this will not damage the HYDRA or the USB chips, the USB chip on the USB2SER and the onboard USB chip on the HYDRA would both potentially be driving the serial TX and RX lines on the HYDRA, and that will cause errors on the system during programming, etc.



Game Programming for the Propeller Powered HYDRA ▶ Page 89

## 4.4 Communicating with the Serial Interface

The USB interface TX and RX lines always go to Propeller chip pins P31 and P30 respectively, as shown in Table 4:1 on page 84. So, all communicating you wish to do will end up on those lines from the Propeller chip's point of view. Now, to communicate with the HYDRA/Propeller chip via the USB interface on the PC, all you have to do is install the VCP (virtual COM drivers) from FTDI (which we already did in Chapter 1) and you can simply open a COM port to whatever COM port the USB is connected to and then use it like you would any COM port with standard C, Visual Basic, or whatever your tool of choice is.

For example, after the Propeller tool is done programming the Propeller chip on the HYDRA, or if you just connect the HYDRA to a USB port with a program already in it, then you can communicate to the HYDRA via serial communications. This is very useful for more advanced applications, tools, and of course debugging. You can write a simple serial driver on the HYDRA that communicates with P31/P30 using a standard serial protocol like N81 at a reasonable speed like 56 or 115 K bits and then send strings to the PC; just run HyperTerminal and you will see the characters on the screen. We will actually do this later in the book.

## 4.5 Summary

The USB interface is one of the most complex interfaces I have ever worked on, and to write drivers, design hardware, etc. is a nightmare, but with a single chip like the FTDI chip and the drivers they supply all these problems go away. Additionally, the problem of DB9 serial ports disappearing the way of the dinosaur isn't an issue. Of course, if you only happen to have an old-style DB9 serial port, then you can probably find a serial to USB converter and still make things work! In any event, if you want to explore USB interfacing in more detail, I suggest reading through the FTDI docs, datasheets, and reference designs, and you also might try picking up a copy of "**USB Complete**" by Jan Axelson.

## Chapter 5:

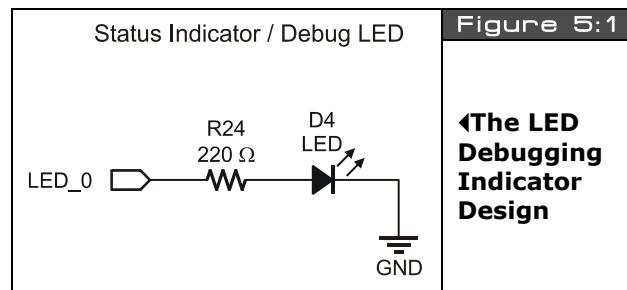
### Debug Indicator Hardware

The Propeller chip has no debugging facilities as of yet. Plans are in place to add debugging to the IDE as well as an API that runs on a cog to help with the debugging, but with the current release of the IDE and tools there is no formal debugging support. Thus, debugging has to be done old school. But, this isn't that bad – I like old school! There are numerous options for this which I will describe momentarily. However, at very least I have put in a single debugging LED, so you can at least use it to indicate "something" is working in your code, and use it for an indicator and debugging tool. In this chapter, we are going to discuss the debugging support on the HYDRA and some ideas to further extend debugging. The topics included are:

- ▶ The debug LED design
- ▶ Additional debugging techniques

### 5.1 Debug LED Design

The only "hardware" for debugging on the HYDRA is the single LED circuit shown in Figure 5:1. The LED is connected to the Propeller chip via port **P0** through a current-limiting resistor. To turn the LED on/off, simply write a 1 or 0 to the port P0 (you will learn about the I/O port communications and more in Part II of this book).



The LED has its cathode to ground, thus a 1 or HIGH on I/O port P0 results in the LED turning ON, a LOW or 0 results in the LED turning OFF.



TIP

Some TTL/CMOS (especially CMOS) circuitry can't source a lot of current, but can sink a lot of current, thus it's a better idea to connect the cathode to the I/O port in that case and use reverse logic to turn the LED on/off. However, this isn't a problem with the Propeller chip since it can source/sink 30 mA per I/O. Of course, you wouldn't want to drive all 32 I/Os at 30 mA, that might be too much current for the chip to handle at one time.

## 5.2 Additional Debugging Techniques

If you are “old school” then you are a master of debugging and can think of 1000 ways to debug code. Using debuggers to debug programs hasn’t been around for that long. In fact, many people still don’t know how to use the debugger in VC++! In any event, it’s “nice” to step through code and watch registers, but there is no “direct” way to do this with the language, IDE, or processor. However, with some clever software we can do this more or less. The first step is to get a simple graphical app working that acts like a “terminal” and runs on a single cog (or the PC), then as you are trying to experiment and debug code you can print to the terminal to “watch” variables. In fact, you can potentially watch single instruction execution by placing hooks in your code to call your terminal update every single instruction. Additionally, you can “synthesize” breakpoints in your code by making a call to your “terminal” or debugger program so that when called it dumps what the cog is doing or memory or whatever and doesn’t return until you hit a key or press the joystick or something like that. So more or less, to debug, think graphically, and think “printf” – try and visualize your code execution by printing state out and using the debugging LED where possible.

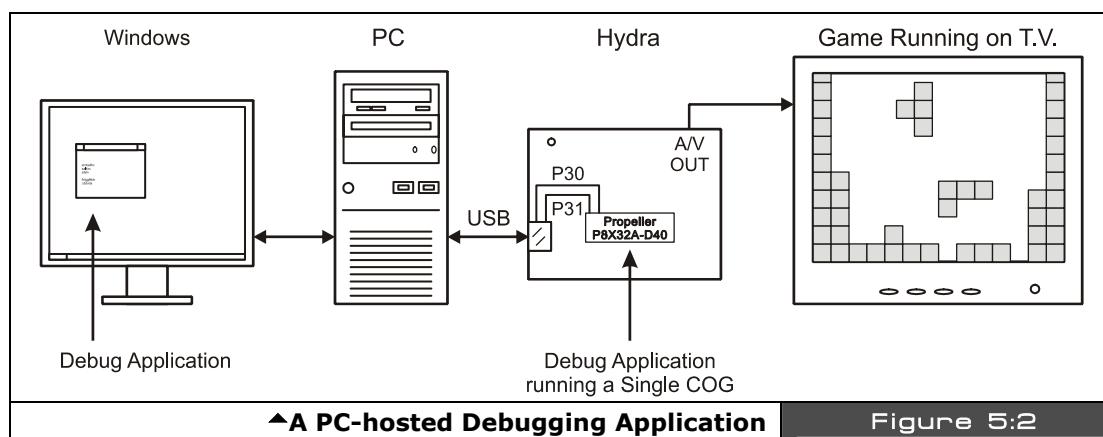


Figure 5:2

Another possibility is to write a PC-hosted app that talks to the Propeller chip over the USB port TX/RX lines, using a single cog to send information to the application as shown in Figure 5:2. For example, you can write an object/program that runs on a cog as a debug client, then you make calls to it and pass it variables to watch something, like this:

```
Debug.Add_Watch(&x, "X position", UNSIGNED_BYTE, DEFAULT_X, DEFAULT_Y, 1000)
```

The intent of this hypothetical call might be to “add” a watch variable to a list with the address of the variable “x”, and indicate that “x” is to be displayed as an unsigned 8-bit value, and on the debugging display print the text “X Position” next to the output and simply place the watch variable at the next available x,y location, finally the 1000 might mean to update every 1000 milliseconds. The debugging client running on a cog would simply add this information to a local list and then it would access global memory or whatever and send it to the PC and the PC host program would do all the display. This way you can have a completely asynchronous debugger running “hidden” on a cog that for the most part does NOT interfere with your game or demo code. Of course, you can’t read a cog’s local memory unless the cog shadows it to global memory.

**TIP**

If you want to you “can” run the Propeller chip at DC and pulse the clock yourself with a single-step button (with debouncing of course), this way you can potentially put probes or whatever on the pins of the chips, or control it. Additionally, you could surround the Propeller chip with some extra debugging hardware that via the PC, you could single-step the chip and so forth. Of course, if you do this then you need to run the Propeller chip’s clock input mode as straight clock in “XIN” mode, without any XTAL reference or PLL modes; more on this later.

Lastly, a really slick way to add a little bit of debugging I/O is with a serial or quasi-parallel LCD. You can buy a number of very simple LCDs from DigiKey or other online vendors and interface them to the HYDRA through the expansion port (which will be discussed later in Part I). Typically, the LCDs take a simple stream of commands to print characters on the LCD and some LCDs even have bitmap displays. Common sizes for monochrome LCDs are 20x2, 40x2, 20x4, and 40x4 characters. Hantronix is one of my favorite vendors, they also make full-color LCDs with entire graphics engines built in, so you could potentially make a plug-in card that had a full color LCD and print debug information to that and forgo the complex PC serial interface.

### 5.3 Summary

In this chapter, we discussed probably the simplest piece of hardware on the HYDRA – the debug LED, but one thing is for certain, a single LED can work wonders when debugging ASM code! Also, we discussed some ideas to get some more advanced debugging techniques online, I highly suggest taking the time and effort to invest in getting your debugging techniques down before you start into heavy coding (in ASM at least) on the Propeller chip, it will definitely save you time in the long run.



## Chapter 6: Game Controller Hardware

Originally I was going to use Atari 2600 joysticks for the HYDRA; however, due to their scarcity and the lack of extra controls on them, the decision was made to go with classic NES (Nintendo Entertainment System) controllers. The primary reasons are that NES controllers are abundant, easy to interface to, have lots of nostalgia, can be interfaced via 4 signal lines, third-party models look really cool, and most importantly, if the HYDRA interfaces to the NES controller then any “NES compatible” device can be interfaced since they all use the same connector! Thus, light guns, VR gloves, and any and all manner of bizarre NES hardware from the 80’s/90’s can be interfaced to the HYDRA through the controller ports, so it’s a good plan. With that in mind, in this chapter we are going to discuss the following topics:

- ▶ Overview of the NES hardware
- ▶ NES controller protocol and interfacing
- ▶ Supporting Super NES controllers

### 6.1 The Classic NES Controller (1983)

If you have never heard of Nintendo, then may I be the first to greet you from Earth, because you must be from another planet! The Nintendo Entertainment System or NES, also known as the Nintendo Family Computer (Famicom) was released in Japan in 1983 and shortly after in the USA in 1985. The system was even more successful than the Atari 2600 and more or less put the last stake in the heart of Atari home consoles forever. The NES sold more than **60,000,000** units worldwide in its heyday and still sells to this day (I just bought 4 of them from eStarland.com)! There are over 200 clones of the system in circulation and the word “Nintendo” is used in many cultures as a youth slang term with many “varied” meanings.

The system itself was nothing compared to the Propeller chip’s computing power, the NES was powered by the 8-bit 6502 running at 1.79 MHz, but the NES did have quite a bit of dedicated graphics hardware making it quite a contender in the 8-bit era, it sported multiple tile maps, graphics planes, sprites, sound, and a lot more. In any event, as noted I opted to use the NES controllers for the aforementioned reasons, plus being an Atari guy, sometimes it’s nice to jump ship and see how the other side lives, so all in all I am very happy with the NES controllers on the HYDRA. They give the system a retro feel, but are powerful enough to use as serious input devices for more than just games. Plus, the final controllers shipped with the HYDRA look very cool.

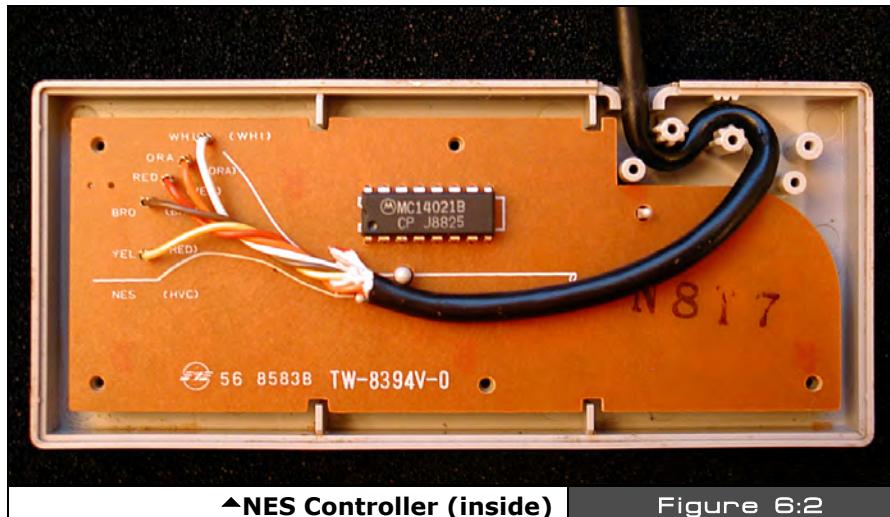


Figure 6:1

▲NES Controller  
(front)

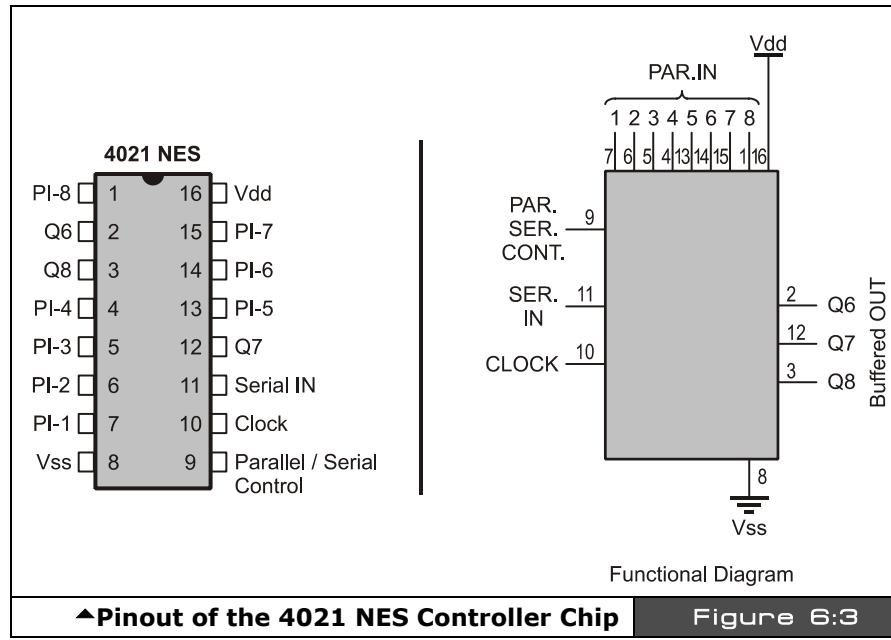
The classic NES controller / gamepad is shown in Figure 6:1, and internal shot is shown in Figure 6:2. As you can see there isn't much to the NES controller electronics (a single 4021 serial chip), but that's the beauty of it. The interface is so simple, we can use 4 lines to interface to the NES controller and read all 8 inputs (Up, Down, Left, Right, A, B, Select, Start).

Of course, we aren't using these collectors' item controllers on the HYDRA, that would be sacrilege; but all NES controllers must be compatible with the original standard, so we are going to discuss NES controllers with the original in mind, but the controller that comes with your HYDRA will be from the 21st century and a bit more sleek in its design.



▲NES Controller (inside)

Figure 6:2



The NES controller is based on a parallel to serial shift register internally that “latches” the button states and then shifts them out to the host. The shift register used in the original NES control is the **CMOS 4021 shift register**. Figure 6:3 shows the pinout of the 4021 and the complete data sheet is on the CD located at:

**CD\_ROOT\HYDRA\DOCS\cd4021b.pdf**

Figure 6:4 shows the HYDRA controller interface for the right and left controllers. As mentioned, all the signals are paralleled except for the JOY\_DATAOUT\_0 and JOY\_DATAOUT\_1 lines since these are the independent data streams from each controller. Also, notice that the LEDs that are connected to the data out lines, the resistors are large enough to minimize current drain, and thus the signals are not degraded, but when the NES controllers are plugged in the weak pull ups on the outputs of these lines power the LEDs and indicate that the controller is plugged in.

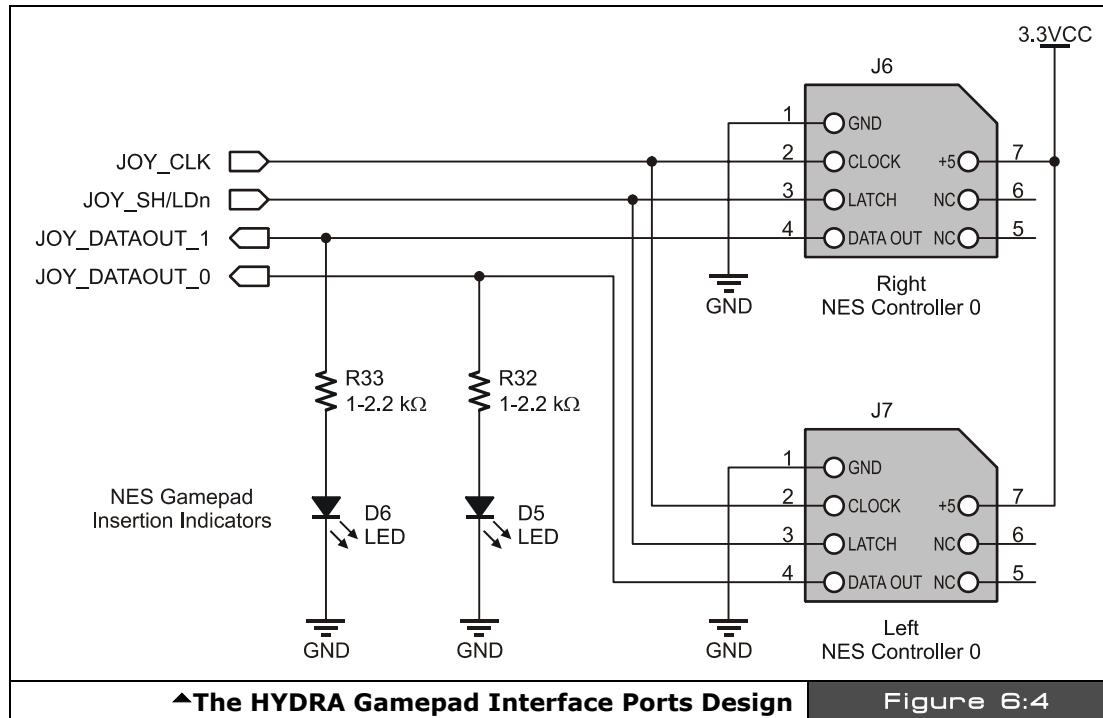


Figure 6:4

The actual pinouts and colors (for the classic NES controller) are shown in Table 6:1. Referring to the table, you can see that the original spec for the NES controllers uses +5 for power. I was a bit worried that the old 4021's wouldn't work at 3.3 V and I would have to Frankenstein the 5 V supply into the NES controller, but then make sure the levels match the outputs and inputs to interface to the Propeller, but the 4021 is a CMOS device and works fine at 3.3 V. Of course, running any CMOS device rated for 3-7 V at lower voltages lowers the maximum clocking rate, but in this context it's irrelevant, since we can read the controller bits at a rate of 200 ns each.

Table 6:1		NES Controller Pinout▼	
Pin #	Function	Wire Color*	Pin on Propeller Chip/Design Designator
1	Ground	Brown	GND
2	Clock	Red	JOY_CLK (P3)
3	Latch	Orange	JOY_SH/LDn (P4)
4	Data Out	Yellow	JOY_DATAOUT_0 (P5), JOY_DATAOUT_1 (P6)**
5	No Connect	None	
6	No Connect	None	
7	+ 5 Power	White	
<b>Notes</b>	* Colors on original NES Nintendo controllers only; 3 <sup>rd</sup> party controllers have different colors. ** Where JOY_DATA_OUT_0 1 are the left and right controller ports respectively.		

**NOTE**

\*These colors are on “stock” controllers ONLY, in fact many third-party manufacturers of NES/SNES controllers not only get the colors wrong, but sometimes use the correct colors and connect them to the wrong pins! The best thing to do is rip the connector apart and see what color is connected to what pin on the 4021 and power supply rails.

## 6.2 Interfacing to the NES Controllers

Interfacing to the NES controllers is a completely digital affair; on the HYDRA for example, we can run the clock, latch, and power lines in parallel, then send the data from each controller (if its plugged in) to the Propeller chip. To read the state of the NES controllers, you must perform the following steps:

**Step 1:** Set the Latch line (P3 on Propeller chip) to LOW (this is connected to the parallel/serial select on the 4021).

**Step 2:** Set the Clock to LOW.

Now, we are in a known state.

**Step 3:** Pulse the Latch line HIGH for at least 200 ns, this will latch the data into the shift register.

**Step 4:** Read the bits in from the Data Out lines at P5 and P6, the first bit will be available after the latching process. To read the remaining bits, pulse the Clock line 7 times, as you are doing this you can shift each bit read from the Data Out line into a BYTE, so that the first bit ends up in the bit7 position and the last bit in the bit0 position. Realize that the HYDRA reads the controllers in parallel, so you can perform the read operation once with some clever bit manipulation.

**Step 5:** The button states are all inverted; that is, pressed is digital 0, released is 1, so you might want to invert the results so 1 means “pressed”, just personal preference.

After performing these steps you simply use bit operations to determine which buttons are pressed. The button encodings are shifted out in the following sequence starting from left to right, where the left-most bit is available on the data out lines after the initial latching operation as shown in Figure 6:5.

Operation	Latch	CLK	CLK	CLK	CLK	CLK	CLK	CLK	Figure 6:5
	bit 0	bit 1	bit 2	bit 3	bit 4	bit 5	bit 6	bit 7	
Data	A	B	Select	Start	Up	Down	Left	Right	◀NES Data Format

Also, a bonus feature of the NES controller is that when you read it on the HYDRA, if the controller is NOT plugged in then the value \$FF will be returned, thus we can use this sentinel to determine if a controller is plugged in or not!



When you latch and clock the bits, remember that the 4021 chip has a maximum clocking rate. I suggest keeping the clocks 200 ns or greater to allow for settling and propagation delays, you don't want to loose the fire button bit under a high stress condition if you are reading the controller too fast!

### 6.3 Super NES Controller Interfacing (1990)

Again for a quick history lesson: the new 16-bit system, Super Nintendo (SNES), was released in Japan in 1990 and 1991 in the USA. The system once again became an instant hit and sold a total of 50,000,000 units worldwide, thus making the combined sales for NES and SNES in excess of 100,000,000 units!!! The SNES had better graphics and a much more powerful 65816 processor (basically a 16-bit version of the 6502) running at 1.79 – 3.58 Mhz in a “variable” speed mode of operation. The overall design of the SNES was a little more sleek and updated, and of course they updated the controllers as well. The new controller has a few more buttons, but the underlying protocol for reading the controller is the same. Additionally, the mechanical interface for the SNES controller (shown in Figure 6:6) is even more bizarre than the NES controller.

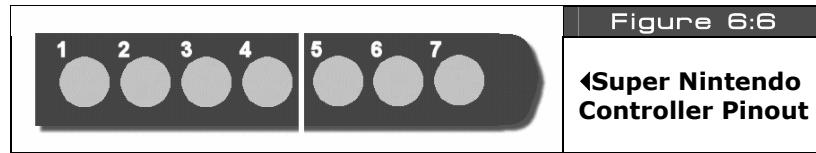


Figure 6:6

◀Super Nintendo Controller Pinout

The Super NES controller is almost identical to the NES controller as far as the protocol goes, so the techniques here are applicable to the SNES controller as well. Figure 6:6 shows the pinout of the Super NES controller and Table 6:2 lists the pinout.

Table 6:2		Super NES Controller Port Pinouts▼	
Pin #	Function	Wire Color	
1	+ 5 power	White	
2	Clock	Yellow	
3	Latch	Orange	
4	Data Out	Red	
5	No Connect	None	
6	No Connect	None	
7	Ground	Brown	

The only difference is that the Super NES streams out 4 more bits representing X, Y, R (right shoulder button), and L (left shoulder button) which makes for a total of 12 bits. However, Nintendo opted to add 4 more cycles for future expansion and made the read protocol a total of 16 bits as shown in Figure 6:7; notice the last 4 bits are always HIGH, or 1s.

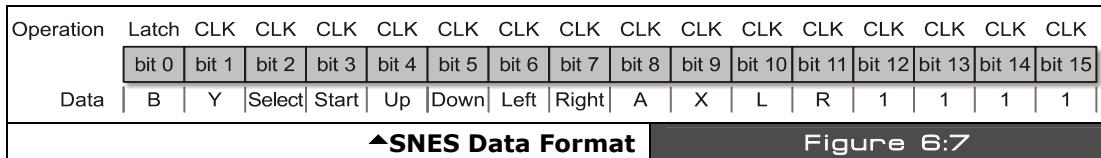


Figure 6:7

## 6.4 Summary

In conclusion, the NES controllers are pretty slick internally since they simplify the HYDRA's need for support hardware due to their built in serializing chips. Also, hopefully you can appreciate how simple and brilliant they were. A piece of software or hardware is seen through its interfaces or GUI; this is true with Windows and true with game consoles, so considering that, any idea that helped sell 100,000,000 units is worth taking a closer look at!

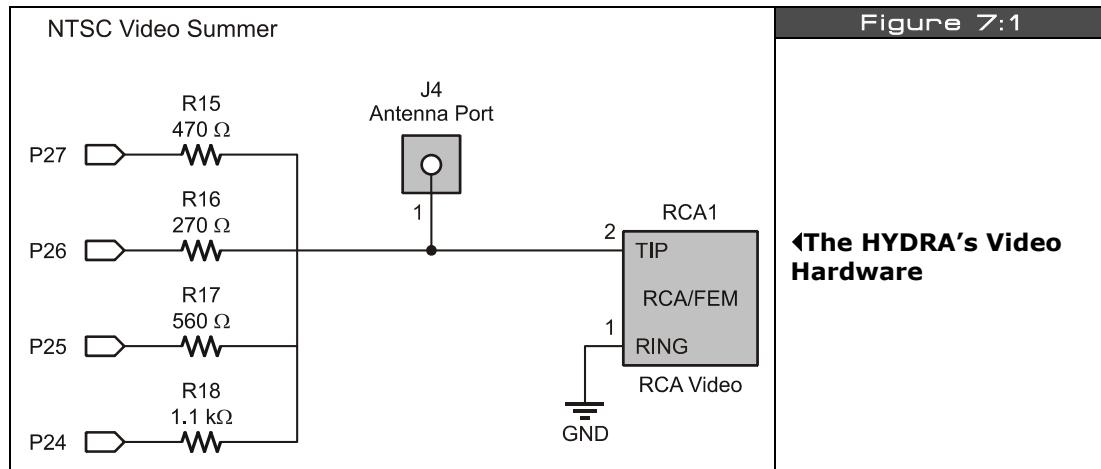
## Chapter 7:

### Composite NTSC / PAL Video Hardware

In this chapter, we are going to take a look at the composite video hardware for the HYDRA and take a brief look at basic NTSC concepts. This is by no means a treatise or even a tidbit about NTSC video generation, later in the chapter I will give you some good book titles and a website to read about NTSC/PAL video engineering. For the HYDRA though, we are for the most part simply going to use the drivers that Parallax, myself, and other coders have written in ASM to generate video and use them as black boxes, as objects, or as functions included in our programs. So without any further ado, here's what's in store this chapter:

- ▶ HYDRA composite video hardware
- ▶ The Propeller chip's video streaming unit hardware
- ▶ Brief NTSC primer

### 7.1 HYDRA Video Hardware



The HYDRA has very little hardware for video. In fact, all the video generation and timing is done within the Propeller chip itself via a mixture of software and hardware; there is no

dedicated GPU, no VRAM, or frame buffer of any kind. Later we will discuss this in detail in Part II, but for now realize that each cog has what's called a "**Video Streaming Unit**" or **VSU**. The VSU of each cog can run independently and more or less simply serializes a stream of data that you pass it in 32-bit chunks. The data is formatted in such a way that it either assumes you are driving a NTSC/PAL device (with a resistor summing network on the output port) or an RGB device (BYTE device with no electronics on the output port) like VGA. The hardware you place on the outside of the Propeller chip to make the internal hardware work is minimal at best. Figure 7:1 shows the actual video hardware for the composite NTSC/PAL signal.

It's more or less a simple 3-bit D/A resistor network (R16, R17, R18) and the 4<sup>th</sup> bit (R15) is for audio modulation when the cog is in RF modulation mode (yes, the cogs can transmit video via RF if you hook a wire to the output at J4!). The resistors are selected such that with a 3.3 V supply and the signal terminating into a  $75\ \Omega$  load (TV load) the maximum voltage will be approximately 1.0 V when all the lines are HIGH (P26..P24), this is WHITE and 0.0 V is SYNC level.

Referring to the circuit, the cog's internal hardware assumes that you have hooked up a resistor network such as that shown in Figure 7:1 to a 4-bit port of the cog and then you use a couple of special instructions to set up the video configuration registers and "feed" the VSU with pixel and color data. So you could say that the Propeller chip uses hardware to stream pixel data out to a 3-bit DAC, that you feed it. The pixel data might be **sync, black**, or **luma, chroma** data (more on this in the NTSC primer below), the cog will output the proper voltage via the DAC along with the proper phase delay for chroma (color) since it knows you are driving NTSC/PAL video hardware (if you configure it this way), but that's all the VSU does.

Additionally, the VSU can work in "dumb" byte-oriented data mode and simply send out BYTES of data, this mode is used to drive VGA of the format RGB (2.2.2) plus Hsync and Vsync, that's a total of 8 bits or one BYTE per output. In this mode, you basically pass the VSU VGA values and it sends them out each clock at 25.175 MHz (VGA clock rate). The NTSC/PAL hardware is very minimal since the cog does all the work. The only downside is that the timing and data feed to the cog's VSU unit must be done with software, and a "**feeder**" loop more or less can only be done with very tight ASM code. Moreover, the cog's video hardware formats that output to the 3-bit DAC only allow 16 colors with a 3-4 shades depending how close you want to go to the sync and white rails. And there is **no** general control on saturation, but there are some tricks to get extra saturated colors in addition to the standard colors (more later during graphics programming in Part III). Therefore, you can control luma and chroma, but not saturation. Nonetheless, you will find that the saturation of colors generated is very pleasing.

**NOTE**

Generating NTSC or PAL is not a matter of hardware, but a matter of software, that is, how you send data to the VSU and time the signal.

SECAM (a French standard loosely meaning “*sequential color with memory*”) on the other hand is a whole other ball park, but can be generated with the VSU as well if you really want to do it.

It's worth mentioning that the VSU is nothing more than a serial streaming unit (not necessarily only for video), it can generate video of any rate at the output, so there are no real limits to the speed you can update video. The downside is that you must use the internal 32K program RAM for video memory. This can be quite disturbing in Spin code, since Spin BYTE codes must reside in main memory, so you will find the demos and games you can make that drive bitmapped video are very constrained since you eat up so much RAM to support double buffering etc. However, in ASM, you have quite a bit of room and crazy demos and games can be made.

Lastly, even though the HYDRA only has one video output, each cog has its **own** VSU that can work independently of other cogs, thus you could potentially drive 8 TV's at the same time with different displays or demos if you wanted to add the resistor networks to each!

## 7.2 Brief NTSC Primer

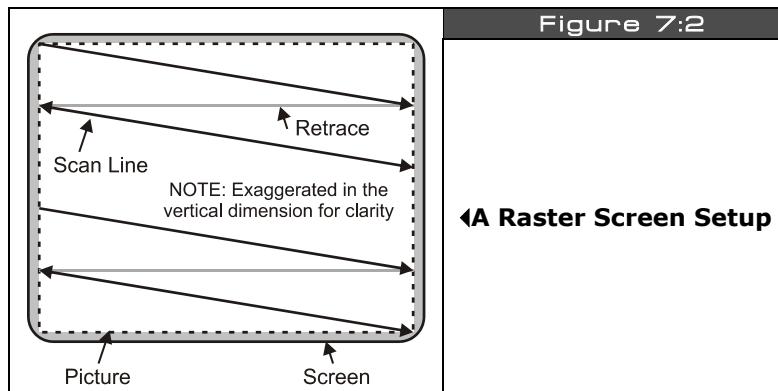
The NTSC standard) is technically referred to as the RS-170 and was ratified in 1941, later color was added and the full standard was updated to RS-170A. NTSC (National Television Systems Committee) is an analog standard designed to be easy to generate and easy to decode. Also, the standard had to be very forgiving. It's amazing that over a half century has passed and NTSC still gets the job done. To cover NTSC in any detail would take a whole book, therefore, we are only going to briefly discuss it, and take more of a hands-on, black box approach when we get to graphics programming. Rather than worrying about generating NTSC signals yourself, the drivers I will provide you with will take care of it. With that in mind, let's take a quick look at NTSC and its underlying principles.

### 7.2.1 Basic Monochrome NTSC

NTSC is designed to be displayed by a raster device, that is, a CRT (cathode ray tube) that draws images a frame at a time, where each frame is composed of a number of horizontal lines.

The rendering device, usually a CRT's electron gun, starts at the top left corner of the screen and draws a line or row of pixels by emitting a stream of electrons toward the phosphor-coated CRT, then when the electron(s) strikes the phosphors they give off light and you see a pixel (monochrome or color, depending on the type of phosphor).

Figure 7:2 shows how the NTSC signal is drawn. As the beam of electrons reaches the right side of the screen, a sync pulse referred to as the **horizontal sync** or **Hsync** instructs the CRT to retrace back to the left to draw another line. When the screen is completely drawn then another sync pulse referred to as the **vertical sync** or **Vsync** instructs the raster beam to make its way back up to the top left and the process starts again.



The standard NTSC screen is composed of **525** lines, where each line consists of about **227** "**pixels**" (picture elements). The 525 lines are broken into two interlaced "**frames**", where each frame is **262.5** lines and the frames are drawn at a rate of **60** frames per second (FPS); interlacing these two frames together results in a "fused" display at **30** frames a second. However, for graphics and games, we don't use interlacing typically, and we simply draw only **262.5** lines at **60** FPS.

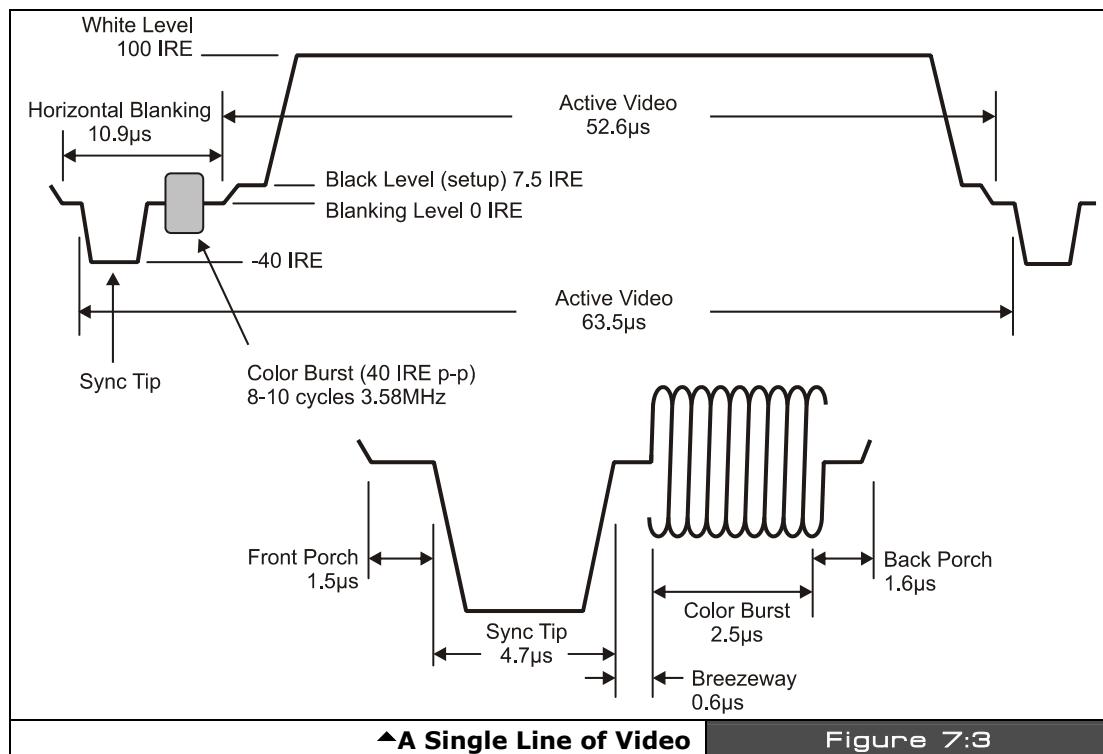
The NTSC signal itself is composed of an analog voltage from 0 to 1.0 V or sometimes from 0 to 1.4 V. The voltage represents different things to the decoder on the TV. A voltage of 0 V means "sync," 0.25 means **blanking level** or "**blacker than black**" and a little bit above this (say 0.3 V) is black, and anything from black to the maximum voltage of 1.0 (or 1.4 V) creates shades of gray, and the maximum voltage (1 or 1.4 V) is **white**. Thus, the NTSC signal is more or less an amplitude-modulated "luminance" signal with syncing information embedded into it as well as color (more on this in a moment).

### 7.2.2 Dissecting a Video Line

Figure 7:3 depicts a standard NTSC video line (not to scale of course), there are a number of specific regions that make up the signal. First, an entire NTSC video line is always  $63.5 \mu\text{s}$ , that means that each line is rendered at a rate of  $(63.5 \mu\text{s})^{-1} = 15.748 \text{ kHz}$ . Now, let's inspect the video line carefully: it starts off with a **horizontal blanking period**, this is the time when the electron gun is sweeping back from the right edge back to the left after drawing a line of video.

The horizontal blanking period is composed of 5 major elements:

- ▶ Front porch ( $1.5 \mu\text{s}$ )
- ▶ Sync tip ( $4.7 \mu\text{s}$ )
- ▶ Breezeway ( $0.6 \mu\text{s}$ )
- ▶ Color burst ( $2.5 \mu\text{s}$ )
- ▶ Back porch ( $1.6 \mu\text{s}$ )



**Front Porch (1.5 µs)** – The front porch is really just the end of the last video line or the beginning of the current line; it's 1.5 µs in length and should be set to the blanking level or blacker than black. In practice the blanking level and black can usually be the same value and 0.25-0.3 V works fine.

**Sync tip (4.7 µs)** – The sync tip, or Hsync to be more precise, is very important; this instructs the TV to initiate the horizontal retrace. The signal itself has a frequency of 15.748 kHz, but is very short, just a sliver really, but the TV electronics are looking for it. The sync tip should be at 0.0 V.

**Breezeway (0.6 µs)** – The breezeway is the period right before the "**color burst**" (which we will discuss shortly) and simply gives the TV a moment to catch its breath before the very important color burst reference tone is sent. The color burst enables the transmission of color in the old black and white signal in a very ingenious way, more on this shortly. The breezeway should again be at the blanking or black level.

**Color burst (2.5 µs)** – The color burst is 9-10 cycles of a 3.58 MHz reference tone, this is locked onto by a phase locked loop in the tuner of the TV and then used as a reference for the color signal. The color burst itself should ride on the blanking level with a peak to peak value of about 0.25 V.

**Back porch (1.6 µs)** – The back porch follows the color burst, and is more or less simply the time after the color burst, but before the active video signal.

Ok, that's the horizontal blanking signal in its entirety, this must be sent at a rate of 15.748 kHz and the entire length of the signal is simply the sum of the constituent parts. The next portion of the video line is the "active video" and this is where all the action happens.

The active video portion of the video line is **52.6 µs** long and is nothing more than an amplitude-modulated signal where the luminance, referred to as "luma" in literature, is encoded as the amplitude of the signal at any one time from black (0.25 V) to white (1.0 V). Now, when talking about a monochrome or black-and-white signal, you could change this signal at any rate you want; however, you are band-limited to about 4.5 MHz on an average TV. In other words, the maximum number of luma changes that the TV can keep up with is about  $52.6 \mu\text{s} / (4.5 \text{ MHz})^{-1} = 234$  per active video line! Ouch! And it gets worse with color, so prepare yourself. Thus if you are trying to map a 640 pixel screen to the TV, you are way out of luck, at most you will be able to see 234 pixels and in reality a lot less, they tend to blend into each other.

**NOTE**

You may have noticed that in the TV signal diagram there is a unit of measure called "IRE" this stands for "Institute of Radio Engineers." There are a total of 140 IRE units in a TV signal from sync to white.

Now here's the clincher: depending on what reference you use and what set you use, 140 IRE units are usually mapped to 1.0 V OR 1.4 V – that's where this 1.0 -1.4 V discrepancy comes into play. However, for all intents and purposes, I have never found a set that wouldn't work with either scale.

In other words, NTSC is so forgiving and so adaptive that whether you use 1.0 V for white or 1.4 V for white, the entire system will work just fine. The HYDRA for example uses a 1.0 V scale for video.

Additionally, the resolution is not only limited by the input bandwidth to the set, but physically by how many phosphors are actually on the front of the TV screen and how fine the "mask" is that lets the electrons through, and so forth. There are lots of factors, but these all new sets are very resolute and can handle even higher resolutions than the NTSC spec specifies.

Anyway, the image is composed of 262 of these video lines, you simply generate the blanking signal at the beginning (end) of each line (however you want to think of it) then stream your pixels out of your D/A and amplitude modulate them based on their brightness in your image buffer from black to white. When you have drawn all 262 lines of video (remember for games and graphics we typically do not interlace) then you need to tell the electron gun to retrace back for another frame; this is called the "***vertical blanking period***" and we need to generate a vertical sync pulse to make this happen.

### 7.2.3 Vertical Blanking Period

If you know anything about video game programming then you have heard about the "vertical blank" – this is the time when the electron gun is retracing from the bottom of the screen to the top, and a literal "eternity" of time to do graphics and game processing. In fact, on early systems like the Atari 2600, 800, C64, Apple II, NES, etc. if it weren't for the "***vblank***" many games would be impossible since there is so little time between feeding the video hardware pixels to do game computations.

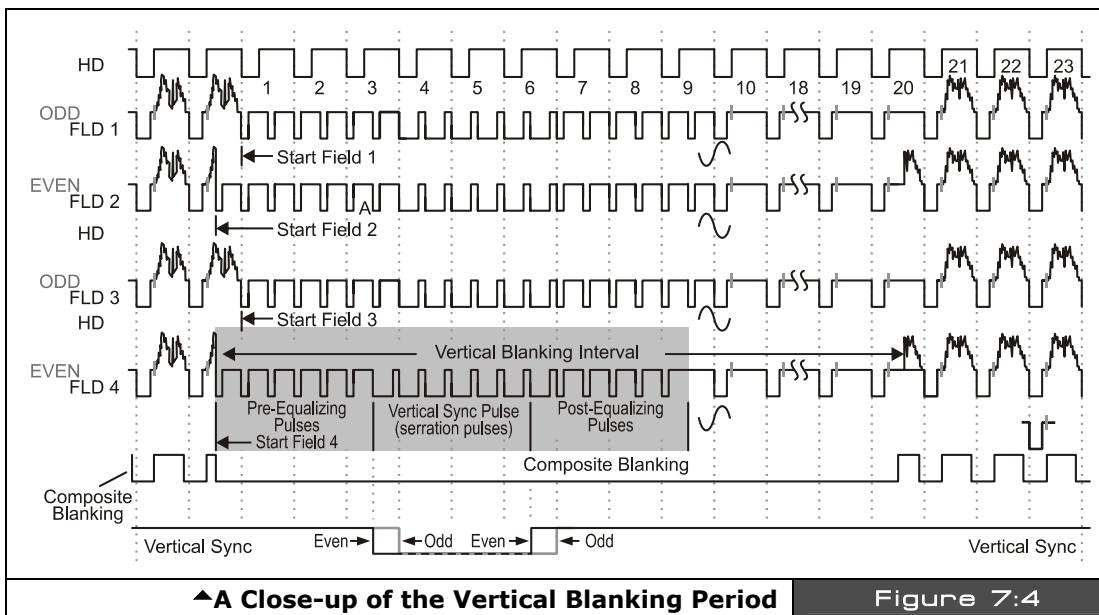


Figure 7:4

Figure 7:4 shows the complete NTSC spec for what's called a "**super frame**." In reality, as the 525 interlaced lines are being drawn as 2 frames there are actually 4 different flavors of slightly different frames then it repeats, but this is irrelevant unless we are making a DVD player or broadcasting CBS. In our case, all we care about it is following the spec close enough. With that in mind, take a look at the shaded area in the figure near field 4, which shows a typical vertical blanking signal. The vertical blanking interval is composed of three major parts that make up a total of **18 lines** of video. Thus, given a screen is **262 lines total**: with 18 for the vertical sync, there are  $262 - 18 = 244$  lines of "**visible video**." Given that, the different phases of the vertical blanking period are:

- ▶ Pre-equalization pulses (6 lines of video)
- ▶ Vertical sync pulse (6 lines of video)
- ▶ Post-equalizing pulses (6 lines of video)

**Pre-equalization pulses** – These pulses are nothing more than Hsync-only pulses that prepare the vertical retrace circuitry for the upcoming vertical sync pulse while keeping the Hsync circuitry locked. There are 6 lines of video that make up these pulses, and they are nothing more than 6 blank lines with just Hsync in them, no color burst, no video.

**Vertical sync pulse** – This is where the action takes place. There is a 6-video-line-long sequence of nothing but Hsync pulses, but they are inverted, that is instead of being at black

and dropping to sync for 4.7 µs, these pulses, referred to as "**serration pulses**" are at sync the entire video line, then for 4.7 µs come back to the blanking or black level. This is filtered by the Vsync filter on the set and gets through to the vertical retrace hardware, but at the same time keeps the Hsync hardware synchronized as well.

**Post-equalization pulses** – These pulses are nothing more than Hsync -only pulses that allow the horizontal sync hardware to catch back up with the signal after the large vertical sync pulse. There are 6 lines of video that make up these pulses, and they are nothing more than 6 blank lines with just Hsync in them, no color burst, no video.

When it's all said and done the total number of wasted lines is 18 for the entire vertical blanking process, so you have the remaining 244 lines to draw your video. However, there is another issue to address – overscan. Overscan is the portion of the screen both vertically and horizontally that you can't see. This anomaly is due to mechanical interfacing, the CRT itself, and other manufacturing issues. Thus, typically, the top and bottom 10-20 lines of video on most TVs are unviewable, thus most game systems center the video and display 192-200 lines of video. Of course, you can render on the overscan area if you wish, but then just make sure to not put scoring information or other vital stats there, since on some TVs users won't be able to see the data, considering that most graphics engines stick to 192-200 lines with 224 being the max (224 is used since it's a multiple of 8 and 16 and those are common bitmap tile sizes).

Additionally, since you don't need to send out active video luma information during the vertical blank and overscan periods, these are the best times to update game logic and/or prepare the next frame of video data. For example, when developing graphics and TV drivers for the Propeller, the vertical blank and overscan times can be used to pre-process video data and get it ready for rendering during the active scan portion of the screen rendering. The reason why is that during the actual rasterization of the screen there is little time between pixels to do calculations, so pre-computing addresses, buffering data, and so forth can be done in the blanking periods then passed on during the rasterization periods.

Let that all sync in (pun intended), and let's talk about color!

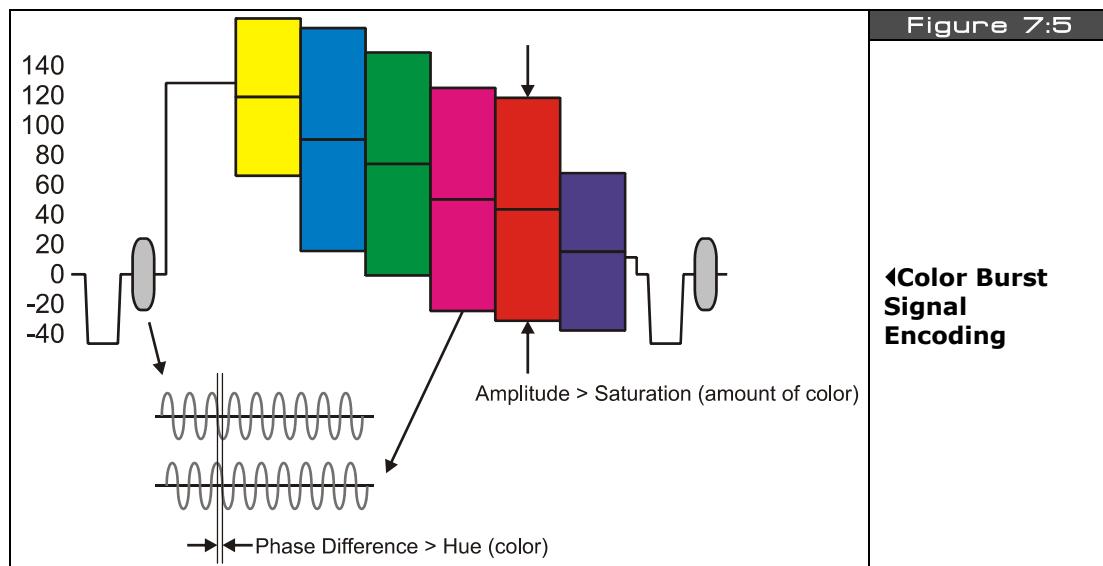
#### 7.2.4 Adding Color to NTSC

Adding color to the NTSC signal is probably one of the greatest hacks in electronics history. After the initial format specification for RS-170 in 1941, engineers, doing what they do best, improved the system and added color to both the cameras and the CRTs. The only problem was that they simply couldn't tell the USA and other adoptive countries to just change the signal specifications overnight. Moreover, hundreds of thousands of B/W TVs were already in use if not millions, so a new broadcast signal format was out of the question. However, color would be added, it had to be "hidden" in the current NTSC B/W luma only signal and it had to not interfere with a standard B/W set. Thus, if a broadcast was sent in full color a B/W set could still pick it up and display it and it would look good, but at the same time, anyone

dishing out the big dollars for a color TV would be able to see the Technicolor version of "Wizard of OZ" in all its glory. The first color TVs and systems were deployed in the USA around 1953 and it went flawlessly. The question is how did they do it?

Referring back to Figure 7:3, you see the section of signal after the Hsync pulse, this is called the color burst. In a luma-only NTSC signal from the 40's you wouldn't see this, but in a color signal from 1953 and on, you would. This little region in the original NTSC signal wasn't used for anything, just a few microseconds before the actual luma signal was sent, but it was enough time for a brilliant hack for the color. The idea was that in this color burst region, the NTSC signal would modulate onto the blanking signal 9-10 cycles of a 3.58 MHz sine wave. This 3.58 MHz signal was decided to be the carrier frequency of "color." So the new color TVs would look for this 3.58 MHz signal via a signal trap tuned to 3.58 MHz, if present then the signal is a color signal and an internal phase locked loop (basically a method to lock onto the frequency and phase of a signal) locks onto and synchronizes the TVs internal color hardware to the signal. So by the time the luma signal portion of the NTSC signal is received the TVs tuner is locked onto the 3.58 MHz color burst as well.

Now comes the ingenious part: the 3.58 MHz signal is above (for the most part) the maximum bandwidth of the luma signal, so anything at 3.58 MHz and above is usually filtered out of the luma and ignored (I know I said most sets have a bandwidth of about 4.5 MHz, but bear with me), so if a 3.58 MHz signal is modulated on the luma signal then we can filter it and look at the signal. So what though? Well, the trick is that instead of the amplitude of the 3.58 MHz that is modulated on the luma encoding color, the phase shift or difference encodes color. Take a look at Figure 7:5 to see this.



In real-time as the luma signal is sent, the phase of the initial color burst after the Hsync is used as a reference point for color, so you basically continually send the 3.58 MHz signal modulated on your luma signal, and the phase difference from the color burst reference signal and the current 3.58 MHz signal is the actual color! Moreover, the saturation of the color or its richness is the local amplitude of the 3.58 MHz signal modulated on the luma. The color signal overall is called the chroma signal. Again, Figure 7:5 has the vertical scale in IRE units, but depending on what the overall range is the chroma saturation usually ranges from 0.1 - 0.3 V, where 0.1 V is washed out and 0.3 V is deep color.

Now, taking all this into consideration, the maximum number of pixels you can have color changes on a standard NTSC TV can be calculated as follows. Given:

Color burst frequency = 3.58 MHz, or 279 ns per cycle.

The visible portion of the active video is 52.6  $\mu$ s.

Therefore, the total number of individual perceivable colors changes per active video line is, or "**Color Clocks**" is:

**Color Clocks = 52.6  $\mu$ s / 279 ns = 188.**

That's it! Not, 320, not 256, but a measly 188! Of course, you can overdrive the color, and maybe people do. In fact, on the HYDRA, many demos drive the color at 256 pixels per line, however, if you were to take a magnifying lens and look at each pixel individually, you couldn't see the color, you need a couple pixels next to each other before the color stabilizes. This is why on old game systems you see resolutions like 160 or 184 across (both multiples of 8), they are both within the bandwidth limit of the color on NTSC. On the other hand if you are writing bitmap games and want higher resolution, it surely won't hurt to have 224 or 256 pixels per line (which are common), you simply won't be able to make out single pixel colors, but when many pixels are combined you get a "free" blurring / anti-aliasing effect which makes things look really good. But do not try this with text, you will see lots of "color artifacting," that is, you have one pixel with one color, then try and put another next to it, and they both change color! This is caused by over-driving the color bandwidth of the TV. Therefore, if you want really crisp text, try suppressing the color signal altogether (which is easy with the HYDRA and Propeller chip) then only using color with games and graphics.

### 7.3 Summary

The composite video hardware on the HYDRA is almost embarrassing since the Propeller does all the work for us, in fact, the Propeller really doesn't have much video hardware either, it's all in the software that generates video. The only hardware the Propeller has is the VSU unit which is a glorified serial shift register, but this is all we need to generate NTSC, PAL, or whatever since we can use software to synthesize the various timings and analog voltages needed for video.

If you are interested in learning more about NTSC and all the myriad of video standards in the world (there are dozens of variants of PAL for example), be sure to pick up "**Video Demystified**" by Keith Jack as well as "**Video Engineering**" by Luther and Inglis, neither are for the faint of heart, but **Video Demystified** is a bit easier to read. Also, there are numerous websites online about NTSC standards, one of the most complete, albeit ugly, is:

[www.ntsc-tv.com](http://www.ntsc-tv.com)

## Chapter 8: VGA Hardware

In this chapter, we are going to take a look at the VGA hardware on the HYDRA. The VGA hardware is a little more exciting than the composite video hardware, in fact, the VGA design actually uses an external chip and a few more components than just resistors, so I am excited. Also, in this chapter we are going to briefly take a look at the VGA spec, so you have a conversational understanding of it and why VGA is both good and bad from a video generation point of view. So, here's what's in store:

- ▶ VGA origins
- ▶ HYDRA VGA hardware design
- ▶ VGA signal primer

### 8.1 Origins of the VGA

Before we start into the design, let's get some history and terminology correct. First, the last time I saw a real VGA monitor was about 20 years ago, the new 21st century monitors that you are used to are super-sets of VGA; they are typically multisync, variable refresh, and can go up to  $2400 \times 2400$  or more. The "VGA" specification is more of a base point than anything anyone actually uses anymore. IBM released the VGA or "Video Graphics Array" technology in 1987 roughly. It was touted to change the world (definitely an improvement from CGA and EGA), but it was doomed from the start with not enough resolution. Shortly after, higher resolution monitors were available and the VGA specification was enhanced with the Super VGA standard, but this was only a momentary hold on its execution; what was needed was a more progressive standard that could change at any time, and thus the VESA "Video Electronics Standard Association" graphics cards and drivers were created and the rest is history. However, the original specs for the VGA are shown below.

- ▶ 256 KB Video RAM
- ▶ 16-color and 256-color modes
- ▶ 262,144-value color palette (six bits each for red, green, and blue)
- ▶ Selectable 25 MHz or 28 MHz master clock
- ▶ Maximum of 720 horizontal pixels
- ▶ Maximum of 480 lines
- ▶ Refresh rates up to 70 Hz
- ▶ Planar mode: up to 16 colors (4 bit planes)
- ▶ Packed-pixel mode: 256 colors, 1 BYTE per pixel (Mode 13h)
- ▶ Hardware smooth scrolling support

- ▶ Some "raster operations" (Raster Ops) support to perform bitmap composition algorithms
- ▶ Barrel shifter in hardware
- ▶ Split screen support
- ▶ Soft fonts
- ▶ Supports both bitmapped and alphanumeric text modes

Standard graphics modes supported by VGA are:

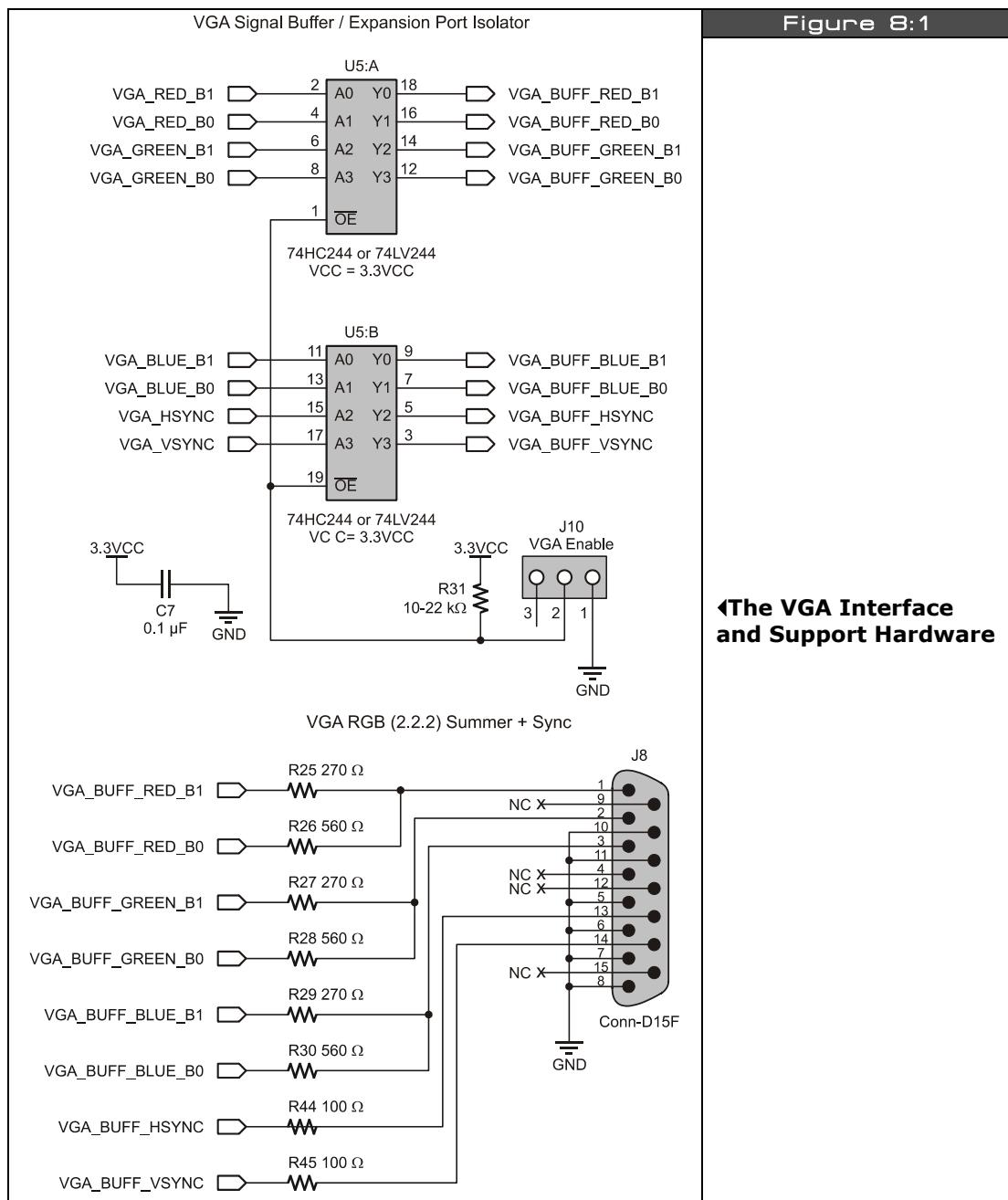
- ▶  $640 \times 480$  in 16 colors
- ▶  $640 \times 350$  in 16 colors
- ▶  $320 \times 200$  in 16 colors
- ▶  $320 \times 200$  in 256 colors (Mode 13h, "chunky graphics mode")

I spent many years writing graphics algorithms and drivers for VGA cards, now my cell phone has better graphics! However, the VGA spec is great for baseline computer displays and any standard modern computer monitor will display old school  $640 \times 480$  VGA modes and refresh rates. This is the design focus on the HYDRA's VGA output, to simply drive a standard VGA monitor at  $640 \times 480$  resolution at 60 Hz refresh rate.

## 8.2 VGA Design

The VGA hardware for the HYDRA is very minimal since the Propeller chip is doing all the signal generation with the aforementioned VSU in the previous chapter. However, to facilitate the use of the expansion port, I have added a buffer on the VGA output port to isolate it when you are using the IO bus on the expansion port which shares the same I/O pins. Otherwise, when not driving the VGA port, if you had a monitor attached your random I/O activity would potentially drive or damage the VGA monitor. Figure 8:1 shows the final design of the VGA hardware.

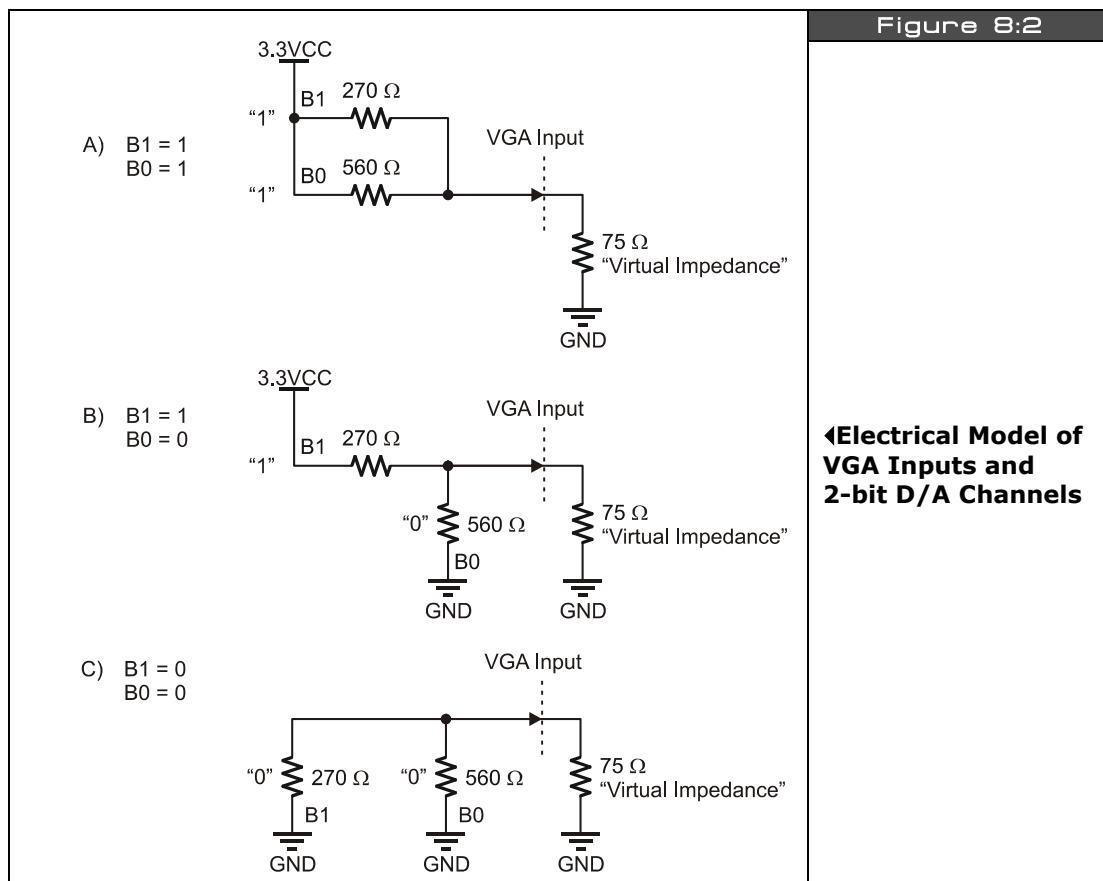
Referring to Figure 8:1, you see that P16 – P23 are connected to all the VGA signals and there are 2 bits for each channel; Red, Green, and Blue, as well as a single bit for Hsync and Vsync. These outputs are connected to the VGA buffer at U5 which is a 74HC244 8-bit tri-state buffer. Its output is connected to the HD15 connector via a series of 2-bit D/A converters that sum each 2-bit channel pair (R0, R1), (G0, G1), and (B0, B1) and directly interface the sync bits. The VGA spec dictates that for each channel 0% intensity is 0.0 V and 100% intensity is 1.0 V (some references use 0.7 V). Also, each channel input to the VGA monitor itself per input has a nominal impedance of  $75 \Omega$  (similar to the NTSC input impedance).



**◀ The VGA Interface  
and Support Hardware**

Therefore, from the D/A's perspective with both bits on, the circuit looks like that shown in Figure 8:2 (for any particular channel; R, G, or B). Recall that the Propeller chip is a 3.3 V device with both channel bits HIGH, that means that we have a  $270\ \Omega$  in parallel with a  $560\ \Omega$  and this combination in series with the intrinsic impedance of  $75\ \Omega$  of the VGA, thus, we can do a simple computation to compute the voltage at the  $75\ \Omega$  VGA input realizing we have a voltage divider configuration:

$$\text{VGA\_IN\_RED} = 3.3\ \text{V} \times 75\ \Omega / ((270\ \Omega || 560\ \Omega) + 75\ \Omega) = 0.96\ \text{V}$$



...which is what we desire; performing similar math for all 4 combinations of inputs we get the results shown in Table 8:1 for codes. Considering there are 4 shades of each channel; R, G, and B that means that there are a total of  $4 \times 4 \times 4 = 64$  colors available in VGA mode. Not bad!

Table 8:1		VGA Input Voltages for all 2-Bit Inputs▼		
B1	B0	Code	VGA Voltage	Description
0	0	0	0.0 V	Black
0	1	1	0.30 V	Dark Gray
1	0	2	0.64 V	Gray
1	1	3	0.96 V	White



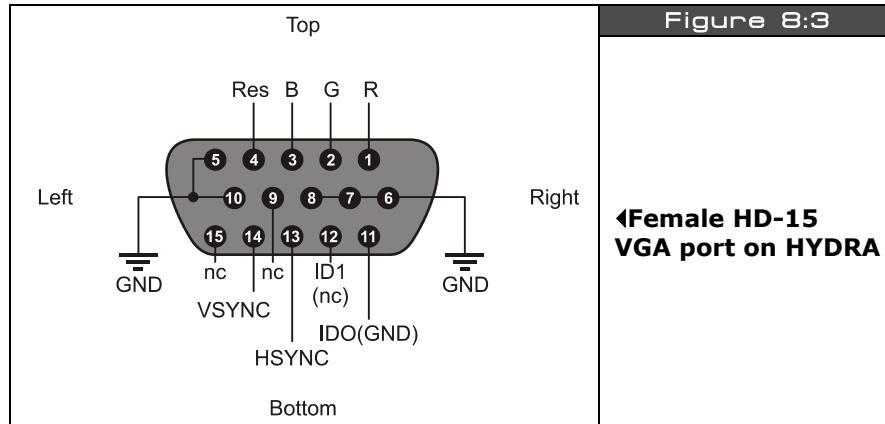
Pay attention to the “VGA Enable” switch J10, it’s next to the 74HC244 chip on the HYDRA and shown in the design (Figure 8:1 on page 117).

You must ENABLE this switch if you want the VGA buffer to send the VGA signals to the VGA port. If you want to use the I/O port and do NOT want the VGA port on then DISABLE the switch at J10.

For reference the VGA port has the following pinout shown in Table 8:2. The VGA port on the HYDRA is a female HD15 (High Density) which is standard on the back of video card hardware. It will connect to any VGA monitor.

Table 8:2		VGA Female Header Pinout (HD15)▼
Pin	Function	Color Code (Most Manufacturers)
1	RED Video	BLACK
2	GREEN Video	BLACK/WHITE
3	BLUE Video	BROWN
4	RESERVED	BROWN/WHITE
5	-Ground	RED+SHIELD
6	-RED Ground	ORANGE
7	-GREEN Ground	YELLOW
8	-BLUE Ground	MINT GREEN
9	NC	NC
10	-GROUND	GREEN
11	ID0 (Ground)	BLUE
12	ID 1 (NC)	PURPLE
13	VSYNC	GREY
14	HSYNC	WHITE
15	NC	SHRIMP

Looking at the VGA port on the HYDRA (the female), the pinout is as show in Figure 8:3.



### 8.3 VGA Signal Primer

The VGA standard is much easier to understand than the NTSC standard, in fact, using a visual explanation (Figure 8:4) is usually all people need to see, but still there are some gotcha's so we are going to discuss them as well in the brief primer. To start, the actual important signals you need to generate for VGA are (referring to Table 8:2) Red, Green, and Blue video as well as Hsync and Vsync. The R,G,B signals are analog voltages representing the instantaneous intensity of any particular channel and range from 0-1.0 V, but the Hsync and Vsync are simply TTL signals, usually active LOW (but these can be inverted on most monitors) where a logic LOW is sync, and a logic HIGH is no sync. Now, let's look more closely at the signal itself.

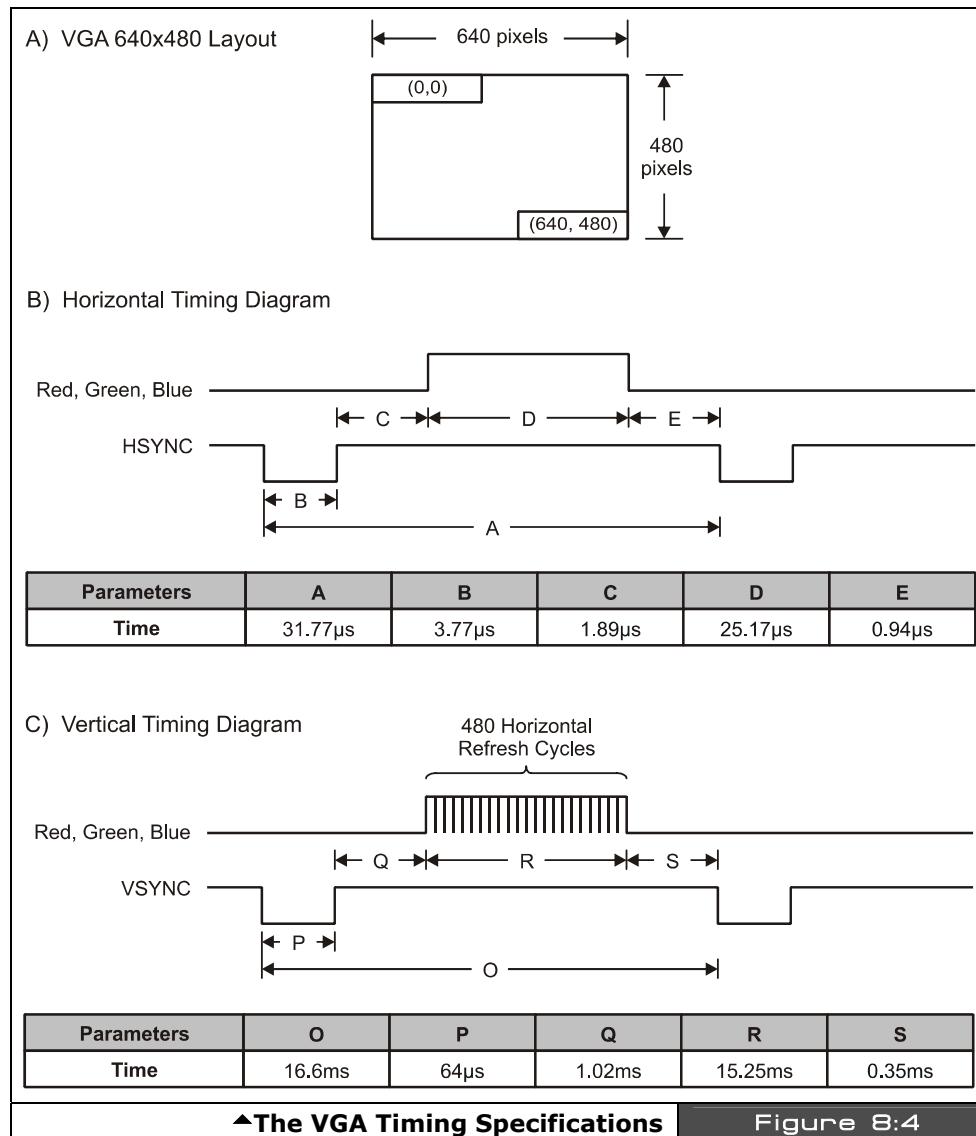
To begin with, the VGA standard as implemented is  $640 \times 480$  pixels across as shown in Figure 8:4(A). The image is rendered left to right, top to bottom, similar to the NTSC/PAL signals, and thus a similar syncing scheme is used that is composed of both a horizontal sync pulse each line and a vertical sync pulse each frame. However, there are no color burst signals, serrations, pre-equalizations pulses, etc. and the interface is nearly digital as noted.

The main clock usually used in a VGA generation system is 25.175 MHz; all timing can be derived from this base frequency. Typically, designers like to run the system dot clock at this frequency and compute all events as a number of clocks.

For example, getting ahead of myself, take a look at Figure 8:4(B), the Hsync pulse which is labeled "B" in the table (and a negative polarity), its  $3.77 \mu s$ , therefore at a dot clock of

25.175 MHz, or inverting this to get the period time we get 39.72194638 ns. This is how long a pixel takes, anyway, dividing this into our Hsync time we get:

Number of dot clocks for Hsync pulse =  $3.77 \mu\text{s} / 39.72194638 \text{ ns} = 94.90$  clocks.



Call it 95 dot clocks, thus you can simply use a counter and count 95 clocks, drive Hsync LOW and that's it. The entire VGA signal can be generated like this. Of course, the tough part is when you get to video, here you only have roughly 39 nanoseconds to do whatever you are going to do; this amounts to more or less doing nothing but accessing a video buffer as fast as you can and getting the next data WORD ready to build the pixel. This is why the Propeller's VSU is so cool, it can do this for you and stream BYTES to the VGA interface (more on this later in Part II). Anyway, let's take a closer look at the video portion of the signal as well as the horizontal and vertical timing aspects of VGA.

### 8.3.1 VGA Horizontal Timing

Referring to Figure 8:4(B), each of the 480 lines of video are composed of the following standard named regions:

- ▶ A (31.77 µs) Scanline time
- ▶ B (3.77 µs) Hsync pulse
- ▶ C (1.89 µs) Back porch
- ▶ D (25.17 µs) Active video time
- ▶ E (0.94 µs) Front porch

As you can see even the names are similar to NTSC. However, unlike NTSC, VGA is very unforgiving and you must follow the spec very closely. The next interesting thing is that all the signals are riding on different lines. For example, the Hsync and Vsync both have their own signal lines, and the R, G, and B signals do as well, so it's much easier to generate all the signals in a large state machine and then route them to the output ports.

Therefore, to generate a line of video (with a negative sync polarity), you start by turning off all the R, G, B channels with a 0.0 V, and simply hold the Hsync line LOW for 3.77 µs (B). Then you wait 1.89 µs (C) and the VGA is ready to take R, G, B data, now you clock out 640 pixels at 25.175 MHz for a total time of 25.17 µs (D) for the active video portion. You then turn the video lines R, G, B off, and wait 0.94 µs (E) and then start the process again. And that's all there is too it. Perform this process 480 times then it's time for a vertical sync and retrace, so let's look at that.

### 8.3.2 VGA Vertical Timing

The vertical sync and retrace is much easier than the horizontal timing since there is no video to interleave in the signal. Referring to Figure 8:4(C) the various named timing regions of the vertical timing are:

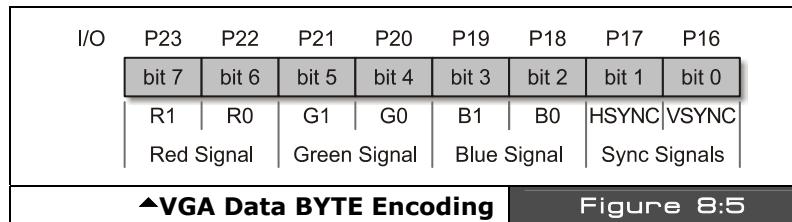
- ▶ O (16.68 ms) Total frame time
- ▶ P (64 µs) Vsync pulse
- ▶ Q (1.02 ms) Back porch
- ▶ R (15.25 ms) Active video time
- ▶ S (0.35 ms) Front porch

The meaning of each is similar to that in the horizontal sync period, except the “event” they are focused around is the 480 lines of active video, so the 480 lines are encapsulated in (R). The most important thing to realize is that these times are measured in milliseconds for the most part except for the Vsync pulse. So once again, the timing of an entire frame starts off with the Vsync pulse (P) for 64 µs, after which comes the back porch (Q) for 1.02 ms, followed by the active video (R) for 15.25 ms. During the active video you don’t need to worry about the Vsync line since you would be generating 480 lines of video, when complete, back to the Vsync timing region (S), the front porch for 0.35 ms, and then the frame is complete.

The thing to remember is that unlike composite video, a VGA signal needs to be driven by multiple signals for each of the constituent controls; R, G, B, Hsync, and Vsync, which in my opinion is much easier than modulating and mixing them all together as in NTSC which is a bloodbath of crosstalk and noise! Now that we have the horizontal and vertical timing for VGA covered, let’s review the actual video data portion of the signal during the active video and see what that’s all about.

### 8.3.3 VGA RGB Video

Generating RGB video is trivial on any system, there is no look-up, no math, just send out BYTES or WORDs that represent the RGB values and that’s it. On the HYDRA for example, there are 2-bits per channel, so the encoding of the VGA data BYTE is as simple as generating BYTES in the format shown in Figure 8:5.



For example, forgoing how to do I/O yet on the Propeller chip, let’s say that we have a BYTE buffer called *vga\_byte* and a function *Write\_VGA(value, time\_us)* that we use to send data to the VGA port, given that, we can write all kinds of functions that send out different signals as long as we stream the BYTES to the port at the 25.175 MHz rate everything will work out fine. For example, say that we are working with a positive sync system, that is a VGA monitor that wants a TTL HIGH for sync, then to generate a Hsync pulse we could use some pseudo-code like this:

```
vga_byte = %00000010;
Write_VGA(vga_byte, 3.77);
```

Ok, now consider we want to draw 640 pixels from an array *video\_buffer[ ]* that is storing the pixel data in BYTE format already in the proper format for our hardware, then all we would do is this:

```
byte video_buffer[640]; // pre-initialized video buffer  
  
for (pixel = 0; pixel < 640; pixel++)  
    Write_VGA(video_buffer[pixel], 0.039721946);
```

Of course, you would need some mighty fast hardware to delay at a resolution of 39 ns, but you get the idea. This is a “model” of the algorithm for a line of video, this coupled with the model for the horizontal timing, vertical timing, and put it all together as a state machine and you have a VGA generator!

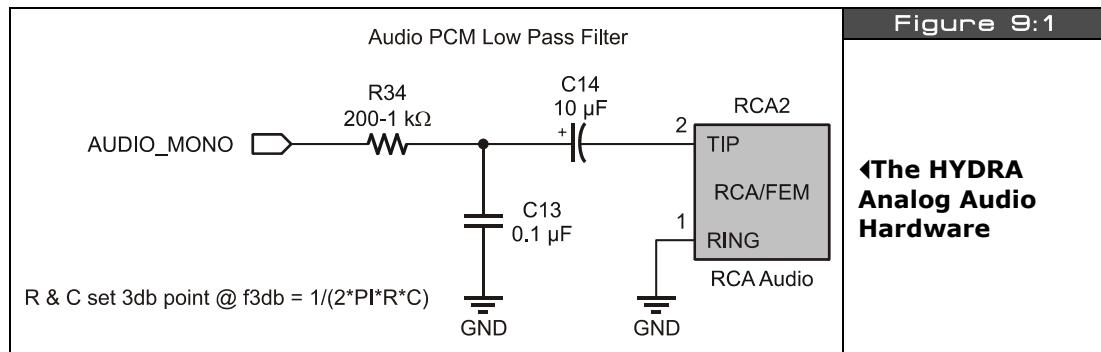
## 8.4 Summary

Hopefully this chapter has shed some light on the VGA standard. It’s a very cool system, the only downside being that it’s really fast at 25.175 MHz (39 ns per pixel) and difficult to drive with a microcontroller that doesn’t have dedicated hardware (like the Propeller chip). But, speed aside, the standard is “nearly” digital, doesn’t have any funny stuff with the color encoding, and lends itself nicely to bitmap hardware designs based on RGB color space.

## Chapter 9: Audio Hardware

There is no dedicated audio hardware inside the Propeller chip or on the HYDRA itself, therefore we have to rely on software audio generation techniques to create sound for the system. However, knowing that software is going to be used to generate sound we can add a little analog circuitry to “help” the audio software out and allow us to use certain common techniques for generating sounds. In this chapter, we are going to take a look at the circuit that is used for the audio output. Once again, the Propeller chip takes the fun out of it by being powerful enough to do everything internally! Anyway, here’s what’s in store this chapter:

- ▶ Audio circuit design
- ▶ Low-pass filters
- ▶ Frequency modulation (FM)
- ▶ Pulse code modulation (PCM)
- ▶ Pulse width modulation (PWM)



### 9.1 Audio Circuit Design and a Little Background on Low-Pass Filters

The audio on the HYDRA is generated completely in software and the output is filtered through a simple analog filter. The circuit is shown in Figure 9:1. Referring to the circuit, we see that the signal **AUDIO\_MONO** (P7 on the Propeller chip) generates the signal input into the network. This signal is passed through a low-pass filter consisting of a resistor (R34 @ 200 – 1 kΩ) and a capacitor (C13 @ 0.1 μF). Note that these reference designators may

change in the future, but the point is there is an R/C network here. Moving on, there is also another AC coupling capacitor (C14 @ 10 µF) which leads to the final output via an RCA connector and that's it. The circuit has two sections and they each serve different purposes, let's follow the signal through these sections.

The input signal, call it  $V_{in}(t)$ , comes in at the port and the low-pass filter made up of R34 and C13 passes low frequencies but blocks high frequencies. This is what's called a "**single-pole RC filter**." The "gain" of the filter or the "transfer function" describes the relationship between the output and the input signal, thus for a single with a gain of 1 or unity, the output, (call it  $V_{out}(t)$ , would be equal to the input (with some possible phase variance, but this is irrelevant for our discussion). The single-pole RC filter acts like a voltage divider, but we have to use more complex math to describe it based on imaginary numbers and/or differential equations. This is tough to analyze with algebra, but there is a trick based on the "**Laplace Transform**" which transforms differential equations into algebraic equations, and then we can work with the circuit as if it were made of resistors and transform back when done. This is all not that important, but its fun to know a little about analog stuff, so let's continue.


MATH

The Laplace transform denoted by  $L[f(t)]$  which looks like this:

$$L[f(t)] = \int_0^{+\infty} f(t)e^{-st} dt$$

...is a simple integral transform where more or less the function  $f(t)$  in the time domain you want to work with is integrated against an exponential term. The result of this is the transformation of the time domain function into the "S-domain" written as  $F(s)$ , where they are much easier to work with.

So given all that, we want to know what the voltage or signal is at the top of C13 ( $V_{out}$ ) since this signal or voltage will then affect the remainder of the circuit. Using a voltage divider made of R34 and C13, we need to write a relationship between the input voltage at AUDIO\_MONO, call it  $V_{in}(t)$ , and the output voltage of the RC filter at the top of C13, call it  $V_{out}(t)$ . Ok, here goes a few steps:

$$V_{out}(s) = V_{in}(s) \times [ (1/sC) / (R + 1/sC) ]$$

Then dividing both sides by  $V_{in}(s)$  we get,

$$\text{Gain} = H(s) = [ (1/sC) / (R + 1/sC) ]$$

Simplifying a bit, results in,

$$\text{Gain} = H(s) = 1 / (1 + sRC)$$

Then transforming back from the S-domain to the frequency domain we get,

$$\text{Gain} = H(f) = 1 / (1 + 2 \times \pi \times f \times RC)$$

Note: Technically there is another term in there relating to phase, but it's not important for this discussion. In any event, now this is interesting, this equation:

$$\text{Gain} = H(f) = 1 / (1 + 2 \times \pi \times f \times RC)$$

...describes the amplification or more correctly the attenuation of our signal as a function of frequency  $f$ . This is very interesting. Let's try something fun. Let's plug in some values really quickly and see what happens, let's try 0 Hz, 1 Hz, 100 Hz, 1000 Hz, 1 MHz and see what we get. Table 9:1 shows the results.

Table 9:1	The Results of Passing Various Frequencies through a Low-Pass Single-Pole RC Filter▼	
Frequency (f Hz)	Gain	Comments
0	1/1	DC gain is 1.0 or no attenuation
1	1/(1+2 × π × 1 × RC)	
10	1/(1+2 × π × 10 × RC)	
100	1/(1+2 × π × 100 × RC)	
1,000	1/(1+2 × π × 1000 × RC)	
1,000,000	1/(1+2 × π × 1,000,000 × RC)	

This is very interesting; ignoring for a moment the actual values of  $RC$ , we see that larger values of  $f$  (frequency) very quickly dominate the denominator and the quotient goes to 0. This is why this filter is called "**single-pole**", as the term in the denominator goes to infinity the quotient goes to zero. Ok, so how does this help us? Well, if we select values of  $RC$ , we can tune the frequency so that this "attenuation" effect gets really strong. This is typically called the "**3dB point**", that is the point where the signal is attenuated by 3 dB (decibels). It's not really important to know what a decibel is, it's a measure of power or ratio of signals more or less, but what is important is that 3 dB is about 70% of the signal. So, if you want to filter out everything above 10 kHz you would set the 3dB point for about 10 kHz (maybe a bit more) and you would see the signal gets filtered. Also, note that at DC, frequency  $f = 0$ , the right-hand term in the denominator sum  $(1 + 2 \times \pi \times 0 \times RC) = 1$ , thus the gain is 1/1 or 1.0 which is exactly what it should be! Cool huh!

Filters can be a lot of fun since you can chain them together; low-pass, high-pass to make a band pass, or multiple low- and high-pass to make them fall off faster and so forth. Here's a cool tool on the web to get a "feel" for filters:

**Low-pass:**

[http://www.st-andrews.ac.uk/~www\\_pa/Scots\\_Guide/experiment/lowpass/lpf.html](http://www.st-andrews.ac.uk/~www_pa/Scots_Guide/experiment/lowpass/lpf.html)

**High-pass:**

[http://www.st-andrews.ac.uk/~www\\_pa/Scots\\_Guide/experiment/highpass/hpf.html](http://www.st-andrews.ac.uk/~www_pa/Scots_Guide/experiment/highpass/hpf.html)

In any event, playing with the math, the 3dB point for our circuit is:

$$f_{3dB} = 1/(2 \times \pi \times R \times C)$$

Notice, f is not in there since we solved for it. Therefore, we have everything we need to use the circuit and the equation. Let R and C in our circuit be 1 kΩ and 0.1 μF respectively; plugging them in we get:

$$f_{3dB} = 1/(2 \times \pi \times 1 \text{ k}\Omega \times 0.1 \mu\text{F}) = 1.59 \text{ kHz}$$

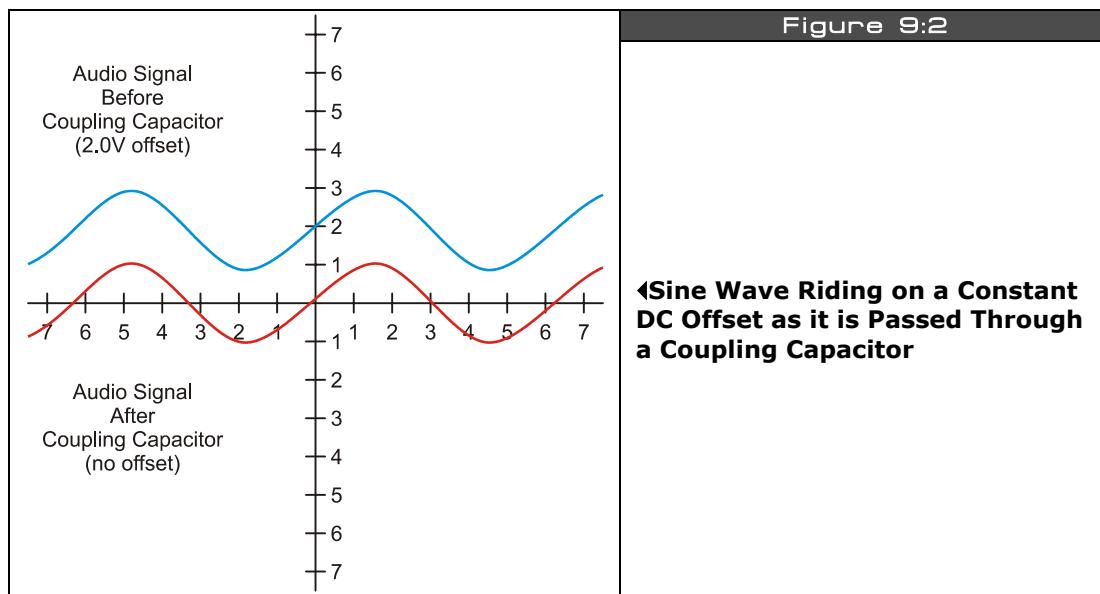
...which might be a little low. To loosen this up, let's make the resistor smaller – 200 Ω:

$$f_{3dB} = 1/(2 \times \pi \times 200 \Omega \times 0.1 \mu\text{F}) = 7.95 \text{ kHz}$$

...which is a rather high frequency, about 50% of the max range of most human ears which top out at 15-20 kHz.

Why is this important? Well, first off if you send a signal through our little low-pass filter to the output (connected to the audio port on the TV) then the signal is going to attenuate at high frequencies. We will get back to this momentarily; let's move on to the second stage in the audio circuit which is based on C14 and POT1. This stage of the circuit is an AC-pass filter, which means that it will only pass AC and the DC component will be blocked.

In other words, say that the input was a sine wave or square wave with a peak-to-peak voltage of 1 V, but it was riding on a 2 V signal, this would look like the top trace in Figure 9:2. However, after going through the AC coupling capacitor, the signal would look like the bottom trace shown in Figure 9:2. So all C14 does is block the DC.



Now, let's talk about some more hardware-related concepts about making sounds with a couple specific techniques with the HYDRA.

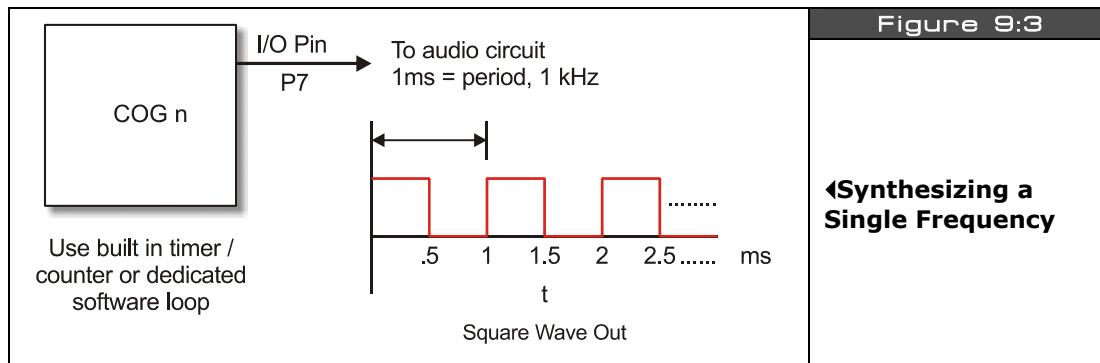
### 9.1.1 Pulse Code Modulation (PCM)

The most common method to make sound on a game console is to use **PCM** or **Pulse Code Modulation**. This is really nothing more than storing a series of samples of the sound in some resolution; 4,8,12,16 bit along at some playback rate. A Windows .WAV file for example is PCM data, you simply output the data at the proper rate to a D/A converter with an amplifier connected to a speaker and you will hear the sound. There are a number of issues with this: first, it takes huge amounts of memory (even with compression), secondly you need a D/A (digital to analog) converter on the hardware and there are no "synthesis" opportunities really (of course you can always synthesize the samples). PCM is not an option for the HYDRA since there is simply so little memory, even with the extended 128K EEPROM's extra 96 K available to you for assets that wouldn't get you very far, so PCM was decided to not make the cut at least as a hardware interface, but you can actually synthesize PCM through PWM (more on this in a moment).

### 9.1.2 Frequency Modulation (FM)

Frequency modulation with a fixed waveform is very easy to do electronically and the HYDRA can do this no problem. The idea here is to output a square wave or sine wave directly to the output device and then modulate the frequency. So if we use the Propeller chip's internal

timers we can do this (more on this later) or we can write a software loop to do it. For example, if you wanted to hear a 500 kHz, 1 kHz, and 2 kHz signal you just write a software loop that toggles the output AUDIO\_MONO at that rate and you will hear the sound on the attached output device. Figure 9:3 shows this graphically.



Now, there are a couple problems with this: first it's not readily apparent how to "add" signals and play more than one sound at once. In fact, it's nearly impossible directly using this technique. Secondly, the only signal you can output is a square wave, you can't output sine waves. This tends to make the sounds have a "textured" sound since harmonics are in the square wave. That is, if you output a square wave at frequency  $f$  then you will find that there are harmonics at  $3f$ ,  $5f$ , etc. all these sine waves are what really make up a square wave. Take a look at Fourier transform theory to see this:

[http://homepages.inf.ed.ac.uk/rbf/CVonline/LOCAL\\_COPIES/OWENS/LECT4/node2.html](http://homepages.inf.ed.ac.uk/rbf/CVonline/LOCAL_COPIES/OWENS/LECT4/node2.html)

Of course our little low-pass filter is going to filter most of these harmonics, but you aren't going to hear a pure sine until you increase the frequency to about the 3 dB cutoff which may be desired.

In any event, if all you need is a single channel, some noise, pure tones, then FM with the AUDIO\_MONO port at (P7) is more than enough. You can use software or the built-in timers to do it on each cog and simply sweep the frequency to get different sounds since you can't change the amplitude.

### 9.1.3 Pulse Width Modulation (PWM)

Pulse width modulation or PCM is a very clever way to create ANY kind of sound with a single bit of output! The bad news is that the relationships of the output and the algorithms are a "bit" complicated and take a little bit of numerical analysis, but once you get it working it's

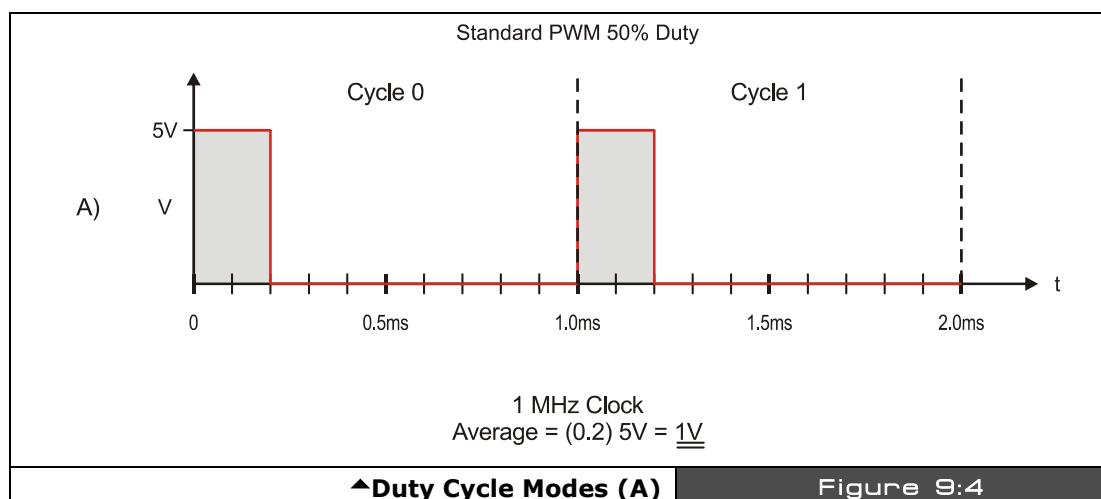
not an issue and you can build libraries to create any sound you wish – in fact many advanced synthesizers use PWM systems, so it's very powerful.

To start with you might want to “Google” for PWM techniques and read up a bit. Watch out since most PWM references are about using PWM for motor control. Here are a few PWM articles to get your started:

[http://www.freescale.com/files/32bit/doc/app\\_note/MC68EZ328PWM.pdf](http://www.freescale.com/files/32bit/doc/app_note/MC68EZ328PWM.pdf)  
[http://www.freescale.com/files/32bit/doc/app\\_note/MC68EZ328DTMF.pdf](http://www.freescale.com/files/32bit/doc/app_note/MC68EZ328DTMF.pdf)  
<http://www.intel.com/design/mcs96/technote/3351.htm>  
<http://ww1.microchip.com/downloads/en/AppNotes/00655a.pdf>

After reading all these documents you should have a fairly good grasp of PCM techniques. More or less, PCM is really a method of digital to analog conversion using a single bit output along with a low-pass filter that acts as an “**averaging**” or “**integration**” device. A PCM signal is at fixed output frequency usually many times the highest frequency you want to synthesize, for example a good rule of thumb is that the PCM signal should be 10-100x greater than the frequencies you want to synthesize. Also, the PCM period is **fixed**, and the modulation of information in the PCM signal is in the duty cycle of the signal. Recall, duty cycle is defined as:

$$\text{Duty Cycle} = \frac{\text{Time Waveform is HIGH}}{\text{Total Period of Waveform}}$$



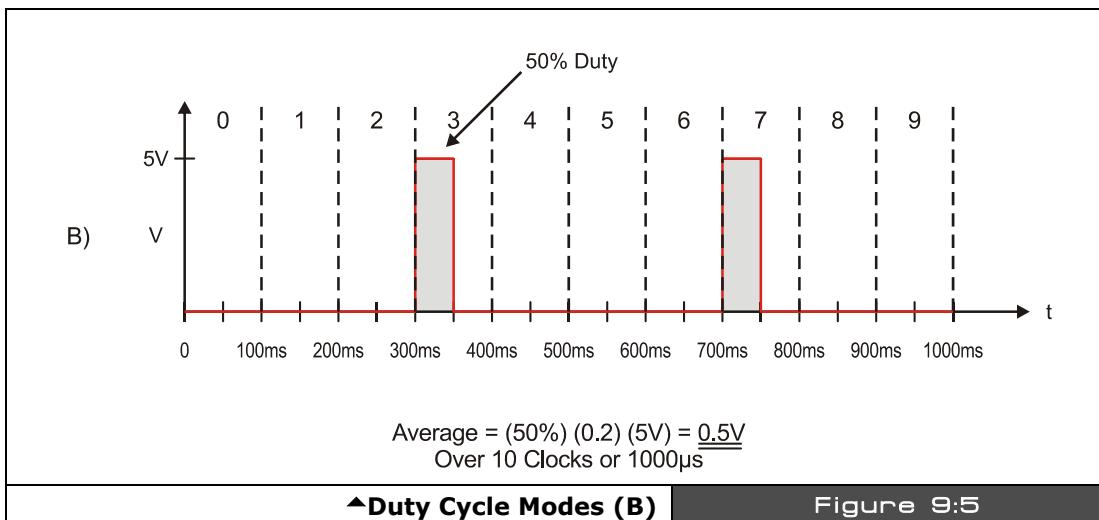


Figure 9:5

For example, say we had a 1 kHz signal, this means the period is  $1/1 \text{ kHz} = 1 \text{ ms} = 1000 \mu\text{s}$ . Now, let's say we are talking about square waves in a digital system with a HIGH of 5 V and a LOW of 0 V. Furthermore, let's say that the duty cycle is 20%; what would the final waveform look like? Figure 9:4 depicts this. As you can see the waveform is HIGH 20% of the total period or  $200 \mu\text{s}$ , and the waveform is LOW for  $800 \mu\text{s}$ . Therefore, if you were to average this signal  $f(t)$  over time you would find that the average is simply the area under the HIGH part divided by the total AREA of the waveform which is:

$$\text{Average Signal @ 20% duty cycle} = (5 \text{ V}) \times [(200 \mu\text{s})/(1000 \mu\text{s})] = 1.00 \text{ V}.$$

This is a VERY interesting result — by just varying the time we pulse a digital output HIGH we can create an analog voltage! Thus, we can modulate the analog voltage in any shape we wish to create a final waveform of any shape we want: sounds, explosions, voices, etc. Plus since this is all digital we can synthesize as many channels as we wish, since at the end of the day we need only a single bit as the output. Figure 9:5 shows another PWM-like technique where instead of modulating the duty cycle, complete 50% duty cycle pulses are sent, but they are interspersed with 0% duty cycles as a function of time. If the rate of these "pulses" is high enough, they too create an "average" voltage over time. In Figure 9:5 there are 10 total cycles and in 2 of them we have 50% duty cycles for a total analog voltage per 10 clocks of:

$$\text{Average Signal @ 20% duty cycle} = (5V) \times (50\%) \times [(100 \text{ ns})/(1000 \text{ ns})] = 0.25 \text{ V}.$$

Notice we are dealing in nanoseconds in the second example; this technique needs to run at a higher frequency to give the “average” enough time to change at the highest frequency rate you want to synthesize in this method of D/A.

Now, the only mystery component to the D/A PWM converter is “averaging” of the signal. Well, fortunately for us, a low-pass filter as used in the HYDRA’s sound circuit (shown in Figure 9:1) acts as an averaging circuit, in fact, those of you with an EE background know that  $1/S$  is integral in the S-Domain and a low-pass filter has a  $1/S$  term in it. Intuitively it makes sense as well since a low-pass filter as shown in Figure 9:1 is really just a charging circuit and as we send these pulses to it, the circuit charges a bit, then another pulse comes and it charges a bit more. When a pulse doesn’t come or the duty cycle is smaller, then the RC circuit discharges, so the PWM-modulated pulse train gets turned into a signal by the averaging process and looks like a stair step where you can see the averaging period superimposed on the signal. But, for now realize that the low-pass filter (LPF) that the HYDRA uses on the audio circuit acts as an LPF as well as an averaging circuit for PWM, so it has two uses – pretty cool.

### Selecting the Filtering Frequency

Also, there are a couple of concerns with the actual values of the LPF so that you don’t get too much noise. Noise is going to come from the PWM frequency itself. For example, say you use a PWM frequency of 1 MHz, then your filter obviously needs to cut this frequency out, but it also needs to cut in at the highest frequency you plan to synthesize. For example, if you plan to have sounds all the way up to CD-quality at 44 kHz then you might set the 3dB point at 50 kHz.

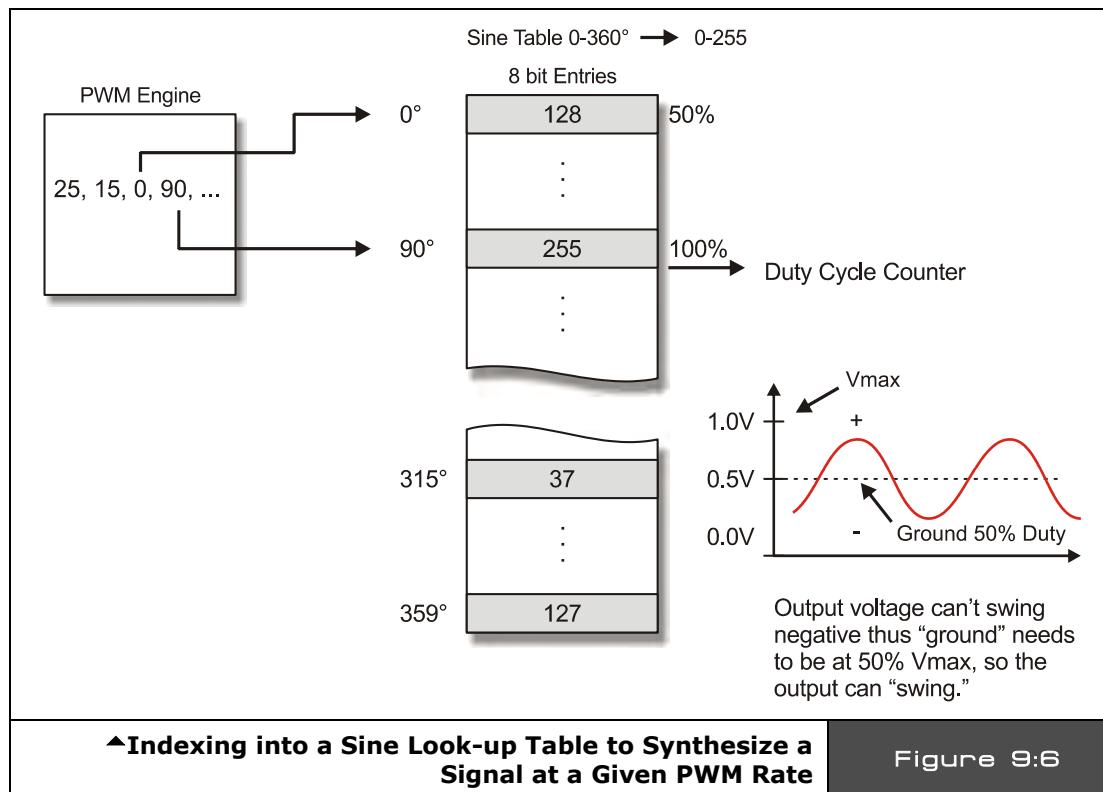
Also, we are using an “inactive” single-pole filter. You might want a “sharper” response in a more high-end sound system like a 2- or 4-pole system. You can achieve this by daisy chaining our little LPFs together OR you can use an “active filter” based on a transistor or better yet a simple operational amplifier like the 741. Or even better yet, pick an 8-pole switched capacitor filter by National, TI, or Linear Tech and the signal will hit a “brick wall” at the cutoff ☺.

But, for our purposes of games, simple music, sound effects, and explosions, a single-pole passive filter will do fine. If there is one thing I know, most people can’t tell the difference between Mozart and Snoop Dogg, so sound can be a little rough.

## PWM Setup Procedure

Let's briefly digress a moment and work up an example with real numbers, so you can see this all in your head. Many readers probably have worked with PWM, but may use more experimental techniques to get results rather than a formal analysis, so this might be interesting for you.

So to PWM modulate a signal we encode the signal onto the PWM carrier by means of encoding the information or analog value of the signal onto the PWM carrier by modulating ***the period or the duty cycle*** of the fixed frequency PWM carrier. This is a VERY important concept to understand – the PWM frequency/period NEVER changes, only the duty cycle of any particular cycle. Thus by modulating the information onto the duty cycle we can then later demodulate the signal by integrating or averaging the PWM signal with a RC circuit and presto, we have an analog voltage!



The first thing we need to do is decide what kind of waveforms we want to synthesize, remember they can be **anything**, they can be periodic and simple like sine, square wave (redundant), triangle, saw-tooth, noise, or even digitized speech. But, to start simple, let's synthesize a single sine wave. So first we need a look-up table for sine wave, let's call it **sinetable[ ]** and assume it has **256** entries and we generate it such that a single cycle has a low of 0 and a high of 255 and is encoded in 8 bits (similar to an example in the references). Now, the algorithm is fairly simple, we need to index through the sine table a rate such that we complete a single cycle of our sine wave at the desired output signal frequency. As a quick and dirty example, let's say that we use a PWM frequency of 256 kHz and we want to play a 1 kHz sine wave, then this means that each second there are 256,000 PWM pulses. We want to index into our table and play 1000 iterations of our data which has a length of 256 entries, thus we need to index into our table at a rate of:

$$256,000 / (1000 \times 256) = 1$$

Interesting; so every cycle we simple increment a counter into the sine table and output the appropriate duty cycle in the table look-up. This is shown in Figure 9:6. As another example, say we want to synthesize a 240 Hz signal, then let's see what we would need:

$$256,000 / (240 \times 256) = 4.16$$

In this case, we would increment a counter until it reached 4, then we would increment our index into our sine table. But this example as well as the last should bring something to your attention: there is a max frequency we can synthesize and our signal synthesis is going to be inaccurate for anything but integral divisors, so that's an issue we need to address in a moment. First, let's look at the maximum signal frequency: if you want to play back all 256 sine samples then the maximum "signal" frequency is always:

$$\text{Maximum Synthesis Frequency} = \text{PWM frequency} / \text{Number of Samples per Cycle}$$

...which in this example is:

$$256,000 / 256 = 1000 \text{ Hz}$$

So, you have two options: either increase the PWM frequency or index into your sample table at larger intervals. This problem along with the lack of precision can be handled by use of fixed-point arithmetic and a little numerical trick. We are going to scale all the math by 8 bits (or in essence multiply by 256) then we are going to create two variables: one called a **phase accumulator** (PHASE\_ACC) and one called a **phase increment** (PHASE\_INC). Then instead of using count-down algorithms, we are going to simply add the phase increment to the phase accumulator and use the phase accumulator as an index into the sine table. Therefore, what we have done is turned out 256 element sine table into a "virtual"  $256 \times 256 = 65536$  element sine table for math purposes to give us more accuracy for slower, non-integral waveforms as well as to allow fast waveforms to index and skip elements in the look-up table, so a possible setup is something like this:

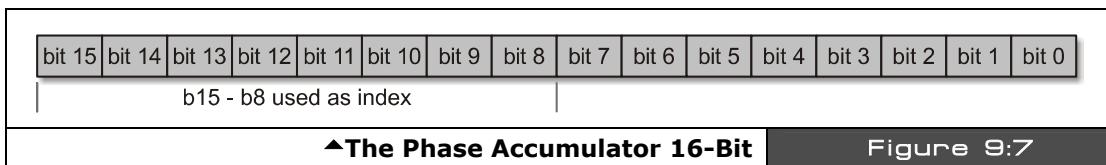


Figure 9:7

Now, we have two interesting properties: first, no matter what the index in the upper 8-bits can never exceed 255, so we can never go out of bounds of our table; secondly, we can put very small numbers into the phase accumulator via that phase increment variable.

So now the algorithm for PWM sound is simple:

**Step 1:** Run the PWM at the output frequency 256,000 Hz.

**Step 2:** Calculate the Phase Increment (PHASE\_INC) to add to the Phase Accumulator (PHASE\_ACC) such that the final desired "signal" frequency is output via the look-up into the sine or waveform table.

**Step 3:** Continually add the Phase Increment to the Phase Accumulator and every cycle use the upper 8-bits of the Phase Accumulator as the index into the 256 element sine table.

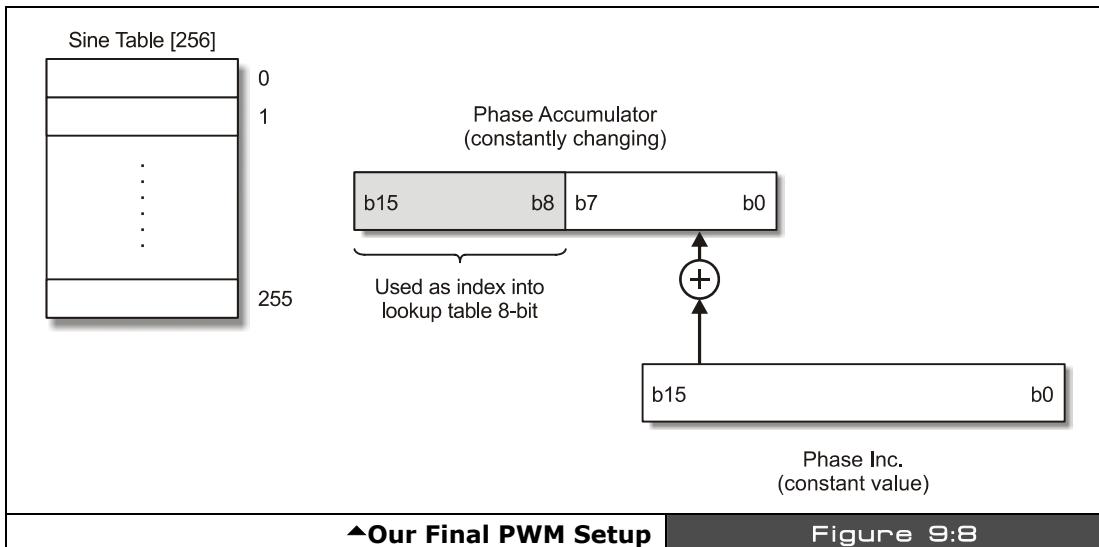


Figure 9:8

Now, to recap, we still have a table that has only 256 elements, but we are going to pretend it has 65536 elements, that is,  $256 \times 256$  to improve our accuracy, this is nothing more than

using a shift  $<< 8$  and create a fixed point value in 8.8 format. Next, we are going to call out a couple variables to make the algorithm easy, one is an accumulator called PHASE\_ACC that simply accumulates the current count, then we convert it back to an integer by shifting it  $>> 8$  times OR just using the upper 8-bits at the index into our 256 element sine table (the later is preferred). Then we simply need the magic number PHASE\_INC that for a given PWM frequency (256,000 in this case) and a desired output signal frequency along with a specific number of data table elements will make the whole thing work. Here's the final math:

Given,

A complete sine waveform has 65536 data entries in our virtual table and 256 in the real table.

The PWM frequency is 256 K.

**NUM\_INCREMENTS** = The number of times that the PWM signal increments through the final signal table in ONE complete wave cycle. This is shown in Figure 9:8.

In other words,

$$\begin{aligned}\text{NUM\_INCREMENTS} &= \text{signal period} / \text{PWM period} \\ &= \text{PWM frequency} / \text{signal frequency}\end{aligned}$$

Now, let's compute PHASE\_INC:

$$\text{PHASE\_INC} = 65536 / \text{NUM\_INCREMENTS}$$

That is, the PHASE\_INC is the rate at which we need to increment through the data table to maintain the relationship so that the output is changing at the rate of the signal frequency. Now, plugging this all in together and moving things around a bit:

$$\text{PHASE\_INC} = 65536 \times \text{signal frequency} / \text{PWM frequency}$$

And of course PHASE\_ACC is simply set to 0 to begin with when the algorithm starts. As an example, let's compute some values and see if it works. First let's try a 1 kHz signal and see what we get:

$$\text{PHASE\_INC} = 65536 \times 1 \text{ kHz} / 256,000 = 256$$

So this means that we add 256 to the phase accumulator each PWM cycle, then use the upper 8 bits of the phase accumulator as the index, let's try it a few cycles as see if it works.

<b>Table 9:2 Test of PWM Algorithm at 1 kHz with PHASE_INC of 256▼</b>			
<b>Iteration</b>	<b>PHASE_INC</b>	<b>PHASE_ACC</b>	<b>PHASE_ACC (upper 8 bits)</b>
<b>0</b>	256	0	0
<b>1</b>	256	256	1
<b>2</b>	256	512	2
<b>3</b>	256	768	3
<b>4</b>	256	1024	4
<b>5</b>	256	1280	5
<b>6</b>	256	1536	6
<b>7</b>	256	1792	7
.			.
.			.
<b>255</b>	256	65280	255

Referring to Table 9:2, we see that for each cycle of the PWM the PHASE\_ACC is incremented by 1 and the next element in the 256 element sine table is accessed, thus the table is cycled through at a rate of  $256,000 / 256 = 1,000$  Hz! Perfect! Now, let's try another example where the frequency is higher than what we could sustain with our more crude approach at the beginning of the section with only a counter and not using the accumulator and fixed point approach. Let's try to synthesize a 2550 Hz signal.

$$\text{PHASE\_INC} = 65536 \times 2550 / 256,000 = 652.8$$

Now, this is a decimal number which will be truncated during the fixed point math to 652, but this is fine, that's only an error or:

$$\text{Truncation error} = 100 \times (0.8 / 652.8) = 0.12\%$$

I think I can live with that! Table 9:3 shows the results of the synthesis algorithm running once again.

Table 9:3		Test of PWM Algorithm at 2500 Hz with PHASE_INC of 652▼	
Iteration	PHASE_INC	PHASE_ACC	PHASE_ACC (upper 8 bits)
0	652	0	0
1	652	652	2
2	652	1304	5
3	652	1956	7
4	652	2608	10
5	652	3260	12
6	652	3912	15
7	652	4564	17
.			.
.			.
255	652	65000	253

As you can see in this case, each cycle the sine table is accessed by skipping an entry or two causing a bit of distortion, but since the table has 256 entries the amount of distortion is 1-2% at most, so once again we see that the technique works perfectly. Also, notice that it takes only 100 cycles of the PWM clock to iterate through one complete cycle of the sine table which makes sense as well.

In conclusion, the software is where the magic is here. The PWM audio circuitry couldn't be simpler than as shown in Figure 9:1. Additionally, you can synthesize multiple channels by simply having multiple phase accumulators and phase increments; in fact, to synthesize a 64-channel system you would just need something like:

```
WORD phase_inc[64], phase_acc[64];
```

...and you simply run a loop over everything, sum up all the phase accumulators each cycle, and use the sum as the index into the sine table. Of course, the sine table itself has to be scaled in the amplitude axis and you must do an auto-scale so that the sum doesn't overflow, but you get the idea. Moreover, you can store other waveforms like square, triangle, sawtooth, and so on and then mix various waveforms. Finally, you can easily overlay an **ADSR** (attack-decay-sustain-release) envelope to a note-based system and create just about anything. The only downside to PWM is that it must be VERY accurate, your ears are VERY sensitive to frequency shifts, so the timing loops must be perfect, thus a hardware timer or a tight loop needs to be used that doesn't vary, otherwise you will hear it.

## 9.2 Summary

Sound is always one of those things in game consoles and game development in general that never gets the attention it deserves. Generating sound can be done in a number of ways: on larger PCs, sound is always generated as PCM data with 8-16 bit D/A's on the output, but on small embedded systems they don't have the memory to do this, thus, a different technique has to generate the final output and limits must be placed on the types of sounds that can be generated. PWM is perfect for sound effects, explosions, game sounds, and even music, but if you want digitized explosions, voice, and so forth, you can use PWM to generate the actual analog output, sure, but you still need to store all the data – and even at 11 kHz with 8-bit samples huge amounts of memory can be eaten up for just a few seconds of digital sound. Thus, on the HYDRA for example, we are going to stick to using FM and PWM techniques with software-based algorithms for the most part to generate "**procedural sounds**" that fit well into the domain of game sound-effects.

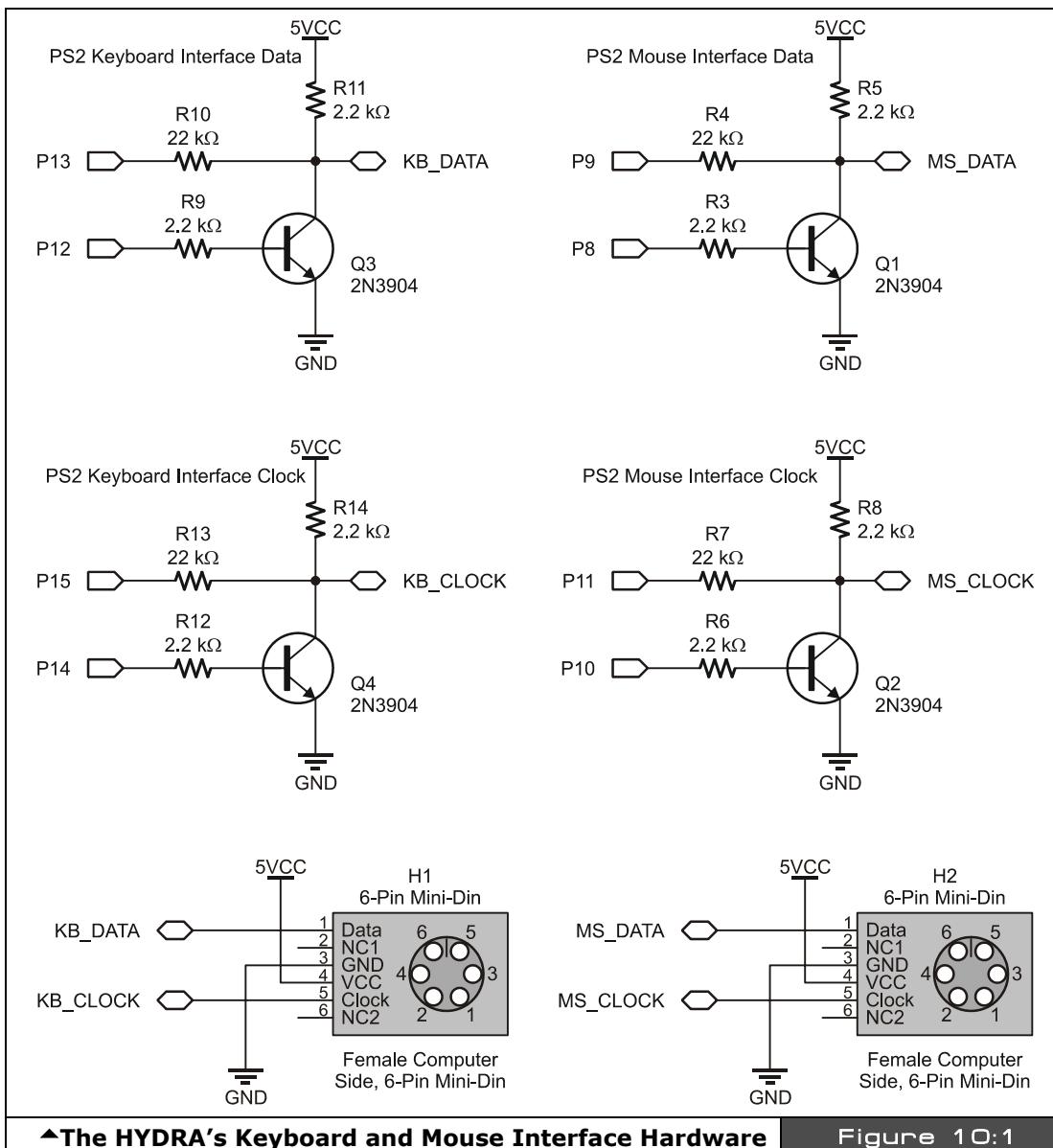
## Chapter 10: Keyboard & Mouse Hardware

The goal of the HYDRA is to of course be a platform to learn the Propeller chip while at the same time having fun with game development, but more importantly the HYDRA platform itself was designed to be a completely stand-alone computing platform for educational, hobby, and even industrial applications. For example, with a built-in BASIC interpreter or other language, you can directly plug the HYDRA into your TV set, plug in a keyboard and mouse, and use it like you would an Atari 800 or Apple II. Thus, the HYDRA has not one but two PS/2 ports on it which are compatible with any PS/2 device. It just so happens that you are typically going to plug a PS/2 keyboard and mouse into these ports, but this is not a necessity, you can plug any PS/2 device you wish into either port as long as you write a driver for it. Currently there are drivers for both keyboard and mouse only, but you are free to write whatever you wish; the hardware interface is robust enough to handle any device. In any case, this chapter is about the PS/2 interfaces and we are going to focus on the keyboard and mouse devices and take a brief look at the protocols of each. If you haven't ever written a driver for either, they are very interesting devices and support a lot more functionality than you might believe. Thus, in this chapter we are going to discuss the following topics:

- ▶ Hardware interfaces for the mouse and keyboard on the HYDRA
- ▶ Interfacing to the keyboard and the keyboard serial protocol
- ▶ Interfacing to the mouse and the mouse serial protocol

### 10.1 PS/2 Hardware Designs

The Propeller chip is a 3.3 V device, but PS/2 keyboards and mice are 5 V devices, thus a little bit of extra electronics had to be added to "buffer" or "isolate" the signals. Typically, to interface to a keyboard or mouse you simply need two bi-directional data lines to connect to the keyboard/mouse; these are referred to as **DATA** and **CLOCK**. PS/2 keyboards and mice both use a simple 2-line serial protocol (similar to I<sup>2</sup>C). In the case of the keyboard there is a microcontroller inside that scans the key matrix and handles the serial communications (in fact it's a full blown embedded system), and the mouse is similar, as it has a microcontroller that tracks the movement of the mouse ball or (optical hardware) by counting pulses and translating them into relative motions. Newer optical mice of course take pictures of the mouse surface and compute image gradients to determine motion (pretty cool stuff), but the idea is the same in that the data is translated into motion data and sent serially to the host.



▲The HYDRA's Keyboard and Mouse Interface Hardware

Figure 10:1

The keyboard and mouse interfaces are identical, so we are only going to review the hardware of one of these devices: the **keyboard**. Referring to Figure 10:1, the connector **H1**

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is the female receptacle that a PS/2 keyboard plugs into. The pinout is shown in the figure which we review in a moment, but the point is that there are only two connections we must concern ourselves with: the **DATA** line at **pin 1** and the **CLOCK** line at **pin 5**. Other than that, we need to provide the keyboard with power at **pin 4** (+5 V), and lastly, the ground reference GND is at **pin 3**.

Normally, if we had a 5V-compatible system, we could use only 2 data lines from the microcontroller (one for clock, one for data), but since the Propeller chip is 3.3 V device, the original design of the keyboard and mouse interface drivers used two (2) lines each for **DATA** and **CLOCK** with transistors to buffer the signals depending on direction. This is not necessary, but a precaution. Technically, one could design hardware that interfaced the 2 lines from the keyboard or mouse to 2 lines on the Propeller chip (and save a total of 4 lines between the keyboard and mouse), but the original software drivers used 4 lines per interface and a buffer design, so I followed it.

To communicate, either the keyboard/mouse or the host (HYDRA) can initiate a conversation. For example, the HYDRA can talk to the keyboard and instruct it to change settings, or the keyboard can send scan codes to the HYDRA as well as status information. In most cases, we can just let the keyboard boot and never worry about it, but if you want to send and receive you **have** the hardware that allows this. The use of 4 lines to talk to the keyboard/mouse along with some simple transistors facilitates this.

To begin with, let's assume that the keyboard wants to talk to the Propeller chip; in this case, the Propeller chip would need to set **P13** and **P15** to inputs and "listen" for the keyboard protocol. The outputs **P12** and **P14** are unused and should be set **LOW** during this transaction, so that transistors **Q3** and **Q4** are **OFF**. Now, in this configuration (**READ mode**), the keyboard drives **P13** and **P15**, the voltage swing is 0 V and 5 V, but this is fine since we have the current limiters **R10** and **R13** in there, so when a 5 V **HIGH** is on either the data or **KB\_DATA** or **KB\_CLOCK** lines the inputs of the Propeller chip will clamp to 3.3 V and the 22 kΩ current limiters will make sure current isn't driven too hard into the Propeller chip. In this case, when **DATA** or **CLOCK** on the keyboard are driven to LOWs by the keyboard they will drive **LOW** and pull the inputs to the Propeller chip **LOW** as well, so all is good. Finally, if the keyboard places the outputs **DATA** or **CLOCK** into a tri-state or high impedance mode then the 2.2 kΩ pull-ups to +5, **R11** and **R14**, will drive the inputs **KB\_CLOCK** and **KB\_DATA HIGH** as well, so there is never a time when there is an undefined logic state on the lines **KB\_DATA** and **KB\_CLOCK**. Of course, the same arguments are valid for the mouse interface.

On the other hand, if the Propeller chip wants to control the conversation then it can drive the **DATA** and **CLOCK** lines either **LOW** or **HIGH**. When driving the lines **HIGH**, the Propeller chip outputs a 3.3 V to either port **P12** or **P14**, a **LOW** is desired on either **CLOCK** or **DATA** then the transistor must be switched **ON**. To do this a **HIGH** must be gated to the base of the transistor at **P12** or **P14**, this will turn **ON** either transistor and connect either **KB\_CLOCK** or **KB\_DATA** to ground which is what we want. If it's desired that **KB\_DATA** or **KB\_CLOCK** is driven **HIGH** then the pull-ups at **R11** and **R14** will do this for us, and we only need to make sure the transistors are **OFF** and therefore the voltage at either **P12** or **P14** is **LOW** respectively.

To review, the keyboard (and mouse) are controlled via two bi-directional data lines: **CLOCK** and **DATA**. PS/2 mouse and keyboards are typically **5 V systems**, so to interface them safely to the Propeller chip and to use the drivers already written for keyboard (and mouse) we use 4 lines, **two** each for the **DATA** and the **CLOCK** lines to allow bi-directional communication and control of the lines while maintaining both the 3.3 V and 5 V systems safely. We will discuss programming the keyboard at length later, but for now let's briefly review how the keyboard and mouse both send data.

## 10.2 Keyboard Operation

The keyboard protocol is straightforward and works as follows: for every key pressed there is a "**scan code**" referred to as the "**make code**" that is sent; additionally when every key released there is another scan code referred to as the "**break code**" that in most cases is composed of \$EO followed by the original make code scan value. However, many keys may have multiple make codes and break codes. Table 10:1 lists the scan codes for keyboards running in default mode (startup).

Table 10:1			Keyboard Default Scan Codes▼					
KEY	MAKE	BREAK	KEY	MAKE	BREAK	KEY	MAKE	BREAK
A	1C	F0,1C	9	46	F0,46	[	54	F0,54
B	32	F0,32	`	0E	F0,0E	INSERT	E0,70	E0,F0,70
C	21	F0,21	-	4E	F0,4E	HOME	E0,6C	E0,F0,6C
D	23	F0,23	=	55	F0,55	PG UP	E0,7D	E0,F0,7D
E	24	F0,24	\	5D	F0,5D	DELETE	E0,71	E0,F0,71
F	2B	F0,2B	BKSP	66	F0,66	END	E0,69	E0,F0,69
G	34	F0,34	SPACE	29	F0,29	PG DN	E0,7A	E0,F0,7A
H	33	F0,33	TAB	0D	F0,0D	U ARROW	E0,75	E0,F0,75
I	43	F0,43	CAPS	58	F0,58	L ARROW	E0,6B	E0,F0,6B
J	3B	F0,3B	L SHFT	12	F0,12	D ARROW	E0,72	E0,F0,72
K	42	F0,42	L CTRL	14	F0,14	R ARROW	E0,74	E0,F0,74
L	4B	F0,4B	L GUI	E0,1F	E0,F0,1F	NUM	77	F0,77
M	3A	F0,3A	L ALT	11	F0,11	KP /	E0,4A	E0,F0,4A
N	31	F0,31	R SHFT	59	F0,59	KP *	7C	F0,7C
O	44	F0,44	R CTRL	E0,14	E0,F0,14	KP -	7B	F0,7B
P	4D	F0,4D	R GUI	E0,27	E0,F0,27	KP +	79	F0,79
Q	15	F0,15	R ALT	E0,11	E0,F0,11	KP EN	E0,5A	E0,F0,5A
R	2D	F0,2D	APPS	E0,2F	E0,F0,2F	KP .	71	F0,71
S	1B	F0,1B	ENTER	5A	F0,5A	KP 0	70	F0,70
T	2C	F0,2C	ESC	76	F0,76	KP 1	69	F0,69
U	3C	F0,3C	F1	05	F0,05	KP 2	72	F0,72
V	2A	F0,2A	F2	06	F0,06	KP 3	7A	F0,7A
W	1D	F0,1D	F3	04	F0,04	KP 4	6B	F0,6B
X	22	F0,22	F4	0C	F0,0C	KP 5	73	F0,73
Y	35	F0,35	F5	03	F0,03	KP 6	74	F0,74
Z	1A	F0,1A	F6	0B	F0,0B	KP 7	6C	F0,6C
0	45	F0,45	F7	83	F0,83	KP 8	75	F0,75
1	16	F0,16	F8	0A	F0,0A	KP 9	7D	F0,7D
2	1E	F0,1E	F9	01	F0,01	]	5B	F0,5B
3	26	F0,26	F10	09	F0,09	;	4C	F0,4C
4	25	F0,25	F11	78	F0,78	'	52	F0,52
5	2E	F0,2E	F12	07	F0,07	,	41	F0,41
6	36	F0,36	PRNT SCRN	E0,12; E0,7C	E0,F0, 7C,E0, F0,12	.	49	F0,49
7	3D	F0,3D	SCROLL	7E	F0,7E	/	4A	F0,4A
8	3E	F0,3E	PAUSE	E1,14,77, E1,F0,14, F0,77	-NONE-			

The keyboard hardware interface is either an old style **male 5-pin DIN** or a new PS/2 male **6-pin mini-DIN** connector. The 6-pin mini DIN's pinout is shown in Figure 10:2 (referenced looking at the computer's female side where you plug the keyboard into, notice the staggering of the pin numbering).

Table 10:2 lists the signals for reference, and the descriptions of the signals are as follows:

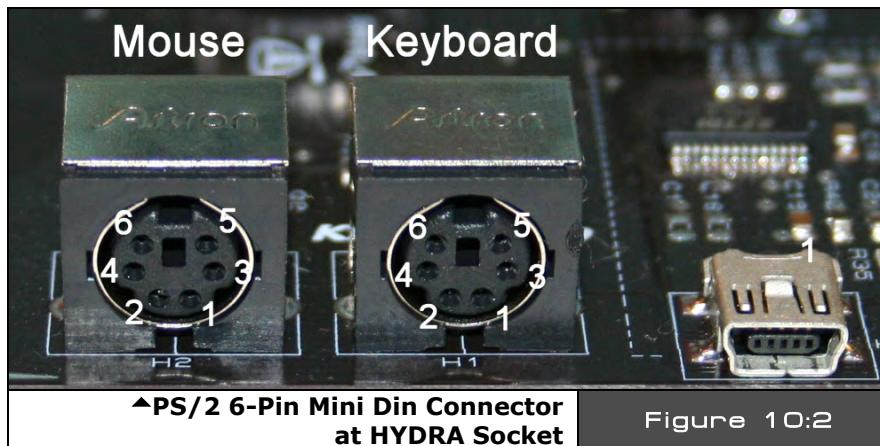
Table 10:2		Pinout of PS/2 6-Pin Mini Din▼
Pin	Function	
1	DATA (bi-directional open collector)	
2	NC	
3	GROUND	
4	VCC (+5 @ 100 mA)	
5	CLOCK	
6	NC	

**DATA** – Bi-directional and used to send and receive data.

**CLOCK** – Bi-directional; however, the keyboard nearly always controls it. The host can pull the **CLOCK** line **LOW** though to **inhibit** transmissions; additionally during host → keyboard communications the **CLOCK** line is used as a “request to send” line of sorts to initiate the host → keyboard transmission. This is used when commands or settings need to be sent to the keyboard.

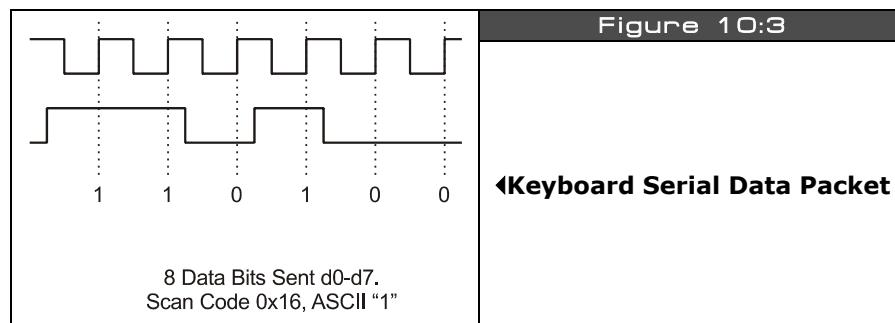
**VCC/GROUND** – Power for the keyboard (or mouse). Specifications state no more than **100 mA** will be drawn, but I wouldn't count on it and plan for **200 mA** for “blinged-out” keyboards with lots of lights etc.

When both the keyboard and the host are inactive the **CLOCK** and **DATA** lines should be **HIGH** (inactive).



### 10.2.1 Communication Protocol from Keyboard to Host

When a key is pressed on the keyboard, the keyboard logic sends the ***make scan code*** to the host computer. The scan code data is clocked out by the keyboard in an 11-bit packet; the packet consists of a ***single LOW start bit*** (35 µs) followed by ***8 data bits*** (70 µs each), ***a parity bit***, and finally a ***HIGH stop bit***. Data should be sampled by the host computer on the data line on the falling edge of the CLOCK line (driven by keyboard). Below is the general algorithm for reading the keyboard.



### 10.2.2 Keyboard Read Algorithm

The read algorithm makes the assumption that the main host has been forcing the keyboard to buffer the last key. This is accomplished by holding ***CLOCK LOW***. Once the host releases the keyboard, the keyboard will start clocking the clock line and ***drop the DATA line*** with a ***start bit*** if there was a key in the buffer, else the ***DATA line will stay HIGH***. So the following steps are ***after*** the host releases the keyboard and is trying to determine by means of polling if there is a key in the keyboard buffer.

**Step 1:** Delay 5 µs to allow hold on CLOCK line to release and keyboard to send buffered scan code.

**Step 2 (Start of frame):** If both CLOCK and DATA are low (start bit) then enter into read loop, else return, no key present.

**Step 3 (Start of data):** Wait until clock goes high...

**Step 4 (Read data):** Read data bits loop:

```
for t = 0 to t <= 7 do
    wait for CLOCK to go low...
    delay 5 us to center sample
    bit(t) = DATA
next t
```

**Step 5: (Read parity and Stop Bits):** Lastly the parity and stop bits must be read.

And that's it! Of course, if you want to be strict then you should verify the parity bit, but you don't need to unless you want to perform error correction.



#### NOTE

Both the keyboard and mouse use an “odd parity” scheme for error detection. Odd parity is HIGH when the number of 1’s in a string is ODD, LOW otherwise. Even parity is HIGH when the number of 1’s in a string is EVEN, LOW otherwise. Note that parity only tells us there is an error, but not how to correct it.

### 10.2.3 Keyboard Write Algorithm

The process of sending commands to the keyboard or “writing” to the keyboard is identical to that when reading. The protocol is the same except the host initiates the conversation. Then the keyboard will actually do the clocking while the host pulls on the data line at the appropriate times. The sequence is as follows:

**Step 1:** Wait for the keyboard to stop sending data (if you want to play nice). This means that both the DATA and CLOCK lines will be in a **HIGH** state.

**Step 2 (Initiate transmission):** The host drives the CLOCK line **LOW** for 60 µs to tell the keyboard to stop all transmissions. This is redundant if you waited for Step 1; however, the keyboard might not want to shut up, therefore, this is how you force it to stop and listen.

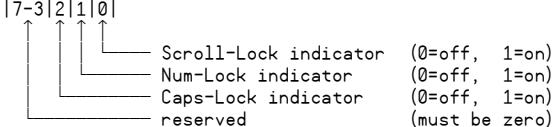
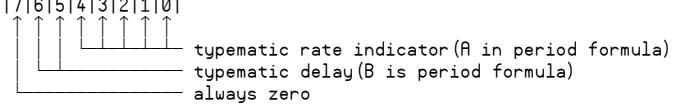
**Step 3 (Data ready for transmission):** Drive the DATA line **LOW**, then release the CLOCK line (by release we mean not to put a HIGH or a LOW, but to set the CLOCK into a tri-state or input mode, so the keyboard can control it). This puts the keyboard into the “receiver” state.

**Step 4 (Write data):** Now, the keyboard will generate a clock signal on the CLOCK line, you retrieve your DATA, and when the CLOCK line is **HIGH** you send it on the DATA line. The host program should serialize the command data (explained momentarily) made up of 8 bits, a parity bit, and a stop bit for a total of **10 bits**.

**Step 5 (End transmission):** Once the last data bit is sent then the parity (odd parity) and stop bit is sent then the host drives the DATA line (stop bit) and releases the DATA line.

### 10.2.4 Keyboard Commands

Table 10:3 illustrates some of the commands one can send to a generic keyboard based on the 8042 keyboard controller originally in the IBM PC spec. This table is not exhaustive and only a reference, many keyboards don’t follow the commands 100% and/or have other commands, so be wary of the commands.

Table 10:3		Keyboard Commands▼								
Code	Description									
\$ED	<p><b>Set/Reset Mode Indicators:</b> keyboard responds with ACK then waits for a following option BYTE. When the option BYTE is received the keyboard again ACK's and then sets the LEDs accordingly. Scanning is resumed if scanning was enabled. If another command is received instead of the option BYTE (high bit set on) this command is terminated. Hardware defaults to these indicators turned off.</p> <p>Keyboard Status Indicator Option BYTE</p>  <table border="0"> <tr> <td>  7   6   5   4   3   2   1   0  </td> <td>scroll-lock indicator (0=off, 1=on)</td> </tr> <tr> <td>↑</td> <td>num-lock indicator (0=off, 1=on)</td> </tr> <tr> <td>↑</td> <td>caps-lock indicator (0=off, 1=on)</td> </tr> <tr> <td>↑</td> <td>reserved (must be zero)</td> </tr> </table>	7   6   5   4   3   2   1   0	scroll-lock indicator (0=off, 1=on)	↑	num-lock indicator (0=off, 1=on)	↑	caps-lock indicator (0=off, 1=on)	↑	reserved (must be zero)	
7   6   5   4   3   2   1   0	scroll-lock indicator (0=off, 1=on)									
↑	num-lock indicator (0=off, 1=on)									
↑	caps-lock indicator (0=off, 1=on)									
↑	reserved (must be zero)									
\$EE	<p><b>Diagnostic Echo:</b> keyboard echoes the \$EE BYTE back to the system without an acknowledgement.</p>									
\$F0	<p><b>PS/2 Select/Read Alternate Scan Code Sets:</b> instructs keyboard to use one of the three make/break scan code sets. Keyboard responds by clearing the output buffer/typematic key and then transmits an ACK. The system must follow up by sending an option BYTE which will again be ACK'd by the keyboard:</p> <ul style="list-style-type: none"> <li>► return BYTE indicating scan code set in use.</li> <li>► select scan code set 1 (used on PC &amp; XT).</li> <li>► select scan code set 2.</li> <li>► 03 select scan code set 3.</li> </ul>									
\$F2	<p><b>PS/2 Read Keyboard ID:</b> keyboard responds with an ACK and a two-BYTE keyboard ID of 83AB.</p>									
\$F3	<p><b>Set Typematic Rate/Delay:</b> keyboard responds with ACK and waits for rate/delay BYTE. Upon receipt of the rate/delay BYTE the keyboard responds with an ACK, then sets the new typematic values and scanning continues if scanning was enabled.</p> <p>Typematic Rate/Delay Option BYTE</p>  <table border="0"> <tr> <td>  7   6   5   4   3   2   1   0  </td> <td>typematic rate indicator (A in period formula)</td> </tr> <tr> <td>↑</td> <td>typematic delay (B is period formula)</td> </tr> <tr> <td>↑</td> <td>always zero</td> </tr> </table> <p>delay = (rate+1) * 250 (in milliseconds)</p> <p>rate = (8+A) * (2^B) * 0.00417 (in seconds)</p> <p>Defaults to 10.9 characters per second and a 500 ms delay. If a command BYTE (BYTE with high bit set) is received instead of an option BYTE this command is cancelled.</p>	7   6   5   4   3   2   1   0	typematic rate indicator (A in period formula)	↑	typematic delay (B is period formula)	↑	always zero			
7   6   5   4   3   2   1   0	typematic rate indicator (A in period formula)									
↑	typematic delay (B is period formula)									
↑	always zero									
\$F4	<p><b>Enable Keyboard:</b> cause the keyboard to clear its output buffer and last typematic key and then respond with an ACK. The keyboard then begins scanning.</p>									

(Table 10:3 is continued on the next page.)

Table 10:3	Keyboard Commands (continued)▼
Code	Description
\$F5	<b>Default w/Disable:</b> resets keyboard to power-on condition by clearing the output buffer, resetting typematic rate/delay, resetting last typematic key and setting default key types. The keyboard responds with an ACK and waits for the next instruction.
\$F6	<b>Set Default:</b> resets to power-on condition by clearing the output buffer, resetting typematic rate/delay and last typematic key and sets default key types. The keyboard responds with an ACK and continues scanning.
\$F7	<b>PS/2 Set All Keys to Typematic:</b> keyboard responds by sending an ACK, clearing its output buffer and setting the key type to Typematic. Scanning continues if scanning was enabled. This command may be sent while using any Scan Code Set but only has effect when Scan Code Set 3 is in use.
\$F8	<b>PS/2 Set All Keys to Make/Break:</b> keyboard responds by sending an ACK, clearing its output buffer and setting the key type to Make/Break. Scanning continues if scanning was enabled. This command may be sent while using any Scan Code Set but only has effect when Scan Code Set 3 is in use.
\$F9	<b>PS/2 Set All Keys to Make:</b> keyboard responds by sending an ACK, clearing its output buffer and setting the key type to Make. Scanning continues if Scanning was enabled. This command may be sent while using any Scan Code Set but only has effect when Scan Code Set 3 is in use.
\$FA	<b>PS/2 Set All Keys to Typematic Make/Break:</b> keyboard responds by sending an ACK, clearing its output buffer and setting the key type to Typematic make/Break. Scanning continues if scanning was enabled. This command may be sent while using any Scan Code Set but only has effect when Scan Code Set 3 is in use.
\$FB	<b>PS/2 Set Key Type to Typematic:</b> keyboard responds by sending an ACK, clearing its output buffer and then waiting for the key ID (make code from Scan Code Set 3). The specified key type is then set to typematic. This command may be sent while using any Scan Code Set but only has effect when Scan Code Set 3 is in use.
\$FC	<b>PS/2 Set Key Type to Make/Break:</b> keyboard responds by sending an ACK, clearing its output buffer and then waiting for the key ID (make code from Scan Code Set 3). The specified key type is then set to Make/Break. This command may be sent while using any Scan Code Set but only has effect when Scan Code Set 3 is in use.
\$FD	<b>PS/2 Set Key Type to Make:</b> keyboard responds by sending an ACK, clearing its output buffer and then waiting for the key ID (make code from Scan Code Set 3). The specified key type is then set to Make. This command may be sent while using any Scan Code Set but only has effect when Scan Code Set 3 is in use.
\$FE	<b>Resend:</b> should be sent when a transmission error is detected from the keyboard.
\$FF	<b>Reset:</b> Keyboard sends ACK and waits for system to receive it then begins a program reset and Basic Assurance Test (BAT). Keyboard returns a one BYTE completion code then sets default Scan Code Set 2.

There are software “objects” written by Parallax that do all this for us on the Propeller chip, but if you want to write your own or optimize the current drivers then this information comes in handy. Now, let’s briefly review the mouse protocol.

## 10.3 Communication Protocol from Mouse to Host

The mouse protocol is exactly the same as the keyboard protocol as far as sending and receiving BYTEs with the 11-bit packet. The only difference of course is the data format the mouse sends to the host and the commands the host (HYDRA) can send the mouse. Again, we will see programming examples in Part II, but let's just review the technical details briefly to get acquainted with the commands and data.

### 10.3.1 Basic Mouse Operation

The standard PS/2 mouse interface supports the following inputs:

- ▶ X (right/left) movement
- ▶ Y (up/down) movement
- ▶ Left, Middle, and Right buttons

The mouse has an **internal microcontroller** that translates the motion of the mouse whether it be a **mechanical ball, optical tracking system**, or something else. These inputs along with the buttons are scanned at a regular frequency and updates are made to the internal “**state**” of the mouse via various counters and flags that reflect the movement and button states. Obviously there are mice these days with a lot more than 3 buttons and 2 axes, but we are not going to concern ourselves with these (extensions), we just need to read the X,Y position along with the state of the buttons for simple mousing and game applications.

The standard PS/2 mouse has **two** internal **9-bit 2's complement counters** (with an overflow bit each) that keep track of movement in the X and Y axis. The X and Y counters along with the state of the three mouse buttons are sent to the host in the form of a **3-BYTE data packet**. The movement counters represent the amount of movement that has occurred since the last movement data packet was sent to the host; therefore they are relative positions, not absolute.

Each time the mouse reads its inputs (controlled internally by the microcontroller in the mouse), it updates the state of the buttons and the deltas in the X, Y counters. If there is an overflow, that is if the motion from the last update is so large it can't fit in the 9 bits of either counter, then the overflow flag for that axis is set to let the host know there is a problem.

The parameter that determines the amount by which the movement counters are incremented/decremented is the **resolution**. The default resolution is **4 counts/mm** and the host may change that value using the “**Set Resolution**” (**\$E8**) command. Additionally, the mouse hardware can do a scaling operation to the sent data itself to save the host the work. The **scaling** parameter controls this. By default, the mouse uses **1:1 scaling**, which means that the reported motion is the same as the actual motion. However, the host may select 2:1 scaling by sending the “**Set Scaling 2:1**” (**\$E7**) command. If 2:1 scaling is

enabled, the mouse applies the following mapping as shown in Table 10:4 to the counters before sending their contents to the host in the data packet.

Table 10:4		Mouse Scaling reported Data Mapping when in 2:1 mode▼	
Actual Movement (delta)		Reported Movement	
0		0	
1		1	
2		1	
3		3	
4		6	
5		9	
delta > 5		delta × 2	

So the scaling operation only takes affect when the actual movement delta is greater than 1, and for delta > 5, the reported movement is always (**delta × 2**). Now, let's look at the actual data packet format for the mouse state.

### 10.3.2 Mouse Data Packets

The PS/2 mouse sends the movement information to the host which includes the position counters, button state, overflow flags and sign bits in the format show in Table 10:5.

Table 10:5		Mouse Data Packet Format▼							
	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
<b>BYTE 1</b>	Y overflow bit	X overflow bit	Y sign bit	X sign bit	Always 1	Middle Button	Right Button	Left Button	
<b>BYTE 2</b>	X Movement (delta)								
<b>BYTE 3</b>	Y Movement (delta)								

The movement counters are 9-bit 2's complement integers; since the serial protocol only supports 8 bits at a time, the uppermost sign bit for each 9-bit integer is stored in BYTE 1 of the overall movement packet. Bit 4 holds the 9<sup>th</sup> bit of the X movement and Bit 5 holds the 9<sup>th</sup> bit of the Y movement. Typically, you don't need to worry about the 9<sup>th</sup> bits since that would be a lot of motion in one update, so just use BYTES 2 and 3 to track motion.

The motion counters are updated when the mouse reads its input and movement has occurred. As noted, the movement counters only record **differential** or delta motion rather than absolute. With a 9-bit value recording each counter, a total amount of -255 to +256 can be represented in 9-bit 2's complement. If this range is exceeded, the appropriate overflow bit is set for either the X or Y counter. Note that the movement counters are reset whenever a movement data packet is successfully sent to the host. The counters are also reset after the mouse receives any command from the host other than the "**Resend**" (\$FE) command. Next, let's discuss the different mouse operation modes.

### 10.3.3 Modes of Operation

There are four standard modes of operation which dictate how the mouse reports data to the host, they are:

- ▶ **RESET:** The mouse enters **Reset mode** at power-up or after receiving the "**Reset**" (\$FF) command. For this mode to occur both the **DATA** and **CLOCK** lines must be **HIGH**.
- ▶ **STREAMING:** This is the default mode (after Reset finishes executing) and is the mode in which most software uses the mouse. If the host has previously set the mouse to Remote mode, it may re-enter Stream mode by sending the "**Set Stream Mode**" (\$EA) command to the mouse.
- ▶ **REMOTE:** Remote mode is useful in some situations and may be entered by sending the "**Set Remote Mode**" (\$F0) command to the mouse.
- ▶ **WRAP:** This diagnostic mode is useful for testing the connection between the mouse and its host. Wrap mode may be entered by sending the "**Set Wrap Mode**" (\$EE) command to the mouse. To exit Wrap mode, the host must issue the "**Reset**" (\$FF) command or "**Reset Wrap Mode**" (\$EC) command. If the "Reset" (\$FF) command is received, the mouse will enter Reset mode. If the "Reset Wrap Mode" (\$EC) command is received, the mouse will enter the mode it was in prior to Wrap mode.

**RESET Mode** - The mouse enters Reset mode at power-on or in response to the "**Reset**" (\$FF) command. After entering reset mode, the mouse performs a diagnostic self-test referred to as **BAT** (Basic Assurance Test) and sets the following default values:

- ▶ Sample Rate = 100 samples/sec
- ▶ Resolution = 4 counts/mm
- ▶ Scaling = 1:1
- ▶ Data Reporting Disabled

After Reset, the mouse sends a BAT completion code of either **\$AA** (BAT successful) or **\$FC** (Error). The host's response to a completion code other than \$AA is undefined. Following the BAT completion code of \$AA (ok) or \$FC (error), the mouse sends its **device ID** of **\$00**. This distinguishes the standard PS/2 mouse from a keyboard or a mouse in an **extended mode**.

After the mouse has sent its device ID of \$00 to the host, it will enter **Stream mode**. Note that one of the default values set by the mouse is "**Data Reporting Disabled**." This means the mouse will not issue any movement data packets until it receives the "**Enable Data Reporting**" command. The various modes of operation for the mouse are:

**STREAM Mode** - In stream mode, the mouse sends movement data when it detects movement or a change in state of one or more mouse buttons. The rate at which this data reporting occurs is the **sample rate** (defaults to **100 samples/sec** on Reset). This parameter can range from **10** to **200** samples/sec on most drivers. The default sample rate value is **100** samples/sec, but the host may change that value by using the "**Set Sample Rate**" command. Stream mode is the default mode of operation following reset.

**REMOTE Mode** - In this mode the mouse reads its inputs and updates its counters/flags at the current sample rate, but it **does not** automatically send data packets when movement occurs, rather the host must "**poll**" the mouse using the "**Read Data**" command. Upon receiving this command the mouse sends back a single movement data packet and resets its movement counters.

**WRAP Mode** - This is an "**echoing**" mode in which every BYTE received by the mouse is sent back to the host. Even if the BYTE represents a valid command, the mouse will not respond to that command — it will only echo that BYTE back to the host. There are two exceptions to this: the "**Reset**" command and "**Reset Wrap Mode**" command, this is obviously the only way to get the mouse back out of the Wrap mode! The mouse treats these as valid commands and does not echo them back to the host. Thus Wrap mode is a good diagnostic mode to test if a mouse is connected and if it's working.

#### 10.3.4 Sending Mouse Commands

A mouse command similar to a keyboard command in that it is sent using the standard 11-bit serial protocol outlined in the Keyboard Write section. The commands supported are shown in Table 10:6.

Table 10:6	Command Set for Standard PS/2 Mouse▼
Code	Description
\$FF	<b>Reset:</b> The mouse responds to this command with "acknowledge" (\$FA) then enters Reset Mode.
\$FE	<b>Resend:</b> The host can send this command whenever it receives invalid data from the mouse. The mouse responds by resending the last packet it sent to the host. If the mouse responds to the "Resend" command with another invalid packet, the host may either issue another "Resend" command, issue an "Error" command, cycle the mouse's power supply to reset the mouse, or it may inhibit communication (by bringing the Clock line low). The action taken depends on the host.
\$F6	<p><b>Set Defaults:</b> The mouse responds with "acknowledge" (\$FA) then loads the following values into its driver:</p> <ul style="list-style-type: none"> <li>▶ Sampling rate = 100</li> <li>▶ Resolution = 4 counts/mm</li> <li>▶ Scaling = 1:1</li> <li>▶ Disable Data Reporting</li> </ul> <p>The mouse then resets its movement counters and enters Stream mode</p>
\$F5	<b>Disable Data Reporting:</b> The mouse responds with "acknowledge" (\$FA) then disables Data Reporting mode and resets its movement counters. This only effects data reporting in Stream mode and does not disable sampling. Disabled Stream mode functions the same as Remote mode.
\$F4	<b>Enable Data Reporting:</b> The mouse responds with "acknowledge" (\$FA) then enables Data Reporting mode and resets its movement counters. This command may be issued while the mouse is in Remote mode (or Stream mode), but it will only effect data reporting in Stream mode.
\$F3	<b>Set Sample Rate:</b> The mouse responds with "acknowledge" (\$FA) then reads one more BYTE from the host which represents the sample rate in unsigned 8-bit magnitude format. The mouse saves this BYTE as the new sample rate. After receiving the sample rate, the mouse again responds with "acknowledge" (\$FA) and resets its movement counters. Most mice accept sample rates of 10, 20, 40, 60, 80, 100 and 200 samples/sec.
\$F2	<b>Get Device ID:</b> The mouse responds with "acknowledge" (\$FA) followed by its device ID (\$00 for the standard PS/2 mouse.) The mouse also resets its movement counters in most cases.
\$F0	<b>Set Remote Mode:</b> The mouse responds with "acknowledge" (\$FA) then resets its movement counters and enters Remote mode.
\$EE	<b>Set Wrap Mode:</b> The mouse responds with "acknowledge" (\$FA) then resets its movement counters and enters Wrap mode.
\$EC	<b>Reset Wrap Mode:</b> The mouse responds with "acknowledge" (\$FA) then resets its movement counters and enters the mode it was in prior to Wrap mode (Stream Mode or Remote Mode.)
\$EB	<b>Read Data:</b> The mouse responds with acknowledge (\$FA) then sends a movement data packet. This is the only way to read data in Remote Mode. After the data packet has been successfully sent, the mouse resets its movement counters.

(Table 10:6 is continued on the next page.)

Table 10:6	Command Set for Standard PS/2 Mouse (continued) ▾																																				
Code	Description																																				
\$EA	<p><b>Set Stream Mode:</b> The mouse responds with "acknowledge" then resets its movement counters and enters Stream mode.</p>																																				
\$E9	<p><b>Status Request:</b> The mouse responds with "acknowledge" then sends the following 3-BYTE status packet (then resets its movement counters) as shown below:</p> <table border="1"> <thead> <tr> <th></th><th>Bit 7</th><th>Bit 6</th><th>Bit 5</th><th>Bit 4</th><th>Bit 3</th><th>Bit 2</th><th>Bit 1</th><th>Bit 0</th></tr> </thead> <tbody> <tr> <td>BYTE 1</td><td>Always 0</td><td>Mode</td><td>Enable</td><td>Scaling</td><td>Always 0</td><td>Left Button</td><td>Middle Button</td><td>Right Button</td></tr> <tr> <td>BYTE 2</td><td colspan="8" style="text-align: center;">Resolution</td></tr> <tr> <td>BYTE 3</td><td colspan="8" style="text-align: center;">Sample Rate</td></tr> </tbody> </table> <p>Right, Middle, Left button = 1 if button pressed; 0 if button is not pressed.  <b>Scaling</b> = 1 if scaling is 2:1; 0 if scaling is 1:1 (Refer to commands \$E7 and \$E6).  <b>Enable</b> = 1 if data reporting is enabled; 0 if data reporting is disabled (Refer to commands \$F5 and \$F4).  <b>Mode</b> = 1 if Remote Mode is enabled; 0 if Stream mode is enabled (Refer to commands \$F0 and \$EA).</p>		Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	BYTE 1	Always 0	Mode	Enable	Scaling	Always 0	Left Button	Middle Button	Right Button	BYTE 2	Resolution								BYTE 3	Sample Rate							
	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0																													
BYTE 1	Always 0	Mode	Enable	Scaling	Always 0	Left Button	Middle Button	Right Button																													
BYTE 2	Resolution																																				
BYTE 3	Sample Rate																																				
\$E8	<p><b>Set Resolution:</b> The mouse responds with acknowledge (\$FA) then reads the next BYTE from the host and again responds with acknowledge (\$FA) then resets its movement counters. The BYTE read from the host determines the resolution as follows:</p> <table border="1"> <thead> <tr> <th>BYTE Read from Host</th><th>Resolution</th></tr> </thead> <tbody> <tr> <td>\$00</td><td>1 count /mm</td></tr> <tr> <td>\$01</td><td>2 count /mm</td></tr> <tr> <td>\$02</td><td>4 count /mm</td></tr> <tr> <td>\$03</td><td>8 count /mm</td></tr> </tbody> </table>	BYTE Read from Host	Resolution	\$00	1 count /mm	\$01	2 count /mm	\$02	4 count /mm	\$03	8 count /mm																										
BYTE Read from Host	Resolution																																				
\$00	1 count /mm																																				
\$01	2 count /mm																																				
\$02	4 count /mm																																				
\$03	8 count /mm																																				
\$E7	<b>Set Scaling 2:1:</b> The mouse responds with acknowledge (\$FA) then enables 2:1 scaling mode.																																				
\$E6	<b>Set Scaling 1:1:</b> The mouse responds with acknowledge (\$FA) then enables 1:1 scaling (default).																																				

Lastly, the only **commands** the standard PS/2 mouse will send **to the host** are "**Resend**" (**\$FE**) and "**Error**" (**\$FC**). They both work the same as they do as host-to-device commands. Other than that the mouse simply sends 3-BYTE data motion packets in most cases.



#### NOTE

If the mouse is in Stream mode, the host should disable data reporting (command \$F5) before sending any other commands. This way, the mouse won't keep trying to send packets back while the host is trying to communicate with the mouse.

### 10.3.5 Mouse Initialization

During the mouse power-up both the DATA and CLOCK lines must be pulled **HIGH** and/or released/tri-stated by the host. The mouse will then run its power-up self-test or BAT and start sending the results to the host. The host watches the CLOCK and DATA lines to determine when this transmission occurs and should look for the code **\$AA** (ok) followed by **\$00** (mouse device ID). However, you can forgo this step if you like and just wait 1-2 seconds and “assume” the mouse was plugged in properly. You do not have to respond to this code in other words. If you wish to **Reset** the mouse, you can at any time send the command code **\$FF**, and the mouse should **respond** with **\$FA** to acknowledge that everything went well.

Once the mouse sends the **\$AA**, **\$00** startup codes, it enters its standard default mode as explained in the sections above. The only thing we need to do to get the mouse sending packets is to tell the mouse to start reporting movement. This is done by sending the command **“Enable Data Reporting” (\$F4)**; the mouse responds with **\$FA** to acknowledge the command worked and then will start streaming out 3-BYTE movement packets at the default rate of 100 samples/sec. This step is necessary, since on start-up if the mouse simply started streaming data packets the host could lose important data, thus the mouse “waits” to be told to start streaming the data and reporting the motion.

The movement data packets are formatted as shown in Table 10:5 on page 152. You simply need to read these packets and send them upstream to your application.

### 10.3.6 Reading Mouse Movement

Assuming that the mouse has been initialized and is in Streaming mode with Reporting mode enabled, you simply loop and read each 3-BYTE movement packet. As you read the first BYTE you use it to determine the state of the buttons as well as any overflows with the counters. Then the next two BYTES, the X and Y deltas, should be added to running counters (16-bit) that track the absolute position of the mouse cursor. That’s it!

## 10.4 Summary

The amount of technology in a PC always amazes me; if you haven’t ever written a keyboard or mouse driver, you are probably thinking, “I had no idea there was so much going on with the mouse and keyboard!” That’s the thing about the PC, it’s truly a marvel of technology and all the interfaces used are very well thought out (usually). This of course makes our lives much easier since there is good documentation on how to interface to the mouse and keyboard, which in turn makes writing drivers much less painful. Also, remember that for games and specific applications you do not need a bulletproof driver as you might for a real PC. The keyboard and mouse drivers provided by Parallax (which we will discuss later) are fairly complete and definitely overkill. When you design games and applications on the HYDRA (and Propeller chip), you will find that these drivers are a good starting point, but you

will tend to strip them and simplify them to save memory so you can write larger and larger programs. For example, I have written both keyboard and mouse drivers in about 20-30 lines of ASM code, that's all you really need to for the really baseline functionality.

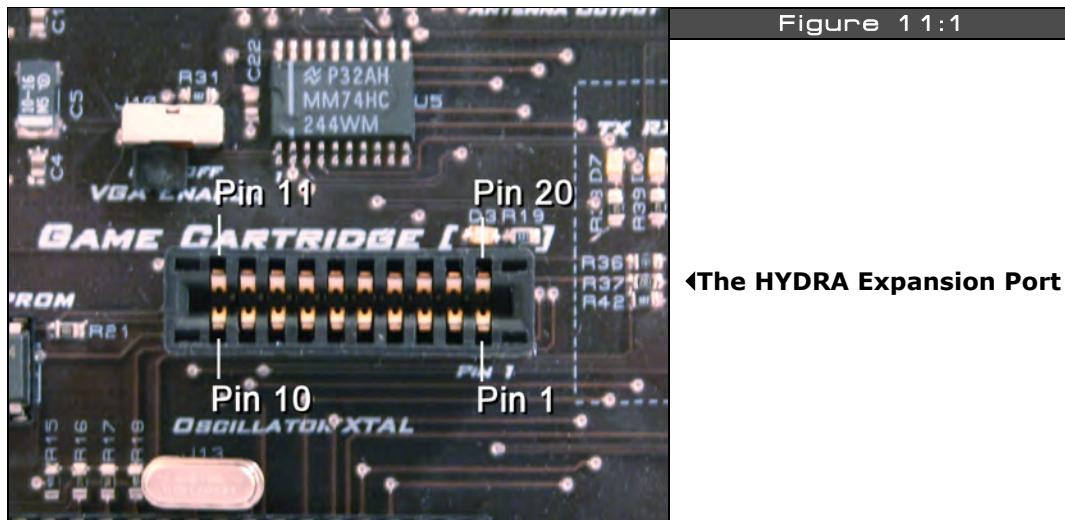
## Chapter 11:

### Game Cartridge, EEPROM & Expansion Port Hardware

In this chapter we are going to discuss the "**expansion port**" on the HYDRA as well as the design of the onboard serial EEPROM since they are related. The expansion port is the most powerful aspect of the HYDRA since it allows you to plug in enhancement products to upgrade the HYDRA including more memory, I/O, extra processors, or whatever you can think up! As is, the HYDRA comes with both a **128 K Game Card** as well as a **Blank Experimenter Card**. We are going to discuss all these topics and more, here's what's in store:

- ▶ Game expansion port design and signals.
- ▶ Blank Experimenter Card design.
- ▶ 128 K Memory Card design.
- ▶ Onboard 128 K serial EEPROM design.

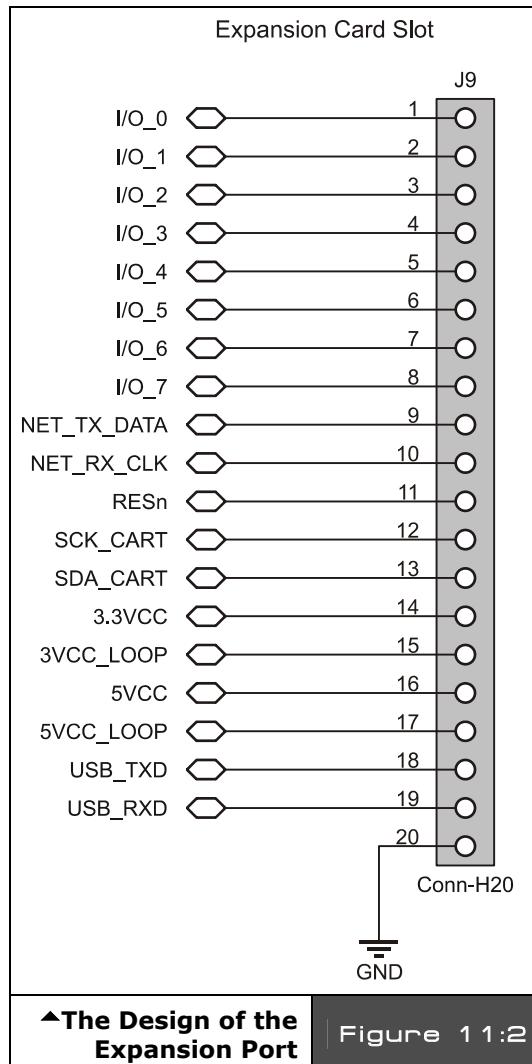
### 11.1 HYDRA Expansion Port Design



The HYDRA has a 20 pin expansion port (J9) as shown in Figure 11:1 that can be used for a number of expansion functions. The port itself is an industry standard female edge connector interface with 0.1" contact spacing on both sides. Typically, the idea of an "expansion port" is to export as much of the system busses and I/O as possible, so future upgrades and add-ons can be built on the platform. With this in mind, the expansion port exports:

- ▶ Power (for both the 3.3 V and 5.0 V supplies)
- ▶ Networking (the built in RJ-11 ad-hoc serial network)
- ▶ USB (serial TX and RX along with ground)
- ▶ 8 I/Os (general I/Os from Propeller chip also used for VGA interface)
- ▶ System reset
- ▶ Serial EEPROM interface (so an EEPROM on the cartridge can be loaded rather than the onboard EEPROM)
- ▶ Loop-back signals to detect cartridge insertions

Everything is self-explanatory except maybe the "**loop-back**" power lines. There are used to indicate a cartridge is plugged in. The power lines are looped back on the cartridge and then "sensed" back on the HYDRA via the signal lines **33VCC\_LOOP** and **5VCC\_LOOP**. This way the HYDRA can tell if something is plugged in and your code can take different execution paths, or you can wire them directly to hardware selection logic to gate in/out various components. Referring to the image in Figure 11:1 of the expansion port take a look at Figure 11:2, it's the actual design of the expansion port and shows the lines that are exported.



▲The Design of the Expansion Port

Figure 11:2

### 11.1.1 Expansion Port Signal Definitions

Table 11:1 below lists the actual signal names and their connections to the Propeller chip as well as their functions for the expansion port.

The Mapping of Expansion Port Signals to the Propeller Chip▼			
Expansion Port Signal	Expansion Port Pin	Propeller Pin# / Name	Description
I/O_0	1	21 / P16	General I/O (shared with VGA_VSYNC)
I/O_1	2	22 / P17	General I/O (shared with VGA_HSYNC)
I/O_2	3	23 / P18	General I/O (shared with VGA_BLUE_B0)
I/O_3	4	24 / P19	General I/O (shared with VGA_BLUE_B1)
I/O_4	5	25 / P20	General I/O (shared with VGA_BLUE_G0)
I/O_5	6	26 / P21	General I/O (shared with VGA_BLUE_G1)
I/O_6	7	27 / P22	General I/O (shared with VGA_BLUE_R0)
I/O_7	8	28 / P23	General I/O (shared with VGA_BLUE_R1)
NET_TX_DATA	9	3 / P2	HYDRA Net Transmit Line
NET_RX_CLK	10	2 / P1	HYDRA Net Receive / Clocking Line
RESn	11	11 / RESn	System Reset Active LOW
SCK_CART	12	37 / P28	Serial Clock for Cartridge / EEPROM
SDA_CART	13	38 / P29	Serial Data for Cartridge / EEPROM.
33VCC	14	POWER	Connects to 3.3 V Power Supply
3VCC_LOOP	15	POWER	Optional Feedback Loop from Cartridge to HYDRA
5VCC	16	POWER	Connects to 5.0 V Power Supply
5VCC_LOOP	17	POWER	Optional Feedback Loop from Cartridge to HYDRA
USB_TXD	18	N/A	USB Transmit Serial Line
USB_RXD	19	N/A	USB Receive Serial Line
GND	20	POWER	Connects to System GROUND

The only signals that deserve some extra explanation are the I/O\_0..7 lines. These lines are shared with the VGA interface, so when you are driving a VGA monitor, you can't use these lines on your plug-in card (unless of course that is the intent). The VGA Enable switch at J10 enables or disables the VGA outputs. So if you want to drive VGA with these lines, you would place the VGA Enable switch into the "on" position. When you are not driving VGA, it's best to keep the VGA Enable in the "off" position. The VGA Enable switch as noted early in the

book simply enables/disables the tri-state buffer logic and doesn't let the I/O's drive the VGA interface if they are not meant to.

Additionally, you might be concerned with power draw from the cartridge port and how much you can pull from the HYDRA? The HYDRA's power adaptor is 300-500 mA, so as long as you leave enough to power the HYDRA and the systems in use then there is no limit to the power-up to the supply current of the power adaptor. However, I suggest that if you do design an expansion card yourself, that you decouple the power coming in on the 3.3 V and 5.0 V supplies with a 0.01–0.1  $\mu$ F cap, and a 1.0–10.0  $\mu$ F tantalum cap to keep the power clean. Both the experimenter card and the 128 K expansion card have power decoupling on them already.

## 11.2 Blank Experimenter Card

To get you started on your own experiments, the HYDRA kit comes complete with a blank experimenter card as shown in Figure 11:3.

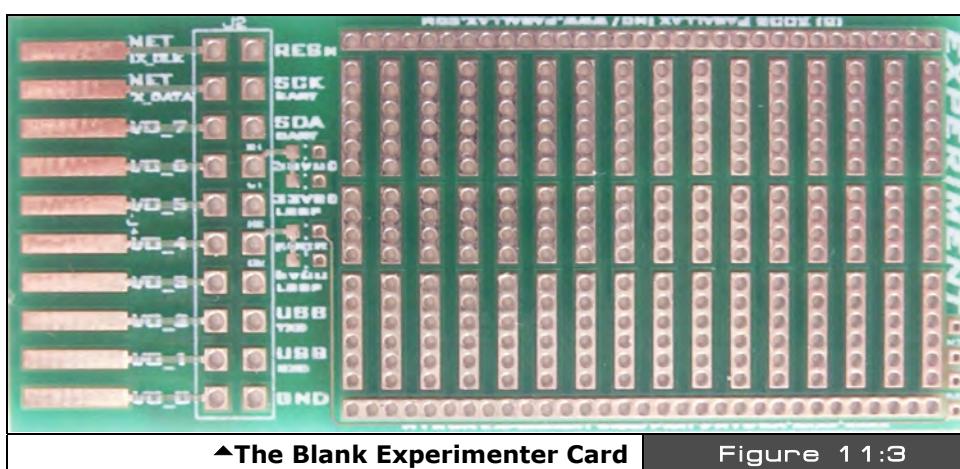
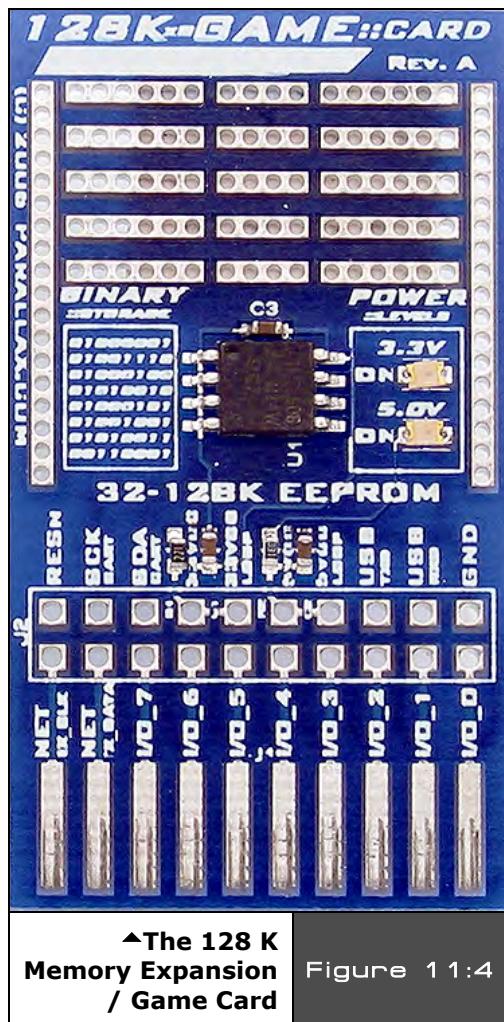


Figure 11:3

As you can see, the card has nothing on it but decoupling caps and power LEDs. The header areas have a solder through-pin for each signal, so you can simply wire into them. Additionally there is space on the surface to place a couple of DIP-style TTL chips along with some passive components. There are 3 rows of 18 contacts, along with large "common" rails along the top and bottom referring to the figure. This is a great way to start experimenting with expanding the HYDRA and/or adding small boards to the Propeller chip's functionality via the expansion port. The 128 KB memory expansion game card was derived from this design.

### 11.3 128K Memory Card

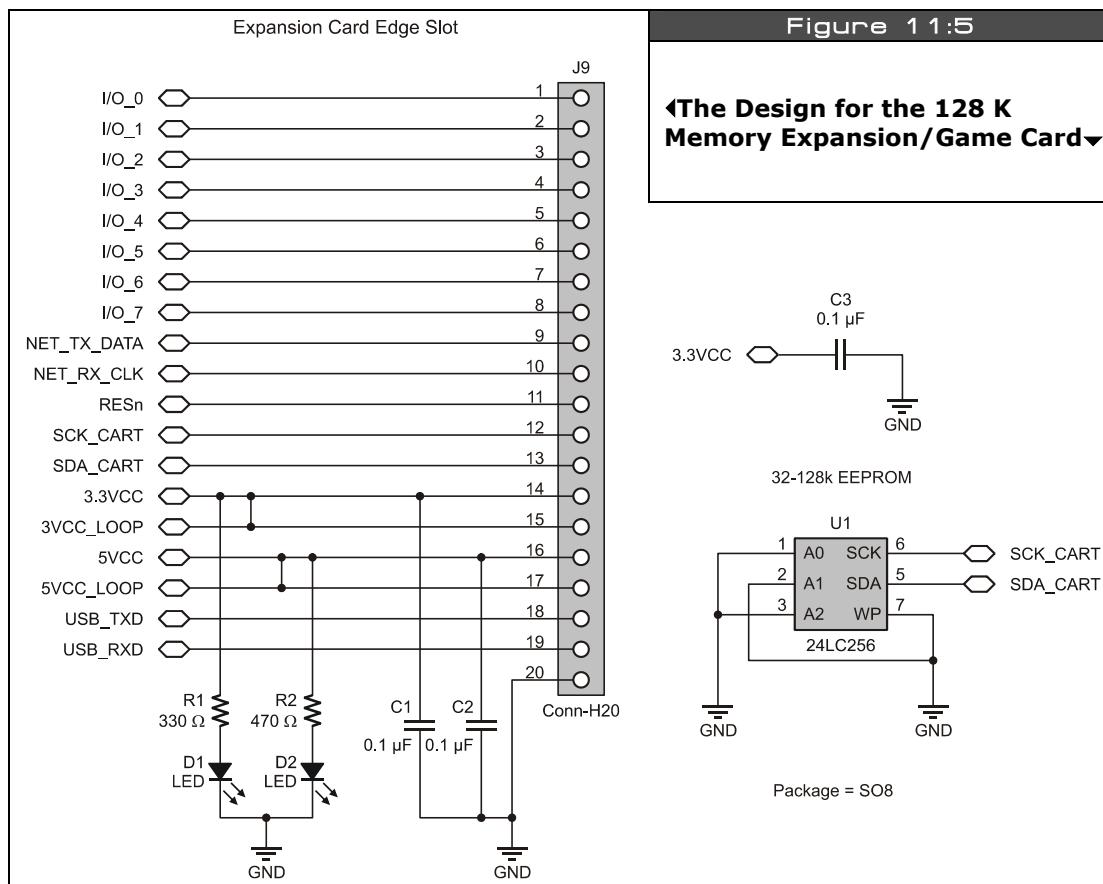
Figure 11:4 shows the 128 KB memory expansion card that comes with the HYDRA kit. The serial EEPROM is based on the 8-pin 24C1024 model which a number of manufacturers sell (Atmel is my favorite).



The 128 KB memory expansion card is more or less a copy of the 128 KB serial EEPROM design found on the HYDRA itself copied to an expansion card. The 32 KB and 128 KB expansion cards are similar, but simply have smaller EEPROMs on them.

The magic of the card is that when plugged in, the Propeller chip on the HYDRA reads the card's serial EEPROM rather than the onboard serial EEPROM. This is facilitated via the loop-back signals. When the card is inserted, the loop-back signals, specifically the **3VCC\_LOOP** signals, are used to enable the card's EEPROM while disabling the onboard serial EEPROM. This is possible since the serial EEPROMs have addressing lines A0..2 that allow up to 8 devices to be chained together on the same buses as long as only one device is selected at a time.

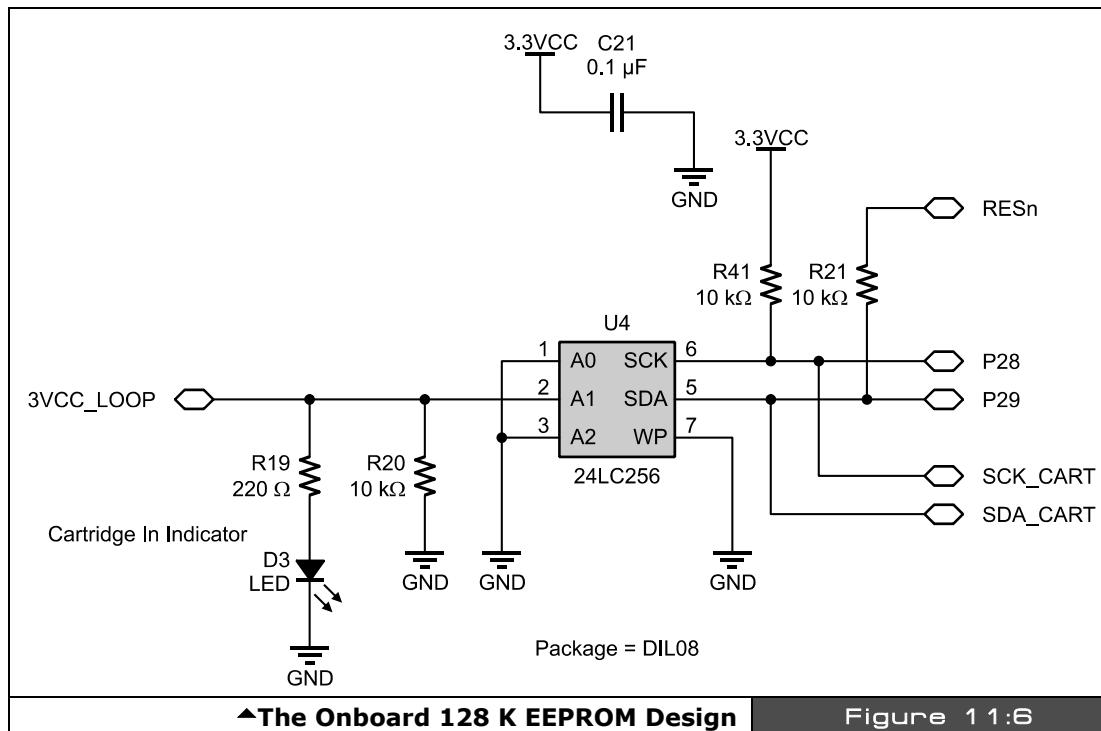
Figure 11:5 shows the design of the expansion card. Notice all 3 address selects are LOW; this always selects the EEPROM, thus when plugged into the HYDRA it will always be addressed. Therefore, it's up to the design of the HYDRA's onboard 128 KB serial EEPROM design which we will take a look at next.



## 11.4 Onboard 128 K Serial EEPROM Design

The Propeller chip works with a 32 KB “image” that the IDE/compiler generates. All your code, assets, and data must fit into this 32 KB. However, after the Propeller chip is done reading the 32 KB memory image from the serial EEPROM on boot, the lines are released and you can still access the EEPROM device yourself. The HYDRA uses the largest available serial EEPROMs which are 128 KB. This way you can fit your 32 KB Propeller program in the

EEPROM, but you have an additional 96 KB of storage for assets, data, real-time monitoring, digitizing – you name it! Also, later when more tools are available from Parallax and others, you will be able to access the expanded 96 KB of the serial EEPROM and place assets there as part of the Propeller took itself. However, for now, we must as programmers write our own tools to do this and write our own drivers to talk to the serial EEPROM's expanded memory.



▲The Onboard 128 K EEPROM Design

Figure 11:6

Figure 11:6 depicts the design for the onboard serial EEPROM, pins 5 and 6 of the EEPROM are connected to the system lines P28/P29 which are the "**serial clock**" (SCK) and "**serial data**" (SDA) respectively on the Propeller chip. Those connections are standard and nothing exciting is going on there. The only action happens on the addressing lines, notice there are 3 addressing lines A2..0. A0 and A2 are grounded, but A1 is driven by a weak pull-down as well as the 3VCC\_LOOP signal from the expansion port. Normally, when A1 is grounded the serial EEPROM is selected and Propeller chip reads from it, but the moment a game card is plugged in the 3VCC\_LOOP is driven HIGH, disabling the onboard serial EEPROM and the EEPROM that the game card is gated in! Presto, plug-and-play that works!

If you're interested in learning more about serial EEPROMs and designing around them as well as programming them please review this file on the CD:

**CD\_ROOT:\HYDRA\DOCS\atmel 24c1024\_datasheet.pdf**

## 11.5 Summary

Having an open interface to expand any hardware device is the #1 feature as far as I am concerned. The Atari 800 for example was a feat of engineering, 10 times more advanced than the Apple II, but the Apple II sold 10 times more units because the Apple II allowed users to build their own expansion cards for the device and also openly documented the hardware interface. The Atari 800 had expansion slots as well, but they were very hard to find information on to interface with. So the moral of the story is: the easier it is to build add on cards the more useful hardware will be. I personally can't think of a fraction of the cool things that can be done with a Propeller chip, but I know that by having an expansion port with a commonly found edge connector interface, others can create their own add-on hardware and expand the HYDRA itself. At some point, I hope to see Ethernet interfaces, LCD, IDE, flash drive, and even SRAM, CPU, and FPGA cards! At very least take the free blank expansion card, throw a 7447 on there and a 7-segment display and use it for debugging!

## Chapter 12: HYDRA-NET Network Interface Port

The simplest interface in the world is the good old RS-232 standard; however, the physical interfaces are usually DB9 or DB25 and are very bulky and expensive. Ethernet is great, but very complex and very expensive as well. So when designing the HYDRA, I wanted to facilitate networking but I didn't want it to be expensive, bulky, or complex to program. On the other hand, I wanted to be able to connect HYDRAs hundreds of feet from each other with commonly available cabling – After thinking about it, I thought why not use phone cables? They have 4 conductors (2-conductor products exist as well), act like twisted pairs, cost nearly nothing (a 100-foot phone extension line is \$5.00 USD) and they are very flexible and look cool and come in colors to boot! So, I was sold. I therefore designed a physical network interface on the HYDRA for RJ-11 standard phone connectors, and designed electronics to help interface the HYDRA using standard RS-232 serial techniques. In this chapter, we are going to look at the networking on the HYDRA, the hardware, and some software demos. Here's what's in store:

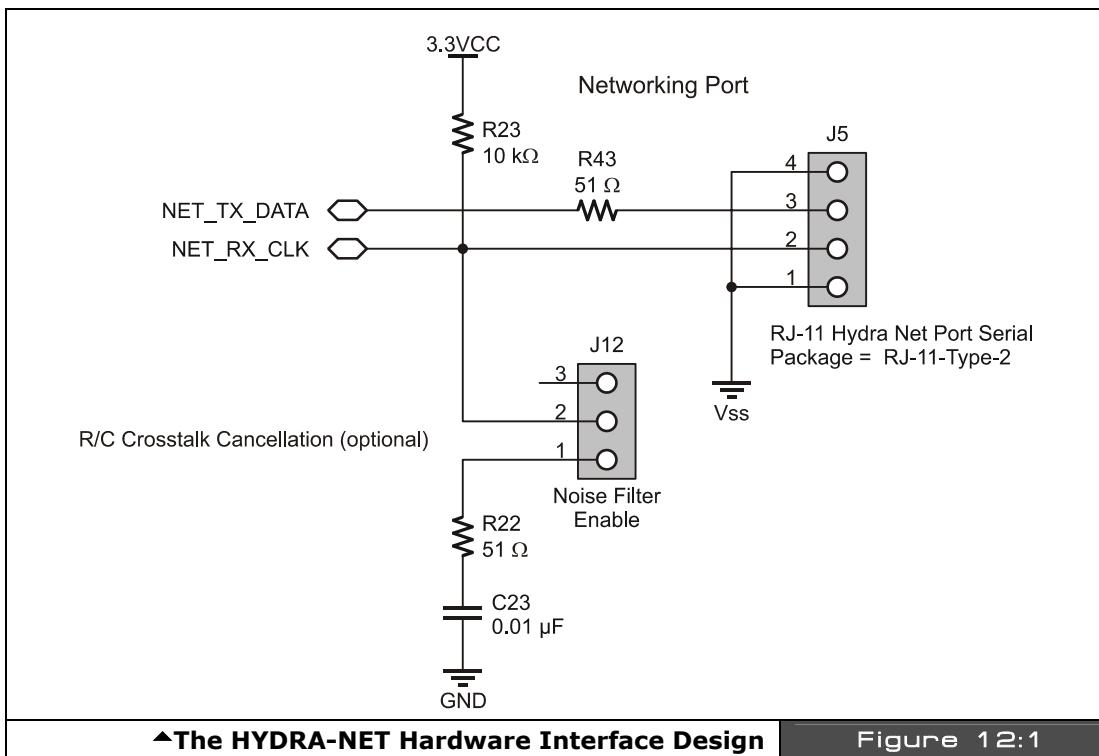
- ▶ The hardware design and reflection cancellation technology
- ▶ Discussion of RJ-11 phone cable interfaces and standards
- ▶ Serial Protocols
- ▶ Demo and ideas for networking games together

### 12.1 HYDRA-NET Hardware Interface Design

Figure 12:1 on the next page shows the design for the network interface. There are only two lines that are interfaced to the Propeller chip: **NET\_TX\_DATA** (I/O P2) and **NET\_RX\_CLK** (I/O P1) (these are the transmit and receive lines respectively). The interface to the physical cabling is via a simple transmission line termination scheme. If you have no idea what a "transmission line" is then consider yourself lucky. But, if you have done any electrical engineering with long lines or communication design then you are familiar with them.

Simply put, when the length of the transmission cable starts to be more than one quarter length the wavelength of the transmission wave, simple connections from A to B do not act like wire anymore – they act like distributed capacitance and inductance, and special care has to be taken when designing circuits with long transmission cables. What happens is that when an output signal changes state (even a TTL or CMOS signal) this happens very quickly, say 5 ns, but this wave "propagates" down the transmission line. For short wires this is

irrelevant, but if you try to send a signal that is changing at a very high frequency more than a few inches all kinds of bad things can happen. For example, with the 5 ns rise time example, one end of the transmission line is at 5V, but the other end is at 0V for a "long" time until the wave arrives, but it gets worse, depending on the "impedance" at the end of the wire run, the wave might even "reflect" back at you and you might find 10 volts on your 5 V output!



To minimize all this nastiness you can do a few things: run your transmission lines very slowly, make them short, or you can add active/passive hardware to "fix" the problems. This is the approach I took when designing the HYDRA-NET: I ran a number of simulations, did some math, tried some experiments and came up with a termination network that gives good results for both slow and fast edges, and low and high frequency transmissions as well as short and long transmission lines. I have run the network at 100 M at 256 Kbits/sec no problem, so the network works fine for most purposes. Moreover, we will learn shortly that RJ-11 phone cable is actually pretty good for this sort of thing.

Anyway, returning back to the design, there is a small  $51\ \Omega$  resistor in series with the transmit circuit, and this dampens the transmission and matches the impedance of the transmission line as much as possible to the output of the circuit. On the receiver pin, I use what's called parallel termination, that is, the design tries to set the termination, so that both LOW and HIGH signals get through in one piece. The pull-up at R23 is always there, but you can switch in the extra  $51\ \Omega$  pull-down resistor via the switch at J12. Also, notice there is a small capacitor there, this is called "AC termination," that is, when idle no current will flow and waste power, only AC transient signals will cause the termination circuit to activate.

Thus, when you are working with the networking, try turning the cancellation on/off depending on your signaling speed and distance, and usually one setting will make a otherwise hopeless serial transmission straighten up and come through loud and clear.

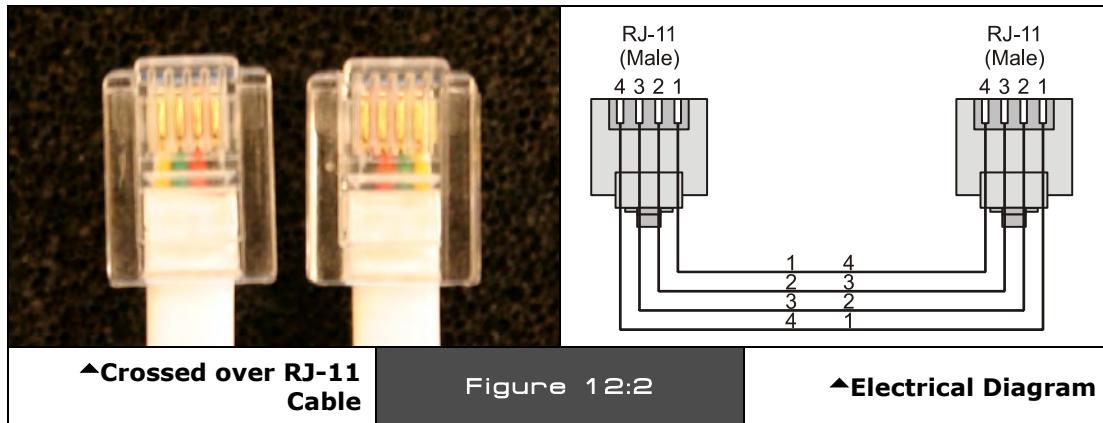
## 12.2 RJ-11 Phone Interfacing

As noted, the HYDRA-NET uses a 4-wire full-duplex communication scheme. A standard RJ-11 (phone jack) and phone line are employed for ease of use and interfacing. The phone line must have all 4-conductors and be "***crossed-over***." I have tested the network at a nominal speed of 256 Kbit and a maximum speed of about 2.56 Mbit. Higher speeds are possible, but synchronization is hard to maintain as noise, crosstalk, and reflections decrease the signal integrity at higher bit rates. The hardware is designed to facilitate full duplex, non-clocked, asynchronous communications; however, you are still free to send data in one direction and use the other line as a "clock" rather than using software algorithms to track start, data, stop bits as most asynchronous serial communication must employ. The pinout of the RJ-11 is show in Table 12:1.

Table 12:1	RJ-11 Pinout and Meaning▼
Pin #	Function
1	Ground
2	Receive
3	Transmit
4	Ground

It's unimportant which way you refer to the pinout orientation, since at the receiver's end the cable is crossed over; that is from one HYDRA unit pin 2,3 become pins 3,2 on the other unit, but always the GROUND pins "surround" the data lines since they are on pin 1 and 4 (giving better noise immunity and decreasing radiation outside the cable).

Figure 12:2 (left) is an actual picture, on the left the wires are colored black, red, green, yellow (left to right), but on the right, notice they are reversed. Similarly, Figure 12:2 (right) shows electrically how the crossing over works. Note that you must always use a crossed over RJ-11 phone cable, these are very common, simply inspect both ends, hold them the same way and you should notice that the colors of the wire through the connector are reversed at each end. This is “crossed” over.

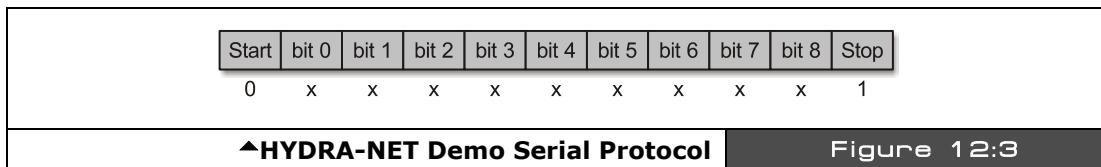


### 12.3 Network Protocol

The HYDRA's networking port is simply a hardware level interface; you may use any protocol you wish to transmit your data since it's under software control, but a standard **NRZ** (non-return to zero) serial scheme is suggested to keep drivers very similar to standard **RS-232** systems. For example, at startup the TX line is driven HIGH (via a pull-up resistor), this could be the “waiting” state then a start bit might be indicated by pulling the line LOW, and then sending the data bits (8 of them usually) along with a final HIGH stop bit to signify the end of the frame along with a parity bit potentially, etc. It's up to you. However, the hardware has been designed such that full duplex transmission on RJ-11 phone cable will be employed. On the HYDRA the following I/O's are being used to transmit and receive data:

Table 12:2		I/O pins used on Propeller Chip for Communication▼	
Propeller Chip Pin	Name	Meaning	
Pin 3	NET_TX_DATA	Transmit data	
Pin 2	NET_RX_CLOCK	Receive data or clock use	

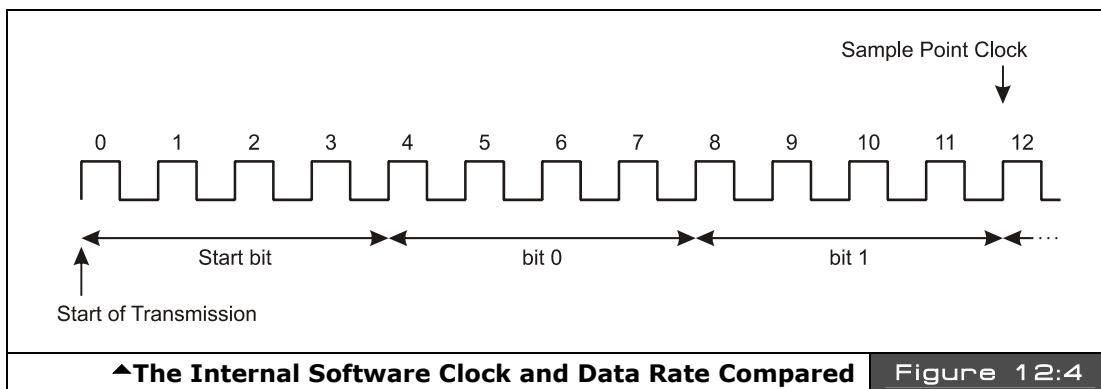
For the networking demos, the following simple packet protocol based on standard RS-232 serial protocol was employed, refer to Figure 12:3.



The clocking scheme might use an internal software loop bit rate that is 4 to 8 times faster than the bit rate to break up each clock into 4 segments to help "center" data sampling, for example, a bit rate of 64 Kbit would require the software clock loop to run at a rate of:

$$64 \text{ K} \times 4 = 256 \text{ K cycles per second.}$$

All samples of the serial input stream are sampled on the 3<sup>rd</sup> clock HIGH phase from the beginning of the data bit.



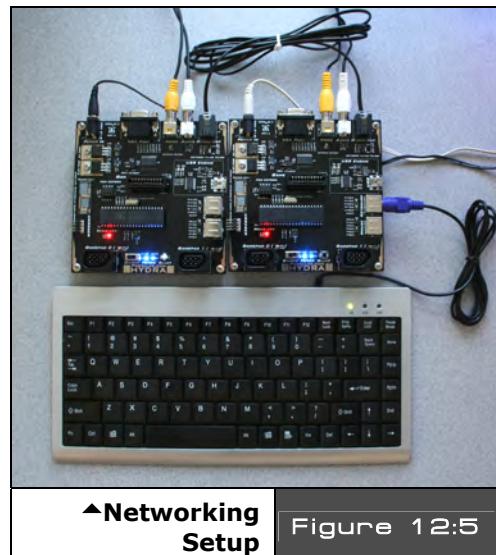
Once the start of transmission is found, the state machine should wait 4 cycles; this is the end of the start bit. Then each data bit consists of 4 cycles, on the HIGH phase of the 3rd clock of each cycle, the data bit is sampled. This continues until all 8 bits are read in, then the state machine confirms a HIGH bit for the 9<sup>th</sup> data bit and the frame is complete. An optional parity bit can be inserted if one wishes; it simply reflects the even/odd parity and can be used for error correction if needed at higher speeds.

## 12.4 Demo Programs

Thus far, we haven't really seen any demo other than the software pre-loaded on the HYDRA; however, I thought that the networking is a large enough system that a simple demo might be in order. Additionally, it's doubtful you have two HYDRA units, thus this might be the only way for you to see two units networked.

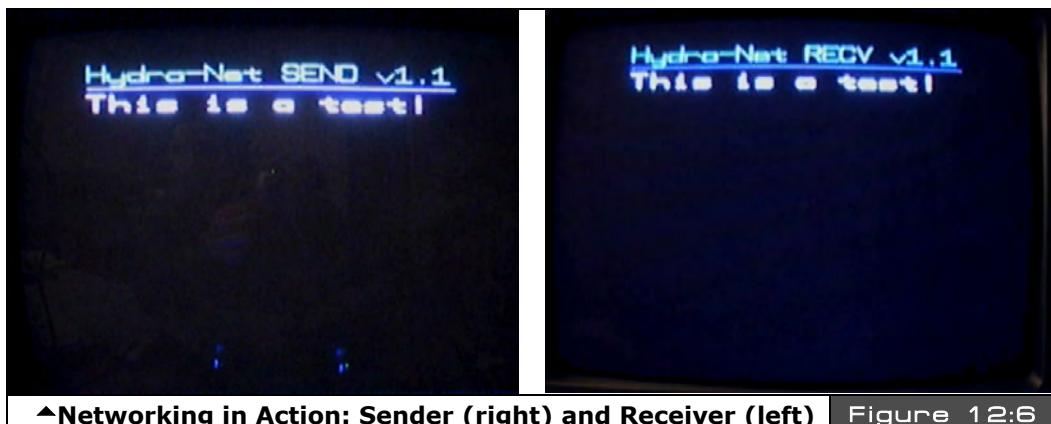
The demo program is a one-way peer-to-peer network demo where each unit is either a sender or a receiver running Spin code and a single processor. This demo simply uses a single character send and receive buffer to hold the outgoing and incoming data on either application along with a graphical terminal display as shown in Figure 12:5, which depicts a messy setup of two HYDRAs with network cable and keyboard.

Screen shots of the sender (right) and receiver (left) programs are shown in Figure 12:6.



▲Networking  
Setup

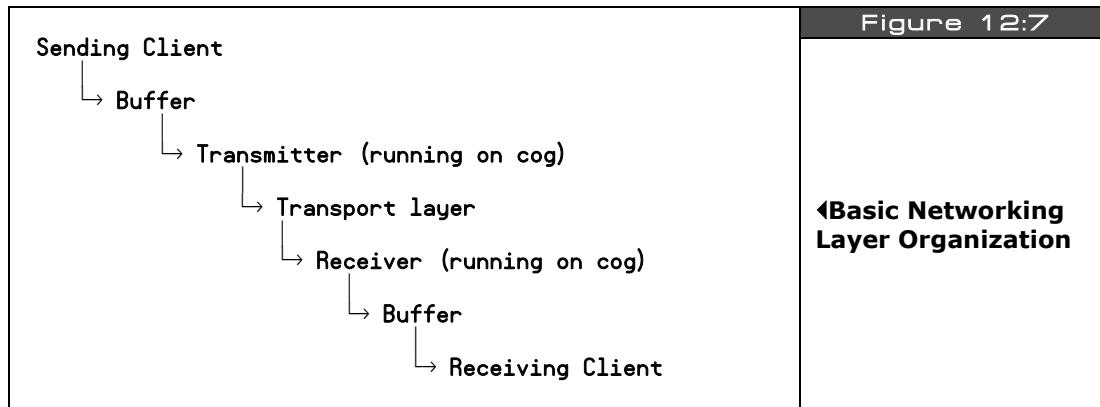
Figure 12:5



▲Networking in Action: Sender (right) and Receiver (left)

Figure 12:6

The basic networking layer organization that is going on is shown with the following graph:



**Transmission** - When transmitting, the sending client simply calls the transmission function with the BYTE to send and can either wait for the transmission or return immediately. Either way, there is no ACK from the receiver that the data was received. A global counts the number of BYTES sent.

**Reception** - When the receiver receives data, it will buffer the BYTE in the receive buffer and set a flag; if the client does NOT poll the flag and retrieve the BYTE by the time another BYTE is received, then the BYTE will be overwritten and the flag still set. A global counter counts the number of BYTES received. The client can either call and return or block for a BYTE as well.

The demo consists of two terminal programs; one is the **sender** and one is the **receiver**. As you type with the keyboard on the "**sender**" it will be echoed, and sent to the "**receiver**" where the receiver will print it on the screen as well. More or less it's a very crude server-client demo that is half duplex, making it full duplex is simply a matter of spinning another cog and running both server and client on each HYDRA at the same time. I leave it to you Neo. We will revisit this demo later in Part II, but if you want to take a sneak peek at the source, check out these files:

- ▶ **CD\_ROOT:\HYDRA\SOURCES\hydra\_net\_sender\_demo\_011.spin**
- ▶ **CD\_ROOT:\HYDRA\SOURCES\hydra\_net\_receiver\_demo\_011.spin**

## 12.5 Networking Games Together

Of course, instead of sending characters one can create a higher level protocol that is block oriented to send more data. However, for simple games a single BYTE and a full duplex system can facilitate most games running peer-to-peer. For example, one possible data encoding is shown Figure 12:8.

bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0	
Mode	Fire	Start	Select	Up	Down	Right	Left	

**Figure 12:8**  
◀BYTE Encoding  
Game Data for  
User Input

By using a “MODE” bit, it’s possible to send the state of the game controller OR to send other information such as ASCII codes or other control codes agreed upon by the clients, this way the data is polymorphic, Table 12:3 shows a way to interpret the MODE bit.

<b>Table 12:3</b>		<b>BYTE Encoding Table▼</b>
<b>Mode</b>	<b>Bit Encoding</b>	
<b>0 (normal)</b>	b6 - b0, single bit encoding, mutually exclusive	
<b>1 (extended)</b>	b6 - b0, 7 bit binary encoding	

## 12.6 Summary

Networking is a fascinating field on all levels; hardware, software, and applications. However, one thing is certain, network programming is hard enough to get working at an application layer without having to deal with Ethernet or USB protocols, thus the HYDRA uses a simple physical interface that works fine for logic level full duplex serial transmissions. Moreover, with the noise cancellation hardware at each end built into the hardware you can get some pretty serious speeds and cable lengths, so some “real” networking experiments and applications can be built with the HYDRAs.

## **PART II: PROPELLER CHIP ARCHITECTURE AND PROGRAMMING**

**Welcome to Part II of the book!** If you aren't a hardware guru then Part II will be much more palatable than Part I. In Part II, we are going to concentrate on the Propeller chip's internals and general programming of the chip, and important details about the Propeller chip's programming considering the HYDRA's hardware support around the chip. These chapters aren't 100% about software, but more of a transition from hardware to low-level programming with some references to hardware. Then in Part III, it's all software and high-level game development, so that's where the fun starts and the pixels will really start to fly (or more technically translate). So let's get started with some low-level discussion of the Propeller chip itself and find out what makes it tick.

**Chapter 13: Propeller Chip Architecture and Programming, p. 177.**

**Chapter 14: Cog Video Hardware, p. 233.**

**Chapter 15: The Spin Language, p. 245.**

**Chapter 16: Programming Examples on the Propeller Chip / HYDRA, p. 319.**

## Chapter 13: Propeller Chip Architecture and Programming

In this chapter, we are going to discuss the Propeller chip's general architecture, internal organization, and register sets, talk about its peripherals, and much more. There is a lot of information in this chapter and you might want to read it a couple times to make it sink in. I wrote it, and I still have to re-read it from time to time to remember all the details about the chip, so I suggest reading it once and not worrying too much about detail, then once you have the "big picture" read the chapter again to reinforce missed details. The chapter covers the following main topics:

- ▶ Propeller chip architecture
- ▶ System startup and initialization sequence
- ▶ Assembly language instruction set
- ▶ The Propeller chip's registers
- ▶ Port I/O techniques
- ▶ Understanding the counters
- ▶ ROM look-up tables and Spin interpreter

The Propeller chip is a 32-bit RISC-like multiprocessing microcontroller with 32 Kbytes of RAM and 32 Kbytes of internal ROM with firmware, tables, and other run-time information. Also, in the 32K ROM is the on-chip language interpreter for the "**Spin**" language that the Propeller chip runs at high level and on boot. As far as multiprocessing goes, the Propeller chip has 8 processing cores numbered 0..7, referred to as "**cogs**." Each cog is exactly identical except that during boot, a Cog 0 takes control until the boot process is complete and the program is loaded and run from the HOST PC or EEPROM.

Figure 13:1 on the next page shows the overall architecture of the Propeller chip. Notice its simplicity: there are no interrupts, no other peripherals other than 2 timers per cog, I/O support, and a video serializer per cog. Other than that, the chip is simply a multiprocessor of the **MIMD** (Multiple Instruction Multiple Data) class. Also, the I/O is interesting. There are 32 I/O pins, but since the Propeller chip has 8 processors, all of which can access all of the I/O, there is a huge possibility for conflict. Therefore, the cogs are each gated to the I/O control via OR and AND gates, so that the "best" possible solution to any I/O conflict is the result. That is if one cog uses an I/O for output then another uses it for input, the idea is to minimize the erroneous results and not hurt any outside hardware. The best course of action

## II ▶ Propeller Chip Architecture and Programming

of course is to watch what you are doing as a programmer and make sure that any process running on one cog doesn't step on the toes of another.

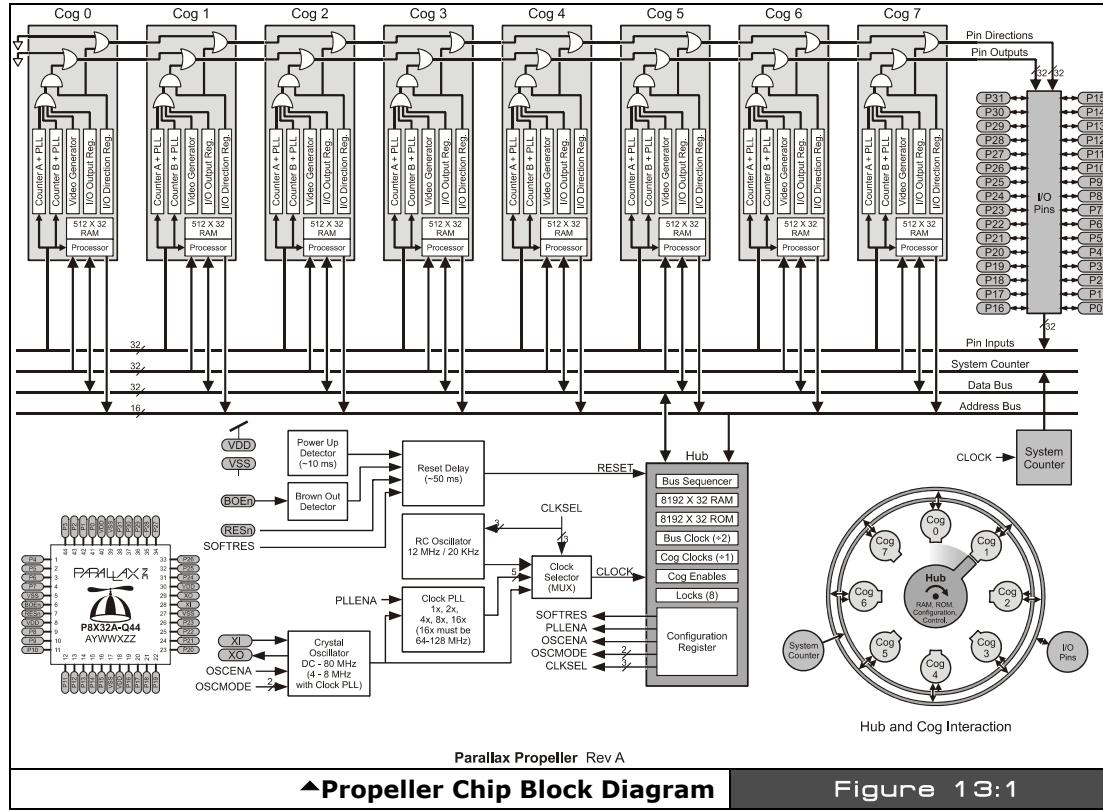


Image from Propeller Manual v1.0 courtesy of Parallax Inc.

As far as main memory, it's very limited as mentioned, with only 32 Kbytes of RAM to hold all program and data under normal conditions. Additionally, there is no dedicated video RAM, therefore, we only have a total of 32K to put all our programs, data, and video RAM in during run time. However, there is some hope for assets. The EEPROM used in the HYDRA is a 128 Kbyte model and the Propeller chip only uses the first 32K of it, thus, one could always store run-time assets and even some form of I-Code on the EEPROM and load it later. There is no facility for this built into the IDE, but as programmers we are free to write tools on the PC to download information to the EEPROM to store larger assets on it.

### 13.1 Propeller Chip on Reset

Upon reset, all 8 cogs are shut down, forcing all pins to become inputs (high impedance). Then, a single cog (Cog 0) is booted with a startup program from the main memory's 32K ROM. This program checks for a serial host connection on **P31 (RX)**. If a host is present, a conversation ensues via **P30 (TX)**, and the host may load the main memory's RAM with high-level code. The host may also direct the code to be programmed into an EEPROM before executing it. If no host is present, the startup program attempts to read and execute high-level code from the first 32K of a 24LC256-1024 EEPROM on **P28 (SCL)** and **P29 (SDA)**. If neither a serial host nor an EEPROM is present, the program will place the chip in shutdown mode. Until a new reset occurs, power is minimized and all pins will be floating.

High-level code is what initially executes from the programmer's perspective. It is capable of booting extra cogs with either other high-level tasks or assembly language programs. In the case of high-level code execution, a cog is loaded with an interpreter program from the main memory's ROM which executes the high-level code residing in the main memory's RAM.

### 13.2 Cog Internal Architecture

Each cog has its own **512 x 32-bit** register space. These 512 registers are all used for RAM and or program instructions, except for the last 16 which are special-purpose Cog Registers. The RAM space is used for executable code, data, and variables. The last 16 locations serve as interfaces to the Hub, I/O pins, and local cog peripherals. Note that the largest ASM program you can have per cog is  $512 \times 16 = 496$  ASM instructions. This is quite a limitation if you want to write a complete game in ASM that fits on one cog; therefore the approach is to write your game in Spin high-level code for the slow stuff and make calls to the cogs running your low-level high-speed functions like graphics, sound, etc. Or, it is possible to write a "loader" that pages in and out more ASM instructions into a single cog.

Additionally, the math is very limited on the cog: there is no multiply, no divide, but there is support for signed and unsigned 32-bit addition and subtraction. Therefore, math-heavy algorithms should use tight loops or look-up tables for multiplication and division.

When a cog is booted, its RAM locations are loaded sequentially from main memory and its special-purpose registers are cleared to zero. After loading, the cog begins executing instructions, starting at location \$000. It will continue to execute code until it is stopped or rebooted by either itself or another cog, or a reset occurs. Table 13:1 on the next page is a summary of the special registers within a cog.

Table 13:1		Cog Registers▼	
Address	Name	Access	Description
\$000-\$1EF	—	Read/Write	General Purpose RAM
\$1F0	PAR	Read-Only*	Boot Parameter
\$1F1	CNT	Read-Only*	System Counter
\$1F2	INA	Read-Only*	Input States for P31..P0
\$1F3	INB	Read-Only*	Input States for P63..P32 **
\$1F4	OUTA	Read/Write	Output States for P31..P0
\$1F5	OUTB	Read/Write	Output States for P63..P32 **
\$1F6	DIRA	Read/Write	Direction States for P31..P0
\$1F7	DIRB	Read/Write	Direction States for P63..P32 **
\$1F8	CTRA	Read/Write	Counter A Control
\$1F9	CTR B	Read/Write	Counter B Control
\$1FA	FRQA	Read/Write	Counter A Frequency
\$1FB	FRQB	Read/Write	Counter B Frequency
\$1FC	PHSA	Read/Write	Counter A Phase
\$1FD	PHSB	Read/Write	Counter B Phase
\$1FE	VCFG	Read/Write	Video Configuration
\$1FF	VSCL	Read/Write	Video Scale
<b>Notes</b>	* Only accessible as a Source Register (i.e. MOV DEST,SOURCE)		
	** Allocated for future use, but not currently implemented.		
<b>Remember:</b> all addresses are LONG or 4-BYTE addresses.			

### 13.3 Propeller Chip ASM Instruction Format

Before discussing the usage of the internal registers, a basic understanding of the instruction format is needed. Each 32-bit instruction is broken into a number of fields from left to right. Each field has a different purpose and in some cases can have more than one purpose. The cog executes 32-bit instructions from its register space. The instruction codes contain several bit fields. Table 13:2 and Table 13:3 show the instruction format and fields.

32-Bit Instruction Format▼							
Operation Code	Update Z Flag	Update C Flag	Update Result	Source #	Execution Condition	Destination Register	Source Register #
31..26	25	24	23	22	21..18	17..9	8..0
iiiiii	z	c	r	i	cccc	ddddddddd	sssssssss

Instruction Field Bit Locations▼		
Field	Range	Description
<b>Operation Code</b>	31..26	Perform ADD, SUB, AND, OR, JMP, etc.
<b>Execution/ Update Effects</b>	25..23	In conjunction with Controls writes to C Flag, Z Flag, and Destination Register: <ul style="list-style-type: none"> <li>▶ If bit 25 is set, the Z Flag will be written.</li> <li>▶ If bit 24 is set, the C Flag will be written.</li> <li>▶ If bit 23 is set, the Destination Register will be written.</li> </ul>
<b>Source Literal</b>	22	If set, bits 8..0 will be zero-extended and used as a 32-bit constant.
<b>Execution Condition</b>	21..18	C and Z flag condition upon which instruction will execute.
<b>Destination Register</b>	17..9	Register which supplies the first 32-bit input to the instruction and/or receives the effect of the operation.
<b>Source Register or Literal</b>	8..0	Register or constant which supplies the second 32-bit input to the instruction.

### Source Register or Literal Value [8..0]

This 9-bit field either selects a register (any of the 512 32-bit registers) or provides a 9-bit (0-511 range) zero-extended literal value to be used as the source by the instruction. Bit 22 controls how this field is used: 0 for register, 1 for literal. When entering assembly code, the # symbol sets literal mode.

### Destination Register [17..9]

This 9-bit field selects which of the 512 registers will be used as the destination by the instruction.

### Execution Condition [21..18]

This 4-bit field selects the condition upon which the instruction executes. The condition is a logical combination of the C and Z flags. The condition codes are shown in Table 13:4 on the next page.

Table 13:4		Instruction Execution Condition Codes▼	
Execution Condition	Instruction Prefix	Instruction Prefix	Instruction Prefix
<b>1111</b>	ALWAYS *		
<b>1100</b>	IF_C		IF_B
<b>0011</b>	IF_NC		IF_AE
<b>1010</b>	IF_Z		IF_E
<b>0101</b>	IF_NZ		IF_NE
<b>1000</b>	IF_C_AND_Z	IF_Z_AND_C	
<b>0100</b>	IF_C_AND_NZ	IF_NZ_AND_C	
<b>0010</b>	IF_NC_AND_Z	IF_Z_AND_NC	
<b>0001</b>	IF_NC_AND_NZ	IF_NZ_AND_NC	IF_A
<b>1110</b>	IF_C_OR_Z	IF_Z_OR_C	IF_BE
<b>1101</b>	IF_C_OR_NZ	IF_NZ_OR_C	
<b>1011</b>	IF_NC_OR_Z	IF_Z_OR_NC	
<b>0111</b>	IF_NC_OR_NZ	IF_NZ_OR_NC	
<b>1001</b>	IF_C_EQ_Z	IF_Z_EQ_C	
<b>0110</b>	IF_C_NE_Z	IF_Z_NE_C	
<b>0000</b>	NEVER		
<b>NOTE</b>	* ALWAYS is the default, in case no condition is specified.		



### NOTE

In some cases, the various fields of an instruction are interpreted in different ways. These cases will be clearly marked in the instruction set listing. When talking about the I-Field, it has 9 bits including the 5 bits of the I-Field itself along with the first 3 bits of the FLAGS field "zcr".

iiiiiii zcri cccc dddddddddd ssssssss

The above underlined 5 bits "i cccc" are left out of I, D, S during register access, etc.

**Execution/Update Effects [25..23]**

The instruction format includes a set of flags which are NOT the processor flags, but indicate which “flags” to update in the processor’s flags when the instruction executes. The Condition Code determines when the instruction executes. This instruction architecture allows each instruction to have an embedded conditional of sorts and allows very optimal coding techniques. These flags are shown in Table 13:5.

Table 13:5		Instruction Set/Processor ALU Flags/Modifiers▼
Flags	Meaning	
Z	Update the Zero flag (WZ).	
C	Update the Carry flag (WC).	
R	Result Flag enable, indicates whether we are going to write the results, whatever they may be, below are the two possible settings that affect this flag.	
- NR	Do not write the result into the destination.	
- WR	Write the result into the destination.	
I	Immediate value or memory pointer for S as address, always 32-bit, if immediate value then 9 bits only ZERO extended, no negatives!	

By default neither the Z or C flags are written for any operation, thus you must always modify the instruction opcode by appending the appropriate modifier(s) at the end of the instruction. The actual syntax for each modifier is as follows:

- WC** Write carry flag
- WZ** Write zero flag
- NR** Override default behavior of operation and do NOT write results
- WR** Override default behavior of operation and write results
- #** Set the immediate

**Instruction Code [31..26]**

This 6-bit field simply encodes the instruction to execute. Although, one shouldn’t rely on current opcode mappings to stay the same, later various Propeller chips may decide to change the opcodes and/or bit encodings. But, nevertheless, these 6 bits define the instruction to execute.

## 13.4 Cog Registers

As noted, each cog has a set of (16) 32-bit registers addressed at \$1EF-\$1FF (LONG addresses) which are available from HLL as well as ASM. The following sections briefly outlines the registers. We will discuss their programming later in the document. Let's briefly cover all the registers then discuss their usage.

### 13.4.1 Parameter Registers (PAR)

**PAR** Parameter address from cog boot, when a cog boots you can access this 14-bit value that tells you the base address of where the cog memory is:

0000000000000000	xxxxxxxxxxxxxx00
16 bits	14-bit address that is shifted left 2 bits resulting always in a LONG base address.



#### NOTE

The caller that sends the PAR value must make sure it's on a LONG 32-bit boundary; otherwise, the lower 2 address bits will simply be ignored.

### 13.4.2 I/O Registers

Each cog has its own set of I/O registers used to communicate with the outside world. On the current version of the Propeller chip there are 32 I/Os which comprise the "A port." On future Propeller chips there will also be another 32-bit "B port" for a total of 64 I/Os. However, the internal hardware is partially in place for "B port" even though there is no physical hardware to support it as of yet, therefore, you can write and read the registers, but nothing will happen on the outside world – however, in a parallel universe there will be some side effects, luckily though we can ignore them!

**INA** Port inputs

**OUTA** Port outputs; since all cogs can write these simultaneously the final outputs are a logical OR of the cogs' outputs.

**DIRA** Port directions, 0 = input, 1 = output. Note: there are NO pull-ups on I/Os.

**INB** Future expansion, read only

**OUTB** Future expansion

**DIRB** Future expansion

### 13.4.3 Timer/Counter Registers

Each cog has two timers: A,B. Each timer is independent and can operate in a number of different modes. However, the inputs and outputs of each timer depending on their setup can be programmed to use any of the I/O pins as well. Also, note that when using the video hardware of a cog. The Video Streaming Unit (VSU, discussed later) uses a timer and some specific constraints must be taken into consideration in this case.

**CNT** Global system 32-bit counter (full-speed)

**CTRA** Counter A configuration

**FRQA** Frequency of counter A

**PHSA** Phase of counter A

**CTRIB** Counter B configuration

**FRQB** Frequency of counter B

**PHSB** Phase of counter B

### 13.4.4 Video Registers

The Propeller chip has no dedicated GPU to speak out, rather it has a very simple video serializer that allows you to set up some timing parameters and then “feed” pixel data to the video serializer, referred to as the Video Streaming Unit (VSU). This pixel data is then sent out to external I/O via a set of pins in a format that is related to NTSC/PAL or VGA depending on how you have set up the VSU unit. There are two registers that control this:

**VCFG** Video configuration

**VSCL** Video scale

We will discuss their setup in detail later in the document. Next we are going to discuss the instruction set and various programming techniques, then review the control registers in detail.

## 13.5 Instruction Set

Table 13:6 on the next two pages is a tentative instruction set reference for the Propeller chip’s cogs. Table 13:7 follows, which lists the opcodes for each instruction. In the future, the actual bit encodings may change, but from a programming point of view and using the assembler, you should be insulated from changes.

<b>Cog Assembly Language Instruction Set▼</b>					
<b>Instruction</b>	<b>Description</b>	<b>Z Out</b>	<b>C Out</b>	<b>r</b>	<b>Clocks</b>
RDBYTE D, S	Read main memory byte S[15..0] into D (0-ext'd)	Result = 0	-	1	7..22 *
RDWORD D, S	Read main memory word S[15..1] into D (0-ext'd)	Result = 0	-	1	7..22 *
RDLONG D, S	Read main memory long S[15..2] into D	Result = 0	-	1	7..22 *
WRBYTE D, S	Write D[7..0] to main memory byte S[15..0]	-	-	0	7..22 *
WRWORD D, S	Write D[15..0] to main memory word S[15..1]	-	-	0	7..22 *
WRLONG D, S	Write D to main memory long S[15..2]	-	-	0	7..22 *
SYSOP D, S	System op, implements the 8 codes below				
CLKSET D	Set the global CLK register to D[7..0]	-	-	0	7..22 *
COGID D	Get <i>this</i> cog number (0..7) into D	Result = 0	-	1	7..22 *
COGINIT D	Initialize a cog according to D	Result = 0	No cog free	0	7..22 *
COGSTOP D	Stop cog number D[2..0]	-	-	0	7..22 *
LOCKNEW D	Checkout a new lock number (0..7) into D	Result = 0	No lock free	1	7..22 *
LOCKRET D	Return lock number D[2..0]	-	-	0	7..22 *
LOCKSET D	Set lock number D[2..0]	-	Prior lock state	0	7..22 *
LOCKCLR D	Clear lock number D[2..0]	Result = 0	Prior lock state	0	7..22 *
ROR D, S	Rotate D right by S[4..0] bits	Result = 0	D[0]	1	4
ROL D, S	Rotate D left by S[4..0] bits	Result = 0	D[31]	1	4
SHR D, S	Shift D right by S[4..0] bits	Result = 0	D[0]	1	4
SHL D, S	Shift D left by S[4..0] bits	Result = 0	D[31]	1	4
RCR D, S	Rotate carry right into D by S[4..0] bits	Result = 0	D[0]	1	4
RCL D, S	Rotate carry left into D by S[4..0] bits	Result = 0	D[31]	1	4
SAR D, S	Shift D arithmetically right by S[4..0] bits	Result = 0	D[0]	1	4
REV D, S	Reverse 32-S[4..0] bottom bits in D and 0-extend	Result = 0	D[0]	1	4
MINS D, S	Set D to S if signed (D < S)	D = S	Signed (D < S)	1	4
MAXS D, S	Set D to S if signed (D => S)	D = S	Signed (D < S)	1	4
MIN D, S	Set D to S if unsigned (D < S)	D = S	Unsigned (D < S)	1	4
MAX D, S	Set D to S if unsigned (D => S)	D = S	Unsigned (D < S)	1	4
MOVS D, S	Insert S[8..0] into D[8..0]	Result = 0	-	1	4
MOVD D, S	Insert S[8..0] into D[17..9]	Result = 0	-	1	4
MOVI D, S	Insert S[8..0] into D[31..23]	Result = 0	-	1	4
JMPRET D, S	Insert PC+1 into D[8..0] and set PC to S[8..0]	Result = 0	-	1	4
JMP S	Set PC to S[8..0]	Result = 0	-	0	4
CALL #S	Like JMPRET, but assembler handles details	Result = 0	-	1	4
RET	Like JMP, but assembler handles details	Result = 0	-	0	4
TEST D, S	AND S with D to affect flags only	Result = 0	Parity of Result	0	4
AND D, S	AND S into D	Result = 0	Parity of Result	1	4
ANDN D, S	AND IS into D	Result = 0	Parity of Result	1	4
OR D, S	OR S into D	Result = 0	Parity of Result	1	4
XOR D, S	XOR S into D	Result = 0	Parity of Result	1	4
MUXC D, S	Copy C to bits in D using S as mask	Result = 0	Parity of Result	1	4
MUXNC D, S	Copy !C to bits in D using S as mask	Result = 0	Parity of Result	1	4

<b>Cog Assembly Language Instruction Set▼</b>					
<b>Instruction</b>	<b>Description</b>	<b>Z Out</b>	<b>C Out</b>	<b>r</b>	<b>Clocks</b>
MUXZ D, S	Copy Z to bits in D using S as mask	Result = 0	Parity of Result	1	4
MUXNZ D, S	Copy !Z to bits in D using S as mask	Result = 0	Parity of Result	1	4
ADD D, S	Add S into D	Result = 0	Unsigned Carry	1	4
SUB D, S	Subtract S from D	Result = 0	Unsigned Borrow	1	4
CMP D, S	Compare D to S	Result = 0	Unsigned Borrow	0	4
ADDRBS D, S	Add absolute S into D	Result = 0	Unsigned Carry	1	4
SUBABBS D, S	Subtract absolute S from D	Result = 0	Unsigned Borrow	1	4
SUMC D, S	Sum either -S if C or S if !C into D	Result = 0	Signed Overflow	1	4
SUMNC D, S	Sum either S if C or -S if !C into D	Result = 0	Signed Overflow	1	4
SUMZ D, S	Sum either -S if Z or S if !Z into D	Result = 0	Signed Overflow	1	4
SUMNZ D, S	Sum either S if Z or -S if !Z into D	Result = 0	Signed Overflow	1	4
MOV D, S	Set D to S	Result = 0	S[31]	1	4
NEG D, S	Set D to -S	Result = 0	S[31]	1	4
ABS D, S	Set D to absolute S	Result = 0	S[31]	1	4
ABSNEG D, S	Set D to -absolute S	Result = 0	S[31]	1	4
NEGC D, S	Set D to -S if C or S if !C	Result = 0	S[31]	1	4
NEGNC D, S	Set D to S if C or -S if !C	Result = 0	S[31]	1	4
NECZ D, S	Set D to -S if Z or S if !Z	Result = 0	S[31]	1	4
NEGNZ D, S	Set D to S if Z or -S if !Z	Result = 0	S[31]	1	4
CMPSS D, S	Compare-signed D to S	Result = 0	Signed Borrow	0	4
CMPSX D, S	Compare-signed-extended D to S+C	Z & (Result = 0)	Signed Borrow	0	4
ADDX D, S	Add-extended S+C into D	Z & (Result = 0)	Unsigned Carry	1	4
SUBX D, S	Subtract-extended S+C from D	Z & (Result = 0)	Unsigned Borrow	1	4
CMPX D, S	Compare-extended D to S+C	Z & (Result = 0)	Unsigned Borrow	0	4
ADDS D, S	Add-signed S into D	Result = 0	Signed Overflow	1	4
SUBS D, S	Subtract-signed S from D	Result = 0	Signed Overflow	1	4
ADDSX D, S	Add-signed-extended S+C into D	Z & (Result = 0)	Signed Overflow	1	4
SUBSX D, S	Subtract-signed-extended S+C from D	Z & (Result = 0)	Signed Overflow	1	4
CMPSUB D, S	Subtract S from D if D => S	D = S	Unsigned (D => S)	1	4
DJNZ D, S	Dec D, jump if not zero to S (no jump = 8 clocks)	Result = 0	Unsigned Borrow	1	4 or 8
TJNZ D, S	Test D, jump if not zero to S (no jump = 8 clocks)	Result = 0	0	0	4 or 8
TJZ D, S	Test D, jump if zero to S (no jump = 8 clocks)	Result = 0	0	0	4 or 8
WAITPEQ D, S	Wait for pins equal - (INA & S) = D	Result = 0	-	0	5+
WAITPNE D, S	Wait for pins not equal - (INA & S) != D	Result = 0	-	0	5+
WAITCNT D, S	Wait for CNT = D, then add S into D	Result = 0	Unsigned Carry	1	5+
WAITVID D, S	Wait for video peripheral to grab D and S	Result = 0	-	0	5+
NOP	No operation, just elapses 4 clocks	-	-	-	4

\* The Hub allows each cog an opportunity to execute a Hub instruction every 16 clocks. Because each cog runs independently of the Hub, each cog must sync to the Hub when executing a Hub instruction. This will cause a Hub instruction to take between 7 and 22 clocks. Afterwards, there will be 9 free clocks before a subsequent Hub instruction can execute and take the minimal 7 clocks. This is enough time to execute two 4-clock instructions without missing the next sync. So, to minimize clock waste, you can insert two normal instructions between any two otherwise-contiguous Hub instructions, without any increase in execution time. Beware that Hub instructions can cause execution timing to appear indeterminate - particularly, the first Hub instruction in a sequence.

Table 13:7	Cog Assembly Language Opcodes▼				
Instruction	iiiiii	zcri	cccc	ddddddddd	sssssssss
RDBYTE D,S	000000	001i	1111	ddddddddd	sssssssss
RDWORD D,S	000001	001i	1111	ddddddddd	sssssssss
RDLONG D,S	000010	001i	1111	ddddddddd	sssssssss
WRBYTE D,S	000000	000i	1111	ddddddddd	sssssssss
WRWORD D,S	000001	000i	1111	ddddddddd	sssssssss
WRLONG D,S	000010	000i	1111	ddddddddd	sssssssss
SYSOP D,S	000011	00ri	1111	ddddddddd	sssssssss
CLKSET D	000-11	0001	1111	ddddddddd	-----000
COGID D	000-11	0011	1111	ddddddddd	-----001
COGINIT D	000-11	0001	1111	ddddddddd	-----010
COGSTOP D	000-11	0001	1111	ddddddddd	-----011
LOCKNEW D	000-11	0011	1111	ddddddddd	-----100
LOCKRET D	000-11	0001	1111	ddddddddd	-----101
LOCKSET D	000-11	0001	1111	ddddddddd	-----110
LOCKCLR D	000-11	0001	1111	ddddddddd	-----111
ROR D,S	001000	001i	1111	ddddddddd	sssssssss
ROL D,S	001001	001i	1111	ddddddddd	sssssssss
SHR D,S	001010	001i	1111	ddddddddd	sssssssss
SHL D,S	001011	001i	1111	ddddddddd	sssssssss
RCR D,S	001100	001i	1111	ddddddddd	sssssssss
RCL D,S	001101	001i	1111	ddddddddd	sssssssss
SAR D,S	001110	001i	1111	ddddddddd	sssssssss
REV D,S	001111	001i	1111	ddddddddd	sssssssss
MINS D,S	010000	001i	1111	ddddddddd	sssssssss
MAXS D,S	010001	001i	1111	ddddddddd	sssssssss
MIN D,S	010010	001i	1111	ddddddddd	sssssssss
MAX D,S	010011	001i	1111	ddddddddd	sssssssss
MOVS D,S	010100	001i	1111	ddddddddd	sssssssss
MOVD D,S	010101	001i	1111	ddddddddd	sssssssss
MOVI D,S	010110	001i	1111	ddddddddd	sssssssss
JMPRET D,S	010111	001i	1111	ddddddddd	sssssssss
JMP S	010111	000i	1111	-----	sssssssss
CALL #S	010111	0011	1111	???????????	sssssssss
RET	010111	0001	1111	-----	-----
TEST D,S	011000	000i	1111	ddddddddd	sssssssss
AND D,S	011000	001i	1111	ddddddddd	sssssssss
ANDN D,S	011001	001i	1111	ddddddddd	sssssssss
OR D,S	011010	001i	1111	ddddddddd	sssssssss
XOR D,S	011011	001i	1111	ddddddddd	sssssssss
MUXC D,S	011100	001i	1111	ddddddddd	sssssssss

Table 13:7	Cog Assembly Language Opcodes▼				
Instruction	iiiiii	zcri	cccc	ddddddddd	sssssssss
MUXNC D,S	011101	001i	1111	ddddddddd	sssssssss
MUXZ D,S	011110	001i	1111	ddddddddd	sssssssss
MUXNZ D,S	011111	001i	1111	ddddddddd	sssssssss
ADD D,S	100000	001i	1111	ddddddddd	sssssssss
SUB D,S	100001	001i	1111	ddddddddd	sssssssss
CMP D,S	100001	000i	1111	ddddddddd	sssssssss
ADDABS D,S	100010	001i	1111	ddddddddd	sssssssss
SUBABS D,S	100011	001i	1111	ddddddddd	sssssssss
SUMC D,S	100100	001i	1111	ddddddddd	sssssssss
SUMNC D,S	100101	001i	1111	ddddddddd	sssssssss
SUMZ D,S	100110	001i	1111	ddddddddd	sssssssss
SUMNZ D,S	100111	001i	1111	ddddddddd	sssssssss
MOV D,S	101000	001i	1111	ddddddddd	sssssssss
NEG D,S	101001	001i	1111	ddddddddd	sssssssss
ABS D,S	101010	001i	1111	ddddddddd	sssssssss
ABSNEG D,S	101011	001i	1111	ddddddddd	sssssssss
NEGC D,S	101100	001i	1111	ddddddddd	sssssssss
NEGNC D,S	101101	001i	1111	ddddddddd	sssssssss
NEGZ D,S	101110	001i	1111	ddddddddd	sssssssss
NEGNZ D,S	101111	001i	1111	ddddddddd	sssssssss
CMPS D,S	110000	000i	1111	ddddddddd	sssssssss
CMPSX D,S	110001	000i	1111	ddddddddd	sssssssss
ADDX D,S	110010	001i	1111	ddddddddd	sssssssss
SUBX D,S	110011	001i	1111	ddddddddd	sssssssss
CMPX D,S	110011	000i	1111	ddddddddd	sssssssss
ADDS D,S	110100	001i	1111	ddddddddd	sssssssss
SUBS D,S	110101	001i	1111	ddddddddd	sssssssss
ADDSX D,S	110110	001i	1111	ddddddddd	sssssssss
SUBSX D,S	110111	001i	1111	ddddddddd	sssssssss
CMPSUB D,S	111000	001i	1111	ddddddddd	sssssssss
DJNZ D,S	111001	001i	1111	ddddddddd	sssssssss
TJNZ D,S	111010	000i	1111	ddddddddd	sssssssss
TJZ D,S	111011	000i	1111	ddddddddd	sssssssss
WAITPEQ D,S	111100	000i	1111	ddddddddd	sssssssss
WAITPNE D,S	111101	000i	1111	ddddddddd	sssssssss
WAITCNT D,S	111110	001i	1111	ddddddddd	sssssssss
WAITVID D,S	111111	000i	1111	ddddddddd	sssssssss
NOP	-----	----	0000	-----	-----

### 13.5.1 Assembler Directives

A complete guide to assembly language programming is beyond the scope of this book; we are rather going to learn by example from reviewing code etc. If you already know assembly language then you will pick up Propeller Assembly very easily, if you aren't an assembly language programmer then just try to follow along, but it won't be important to using Spin based coding. But, to begin with there is no "assembler" per se, your Spin code and ASM code can exist in the same source file. There is no such thing as "inline" assembly, but the point is that from the compiler's point of view it understands both Spin and assembly code. All assembly code must start in a **DAT** section though, so you will see all examples of assembly after a DAT declaration. During compilation of your program files, when a DAT is seen by the compiler, it then starts assembling the ASM instructions into their proper formats and computing addresses correctly for you. The following are the most important assembler directives:

**ORG** — When programming in ASM, you must direct the assembler to place the ASM code into cog memory in the range from \$000 - \$1FF. Thus, ORG resets the assembler's data output offset to cog address \$000 (LONG address) for purposes of creating the ASM in the cog's 512 LONG register file (\$000 - \$1FF). ORG also supports an offset parameter from base \$0. For example, say you wanted your ASM to start at LONG address \$100, then you could use the ORG directive as follows:

**Example:** Generate all ASM code starting at LONG cog address \$100.

```
ORG $100 ' start all assembler output at cog address $100
```

**FIT addr** — The FIT directive simply safeguards your data tables from the ASM code generated. By using the FIT directive you can tell the assembler where it shouldn't encroach upon. If during assembly the code and data exceed the address in the FIT directive then an error would be thrown. Note: the FIT directive should always go at the end of your ASM code.

**Example:** Tell assembler not to exceed memory location \$150 with code + data.

```
FIT $150 ' if anything goes past $150 then an error is thrown
```

**RES** — Simply reserves data space for future storage, simply advances the data pointer by the size of the memory reserves. Also, reserves LONGs since LONGs are the basic unit of cog memory/instructions.

**Example:** Reserve 16 LONGs for a sine table.

```
Sinetable Res 16 ' the data pointer is advanced by 16, to skip this
                  ' region and sinetable is an alias
                  ' to the beginning of the reserved memory.
```

**Example:** A complete “object” that is composed of both Spin and ASM code.

```
CON
DEBUG_LED_PORT_MASK = $00000001 ' debug LED is on I/O P0

VAR
    long  cogon, cog

PUB start(glow_led_parms_ptr) : okay
    '' Start glowing LED- starts a cog
    '' returns false if no cog available
    ''
    stop
    okay := cogon := (cog := cognew(@entry,glow_led_parms_ptr)) > 0

PUB stop
    '' Stops driver - frees a cog
    if cogon~
        cogstop(cog)

DAT
    org $000
    ; Entry point
    entry
        ' initialize debug LED
        or  DIRA, #DEBUG_LED_PORT_MASK      ; set pin to output
        and OUTA, #!DEBUG_LED_PORT_MASK   ; turn LED off to begin
        mov lptr, par                     ; copy parameter pointer
                                            ; to global pointer for
                                            ; future ref
```

```

        rdlong debug_led_inc, lptr      ' now access main memory
                                      ' and retrieve the value

:glow_loop

        ' add the current brightness to the counter
        add debug_led_ctr, debug_led_brightness      wc

        ' based on carry turn LED on/off
        if_c   or OUTA, #DEBUG_LED_PORT_MASK
        if_nc  and OUTA, #!DEBUG_LED_PORT_MASK

        ' update brightness and invert increment if we hit 0
        add debug_led_brightness, debug_led_inc      wz
        if_z   neg debug_led_inc, debug_led_inc

        ' loop and do forever
        jmp #:glow_loop

// VARIABLES /////////////////////////////////
debug_led_ctr    long      $00000000  ' PWM counter
debug_led_inc    long      $00000000  ' increment to add to counter
debug_led_brightness long    $80000000  ' current brightness level
lptr             long      $00000000  ' general long pointer

```

The Spin code at the top is “glue” that allows other objects to call this object, but the important part to note is that the ASM code starts where you see the DAT section at the bottom half of the listing with an ORG \$000. Also, note that you can have many DAT sections with ASM code in them and then load them into other cogs, the assembler doesn’t care, but be advised that a single cog can only fit 512-16 LONGs of ASM code into it at load.

## 13.6 Hub Instructions

The instructions which access main memory, the global CLK register, the cogs, and the locks are all “Hub” instructions. What critically transpires during their execution is a function of the central Hub, which coordinates chip-wide operations.

The Hub runs at half the cogs’ clock frequency, serving each of the eight cogs, in turn, with each subsequent clock. From the cog’s perspective, this is once every 16 cog clocks. Because the Hub runs steadily, dedicating a Hub clock cycle to each cog, and because the cogs run independently, taking various numbers of cog clocks for different instructions, each cog must re-sync to the Hub whenever it executes a Hub instruction. This results in execution times ranging from 7 to 22 clocks for each Hub instruction. Once a Hub instruction has executed on any particular cog, there will be 9 free clocks before another Hub instruction could execute on the same cog, at that point the next Hub instruction will take the minimum number of

clocks – 7 rather than up to 22. Luckily, 9 clocks is enough time for two 4-clock instructions to execute before another Hub instruction would take 8 clocks. So, to minimize clock waste, you can insert two 4-clock instructions between any two otherwise-contiguous Hub instructions without any increase in execution time. Beware that Hub instructions can inject jitter into your execution schedule – specifically, the first Hub instruction in the sequence.



TIP

For deterministic timing, you might want to place them outside of time-critical code sequences in which the Hub-sync is unknown.

Summing up, when you execute the first Hub instruction in some algorithm or loop on a cog, the cog must sync up with the Hub; this synchronization plus the actual Hub instruction executing always takes from 7..22 clocks. Then once this first Hub instruction executes taking from 7..22 clocks, it takes 9 clocks before the Hub comes back around. When it does, it will take 7 clocks to execute the next Hub instruction, and this pattern of 9,7 will continue, thus in the 9 clocks of wait time you can execute 2 normal 4-clock instructions. Thus the execution stream of a Hub algorithm loop might look like this:

Given,

**H<sub>0</sub>** – 1<sup>st</sup> Hub instruction, requires synchronization, sync+execution time always 7..22 clocks

**H<sub>i</sub>** – ith Hub instruction, since the Hub is synced, always executes in 7 clocks, but will take 9 clocks before the Hub instruction can execute thus it's a good time to "interleave" other instructions in the stream

**W** – A single unused wait clock

**Op<sub>4</sub>** – Any 4-clock opcode

Instruction stream at beginning of 1<sup>st</sup> Hub instruction...

**H<sub>0</sub>(7..22)**, Op<sub>4</sub>(4), Op<sub>4</sub>(4), W(1), H<sub>i+1</sub>(7), Op<sub>4</sub>(4), Op<sub>4</sub>(4), W(1), H<sub>i+2</sub>(7), Op<sub>4</sub>(4), Op<sub>4</sub>(4), W(1), H<sub>i+3</sub>(7), Op<sub>4</sub>(4), Op<sub>4</sub>(4), W(1), H<sub>i+4</sub>(7)...

The following sub-sections elaborate on different Hub instruction groups.

### 13.6.1 Main memory access

The Hub instructions which access main memory are:

RDBYTE D, S	'Read byte at S into D and zero-extend
RDWORD D, S	'Read word at S into D and zero-extend
RDLONG D, S	'Read long at S into D
WRBYTE D, S	'Write D into byte at S
WRWORD D, S	'Write D into word at S
WRLONG D, S	'Write D into long at S

The main Propeller chip memory is 64 Kbytes in size and can be accessed from any cog. It is accessible as 64 Kbytes, 32 K-words, or 16 K-longs, each on their respective boundaries.

All accesses are aligned according to data size. WORDs can only begin at even addresses (multiples of 2) and LONGs can only begin at even-even addresses (multiples of 4). Of course, you can arrange your data any way you want, but to take advantage of efficient WORD and LONG accesses, you must pay attention to alignment.

### 13.6.2 CLK Register Write

Inside the Hub is a global CLK register which selects the master clock. A single Hub instruction used to set this register:

CLKSET D	'Write D[7..0] into the global CLK register
----------	---

More on this register later in this chapter.

### 13.6.3 Cog Control

There are three Hub instructions which govern the starting and stopping of cogs:

COGID D	'Get this cog number into D
COGINIT D	'Init a cog according to D
COGSTOP D	'Stop cog number D

**COGID** writes the executing cog number into D. This instruction is used when a cog needs to know "who" it is, among the eight, for the purpose of stopping or restarting itself.

**COGINIT** is the instruction used to start or restart a cog. The D register has three fields within it that determine which cog gets started, where its program begins in main memory, and what its PAR register will contain.

- ▶ **D[31..18]** will be written to bits [15..2] of the started cog's PAR register. By this mechanism, a LONG address parameter can be conveyed to a cog at start-time. This parameter is intended to be used as a pointer to some agreed-upon structure in main memory via which communication with another cog (or cogs) may take place.

- ▶ **D[17..4]** specifies the LONG address in main memory of the cog program to be loaded. Cog registers \$000..\$1EF will be loaded sequentially, starting at this address. The writable cog registers \$1F4..\$1FF will be initialized to 0. When the loading and initialization are complete, the started cog begins executing at register address \$000, thus there better be an instruction there!
- ▶ **D[3]** determines whether a new cog or a specified cog will be started.
  - ▷ If D[3] is '1', the Hub will start the lowest-numbered inactive cog and return that cog's number (0..7) into D. The C flag will also be used to convey whether or not there was an inactive cog available. A '0' in C indicates that the operation was successful. A '1' indicates that no cog was available and none was started. Be sure to put both the 'WR' and 'WC' modifiers after the COGINIT instruction so that these results will be written into D and C. Starting cogs in this fashion means that you will never have to plan which cog will run what program. The Hub, which knows the instantaneous state of all cogs, will do the picking for you.
  - ▷ If D[3] is '0', the Hub will start the cog numbered in D[2..0]. This is useful for restarting active cogs. To start a new cog, it is recommended that you use the D[3] = '1' approach, detailed above.

**COGSTOP** simply stops the cog numbered in D[2..0]. When a cog is stopped, it receives no clock and consumes no power. It will be held in an inactive reset state until started by a COGINIT instruction.

#### 13.6.4 Lock usage

Locks are special global bits which can be utilized to solve the problem of multiple-access contention, that is, multiple cogs writing the same data at the same time.

Imagine you have an area in main memory which holds some data that is to be accessed by more than one cog. If the elemental data exceeds a LONG in size, it will take multiple reads or writes for any cog to access it. It would be necessary to avoid the possibility of one or more cogs reading data while one or more other cogs are writing (or think they are writing) the same data. Access needs to be limited to one cog at a time in order to avoid misreads and miswrites. Such exclusive access control can be achieved by using a lock.

A lock is a global bit that can be set or cleared by any cog through certain Hub instructions. At the time a cog sets or clears a lock, it can also learn the prior state of that lock. The fact that the Hub allows only one cog at a time to set or clear a lock makes this an effective access control mechanism.

To use a lock, all cogs which intend to share some resource must agree on a lock number and its initial state. For our discussion, let's make the lock's initial state '0'. Now, for any cog

to gain exclusive access to the shared resource, it must keep setting the lock until it sees that its prior state was '0'. After this, all other cogs will get only '1's back. The winning cog now has exclusive access to the resource. When it is done accessing the resource, it must clear the lock so that another cog can gain access. Locks may be used creatively for many such purposes.

The Hub maintains an inventory of eight locks. It keeps track of which locks are available for check-out and notes when a lock is returned. On reset, all locks are 'returned' and ready for check-out. Though it's possible to set or clear any arbitrary lock, it is recommended that you check out a lock, so that the Hub will know that it is in use and will not grant it to some other cog. It's also critical to return the lock when you are through with it, so that it may be checked out again.

There are four Hub instructions used to manipulate locks:

<b>LOCKNEW D</b>	<b>wc</b>	'Check-out a new lock number into D, C=1 if none
<b>LOCKRET D</b>		'Return lock number D
<b>LOCKSET D</b>	<b>wc</b>	'Set lock number D, C=prior lock state
<b>LOCKCLR D</b>	<b>wc</b>	'Clear lock number D, C=prior lock state

**LOCKNEW** Checks out a new lock from the Hub and puts its number (0..7) into D. The C flag is used to convey whether or not the operation was successful. A '0' indicates success, while a '1' indicates that no free lock was available. Be sure to put a 'WC' modifier after the instruction, so that C will be written.

**LOCKRET** Returns the lock numbered in D[2..0] to the Hub's inventory.

**LOCKSET** Sets the lock numbered in D[2..0] and, if 'WC' is after the instruction, writes the lock's prior state into the C flag.

**LOCKCLR** Clears the lock numbered in D[2..0] and, if 'WC' is after the instruction, writes the lock's prior state into the C flag.

## 13.7 Branching Instructions

Branching instructions are used to alter the course of the cog's program counter, or PC. The PC is a 9-bit counter that tracks the program's execution address. It normally increments with each instruction, but it can be loaded with an arbitrary value via branching instructions. Additionally, all the branching instructions (except "RET") use the source register S to specify the branch address. Always remember to put "#" in front of the S expression when you intend to jump to a constant address. This will almost always be the case in your code. If you don't use the "#" you will be specifying a register's contents as your branch address. Sometimes you may want to do this, but most often your intent will be to branch to a constant address and you must remember to use "#.". For the applicable instructions cited in this section, both forms will be shown to keep you mindful of this critical issue.

Also, remember, like all other instructions, branches can be ***preceded*** by conditionals (if\_z, If\_c, etc.), making them into conditional branches.

The simplest branch instruction is "JMP S." This simply sets the PC to S[8..0]:

```
JMP      #S      'Jump to the constant address S
JMP      S       'Jump to where register S points
```

The most complex branch instruction is "JMPRET D,S." This is like "JMP S" but has the additional effect of writing PC+1 (what would have been the next execution address) into bits 8..0 of D. The purpose of that extra action is to insert a "return address" into a "JMP #S" instruction's source bit field. This way, if the code branched to by "JMPRET D,S" ends with a "JMP #S" instruction at the D address, that segment of code effectively becomes a subroutine that many identical "JMPRET D,S" instructions could branch to, and then return from.

Here is JMPRET:

```
JMPRET  D,#S    'Jump to the constant address S and set D[8..0] to PC+1
JMPRET  D,S     'Jump to where register S points and set D[8..0] to PC+1
```

To keep you sane, the assembler provides special "CALL" and "RET" instructions which form "JMPRET D, #S" and "JMP #S" instructions, respectively. This makes it easy to realize the subroutine scheme described above. These special instructions must be used with coordinated symbol names that you make up. To use the "CALL" instruction, you must specify a "#" followed by the symbolic name of the subroutine you are calling. There must be, somewhere in your program, an identical symbol name which ends with "\_RET" and precedes a "RET" instruction. The assembler uses the address of the '\*\_RET' symbol as the D in the "JMPRET D,#S," or "CALL" instruction; the S comes from the subroutine's start symbol. The "RET" instruction is assembled as "JMP #0", but gets modified at run time. Here is an example of these instructions in action:

```
CALL    #sub1   'Call to the constant address "sub1"
          '...and set the ssssssss bit field of "sub1_ret" to PC+1
'-----
sub1      <code>      'Start of "sub1" subroutine
sub1_ret  RET        'Return to caller (ssssssss modified, jump to #S)
```

Note that cogs have no call stack. They use end-of-subroutine jumps to return to callers. For this reason, subroutines can't be called recursively under normal conditions (without extra coding). However, there is no depth limit.

Finally, there are three conditional branching instructions which branch according to D:

DJNZ	D, #S	'Decrement D, jump to constant address S if D is not 0
DJNZ	D, S	'Decrement D, jump to where register S points if D is not 0
TJNZ	D, #S	'Test D, jump to constant address S if D is not 0
TJNZ	D, S	'Test D, jump to where register S points if D is not 0
TJZ	D, #S	'Test D, jump to constant address S if D is 0
TJZ	D, S	'Test D, jump to where register S points if D is 0

These D-dependent branches are very useful for fast looping. They take 4 clocks when they branch, and 8 clocks when they don't.

### 13.8 Add, Subtract, and Compare Instructions

There is a variety of add, subtract, and compare instructions which warrants elaboration. Some instructions perform unsigned math, while others perform signed math. Some perform base-LONG operations, while others perform extended-LONG operations. The differences are in how the Z and C flags are treated, particularly the C flag. Table 13:8 below contains the basic math instructions:

Table 13:8		Basic Math Instructions▼			
ADD/SUB/CMP		Base		Extended	
Unsigned	ADD	D, S	ADDX	D, S	
	SUB	D, S	SUBX	D, S	
	CMP	D, S	CMPX	D, S	
Signed	ADDS	D, S	ADDSX	D, S	
	SUBS	D, S	SUBSX	D, S	
	CMPS	D, S	CMPSX	D, S	

Here are the unsigned base instructions, shown with both flags written:

ADD	D, S	wz,wc	'Add S into D, Z=1 if 0, C=1 if carry
SUB	D, S	wz,wc	'Subtract S from D, Z=1 if 0, C=1 if borrow
CMP	D, S	wz,wc	'Compare D to S, Z=1 if 0, C=1 if borrow

The "ADD" instruction produces a carry, or C=1, if the addition of S into D causes a roll-over in D. In other words, the result is greater than \$FFFFFF. The "SUB" instruction produces a borrow, or C=1, if the subtraction of S from D causes a roll-under in D. Or, in other words, the result is less than 0 (S is greater than D). The "SUB" and "CMP" instructions are the

same, except that “CMP” does not store the result – it only indicates through the Z and C flags if D is above, below, or equal to S.

Next are the signed base instructions, shown with both flags written:

ADDS	D, S	wz, wc	'Add-signed S into D, Z=1 if 0, C=1 if overflow
SUBS	D, S	wz, wc	'Subtract-signed S from D, Z=1 if 0, C=1 if overflow
CMPS	D, S	wz, wc	'Compare-signed D to S, Z=1 if 0, C=1 if borrow

In the signed “ADDS” and “SUBS” instructions, an overflow, or C=1, occurs when the result is either above \$7FFFFFFF or below \$00000000 – the range of signed LONG values. The signed “CMPS” instruction, however, produces a signed borrow, or C=1, if S is greater than D, signs considered.

The unsigned and extended instructions are shown below with both flags written:

ADDX	D, S	wz, wc	'Add-extended S+C into D, AND Z, C=1 if carry
SUBX	D, S	wz, wc	'Subtract-extended S+C from D, AND Z, C=1 if borrow
CMPX	D, S	wz, wc	'Compare-extended D to S+C, AND Z, C=1 if borrow

These instructions differ from “ADD,” “SUB,” and “CMP” by incorporating C into the computation, and by ANDing the old Z with what would have been the new Z. These extra qualities make these instructions chainable. For example, the following double-LONG operations wind up with Z and C valid for the entire 64-bit operation:

ADD	D0,S0	wz, wc	'Add lower longs, affect flags
ADDX	D1,S1	wz, wc	'Add upper longs, Z=1 if 0, C=1 if carry
SUB	D0,S0	wz, wc	'Subtract lower longs, affect flags
SUBX	D1,S1	wz, wc	'Subtract upper longs, Z=1 if 0, C=1 if borrow
CMP	D0,S0	wz, wc	'Compare lower longs, affect flags
CMPX	D1,S1	wz, wc	'Compare upper longs, Z=1 if 0, C=1 if borrow

These operations could be further extended by adding an extra “ADDX,” “SUBX,” or “CMPX” for every additional LONG pair to be operated on.

The signed and extended instructions are as follows, shown with both flags written:

ADDSX	D, S	wz, wc	'Add-signed-extended S+C into D, AND Z, C=overflow
SUBSX	D, S	wz, wc	'Sub-signed-extended S+C from D, AND Z, C=overflow
CMPSX	D, S	wz, wc	'Compare-signed-extended D to S+C, AND Z, C=borrow

Like “ADDX”, “SUBX”, and “CMPX”, these instructions incorporate C into the operation, and logically AND the old Z with what would have been the new Z. The difference is in their C

flag output, which is signed. Here they are, used in double-LONG operations, with both Z and C valid afterwards for the entire 64-bit operation:

```

ADD    D0,S0  wz,wc  'Add lower longs, then signed-extended uppers
ADDSX  D1,S1  wz,wc  'Z=1 if 0, C=1 if overflow

SUB    D0,S0  wz,wc  'Subtract lower longs, then signed-extended uppers
SUBSX  D1,S1  wz,wc  'Z=1 if 0, C=1 if overflow

CMP    D0,S0  wz,wc  'Compare lower longs, then signed-extended uppers
CMPSX  D1,S1  wz,wc  'Z=1 if 0, C=1 if signed borrow

```

To extend these further, "ADDX," "SUBX," and "CMPX" instructions may be inserted between the shown pairs to handle any middle-LONGs. In a multiple-LONG signed operation, the beginning instruction is unsigned, any middle instructions are unsigned-extended, and the last instruction is signed-extended.

All these add, subtract, and compare instructions are quite similar. The differences lie in whether they are signed (C indicates overflow or signed borrow) and whether they are extended (C flag incorporated into operation, and Z flag ANDed).

### 13.9 Multiplication, Division, and Square Root

Since the Propeller chip has no built-in multiplication or division instruction, these and any other complex mathematical operations must be performed via software. For example, multiplication, division, and square root can be computed by using add, subtract, and shift instructions.

The most common approach to multiplication is a simple shift and add algorithm where the multiplier's bits are tested and for each bit of the multiplier that is "1" the multiplicand is added to the product with the appropriate shift. Here is an unsigned multiplier routine that multiplies two 16-bit values to yield a 32-bit product:

```

' Multiply x[15..0] by y[15..0] (y[31..16] must be 0)
' on exit, product in y[31..0]

multiply      shl      x,#16          'get multiplicand into x[31..16]
              mov      t,#16          'ready for 16 multiplier bits
              shr      y,#1   wc     'get initial multiplier bit into c
:loop      if_c    add      y,x   wc     'if c set, add multiplicand into product
              rcr      y,#1   wc     'get next multiplier bit into c, shift prod.
              djnz    t,:loop        'loop until done
multiply_ret  ret      'return with product in y[31..0]

```

The above routine's execution time could be cut by about one third if the loop was unrolled, getting rid of the "DJNZ" instruction.

Division is like multiplication, but backwards. It is potentially more complex though, because a comparison test must be performed before a subtraction can take place. To remedy this, there is a special "CMPSUB D,S" instruction which tests to see if a subtraction can be performed without causing an underflow. If no underflow would occur, the subtraction takes place and the C output is 1. If an underflow would occur, D is left alone and the C output is 0.

Here is an unsigned divider routine that divides a 32-bit value by a 16-bit value to yield a 16-bit quotient and a 16-bit remainder:

```
' Divide x[31..0] by y[15..0] (y[16] must be 0)
' on exit, quotient is in x[15..0] and remainder is in x[31..16]

divide    shl      y,#15          'get divisor into y[30..15]
           mov      t,#16          'ready for 16 quotient bits

:loop      cmbsub   x,y      wc  'if y <= x then subtract it, quotient bit into c
           rcl      x,#1           'rotate c into quotient, shift dividend
           djnz    t,:loop         'loop until done

divide_ret ret                  'quotient in x[15..0], remainder in x[31..16]
```

Like the multiplier routine, this divider routine could be recoded with a sequence of 16 "CMPSUB" plus "RCL" instruction pairs to get rid of the "DJNZ" and cut execution time by ~1/3. By making such changes, speed can often be gained at the expense of code size.

Finally, here's a square-root routine that uses the "CMPSUB" instruction:

```
' Compute square-root of y[31..0] into x[15..0]

root      mov      a,#0          'reset accumulator
           mov      x,#0          'reset root
           mov      t,#16         'ready for 16 root bits

:loop      shl      y,#1      wc  'rotate top two bits of y into accumulator
           rcl      a,#1
           shl      y,#1      wc
           rcl      a,#1
           shl      x,#2          'determine next bit of root
           or       x,#1
           cmbsub  a,x      wc
           shr      x,#2
           rcl      x,#1
           djnz    t,:loop         'loop until done

root_ret  ret                  'square root in x[15..0]
```

Many complex math functions can be realized by additions, subtractions, and shifts. Though specific examples were given here, these types of algorithms may be coded in many different ways to best suit the application. For applications as demanding as games and graphics typically you may have multiple algorithms for multiplication and division that take advantage of a-priori knowledge of the data set. For example, if you always know the multiplier will be a power of 2 then you can always use shifts alone. Or if both the multiplicand and multiplier are both very small then look up tables can be used and so forth.

### 13.10 WAIT Instructions

The “wait” instructions are used to stall the cog until some target condition is met. Once a wait instruction is engaged, the target condition is re-checked every clock cycle. Once the condition is met, the instruction finishes and the next instruction executes. During the wait, cog power consumption is reduced. These instructions are mainly used to align a cog’s execution timing with some event.

The first two wait instructions deal with the I/O pins’ input states. They wait for some set of pins to either equal, or not equal, some set of states. The S operand is used as a mask to isolate the pins of importance, while the D operand is the value to compare the isolated pins to. These instructions are as follows:

WAITPEQ D,S	'Wait for (INA & S) to equal D
WAITPNE D,S	'Wait for (INA & S) to not equal D

The “WAITCNT D,S” instruction waits for the global free-running 32-bit counter to equal some value. The global counter increments at the cog clock rate and can be read via the CNT register in each cog. Keep in mind that 32 bits can take a long time to wrap around if you miss the mark. This instruction is:

WAITCNT D,S	'Wait for CNT to equal D, then add S into D
-------------	---

By adding S into D, this instruction can singly serve as a synchronization mechanism to align execution to a fixed period. Here is an example of this:

```

    mov     dira,#1      'Make P0 an output
    add     time,cnt     'Add cnt into time to accommodate the initial sync

:loop   waitcnt time,period  '(re)sync to cnt, adding in the period afterwards
        xor     outa,#1      'toggle P0 - always on the same relative clock
        <code>                'put deterministic code after time-critical code
        jmp     #:loop       'loop to resync to the next period

time   long   3          'cnt-tracking variable, initial 3 accommodates sync
period long   100        '100 clocks per period

```

Lastly, there is the “WAITVID D,S” instruction which passes color and pixel data to the video peripheral. The video peripheral must be running for this instruction not to hang:

WAITVID D,S	'Hand off colors in D, pixels in S
-------------	------------------------------------

When the video peripheral is ready for its next set of color and pixel data, it grabs D and S, regardless of what instruction the cog is currently executing. It is critical that the cog be waiting in a “WAITVID D,S” instruction when this happens; otherwise, the video peripheral picks up indeterminate data and displays it. You have to make sure your program beats the video peripheral to the pickup.

### 13.11 Main Memory

Main memory consists of 32 Kbytes of RAM followed by 32 Kbytes of ROM. The RAM is completely user-programmable while the ROM is fixed and contains the Spin interpreter, boot code, and some mathematical lookup tables as well as the system character set. Table 13:9 below outlines the memory map.

<b>Table 13:9</b>		<b>Main Memory Map▼</b>
Address Range	Memory Type	Contents
\$0000-\$7FFF	RAM	User Memory – 8,192 LONGs / 16,384 WORDs / 32,768 BYTES
\$8000-\$BFFF	ROM	Character Definitions 4,096 LONGs define 256 different 16 x 32-pixel characters
\$C000-\$CFFF	ROM	Log Table – 2,048 WORDs of fractional exponents
\$D000-\$DFFF	ROM	Anti-Log Table – 2,048 WORDs of top-bit-set 17-bit mantissas
\$E000-\$F001	ROM	Sine Table – 2,049 unsigned WORDs cover 0° to 90° of sine, inclusively
\$F002-\$FFFF	ROM	Booter and Interpreter programs

The tables in ROM are intended to facilitate real-time signal processing by high-speed assembly language programs. High-level programs may not find much direct use for this data, though they may leverage objects which take advantage of it.

#### 13.11.1 User Memory (\$0000-\$7FFF)

The first half of main memory is all RAM. This space is used for your program, variables, and stack(s).

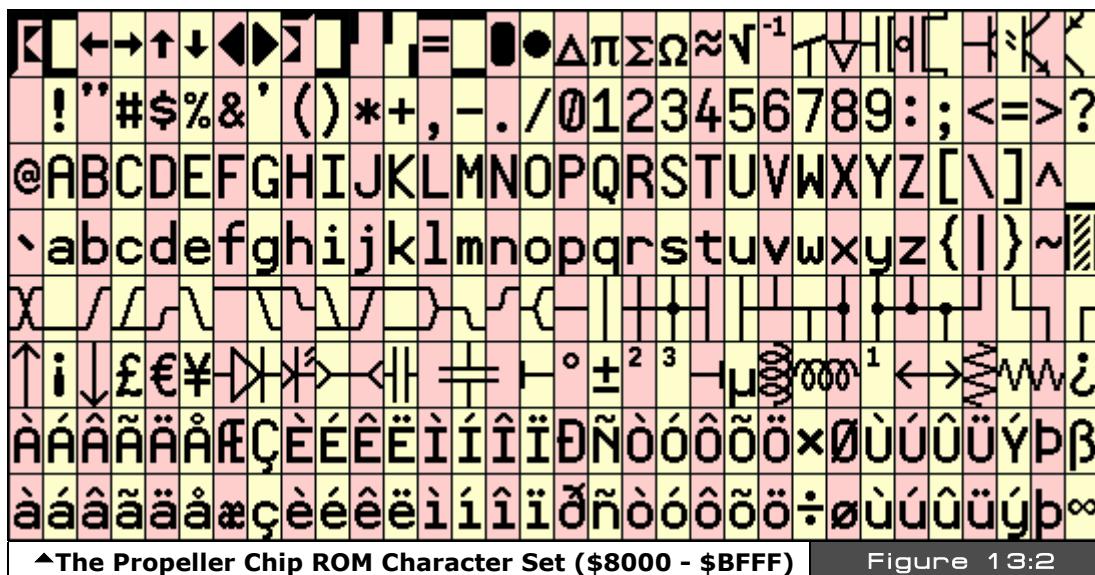
When a program is loaded into the chip, either serially or from an external EEPROM, this entire memory space is written. Your program begins at \$0010 and extends for some number

of LONGs. The area after your program, extending to \$7FFF, is used as stack space (for Spin only). Data spanning from \$0000 to \$000F is used mainly to hold the initial interpreter pointers. However, there are two values stored here that might be of interest to your program: the LONG at \$0000 contains the initial master clock frequency, in Hz, and the BYTE at \$000F contains the initial value written into the global CLK register. If you change the global CLK register, you will need to update these two variables so that objects which reference them will have current information. The master clock frequency can be read as "FREQ" in the high-level language. It can also be read and written with the Spin code "LONG[0]." The global CLK register copy can be read and written with "BYTE[15]," more later on these "direct memory access keywords" later when we cover the Spin language in more depth.

### 13.11.2 Character Definitions (\$8000-\$BFFF)

The first half of ROM is dedicated to a set of 256 character definitions. Each character definition is 16 pixels wide by 32 pixels tall. These character definitions can be used for video generation, graphical LCDs, printing, etc. The character set is based on a North American/Western European layout, with many specialized characters added and inserted. There are connecting waveform and schematic building-block characters, Greek characters commonly used in electronics, and several arrows and bullets.

The character definitions are numbered 0 to 255 from left-to-right, then top-to-bottom, as shown in Figure 13:2. They are arranged as follows: Each pair of adjacent even-odd characters is merged together to form 32 LONGs (evens shown in red, odds shown in yellow). The first character pair is located in \$8000-\$807F. The second pair occupies \$8080-\$80FF, and so on, until the last pair fills \$BF80-\$BFFF. The character pairs are merged such that each character's 16 horizontal pixels (per row) are spaced apart and interleaved with their neighbors' with the even character taking bits 0, 2, 4, ...30, and the odd character taking bits 1, 3, 5, ...31. The leftmost pixels are in the lowest bits, while the rightmost pixels are in the highest bits. This forms a LONG for each row of pixels in the character pair. 32 such LONGs, building from top row down to bottom, make up the complete merged-pair definition. The definitions are encoded in this manner so that a cog video peripheral can handle the merged LONGs directly, using color selection to display either the even or the odd character.



▲The Propeller Chip ROM Character Set (\$8000 - \$BFFF)

Figure 13:2

Some character codes have inescapable meanings, such as 9 for Tab, 10 for Line Feed, and 13 for Carriage Return (0 can also be touchy). These character codes invoke actions and do not equate to static character definitions. For this reason, their character definitions have been used for special four-color characters. These four-color characters are used for drawing 3-D box edges at run time and are implemented as  $16 \times 16$  pixel cells, as opposed to the normal  $16 \times 32$  pixel cells. They occupy even-odd character pairs 0-1, 8-9, 10-11, and 12-13.

### 13.11.3 Base 2 Log and Anti-Log Tables (\$C000-DFFF)

The log and anti-log tables are useful for converting values between their number form and exponent form. The log tables are base 2. If you are rusty on math, a logarithm is a way of referring to one number raised to the power of another. Let's review base 10 logs first. For example, you are probably used to seeing something like this:

$$10^2 = 100$$

...which states "10 to the 2<sup>nd</sup> power is 100", but what if we were to ask the question, "10 raised to what power equals 100?" This is the idea of a logarithm. And this is how we would write that statement out:

$$\log_{10} 100 = 2$$

The subscripted "10" is referred to as the "base" of the logarithm, and you would normally say something like "the log base 10 of 100 equals 2". Additionally, if the base is assumed by convention then it can be omitted, for example, in electrical engineering typically base 10

numbers are used so much that "log" with no base by convention always means base 10 log, thus you might see an engineer write something like:

Log 1000

...which means, "10 to the what power equals 1000?" The answer is of course 3. In general, logs have the following format:

$\text{Log}_b x = y$

...where b is the base.

In other words, "b to the power of y equals x" or mathematically:

$b^y = x$

So logs can help analyze data that grows in an exponential way with numbers that are smaller and that increment by single digits. Also, you may have seen "log" written as "ln" which is called the "natural logarithm." It is just a specific log with a specific base, that base being the mathematical constant "e" which is equal to 2.71828. Thus, a natural log is really just this:

$\text{Log}_e x = y$

And "e" is so common in engineering and physics that someone named a log after it, so they could stop writing "e" as the base, and that name is "ln" or natural log, written as:

$\text{Ln } x = y$

And that's it.

So how do logarithms help us? Well, they turn multiplication and division into addition and subtraction for one thing, take a look at these rules:

$\text{Log } A * B = \text{Log } A + \text{Log } B$

$\text{Log } A / B = \text{Log } A - \text{Log } B$

And this holds for any base; 10, e, etc. So referring to these Log formulas, if you wanted multiply two numbers together, you could simply convert them to logs then add! But, there is a catch, and that catch is once you convert them to logs (with a lookup table usually) then how do you convert the final sum of logs back to a normal number? This is where the anti-log comes into play.

Anti-log is the inverse function of Log; that is, antilog is really the exponential function itself:

$b^y = x$

Where b is the base 10 by convention, therefore,

$$\text{Antilog } (y) = 10^y$$

Example:

$$\text{Antilog } (3) = 1000, \text{ since } \text{Antilog } (3) = 10^3 = 1000$$

Finally, if you take the antilog of a log then results will cancel out and you will be left with the original value. That is say you had this:

$$\text{Log } 1000$$

We know that this is equal to 3, but if you take the antilog of this you get:

$$\text{Antilog } (\text{Log } 1000) = \text{Antilog } (3) = 10^3 = 1000$$

That is the original inner parameter 1000 is “pulled” out. Thus going back to our original formula:

$$\text{Log } A \times B = \text{Log } A + \text{Log } B$$

If we want to multiply two numbers, we simply need to find the log of each, and then find the antilog of the sum like this:

$$\text{Antilog } (\text{Log } A \times B) = \text{Antilog } (\text{Log } A + \text{Log } B)$$

$$A \times B = \text{Antilog } ((\text{Log } A + \text{Log } B))$$

Let's give it a try using a simple numbers that are powers of 10, thus easy to compute logs for:

$$100 \times 1000 = ?$$

$$\begin{aligned} \text{Log } (100 \times 1000) &= \text{Log } 100 + \text{Log } 1000 \\ &= 2 + 3 \\ &= 5 \end{aligned}$$

Now, to finish we need to take the antilog of the right hand side:

$$100 \times 1000 = \text{antilog } (5) = 10^5 = 100,000!$$

For algorithms where you are performing lots of multiplies and divides rather than additions and subtractions, using logs can greatly speed things up. Logarithmic encoding is also useful for compressing numbers into fewer bits – sacrificing resolution at higher magnitude. In many applications, such as audio synthesis, the nature of signals is logarithmic in both frequency and magnitude. Processing such data in exponential form is quite natural and efficient, as it transforms logarithmic data to linear data.

Now, before looking at the actual log and antilog tables, there is no point in using base 10 numbers on a computer, since all calculations are done in binary anyway (base 2), thus the

log and antilog tables are base 2. Of course, the same rules for multiplication, division, and so forth all hold for any log base, so this is exactly what we want to do.

#### 13.11.4 Log Table (\$C000-\$FFFF)

The log lookup table contains pre-computed data used to convert unsigned numbers into base-2 exponents. The log table is comprised of 2,048 unsigned WORDs which make up the base-2 fractional exponents of numbers. To use this table is a bit tricky, so let's try an example so you can see how it works. The first step to computing the base 2 log of a number is to determine the **integer** portion of the exponent of the number you are converting (trying saying that 3 times fast!). This is simply the leading bit's position (0..31) of the number you are converting:

##### Example: compute the log base 2 of \$60000000

Find the leading bit position?

```
$60000000 = 0110_0000_0000_0000_0000_0000_00002
          ↑
          30th bit position or $1E, this is the "leading bit's position."
```

So the integer portion of the log would be 30 or \$1E. This makes sense, since what we are really asking is "What smallest value of  $y$  for  $2^y$  is at least as large as our target log of \$60000000?" And that would be  $2^{30}$ .

Note, that this "integer" portion will always fit within 5 bits, since at most the largest number we might want to compute the log base 2 of is \$8xxxxxxxx (that is the 31<sup>st</sup> bit is HIGH and to represent 31 we need 5 bits). The **second** step in the algorithm to is to isolate this 5 bit number (\$1E in this case) into our partial result so that they occupy bit positions 20..16. In the case of the example we are using of \$60000000 to start with, we would place the 30 decimal or \$1E hex into bit positions 20..16 of our partial result, like so:

```
= $001E0000
= 0000_0000_0001_1110_0000_0000_00002
          ↑↑
          20th..16th bit positions
```

So far we have a partial result of \$001E0000.

The **third** step is to top-justify and isolate the first 11 bits below the leading bit of the original \$60000000 into positions 11..1 of the partial result, we use bits 11..1 rather than 10..0 since each entry in the log table is a WORD or 2 BYTES. Anyway, here are the details of the step:

Once again we refer to the original number \$60000000

```
$60000000 = 0110_0000_0000_0000_0000_0000_00002
      ↑      ↑
      11 bits below the leading "1"
```

...of which we left or "top justify" these 11 bits into 12 bits resulting in:

```
1000_0000_00002
```

...then pad 4 more bits resulting in:

```
0000_1000_0000_00002 = $0800
```

...and we are almost done! We take this result \$0800 which is the "index" into the lookup table and look up the fractional value in the log look up table, so we perform the following step:

```
Fractional_log = Log_Table[ $0800 ]
```

...and in this case, the value there happens to be \$9C50 (I looked it up), then the ***final*** step is to add the ***integer*** part we manually computed to the ***fractional*** part we just looked up:

```
$001E0000 + $9C50 = $001E9C50.
```

```
↑          ↑
Integer part   Fractional part
```

...which is indeed the log base 2 of \$60000000. Note that bits 20..16 make up the integer portion of the exponent, while bits 15..0 make up the fractional portion, with bit 15 being the  $\frac{1}{2}$ , bit 14 being the  $\frac{1}{4}$ , and so on, down to bit 0. The exponent can now be manipulated by adding, subtracting, and shifting. Always insure that your math operations will never drive the exponent below 0 or cause it to overflow bit 20. Otherwise, it may not convert back to a number correctly.

Here is a routine that will convert an unsigned number into its base-2 exponent using the log table:

```
' Convert number to exponent
;
' on entry: num holds 32-bit unsigned value
' on exit:  exp holds 21-bit exponent with 5 integer bits and 16 fractional bits
;
numexp      mov     exp, #0           'clear exponent
            test    num,num4      wz    'get integer portion of exponent
            muxnz  exp,exp4      'while top-justifying number
```

```

if_z      shl    num,#16
          test   num,num3      wz
          muxnz exp,exp3
if_z      shl    num,#8
          test   num,num2      wz
          muxnz exp,exp2
if_z      shl    num,#4
          test   num,num1      wz
          muxnz exp,exp1
if_z      shl    num,#2
          test   num,num0      wz
          muxnz exp,exp0
if_z      shl    num,#1

          shr    num,#30-11     'justify sub-leading bits as word offset
          and   num,table_mask  'isolate table offset bits
          add   num,table_log   'add log table address
          rdword num,num        'read fractional portion of exponent
          or    exp,num         'combine fractional and integer portions

numexp_ret ret               '91..106 clocks
                           '(variance is due to Hub sync on RDWORD)

num4      long   $FFFF0000
num3      long   $FF000000
num2      long   $F0000000
num1      long   $C0000000
num0      long   $80000000
exp4      long   $00100000
exp3      long   $00080000
exp2      long   $00040000
exp1      long   $00020000
exp0      long   $00010000
table_mask long   $0FFE      'table offset mask
table_log  long   $C000       'log table base

num       long   0           'input
exp       long   0           'output

```

### 13.11.5 Anti-Log Table (\$D000-\$FFFF)

The anti-log table contains data used to convert base 2 exponents into unsigned numbers, much simpler than the log table. The anti-log table is comprised of 2,048 unsigned WORDs which are each the lower 16 bits of a 17-bit mantissa (the 17<sup>th</sup> bit is implied and must be set separately). To use this table, shift the top 11 bits of the exponent fraction (bits 15..5) into bits 11..1 and isolate. Add \$D000 for the anti-log table base. Read the WORD at that location into the result – this is the mantissa. Next, shift the mantissa left to bits 30..15 and set bit 31 – the missing 17<sup>th</sup> bit of the mantissa. The last step is to shift the result right by 31 minus the exponent integer in bits 20..16. The exponent is now converted to an unsigned number.

Here is a routine that will convert a base-2 exponent into an unsigned number using the anti-log table:

```

; Convert exponent to number
;

; on entry: exp holds 21-bit exponent with 5 integer bits and 16 fraction bits
; on exit: num holds 32-bit unsigned value
;

expnum      mov     num,exp          ;get exponent into number
            shr     num,#15-11       ;justify exponent fraction as word
                                ;offset
            and     num,table_mask   ;isolate table offset bits
            or      num,table_antilog ;add anti-log table address
            rdword  num,num          ;read mantissa word into number
            shl    num,#15           ;shift mantissa into bits 30..15
            or     num,num0          ;set top bit (17th bit of mantissa)
            shr    exp,#20-4         ;shift exponent integer into bits 4..0
            xor    exp,$$1F           ;inverse bits to get shift count
            shr    num,exp          ;shift number into final position

expnum_ret   ret                 ;47..62 clocks
                                ;(variance is due to Hub sync on RDWORD)

num0        long   $80000000      ;17th bit of the mantissa
table_mask  long   $0FFE          ;table offset mask
table_antilog long  $C000          ;anti-log table base

exp         long   0              ;input
num         long   0              ;output

```

### 13.11.6 Sine Table (\$E000-\$F001)

The sine table provides 2,049 unsigned 16-bit sine samples spanning from 0° to 90°, inclusively (resulting in a 0.0439° resolution). A small amount of assembly code can mirror and flip the sine table samples to create a full-cycle sine/cosine lookup routine which has 13-bit angle resolution and 17-bit sample resolution:

```

' Get sine/cosine

'     quadrant: 1          2          3          4
'     angle:    $0000..$07FF $0800..$0FFF $1000..$17FF $1800..$1FFF
' table index: $0000..$07FF $0800..$0001 $0000..$07FF $0800..$0001
'     mirror: +offset      -offset      +offset      -offset
'     flip:   +sample      +sample      -sample      -sample

' on entry: sin[12..0] holds angle (0° to just under 360°)
' on exit:  sin holds signed value ranging from $0000FFFF (1) to $FFFF0001 (-1)
'

getcos      add     sin,sin_90      'for cosine, add 90°
getsin      test    sin,sin_90    wc  'get quadrant 2|4 into c
                                    test    sin_sin_180   wz  'get quadrant 3|4 into nz
                                    negc   sin,sin      'if quadrant 2|4, negate offset
                                    or     sin,sin_table 'or in sin table address >> 1
                                    shl    sin,#1       'shift left to get final word address
                                    rdword sin,sin      'read word sample from $E000 to $F000
                                    negnz  sin,sin      'if quadrant 3|4, negate sample
getsin_ret
getcos_ret  ret                '39..54 clocks
                                    '(variance is due to Hub sync on RDWORD)

sin_90      long   $0800
sin_180      long   $1000
sin_table    long   $E000 >> 1      'sine table base shifted right
sin         long   0

```

As with the log and anti-log tables, linear interpolation could be applied to the sine table to achieve higher resolution. Also, remember the following simple trigonometric identities (they come in handy when trying to relate sine to cosine):

$$\begin{aligned}
 \text{Cos}(x) &= \text{Sin}(x + 90^\circ) \\
 \text{Cos}(-x) &= \text{Cos}(x) \\
 \text{Sin}(-x) &= -\text{Sin}(x) \\
 \text{Sin}(2x) &= 2 \text{ Sin}(x) \text{ Cos}(x) \\
 \text{Cos}^2 x + \text{Sin}^2 x &= 1
 \end{aligned}$$

### 13.12 Booter and Interpreter (\$F002-\$FFFF)

The last part of ROM contains the **boot loader** and the **Spin interpreter**. These are assembly language programs which are critical to the operation of the Propeller chip. The boot loader program runs automatically on reset and is responsible for booting the chip. On reset, the boot loader begins by waiting briefly to see if a host (PC in most cases) is attempting to connect serially on pins P31 and P30. If a host is present, it can command the boot loader to receive a high-level program to transfer into RAM. It may also command the booter to program that data into an external EEPROM and/or to launch the interpreter to execute it. If no serial host is present, the boot loader attempts to load a high-level program into RAM from an external EEPROM connected on pins P29 and P28. If successful, the interpreter will be launched to execute it. If no EEPROM is present, or the high-level program was corrupted, the boot loader will shut down the chip to conserve power.

The Spin interpreter program's job is to execute high-level programs only. It is initially launched by the boot loader into Cog 0. As the interpreter executes a high-level program, it may be directed to re-launch itself into other cogs, so that other high-level programs can run concurrently.

### 13.13 The Global CLK Register

The global CLK register controls the Propeller chip's master clock source. It is writable from Spin with the instruction "CLKSET(value)" or the assembly language "CLKSET D" instruction. Whenever the CLK register is written, a global delay of ~100 µs will occur as the clock-switchover circuit transitions from potentially one clock source to another.

Whenever you change this register, a copy of the value written should be placed in BYTE[15]. Also, LONG[0] should be updated with the resulting master clock frequency. This is done so that objects which reference these data will have current information upon which to base their timing calculations. In most cases, you will not do this though and will simply run the chip at a constant speed; however, if you are doing "on demand performance" computing and want to minimize power consumption then this detail becomes important. The CLK register is outlined in Table 13:10 on the next page.

Table 13:10		Bit Encodings for the Global CLK Register▼							
Bit	7	6	5	4	3	2	1	0	
Name	RESET	PLLENA	OSCENA	OSCM1	OSCM2	CLKSEL2	CLKSEL1	CLKSEL0	
<b>RESET</b>	<b>Effect</b>								
<b>0</b>	Always write '0' here unless you intend to reset the chip.								
<b>1</b>	Same as a hardware reset – reboots the chip.								
<b>PLLENA</b>	<b>Effect</b>								
<b>0</b>	Disables the PLL circuit.								
<b>1</b>	Enables the PLL circuit. The PLL internally multiplies the XIN pin frequency by 16. OSCENA must be '1' to propagate the XIN signal to the PLL. The PLL's internal frequency must be kept within 64 MHz to 128 MHz – this translates to an XIN frequency range of 4 MHz to 8 MHz. Allow 100 µs for the PLL to stabilize before switching to one of its outputs via the CLKSEL bits. Once the OSC and PLL circuits are enabled and stabilized, you can switch freely among all clock sources by changing the CLKSEL bits.								
<b>OSCENA</b>	<b>Effect</b>								
<b>0</b>	Disables the OSC circuit.								
<b>1</b>	Enables the OSC circuit so that a clock signal can be input to XIN, or so that XIN and XOUT can function together as a feedback oscillator. The OSCM bits select the operating mode of the OSC circuit. Note that no external resistors or capacitors are required for crystals and resonators. Allow a crystal or resonator 10ms to stabilize before switching to an OSC or PLL output via the CLKSEL bits. When enabling the OSC circuit, the PLL may be enabled at the same time so that they can share the stabilization period.								
<b>OSCM1</b>	<b>OSCM2</b>	<b>XOUT Resistance</b>		<b>XOUT Capacitance</b>		<b>Frequency Range</b>			
<b>0</b>	<b>0</b>	Infinite		6 pF		DC to 160 Hz Input			
<b>0</b>	<b>1</b>	2000 Ω		36 pF		4 MHz to 6 MHz Crystal/Resonator			
<b>1</b>	<b>0</b>	1000 Ω		26 pF		8 MHz to 32 MHz Crystal/Resonator			
<b>1</b>	<b>1</b>	500 Ω		16 pF		20 MHz to 60 MHz Crystal/Resonator			
<b>CLKSEL2</b>	<b>CLKSEL1</b>	<b>CLKSEL0</b>	<b>Master Clock</b>		<b>Source</b>	<b>Notes</b>			
<b>0</b>	<b>0</b>	<b>0</b>	≈ 12 MHz		Internal	No internal parts; range 8 to 20 MHz			
<b>0</b>	<b>0</b>	<b>1</b>	≈ 20 kHz		Internal	Very low power; range 13 to 33 kHz			
<b>0</b>	<b>1</b>	<b>0</b>	XIN		OSC	OSCENA must be '1'			
<b>0</b>	<b>1</b>	<b>1</b>	XIN × 1		OSC+PLL	OSCENA and PLLENA must be '1'			
<b>1</b>	<b>0</b>	<b>0</b>	XIN × 2		OSC+PLL	OSCENA and PLLENA must be '1'			
<b>1</b>	<b>0</b>	<b>1</b>	XIN × 4		OSC+PLL	OSCENA and PLLENA must be '1'			
<b>1</b>	<b>1</b>	<b>0</b>	XIN × 8		OSC+PLL	OSCENA and PLLENA must be '1'			
<b>1</b>	<b>1</b>	<b>1</b>	XIN × 16		OSC+PLL	OSCENA and PLLENA must be '1'			

### 13.14 Counter Operations and Modes

As mentioned, each cog has **two** internal 32-bit counters A and B, and these counters are controlled via the counter control register file for the cog. Additionally, there is a "**global**" counter accessed via the **CNT** register in the register file for each cog that allows any cog to use a common synchronous clock for event timing etc.

Once again, three pairs of registers make up a counter module:

**CTRA/B** Configuration register, full R/W

**PHSA/B** Phase accumulator, full R/W (automatically updates per mode)

**FRQA/B** Phase adder, write-only, though R/W okay

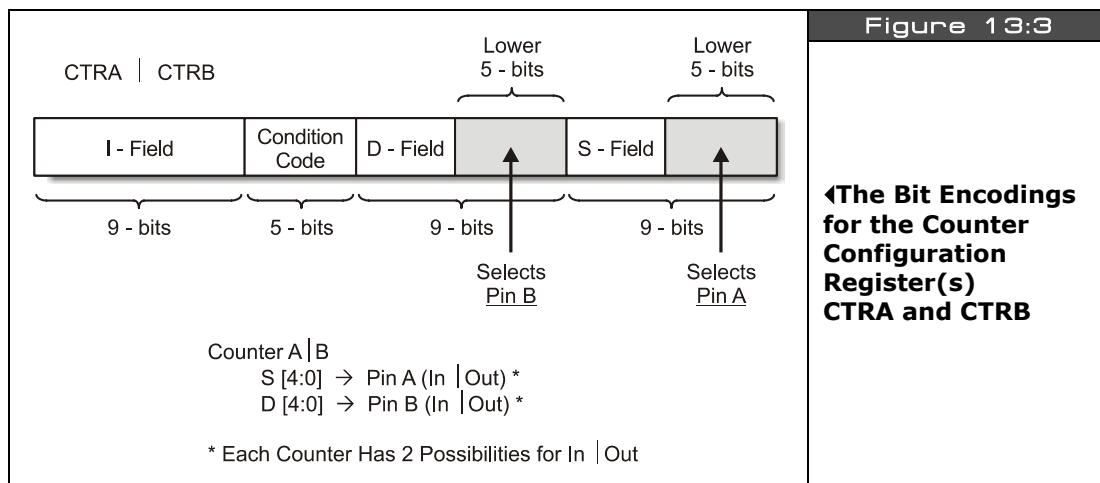
Additionally, there is a bit of naming that might confuse you. Each counter A and B each has two pins that can be selected as inputs or outputs; these are also referred to as A and B, so diagrammatically we have:

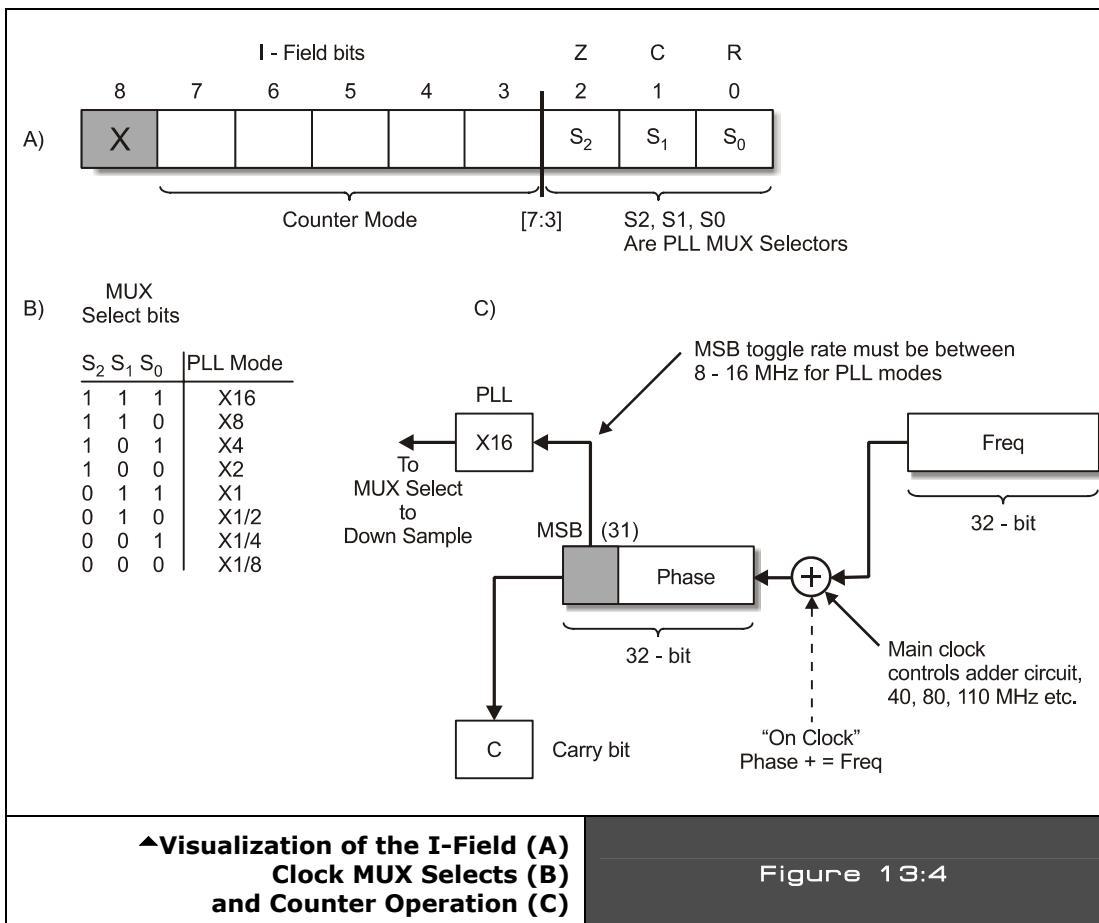
**Counter A** has two pins of interest referred to as A and B.

**Counter B** has two pins of interest referred to as A and B.

Thus, when discussing counters I will refer to counter/pin always in that order. This will make more sense when we see the counter control modes in the tables below, but watch out – it's easy to get confused.

#### 13.14.1 Bit Encodings for the Counter Configuration Registers





Referring to Figure 13:3 and Figure 13:4, and the bit encodings for the counter configuration register as shown in Table 13:11 below, let's begin our discussion of counter operation. To begin with, remember that all registers and instructions can be referenced by their various fields; I, CC, D, and S. With that in mind, the uppermost 9 bits of the CTRA (or CTRB) register are referred to at the I-field; these bits control two things. First the counter mode (PLL, duty cycle, numerically controlled oscillator, etc. as shown in Table 13:10 on page 214) is selected via bits [7-3]; bits [2-0] select which PLL "tap" is used to finally select the output signal by from 1/8<sup>th</sup> to 16. If you refer to Figure 13:4(B), you see that the 3 bits form a selector which selects which frequency the final output of the counter hardware is multiplied by. We will discuss this in more detail in a moment.

Next, depending on the mode the counter is set in, you can select a Pin A or B option for each counter (where it makes sense). So for either counter A or B, the selection of pins is encoded in the control register's S and D fields like so:

Counter A or B S-field bits [4-0] selects Pin A (in/out depending on mode of operation)

D-field bits [4-0] selects Pin B (in/out depending on mode of operation)

Refer to Figure 13:3 to see this a little bit better. Anyway, so now we can select the counter mode in I-field bits [7-3], we can select the PLL multiplier in I-field bits [2-0], and we select the Pin A option in S-Field bits [4-0] and the Pin B option in D-field bits [4-0]. And of course, there are two counters and we have two control registers named CTRA and CTRB respectively. Also, note we do not need to set Pin A or Pin B options to input or output as they are inferred to be input or output respectively by the counter mode you select (however, at the I/O level you must set the pins for input or output with the direction register).

<b>Table 13:11 Bit Mapping for Counter Control Registers CTRA and CTRB</b>		
Field	Bits	Function
I-Field	CTRA/B[30..26]	Sets counter "mode"
I-Field	CTRA/B[25..23]	Selects PLL tap (0..7 map to x1/8, x1/4, x1/2, x1, x2, x4, x8, x16)
S-Field	CTRA/B[4..0]	Selects pin Out A / In A (0-31)
D-Field	CTRA/B[13..9]	Selects pin Out B / In B (0-31)



You can use the following ASM instructions to write into the fields of CTRA/CTRB:

**MOVI** — sets mode  
**MOVD** — sets Pin B  
**MOVS** — sets Pin A

Alright, this is great, but how does the counter actually work? Referring to Figure 13:4(C), you see a diagram that visualizes what the counter does, so let's break it down step by step and work through the flow diagram of how the counters A and B work; both are identical of course.

**Step 1:** The 32-bit value stored in the FRQx register is added to the PHSx register at the final system clock frequency. So if you are running the Propeller chip at a final frequency of 80 MHz, then this is the frequency at which this addition takes place. Example: if you have a 0x00000001 in FRQx then it will take PHSx  $2^{32}$  counts to overflow.

**Step 2:** PHSx is used as an “accumulator” and continuously accumulates the additions of FRQx. The MSB (most significant bit) feeds the PLL (phase-locked loop) and that clock rate is always multiplied by 16, then you select which PLL tap you want from x1/8<sup>th</sup> to x16 with bits 25..23 of the I-field.

**Step 3:** Now, depending on what “mode” the counter is in, the output will be one of the following:

**PLL Modes** – The output from bit 31 of PHSx is multiplied by 16 and then the PLL multiplexer selection bits S2, S1, S0 (in I-field [25..23]) select the “tap” frequency from 1/8<sup>th</sup> to x16.

**NCO Modes** – The MSB (bit 31) of PHSx is the output, there is no PLL multiplication in this mode.

**DUTY Cycle Modes** – The resulting overflow carry out bit C (from bit 31) from the resulting additions is the output. The carry bit is also referred to as bit 32, so PHSx[31] would be the MSB and PHSx[32] is the carry bit from the additions of FRQx into PHSx.

Now, there are other modes that the counter can run in that can be used for A/D (analog to digital conversion) as well as performing logic functions, but these aren’t very important to HYDRA programming. Table 13:12 on the next page lists these though.

So to use a counter you must at very least setup the CTRx register for either the A or B counter and then depending on the mode you select modify PHSx and FRQx as desired to get the desired effect; PLL, NCO, or Duty Cycle. We will discuss what you can do with these modes shortly, but first let’s take a look at the counter configuration mode table, Table 13:12.

### 13.14.2 Counter Configuration Mode Table

Table 13:12 below lists all the counter configuration modes that are available for either Counter A or B, these modes are selected via the cog registers CTRA and CTRB.

Counter Configuration Mode▼				
CTR <sub>x</sub> [30..26]	PHS <sub>x</sub> += FRQ <sub>x</sub>	OUTA	OUTB	Description of Mode
(0) 00000	FALSE	FALSE	FALSE	Off
PLL Modes				
(1) 00001	TRUE	FALSE	FALSE	PLL internal, FM aural carrier TV or routed to video
(2) 00010	TRUE	PLL	FALSE	PLL singe
(3) 00011	TRUE	PLL	! PLL	PLL differential
Numerically Controlled Oscillator Modes				
(4) 00100	TRUE	PHS <sub>x</sub> [31]	FALSE	NCO single
(5) 00101	TRUE	PHS <sub>x</sub> [31]	!PHS <sub>x</sub> [31]	NCO differential
Duty Cycle Modes				
(6) 00110	TRUE	PHS <sub>x</sub> [32]	FALSE	duty single
(7) 00111	TRUE	PHS <sub>x</sub> [32]	!PHS <sub>x</sub> [32]	duty differential
Special Analog Modes				
(8) 01000	INA'	FALSE	FALSE	pos
(9) 01001	INA'	FALSE	!INA'	pos with feedback
(10) 01010	INA' & !INA"	FALSE	FALSE	pos edge
(11) 01011	INA' & !INA"	FALSE	!INA'	pos edge with feedback
(12) 01100	!INA'	FALSE	FALSE	neg
(13) 01101	!INA'	FALSE	!INA'	neg w/ feedback
(14) 01110	!INA' & INA"	FALSE	FALSE	neg edge
(15) 01111	!INA' & INA"	FALSE	!INA'	neg edge w/feedback
Logic Function Implementation Mode				
(16) 1xxxx	See * below	FALSE	FALSE	Logic implementation mode *Add if FUNC (MUX (INA', INB')) = 1 Where, INA' = INA from 1 clock ago. INA" = INA from 2 clocks ago. INB' = INB from 1 clock ago.
DELAYS	' = 1 clock delay, " = 2 clock delays			



When using the counters or any I/O for that matter, no matter what, you always have to set the appropriate pins A,B as input or output to coincide with the mode setting.

Now, let's briefly discuss what you might use each mode for, but before doing that, I want to make sure you can make sense of Table 13:12 above. The table is read as follows: first you find the mode you are interested in, say mode 2 "(2)" for example. Ok, now there are five column heads in this table. The first column head "CTR<sub>x</sub>" simply means the mode bits that you must set in the CTR<sub>x</sub> register to select the related mode, easy enough. The next column "PHS<sub>x</sub>+ = FRQ<sub>x</sub>" means that the value in the frequency register is added to the phase register each system clock under a specific condition: always, or never. For example, in the case of mode 2, this addition always takes place, but in mode 0, we see a FALSE in the column, thus frequency is never added; this makes sense since mode 0 is OFF. Moving onto the next column headings OUTA and OUTB, these columns tell us what exactly is getting output by the counter. For example, in mode 2 the OUTA column shows "PLL" and in the OUTB column it shows FALSE. This means that if you set a counter (A or B) to PLL mode 2, then you can select a single output Pin A and the PLL output will drive it. Of course, you set this pin in the S-field bits [4..0] of the counter control register and you **MUST** make sure that on the DIRA I/O control you have that pin set as an output as well. Lastly, the "Description..." column is just that, a description.

So, now that we can read this table, let's take a look at yet another mode and see if we can understand its use. Take a look at mode 5. This mode is NCO (numerically controlled oscillator) mode, that's easy to see from the description and header. Ok, next let's see when the phase register is updated, we look in the "PHS<sub>x</sub>+ = FRQ<sub>x</sub>" column and we see TRUE, thus all the time, every system clock, the addition takes place, good enough. Next, we look at the OUTA and OUTB columns and they get interesting, we see the final output to Pin A is PHS<sub>x</sub>[31], that is the MSB of the PHS<sub>x</sub> register, this is fine, but then we see that the output to Pin B is !PHS<sub>x</sub>[31], the "!" means *not* or *invert*, thus mode 5 is interesting since it's a "**differential mode**," while the pin you select as output A is going HIGH, the pin you select as output B is going LOW, thus they are 180 degrees out of phase or referred to as a differential signal. Now that you can read the table a bit, let's discuss what these modes do for us.



If you want to use any of the system counters to generate sound, either simple tones or more complex PWM sounds, then obviously you **MUST** set the output pin to drive the sound hardware at I/O pin P7 (8) which is named AUDIO\_MONO in the HYDRA design.

### 13.14.3 PLL (Phase-Locked Loop) Modes

The PLL modes 1, 2, 3 are used to generate a standard square wave output (except mode 1 which has no output, but it's useful for video and FM aural generation since the signal is routed to that hardware). The main clock frequency F (usually 64-100 MHz) drives the adder circuit and the value in FRQ<sub>x</sub> is added/accumulated into PHS<sub>x</sub>, the MSB of the PHS<sub>x</sub> register

PHSx[31] is multiplied by 16 using a phased locked loop circuit or PLL (PLLs can be used for many things and one of them is frequency multiplication), then you can select which sub-multiple of this you wish with the PLL MUX select bits in the CTRx register bits [2..0], as shown in Figure 13:4(B) on page 216 there are 8 different frequencies you can select as shown in a slightly different form in Table 13:13 below.

<b>Table 13:13</b> <b>PLL Final Frequency Selection▼</b>		
<b>Mode</b>	<b>Bits [S2,S1,S0]</b>	<b>Final Rate Output</b>
<b>0</b>	000	$\times 1/8$
<b>1</b>	001	$\times 1/4$
<b>2</b>	010	$\times 1/2$
<b>3</b>	011	$\times 1$
<b>4</b>	100	$\times 2$
<b>5</b>	101	$\times 4$
<b>6</b>	110	$\times 8$
<b>7</b>	111	$\times 16$

For example, whatever rate the MSB toggles at, if you wanted that  $\times 16$  you would select 111 or mode 7.



**There are two very important rules when using the PLL modes. The frequency that gets driven into the PLL must be between 4 and 8 MHz inclusive. This means that the final output will always be between 64 and 128 MHz.**

Now, let's do a concrete example of what values would do what since PLL modes are very useful for generating sound using PWM modes as well as generating high frequency clocks (remember the final PLLs  $\times 16$  output must ALWAYS be between 64 and 128 MHz, so it's fairly high frequency).

### Example Derivation of Frequency Formula for PLL Modes

The MSB of the PHSx register always needs to toggle at a rate between 8 and 16 MHz or a frequency between 4 and 8 MHz. This first constraint is the key to programming the PLL. So, first, we need to realize that we ONLY can generate frequencies at the MSB between 4 and 8 MHz then this is always multiplied by 16 then with the PLL mux we can pick off any sub-multiple from  $1/8^{\text{th}}$  to the full  $16\times$ . To make the derivation simpler, let's forget about the  $\times 16$

part since this is a scaling operation and we can always look at it later. First let's just find a formula that describes the PLL counter mode up to the MSB before the x16 to the multiplier.

Ok, so reviewing the flow chart in Figure 13:4(C) on page 216, FRQx is added to PHSx each main system clock cycle, let's call this Fm Hz. So, at Fm Hz we are adding FRQx into PHSx and it overflows whenever the sum is greater than  $(2^{32} - 1)$ . For example, if we were to put a 0x8000\_0000 into FRQx then it would take 2 additions to overflow PHSx or as a function of the main clock Fm, we would see the MSB look like this (assuming everything starts at 0), Table 13:14 illustrates what happens.

Table 13:14		Digital Mechanics of the PLL Mode Addition as a Function of the Main Clock C▼		
Clock Cycle	PHSx[32] carry bit	MSB PHS[31]	PHSx	FRQx
0	0	0	0x0000_0000	0x8000_0000
1	0	1	0x8000_0000	0x8000_0000
2	1	0	0x0000_0000	0x8000_0000
3	0	1	0x8000_0000	0x8000_0000
4	1	0	0x0000_0000	0x8000_0000
5	0	1	0x8000_0000	0x8000_0000
6	1	0	0x0000_0000	0x8000_0000
7	0	1	0x8000_0000	0x8000_0000
8	1	0	0x0000_0000	0x8000_0000

As you can see from the table, the pattern of 010101010...01 continues forever with this addend in FRQx's MSB, remember the high hex digit "8" is really 1000 binary, so that high bit is set. Also, note the carry bit PHSx[32] is the invert of the MSB bit. This is just a result of adding half the max magnitude each time.

Now, analyzing the situation, basically it takes 2 adds to overflow the counter, or in other words if we take the maximum number of values represented in magnitude only by PHSx, a 32-bit register, this is  $2^{32}$ , if we divide this by the number we are adding, 0x8000\_0000, the result should be how many cycles it takes to overflow or toggle the MSB, or in general the formula that relates FRQx to how many cycles it takes to overflow the PHSx counter is:

$$\text{cycles to overflow PHSx} = (2^{32}) / \text{FRQx}$$

Now we are getting somewhere, so in the case of our example, it took 2 cycles to overflow the counter, or the counter PHSx MSB is toggling every main clock cycle Fm. So, in other words the MSB is toggling at a frequency 1/2 that of the main clock frequency Fm. So if we

were running the main clock at 80 Mhz, then the MSB would be clocking at a rate of 40 Mhz, this is too high for the constraint of that it should run between 4 and 8 MHz, but this is irrelevant for now. Let's see if we can find the final relationship with any main clock frequency. This is fairly simple, if we think about it: let's say it took 10,000 clocks to overflow the PHSx – that means that if we run our system at 80 MHz, this overflow would occur every  $80,000,000/10,000 = 8000$  times a second, but this is the toggle rate, NOT the frequency. The frequency is 1/2 this, or 4000 Hz, thus we can use this insight to create a final formula that relates everything together: the system clock Fm, the value in FRQx, and the final MSB frequency Fmsb (that gets sent to the PLL multiplier). The formula is:

$$\mathbf{Fmsb} = \frac{\mathbf{Fm}}{(2^{32}/\mathbf{FRQx})}$$

Fmsb as a function of main system frequency Fm and FRQx value:

$$\mathbf{Fmsb} = (\mathbf{Fm} \times \mathbf{FRQx}) / (2^{32})$$

Fmsb as a function of main system frequency Fm and FRQx value:

$$\mathbf{Fmsb} = (\mathbf{Fm} \times \mathbf{FRQx}) / (2^{32})$$

And that's it! Of course, you can re-arrange this anyway you like to solve for the unknown. For example, if you have a main system clock frequency of 80 MHz, you want to synthesize a 6 Mhz Fmsb frequency, what FRQx value would you use? Then you would use this variant of the formula:

FRQx as a function of desired Fsm and main system frequency Fm:

$$\mathbf{FRQx} = (\mathbf{Fmsb} \times (2^{32})) / \mathbf{Fm}$$

Plugging in our knowns, we get:

$$\begin{aligned}\mathbf{FRQx} &= ((6.0 \times 10^6) \times (2^{32})) / 80 \times 10^6 \\ &= 322.1225472 \times 10^6\end{aligned}$$

So, we plug 322 million and change into the FRQx register and let the PLL run, the output at the MSB of PHSx will clock at a rate of 6 Mhz, and we are in business. Then we can get any multiple of this 6 MHz by selecting the appropriate tap in the PLL mux, from 1/8<sup>th</sup> to x16, so we can get any of these frequencies as shown in Table 13:15 on the next page:

Table 13:15		Computation of Final PLL Output Based on MSB Frequency and Divider Select▼		
Mode	Bits [S1,S2,S0]	/ Rate	MSB Frequency into PLL	Final PLL Rate Output at Pin
0	000	x1/8	6.0 MHz	0.75 MHz
1	001	x1/4	6.0 MHz	1.5 MHz
2	010	x1/2	6.0 MHz	3.0 MHz
3	011	x1	6.0 MHz	6.0 MHz
4	100	x2	6.0 MHz	12.0 MHz
5	101	x4	6.0 MHz	24.0 MHz
6	110	x8	6.0 MHz	48.0 MHz
7	111	x16	6.0 MHz	96.0 MHz

Hopefully, this laborious example gives you an idea of how the PLL mode works. It's not that complex, but yet is unintuitive, since you have to work your example such that you find a FRQ<sub>x</sub> value that results in a MSB frequency that is ALWAYS between 4 and 8 MHZ, but then the FINAL frequency out of the PLL is multiplied by 16 then you select any rate from this divider chain in the PLL mux, so you have to work a bit to get what you want.

#### 13.14.4 NCO (Numerically Controlled Oscillator) Modes

The NCO or numerically controlled oscillator modes are much easier to understand since there is no PLL multiplication and there are no constraints on the frequency you can toggle the MSB at. In NCO modes, the MSB of PHSx (that is, PHSx[31]) is used as the final out at the pin(s) you select. There are two NCO modes, single and differential. In single mode 4, only Pin A is used as an output; in differential mode 5, both Pin A and Pin B are used and Pin B is 180 degrees out of phase, or the logical inversion of, Pin A.

The formula that describes the output frequency can be derived directly from our work with the PLL modes, but we don't have to worry about the 4 to 8 MHz frequency rule and there is no PLL scaling, so the formula that relates the system clock frequency F<sub>m</sub>, the value in FRQ<sub>x</sub>, and the desired output frequency F<sub>msb</sub> is:

$$\text{FRQ}_x = (\text{F}_{\text{msb}} \times 2^{32}) / \text{F}_m$$

Now, let's try it. Let's assume we want to synthesize a 1 kHz square wave at Pin A, so we want to use single mode NCO which is mode 4, and we would need to compute the FRQ<sub>x</sub> value and that's it, which is:

$$\text{FRQx} = ((1.0 \times 10^3) \times (2^{32})) / 80.0 \times 10^6$$

$$= 53687.09$$

Rounding off, we get 53687 or in hex we would load FRQx with 0x0000\_D1B6 and we would be off and running with a 1 kHz square wave (almost minus the error incurred by truncation).

### **13.14.5 Duty Cycle Modes**

The duty cycle modes 6 and 7 are very similar to the NCO modes, except that instead of the MSB bit PHSx[31] driving the output pin, the carry out of PHSx[31] drives the output pin. So you see either a carry or no carry every cycle. Now, some interesting things happen when you track the carry bit, for example if the value in FRQx (the addend) is always the same, then you will always get one or more carry pulses followed by 0's. For example, the carry out will look something like this:

**Example 1:** 1,0,0,1,0,0,1,0,0

...or maybe,

**Example 2:** 1,0,1,0,1,0,1,0

...or maybe,

**Example 3:** 1,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,

..or maybe,

**Example 4:** 1,1,1,0,1,1,1,0

That is, with a constant value in FRQx, at best you can get the carry to toggle each cycle with the value of 0x8000\_0000 in FRQx, or you can get it to be 1 most of the time with a number larger than 0x8000\_0000, or you can make the carry happen seldom with a number less than 0x8000\_0000. Of course if you change FRQx each cycle, you could get the carry to do what you want dynamically, but this is not how these modes are intended to be used; you should keep the value in FRQx constant until you are ready to change your final averaged duty cycle value. If you look at Example 1, and assume a very high clock rate like 80 MHz is driving this toggle then for all intent purposes this is happening at an infinite rate to a low-pass filter. Therefore, if we average the carry pulses over time then as time goes forward they will "settle" to a value. In Example 1, we see there is a single 1 carry pulse, then two 0's, then it repeats, so it looks like over time this will average to a "duty cycle" of 30%, since there is one 1 per each three clocks.

In Example 2, we can run the same analysis. Here if we are running at a very high clock rate like 80 MHz, then the toggling of the 1's is happening very quickly, so fast that we can average the signal together again over a long set of pulses. Looking at Example 2, we see

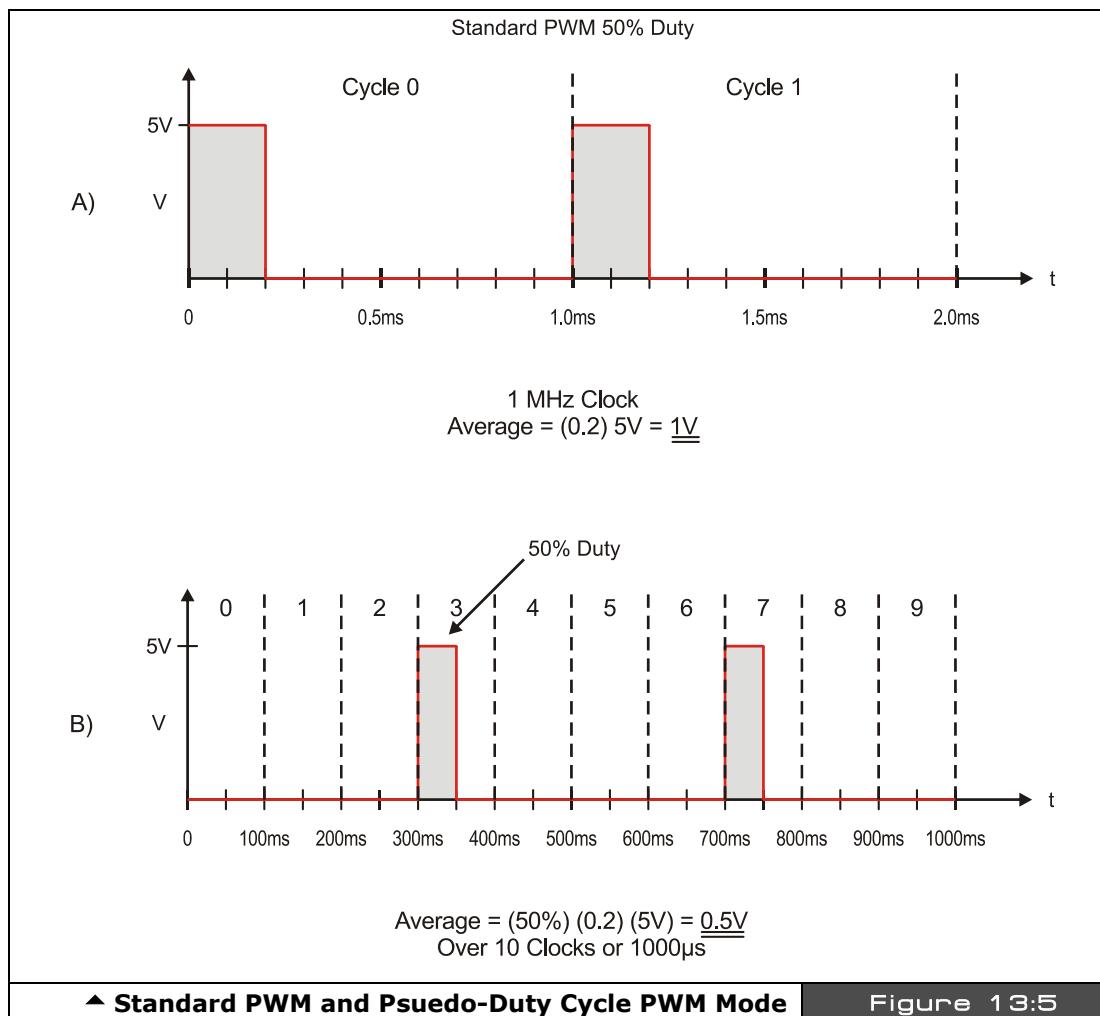
the pattern repeats every 12 pulses, and out of those 12 pulses, there is only one carry pulse that is 1; the other 11 are 0. Thus, we have a duty cycle of  $1/12 = 8.3\%$ .

This is very interesting, why? Because if we pass this signal through our low-pass filter, it will “average” the pulses into an analog voltage almost instantly due to the high clock rate. Thus by modulating the number of carry pulses as a ratio to the number of 0 pulses over a number of cycles, we can get any analog voltage we want! Therefore, if we feed our little “duty cycle” D/A converter with sine values we can generate a sine wave or whatever, thus it’s an ad-hoc PWM generator. But, instead of generating a constant clocked PWM cycle and modulating the width of the high to low cycle to change the final analog output, this duty cycle mode streams 1’s and 0’s out at a constant rate; the overall “averaging” frequency changes, but the final analog value will be that of the repeat cycle length of the stream. Thus in Example 1, we see the pattern repeating at a rate of 3 clock pulses with an average of 30%, but in Example 2, the repeat doesn’t happen for 12 clock pulses, therefore the frequency response of the first example is 6x better roughly than the second. However, since the main clock is at 80 MHz and this is the rate the “clocking” is happening, we don’t notice this too much. In any event, take a look at Figure 13:5 to see this duty mode compared to a normal PWM waveform.

As you can see in Figure 13:5(A), in standard PWM D/A we fix the clock rate, in this case 1 MHz, and then we modulate the signal’s duty cycle on a per cycle basis, that is the ratio of the HIGH to the LOW. But, in this modified “duty cycle” mode we aren’t doing that, rather we use a fixed frequency to clock the system at, yes, but we use the ratio of 1 pulses to 0 pulses to generate the average where the length of all the 1’s is the same. As long as we send the signal to a low-pass filter, then it will average the signal out almost immediately and we will get a nice analog signal out.

Now, as mentioned the only downfall to this technique is the cycle length before the carry pattern repeats changes, thus frequency of the overall averaging isn’t constant for different values of final output, but at high frequencies this is ok. Additionally, there is another good aspect to this duty cycle mode for sound generation and D/A conversion and that is as you change the value in FRQ<sub>x</sub> the carry ratio immediately changes, thus the “response” is very quick. Unlike normal duty cycle mode used in PWM with fixed frequency, you don’t have to wait for the current cycle to complete, you just change the FRQ<sub>x</sub> value any time you want and the output will change almost immediately with no glitches.

And of course, there is no PLL involved in this mode, so that’s not a concern and you need not worry about any frequency constraints on PHS<sub>x</sub>[32], the carry bit, either.



As an example, let's see the equation to generate a 50% overall duty cycle? Well, we already did this! Remember back on our PLL example Table 13:14 on page 222, and take a look at the carry column. Notice it makes the pattern:

0,0,1,0,1,0,1,0,1,0,1...,0,1

This is exactly what we want: once the pattern gets going we get a constant stream of (0,1)'s which will average to 50% duty. So we program the duty cycle mode the exact same way as the NCO mode, and simply select a FRQx value of 0x8000\_0000 in this case.

So this would get us 50% analog voltage out, now what if we needed 25%? No problem, we need a pattern of (1,0,0,0) to repeat or in other words, we want to overflow into the carry every 4 clocks, so what 32-bit number does this? 0x4000\_0000 will do the job, let's see with another table exercise. take a look at Table 13:16 below:

<b>Table 13:16</b>		<b>Duty Cycle Mode to Generate a 25% Duty Cycle Signal▼</b>		
<b>Clock Cycle</b>	<b>PHSx[32] carry bit</b>	<b>MSB PHSx[31]</b>	<b>PHSx</b>	<b>FRQx</b>
<b>0</b>	0	0	0x0000_0000	0x4000_0000
<b>1</b>	0	0	0x4000_0000	0x4000_0000
<b>2</b>	0	1	0x8000_0000	0x4000_0000
<b>3</b>	0	1	0xC000_0000	0x4000_0000
<b>4</b>	1	0	0x1000_0000	0x4000_0000
<b>5</b>	0	0	0x5000_0000	0x4000_0000
<b>6</b>	0	1	0x9000_0000	0x4000_0000
<b>7</b>	0	1	0xD000_0000	0x4000_0000
<b>8</b>	1	0	0x2000_0000	0x4000_0000
<b>9</b>	0	0	0x6000_0000	0x4000_0000
<b>10</b>	0	1	0xA000_0000	0x4000_0000
<b>11</b>	0	1	0xE000_0000	0x4000_0000
<b>12</b>	1	0	0x3000_0000	0x4000_0000
<b>13</b>	0	0	0x7000_0000	0x4000_0000
<b>14</b>	0	1	0xB000_0000	0x4000_0000
<b>15</b>	0	1	0xF000_0000	0x4000_0000
<b>16</b>	1	0	0x4000_0000	0x4000_0000

Reviewing the table is interesting, we see a 50% duty cycle in PHSx[31], while at the same time we see a 1 to 4 carry pulse ratio in PHSx[32], this is exactly what we want, so at a rate of  $80/4 = 20$  Mhz, we will put out this "fuzz" of 1's and 0's that average to 25% since there is one 1 and three 0's per 4 pulses. Also, notice where the pattern repeats, its takes it until clock 16 to repeat and it takes it 1 clock to "start up" into the pattern. Now, there is an interesting note, it is impossible to get a 100% signal out, why? Well, even if we add the largest possible number to itself every time and overflow the PHSx register each time, there

will be one time at 4 billion cycles into the pattern that the PHSx register will cycle to 0 and we won't get a carry, this will happen once every 53 seconds or so, and since we are synthesizing sound that is changing at a rate in the kHz range this will never be an issue, but it is a numerical fact nonetheless. Let's see it in action and try to get a 100% duty cycle, by adding the max number that can be represented in FRQx which is  $(2^{32}-1)$ , this is shown in Table 13:17.

Table 13:17		Duty Cycle Mode to Generate a 99.99999999% Duty Cycle Signal▼		
Clock Cycle	PHSx[32] carry bit	MSB PHSx[31]	PHSx	FRQx
0	0	0	0x0000_0000	0xFFFF_FFFF
1	1	0	0xFFFF_FFFF	0xFFFF_FFFF
2	1	1	0xFFFF_FFFE	0xFFFF_FFFF
3	1	1	0xFFFF_FFFD	0xFFFF_FFFF
4	1	1	0xFFFF_FFFC	0xFFFF_FFFF
5	1	1	0xFFFF_FFFB	0xFFFF_FFFF
6	1	1	0xFFFF_FFFA	0xFFFF_FFFF
7	1	1	0xFFFF_FFF9	0xFFFF_FFFF
8	1	1	0xFFFF_FFF8	0xFFFF_FFFF
9	1	1	0xFFFF_FFF7	0xFFFF_FFFF
10	1	1	0xFFFF_FFF6	0xFFFF_FFFF
11	1	1	0xFFFF_FFF5	0xFFFF_FFFF
12	1	1	0xFFFF_FFF4	0xFFFF_FFFF
13	1	1	0xFFFF_FFF3	0xFFFF_FFFF
14	1	1	0xFFFF_FFF2	0xFFFF_FFFF
.				
.				
$2^{32}$	1	1	0x0000_0000	0xFFFF_FFFF
$2^{32} + 1$	0	1	0xFFFF_FFFF	0xFFFF_FFFF
$2^{32} + 2$	1	0	0xFFFF_FFFE	0xFFFF_FFFF

Notice how we get a 0 as the first cycle completes and when we reach the end of the pattern  $2^{32}$  iterations later. Also, notice how the number in PHSx counts down. This makes sense since you can think of this as a 2's complement problem, and we are adding

`0xFFFF_FFFF` = 1 in 2's complement, thus, we are subtracting away from the initial `0x0000_0000` value each time.

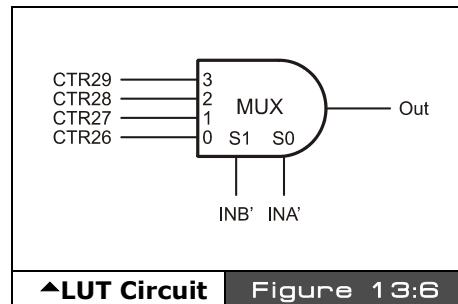
To generate any analog voltage at the output pin simply select a number in `FRQx` that results in the desired ratio of 1's to 0's in the carry bit `PHSx[32]`.

### 13.14.6 Special Analog Modes

These modes are used for analog to digital conversion and other such analog processes. They also make use of clocking or timing flip flops which can be used to delay the input `INA` one to two clocks resulting in `INA'` and `INA''` as shown in Table 13:12 on page 219. These modes are advanced and not important for game development; refer to the Propeller Manual for more information on these modes.

### 13.14.7 LUT Logic Mode (1xxxx)

Mode 1xxxx allows a logic function to be implemented with the counter that increments if and only if the output of the logic function is "1". The system works by setting `CTR29..CTR26` to the desired bits "look up table style" and then `INA'` and `INB'` selects one of the 4 values, this value is then gated to the output, and if the output is "1", true, the counter is updated and `FREQ` is added to `PHASE`. Abstractly, the circuit looks like that shown in Figure 13:6.



▲LUT Circuit Figure 13:6

Example: Say we want to implement a logical AND, then we might generate the following truth table that implements the AND function and then we simply map the 1's and 0's into `CTR26..CTR29` that realize the AND function. This is shown in Table 13:18 below:

Table 13:18		Logic Function Mapping for <code>INA'</code> and <code>INB'</code> to Realize AND	
<code>INB'</code>	<code>INA'</code>	Desired Output	Selected Input
0	0	0	<code>CTR26</code>
0	1	0	<code>CTR27</code>
1	0	0	<code>CTR28</code>
1	1	1	<code>CTR29</code>

Reviewing the table, we see that `CTR26, 27, 28` should all be 0, and `CTR29` should be 1. Again, not very useful for game development or graphics.

### 13.15 Summary

This chapter hopefully has given you both a detailed overview of the Propeller chip as well as some concrete examples of each of the systems. I can say that hands-down people have the most trouble understanding the counters. The best approach to all this stuff is simply to write it down and do examples bit by bit, that's how I figured it out! In any event, the Propeller chip is a true "RISC" processor not only formally in as much as it has a fixed instruction width, but the Propeller chip has nearly no on-board peripherals. One of the design trade-offs on the Propeller chip was to give you sheer processing speed and let you decide what to do with it, rather than use silicon for on-board peripherals that you will never use like a CAN networks, 32-channel D/As, USB and Ethernet controllers, etc. But, you can **always** create them with a few external passive components and some assembly code! The main idea of the Propeller chip is to give you a lot of parallel computing "fabric" and let you decide what to do with it – in our case, we are going to make games ☺.

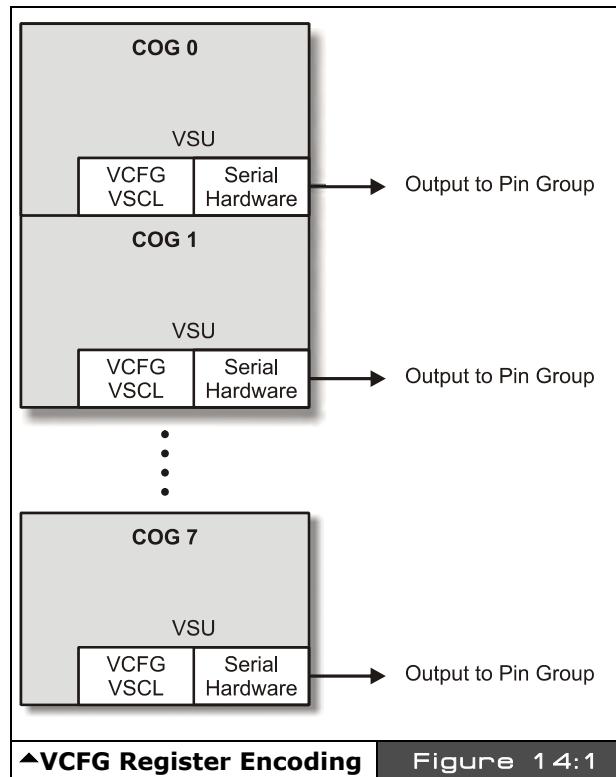


## Chapter 14: Cog Video Hardware

In this short chapter we are going to discuss the video hardware support within each cog of the Propeller chip. I am very proud of the information in here since it was very difficult to come by, many hours of reverse engineering, discussions with Chip Gracey, and experimentation were needed to figure it out down to the details since in graphics every bit counts! I began designing the HYDRA and writing this book with early prototypes of the Propeller chip, and the early documentation I had had a single line of text to describe the video hardware! Alas, a lot of work went into this. As I discovered things I gave them my own names as I went along, so you will see me refer to the video hardware with certain acronyms like the "VSU" etc., that you won't find in the Propeller manual but the ideas are the same. Likewise other authors writing about the Propeller chip may use their own words and phrases. Anyway, in this chapter we are going to discuss the following topics:

- ▶ Video hardware configuration registers
- ▶ Understanding the Video Streaming Unit (VSU)
- ▶ Setting up NTSC and VGA modes

The Propeller chip has no GPU or other such dedicated graphics processing unit; graphics are achieved through a mixture of software and hardware. Each cog has a VSU or "Video Streaming Unit" which is clocked via the cogs PLL "A" channel in mode 1. The VSU more or less streams data out to a port that is feed via software by your program. On this port a simple D/A resistor network or straight 8-bit VGA is connected. The VSU knows nothing about graphics, it only knows how to serialize data and send it out. Figure 14:1 shows a diagram of the VSU in relation to its cog.



As indicated by the figure, each cog has a VSU unit. Therefore up to 8 different video devices could in theory be connected to a single Propeller chip; however, due to the lack of memory it would be difficult to have 8 different applications doing something different especially with bitmapped modes. In essence, the VSU hardware helps convert pixel/color data into a NTSC/PAL/VGA signal, but your program driving the VSU needs to know about all the timing of the signal. The VSU's final output does understand the NTSC/PAL signal and can help in converting your data into chroma/luma information and is designed such that it's easy to generate NTSC/PAL sync levels and so forth, but this is all the help you get. It seems minimal, but another way to think of it is that a single "cog" and the software you write become a virtual software GPU, so ultimately this gives you the best of all worlds, true you have to code a "GPU," but you can in theory do anything you wish! For those of you who are DirectX programmers, this is very reminiscent of pixel or shader programming, you have to put a lot of work in to get the shader working, but its worth it since you can change its behavior on the fly.

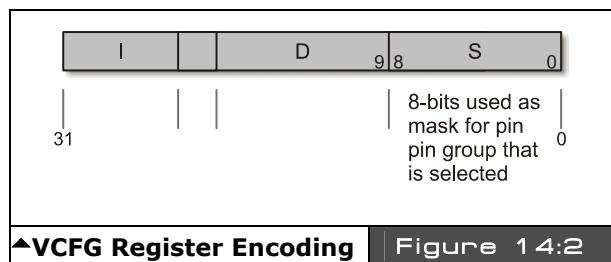
In any case, the following paragraphs explain how to use the VSU units and how to set up the two control registers that initialize the streaming process. To refresh your memory, each cog has 16 registers, two of which are the video registers:

**VCFG** - Video Configuration Register

**VSCL** - Video Scale Register

## 14.1 Video Configuration (VCFG) - \$1FE

Each cog has a small "Video Streaming Unit" or VSU. This Video Streaming Unit simply sends "frames" of data out at a constant rate which is determined by the settings in the Video Scale Register or (VSCL). The configuration of the VSU is determined by the Video Configuration Register or VCFG.



The VCFG register sets color modes, pin groups, enables or disables chroma signals, and allows the VSU to function in a number of ways. The VCFG register is encoded using the nomenclature for an instruction that is the I field, D field, and S field, and is organized as shown in Figure 14:2.

### 14.1.1 The I-Field Bit Definitions

The following tables define the various bit encodings for the VCFG register as laid out in the I-field portion of the generic instruction format discussed throughout the text.

#### Video Hardware Select bits [30:29]

These bits select whether video is enabled and where the baseband and broadcast video is sent, that is, which nibble on the port gets the data streams.

Bit 30	Bit 29	Video Hardware Select
0	0	Video hardware is Disabled.
0	1	Enables 8-parallel discrete outputs, used for VGA mode.
1	0	Selects composite video mode with Baseband video sent to bottom nibble [3:0] and Broadcasted video sent to top nibble [7:4].
1	1	Selects composite video mode with Baseband video sent to top nibble [7:4] and Broadcasted video sent to bottom nibble [3:0].


**INFO**

Baseband video means the signal ranges from 0 Hz to n Hz, that is there is no “carrier” that the signal is modulated on. The baseband signal is just the signal, you standard video in ports on your TV set are baseband ports. Now, broadcast, is more complex in this case the baseband signal is “modulated” onto a carrier frequency using various modulation techniques such as AM (amplitude modulation) or FM (frequency modulation). TVs use AM, radio's use both.

#### Color Mode bit [28]

The color mode bit selects with 1 or 2 bits per pixel. In 1-bit per pixel mode (2-color), a single pixel data LONG represents 32 screen pixels, in 2-bit mode (4-color), each data LONG represents 16 pixels.

Bit 28	Color Mode
0	2-color mode; means that the data in pixels is 1 bit per pixel, only color 0,1 are used during video hardware output.
1	4-color mode; means that the data in pixels is 2 bits per pixel, all 4 colors 0,1,2,3 are used.

**Broadcast Chroma Enable bit [27]**

Useful if you want to use the upper bit of the video out as an S-video chroma output and you don't want the chroma on the broadcast signal (video modulated on a standard TV channel frequency).

Bit 27	Broadcast Chroma Enable
0	Disable Chroma on Broadcast.
1	Enable Chroma on Broadcast.



TIP

S-video stands for “Super Video” and is simply normal NTSC, but the luma and chroma aren’t mixed, they are separate on two different wires. There is also “P-Video” which stands for Pimp Video ☺.

**Baseband Chroma Enable bit [26]**

Useful if you want to use the upper bit of the video out as an S-video chroma output and you don't want the chroma on the baseband signal.

Bit 26	Baseband Chroma Enable
0	Disable Chroma on Baseband Video.
1	Enable Chroma on Baseband Video.

**Aural FM sub-carrier select bits [25..23]**

When broadcasting video (which we aren't using this feature for games), you can select which cogs PLL A is using to generate the FM aural sub-carrier frequency that the sound will be modulated on, of course as with video you must always use PLL mode 1 (no outputs on Pin A and B) for the counter mode.

Bit 25	Bit 24	Bit 23	Aural Sub-Carrier Select
0	0	0	Use Cog 0's PLL A
0	0	1	Use Cog 1's PLL A
0	1	0	Use Cog 2's PLL A
0	1	1	Use Cog 3's PLL A
1	0	0	Use Cog 4's PLL A
1	0	1	Use Cog 5's PLL A
1	1	0	Use Cog 6's PLL A
1	1	1	Use Cog 7's PLL A

### 14.1.2 S-Field Bit Definitions

The lower 8 bits of the S-Field act as an AND “mask” that masks off the pin group selected as video output (see D - Field). In other words, you would set these bits to 11110000 if you want the upper 4 bits only, or 00001111 if you wanted the lower 4 bits only (these would be in NTSC modes), or 1111\_1111 if you wanted all the bits enabled which is appropriate for VGA modes since all 8 signals are needed, 6 for R, G, B and 2 for Hsync and Vsync.

### 14.1.3 D-Field Bit Definitions

The lower 3 bits of the D-field form the pin group selection bits [d2,d1,d0], so the value 0..7 in these bits select which group of 8 I/O pins get the video data stream. Of course, the current Propeller chips only have 32 I/Os, so values 1XX are useless in this register. Table 14:1 shows the various pin groups selected by each pattern.

Table 14:1			Pin Group Selection Encoding▼
Bit D2	Bit D1	Bit D0	Pin Groups on Propeller Chip
0	0	0	Group 0: P0 – P7
0	0	1	Group 1: P8 – P15
0	1	0	Group 2: P16 – P23
0	1	1	Group 3: P24 – P31
1	x	x	Reserved for Future Expansion



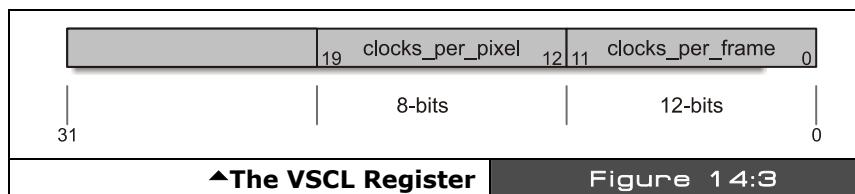
Make sure that DIRA sets the proper pins to OUTPUTS, they are not assigned outputs by simply setting up the VCFG etc. registers. For example, on the HYDRA pin group 2 is used, thus you would need to set pins P16-P23 to outputs before the video would even have a chance of getting out to the pins.

## 14.2 Video Scale (VSCL) - \$1FF

The Video Scale Register or VSCL sets the rate at which “pixels” and “frames” are processed and sent out to the external DAC (selected by the pin group bits you set). The video driver program basically passes the VSU two 32-bit LONGs, one LONG is the “pixels” to process and the other LONG is the “colors” that the “pixels” represent. The format of the pixel and color LONGs are shown in the following sections.

A “frame” consists of one LONG of data or 32 bits; these 32 bits can represent either 16 or 32 pixels of video depending on the setting of the color mode bit 28 in the VCFG (1 or 2-bit per pixel mode). The VSU hardware is clocked not by the master clock directly, but by Counter A’s PLL mode of the cog the program is running on. So you must set the Counter A

to PLL mode and place the proper value into the freq register. The final PLL muxed clock signal from the PLL is fed into the VSU hardware and controls the timing chain thereof. The VSCL register is shown below in Figure 14:3.



**clocks\_per\_pixel** is the number of clocks that occur before each pixel is shifted out.

**clocks\_per\_frame** is the number of clocks that occur for an entire frame. This is usually 16 or 32 times the **clocks\_per\_pixel** value since there are 16 pixels per 32-bit pixel LONG in 4-color mode, and 32 pixels per 32-bit pixel LONG in 2-color mode.

**Example:** VSU running in 4 color mode, therefore, 16 pixels per 32 bit pixel WORD.

If **clocks\_per\_pixel** was set to 32 or \$20 then you would set **clocks\_per\_frame** to  $16 \times 32 = 512 = \$200$  or the final value of the 32-bit LONG would be:

\$20200

But, this says nothing about how fast the video would clock out, this is controlled by PLL A.

#### 14.2.1 Pixel and Color Data format

The VSU simply streams data out to the pin group selected in the VCFG with the color and format selected in the VCFG (2-color, 4-color, or VGA). But, it's the responsibility of the video driver program itself (that you write) to generate the pixel and color data and pass it to the VSU. Once the VCFG and VSCL registers are initialized then the VSU will start streaming data out. It's up to the program to pass the proper data and to keep up with the VSU. So typically the following steps are needed to get video working:

**Step 1:** Set up the VCFG register. In most cases you will set it to 4-color chroma (2-bits per pixel) enabled on base band with pin group x, on the HYDRA the pin group should be pin group 3, I/Os [27..24].

**Step 2:** Set up Counter A in PLL mode 1 and run it at a rate that is some multiple of the color burst ideally; this clock signal will "feed" the shifting logic.

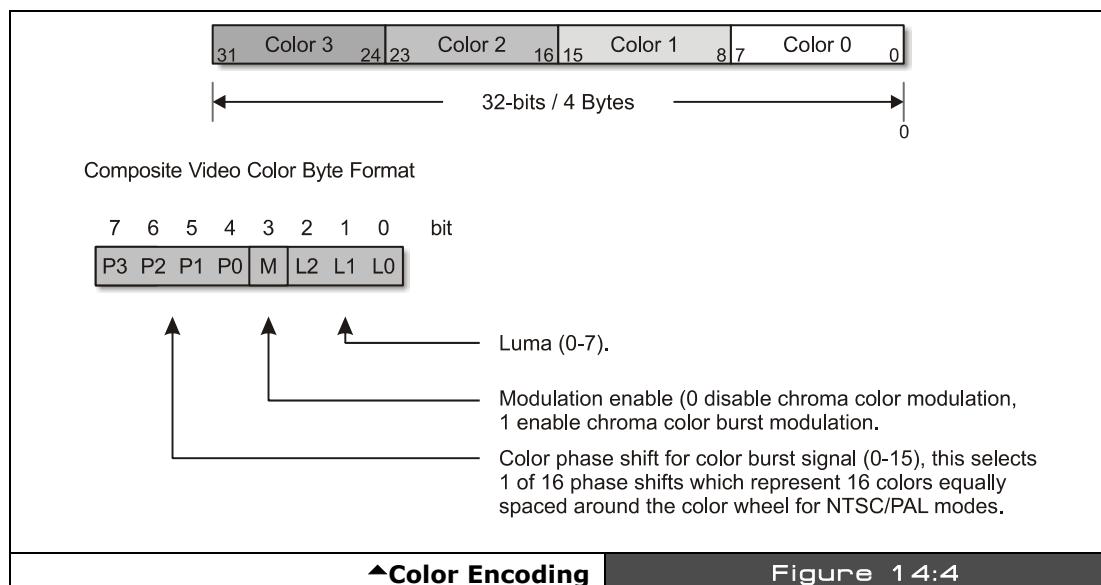
**Step 3:** Initialize the VSCL register with the **clocks\_per\_pixel** and **clocks\_per\_frame** that you desire, remember **clocks\_per\_frame** will typically be either 16 or 32 times the

`clocks_per_pixel`, since there can only be 16 or 32 pixels per pixel LONG depending if you are in 4- or 2-color mode respectively.

**Step 4:** Use the "WAITVID D, S" instruction where D holds the colors and S holds the pixels. The VSU suspends the cog until it can process your request, once it does, the VSU will buffer D and S and then allow your execution thread to continue. When this happens you must do whatever processing you wish and then loop back to Step 3 with the NEXT set of colors and pixels BEFORE `clocks_per_frame` are up! The format of "colors" and "pixels" are described in the sections following.

#### 14.2.2 Color 32-bit LONG Format

The color format is always the same, the 32 bits represent 4 possible colors that are "indexed" by the pixel data, and the colors are encoded as a single BYTE each in the following way:



The color byte is used to represent everything you do with video, for example: sync, black, color burst, and active video. By setting different bits you can create "colors" that represent these signals. For example, Table 14:2 on the next page shows how to create black, sync, color burst, shades of gray, and all 1ddddd6 colors with 75% intensity.

Table 14:2		Color Encoding for Various Color Values▼						
Desired Signal	Bit Encoding							
	P3	P2	P1	P0	M	L2	L1	0
Sync (Control Values)	0	0	0	0	0	0	0	0
Grayscale Values Group								
Black	0	0	0	0	0	0	1	0
Dark Gray	0	0	0	0	0	0	1	1
Grey	0	0	0	0	0	1	0	0
Light Grey	0	0	0	0	0	1	0	1
Bright Grey	0	0	0	0	0	1	1	0
White	0	0	0	0	0	1	1	1
Color Values Group								
Blue	0.0	0	0	0	1	x	x	x
*	22.5	0	0	0	1	x	x	x
Purple	45.0	0	0	1	0	x	x	x
Magenta	67.5	0	0	1	1	x	x	x
*	90.0	0	1	0	0	x	x	x
Red	112.5	0	1	0	1	x	x	x
Orange	135.0	0	1	1	0	x	x	x
Brown	157.5	0	1	1	1	x	x	x
Yellow	180.0	1	0	0	0	x	x	x
Yell/Grn	202.5	1	0	0	1	x	x	x
Green	225.0	1	0	1	0	x	x	x
*	247.5	1	0	1	1	x	x	x
*	270.0	1	1	0	0	x	x	x
Cyan	292.5	1	1	0	1	x	x	x
*	315.0	1	1	1	0	x	x	x
*	337.5	1	1	1	1	x	x	x
Where $011 < \text{xxx} < 110$ , i.e. $3 < \text{xxx} < 6$								
Notes		*Colors without names are simply linear mixes of the adjacent colors.						
		When chroma/color is enabled the luma signal is modulated $\pm 1$ .						

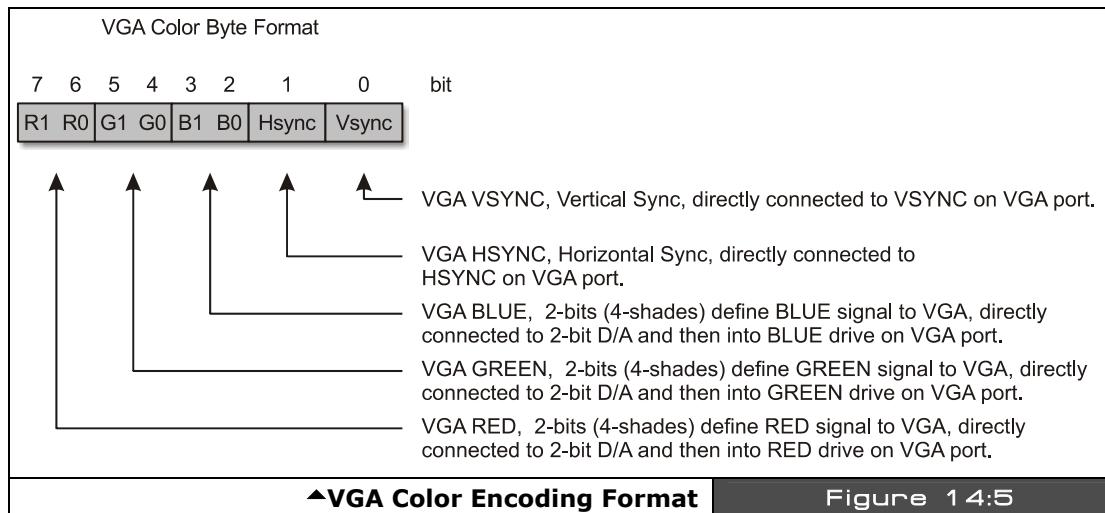
Referring to the table, the highest ‘safe’ value to use for brightness/luma is 6 and the lowest “safe” value is 3, so keep your luma in the range of [3,6] when using chroma, otherwise, the system won’t have enough freedom to encode the color signal modulation since a +/- modulates your luma signal and you don’t want it going out of range.



TIP There is a trick to get more colors that “does” work: if you set the LUMA to 0 and ENABLE chroma then you will get the values  $0 - 1 = 7$  and  $0 + 1 = 1$ , which create a “super” saturated color set and the LUMA value of 1 is just enough to keep from going into sync, so it all works out.

### 14.2.3 VGA Modes

When the VSU is configured for VGA modes via the VCFG register, each 1 or 2-bit color refers to either 2 or 4 VGA "color.". A VGA color is really just a BYTE that gets streamed out via a lookup table that translates your color select to a bit pattern. This 8-bit value just gets dumped to the I/O port, the Propeller chip has no idea it's VGA, but we wire it to the VGA header in such a way that with the proper programming it's a VGA signal. Figure 14:5 shows how the VGA signal, colors, and sync are encoded on the HYDRA.



### 14.2.4 "Pixel" data 32-bit LONG Format

When calling the VSU with pixel and color data, the pixel data is either interpreted as 1 or 2 bit pixels, thus a 32-bit LONG pixel data can represent either 32 or 16 bits respectively. In 2 color mode then only the first colors 0,1 in the color long are used, in 4 color mode then all 4 colors in the 32-bit color WORD are used. In any case, the 32-bit pixel data formats are shown on the next page.

### 2-color (1 bit per pixel) format, 32 total pixels

In 2-color mode, there is 1-bit per pixel therefore, each pixel can be 0 or 1, which references/indexes color BYTES 0,1 in the 32-bit/4-BYTE color descriptor. Therefore, each of the bits shown in Figure 14:6 below represent either color 0 or 1.

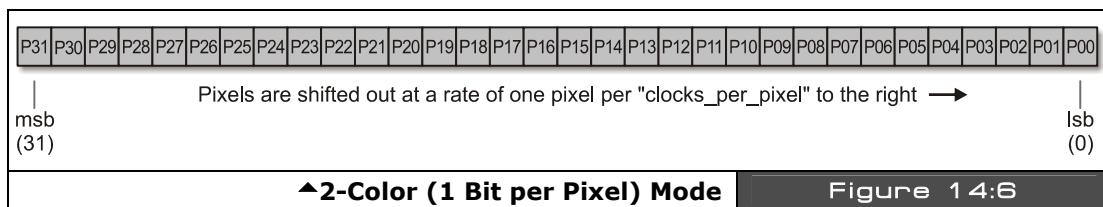


Figure 14:6

### 4-color (2-bits per pixel) format, 16 total pixels

In 4-color mode, each pixel can be 0, 1, 2, 3, which references/indexes color BYTES 0,1,2,3 in the 32-bit/4-BYTE color descriptor. Therefore, there are only 16 pixels, each 2 bits in size as shown in Figure 14:7.

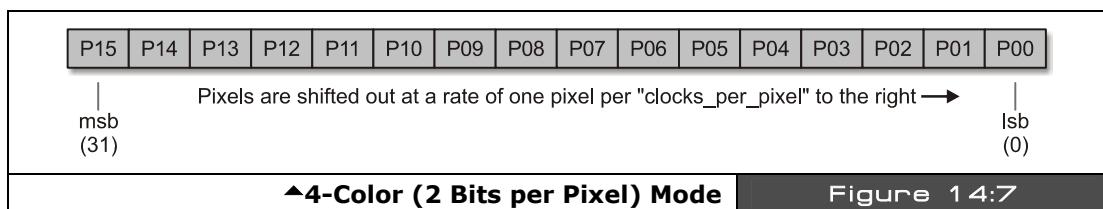


Figure 14:7

## 14.3 Summary

In this chapter we tackled the video hardware on the Propeller chip, as you can see, it's nothing more than a serializer with some features that help it generate NTSC and VGA video. But, you could use the VSU for anything from an IDE interface to a sound port! The main take-away is to realize that all the magic happens in the software, the VSU only serializes your data and allows you to continue your "work" while it streams the data out (i.e. WAITVID instruction). This is the key to generating video, that is, to pre-compute your pixels and color, pass them to the VSU and move on. Also, remember that EVERYTHING is generated by the VSU: sync, pixels, color, luma, all of it; as far as the VSU is concerned everything is just bit patterns. The only thing that that really does any analog work for us is the simple 3-resistor DAC on the output of the Propeller chip that generates an analog voltage for us driven by the VSU (if we set it up correctly). Now, you're probably wondering how exactly to

write an assembly program to generate video? This is a lot of work and very complex, we aren't going to tackle that yet since we are trying to keep things high-level and to leverage the drivers Parallax, myself, and other coders have spent weeks writing. But, rest assured in Part III of the book we will cover a very simple video driver and I will explain every section of it in detail. For now, let the VSU sink into your brain....



## Chapter 15: The Spin Language

"**Spin**" is the High-Level Language (HLL) that the Propeller chip is programmed in. Spin was developed by **Chip Gracey** as an easy-to-use language with syntax supporting simplified operations. The language itself is influenced by Pascal, BASIC, and Assembly language. When programming Spin, in the IDE the Spin code is compiled into a "**BYTE Code**" meaning that operations are translated to single BYTE-sized operations. This byte code program is then written into the final binary object of the 32 Kbyte program image space which ultimately is downloaded directly into the Propeller chip or stored on a serial EEPROM that the Propeller chip boots from on startup. Then the ROM-based Spin interpreter runs the BYTE Code, much like a JAVA machine works. In this chapter, we are going to discuss the majority of concepts related to Spin, see the syntax of the language, and look at examples and some demos that do various things to give you a starting point. If you do not know how to program in BASIC, C/C++, or some other high-level language you will need to augment your reading here with a basic programming book. Here are the major topics we are going to cover:

- ▶ Spin and its relationship to the Propeller on boot
- ▶ General Propeller program organization
- ▶ Spin language reference
- ▶ Spin programming
- ▶ Various Spin demos
- ▶ Tricks and tips with Spin

### 15.1 Spin on Boot

When the Propeller chip boots, first it determines if there is a host on the communication lines. If so, then the firmware loads the external program into the Propeller chip's 32K program memory as a single binary image, else the Propeller chip looks to the external EEPROM interface and tries to load the program from there in a similar fashion. If neither is present the Propeller chip goes into a reset/sleep state waiting for a host connection. In most cases, you will have a host PC or an EEPROM with the pre-programmed Propeller chip code in it. In this case, the Propeller chip always boots **Cog 0** up and loads the Spin interpreter into it. The Spin interpreter is an ASM application, and must fit into the 512 32-bit LONGs of Cog 0, in fact there are less than that (512 –16 LONGs) for the interpreter due to the cog's register space which takes up 16 LONGs! In any case, Cog 0 is loaded with the interpreter and your code will start executing at the first "public" declaration.

**NOTE**

All Propeller chip programs must start with **SOME** Spin code as the entry point (a single public function at least). After the initial Spin code, you can launch more cogs with Spin or ASM, but the Propeller chip always starts off by loading the Spin interpreter into Cog 0 and attempts to run a Spin program at startup.

## 15.2 Programming in Spin

Spin BYTE code resides in main memory. While more memory-efficient than assembly language, Spin is considerably slower. For simple operations it is up to 250 times slower than assembly code, but this gap narrows for more complex operations (i.e. square root). Therefore, tradeoffs can be made when coding in either language. Generally, high-level operations which are not too timing-critical can be most easily and efficiently coded in Spin. Where blistering speed is required, assembly language would be your choice.

The compiler does not currently support optimization of any kind such as aliasing, loop unrolling, or intermediate value reusing during complex calculations, so beware, what you write is what you get! In general, with bitmapped video memory for a game, assets, and driver objects, a few hundreds lines of Spin will use up all the remaining memory; therefore, when developing games and high performance graphics applications you will typically use Spin more as a housekeeping language for global control and write your game code in assembly language. Of course, for simple demos along the lines of the "Parallaxaroids" demo I provided you with, Spin will suffice, but will quickly run you out of memory as it did in the demo which uses all the available 32 Kbytes of memory when the various other objects are included. On the other hand, if you stick to low memory footprint "character/tile" based graphics then Spin can get you a long way and entire games can be written with Spin and some ASM drivers to do graphics, etc.

Also, it's of interest that Spin is also loosely an "**Object Oriented**" language in as much as all programs are considered "**Objects**." Objects can be included as files and then you access the subroutines using syntax much like any other OO language. But other than that there is no **inheritance, operator overloading, polymorphism** etc. (which is probably a good thing!)

**NOTE**

The Spin environment is smart enough that during compilation of your program if it notices that multiple objects have been included that are the same it will strip them and make sure only one copy of the object is stored in the final binary image, therefore there is some modicum of code reuse with objects, so you don't have to worry about that.

Since I am hoping you are already a programmer or familiar with programming at some level, I am simply going to show you the syntax of the language and its various constructs

with examples sprinkled about. A bit of experimentation will be necessary on your part to get a good feel for the language, but as mentioned it's derived from ideas based on BASIC / PASCAL, so its easy to pick up, the only "gotcha" is the use of **indentation** for block nesting level, the built in syntax highlighting helps resolve this, but nonetheless, it takes some getting used to, so be patient. For example, the program:

```
' initialize y
y:=0

' a dead loop, that iterates 100 times and does nothing but waste time
Repeat x from 0 to 99
y:=y+1

' y still equals 0 here
```

... is entirely different from this program:

```
' initialize y
y:=0

' this loop iterates 100 times and contains the y increment block
Repeat x from 0 to 99
  y:=y+1 ' this line is now WITHIN the block of the repeat loop!

' y now equals 100
```

Thus, with a high resolution monitor, small font size, a single space can change the operation of your program – more on this later.

We have had enough theory in the previous chapters, so for the first step, let's just load and run some programs to get the hang of the environment and programming the Propeller chip, then we can get into the syntax and details of the language itself. To make sure we are on the same page (any SX programmers out there?) follow the steps below to make sure we both have the same starting environment.

**Step 1:** Insert your USB cable into your PC and insert the mini-B connector into the HYDRA's USB port (also, if you happen to be using other Parallax devices and a USB2SER device then you can insert it into the secondary programming header to the left of the board). If you followed the installation in Chapter 1 of the book, you should have already installed USB drivers for the FT232 chip; otherwise, you will need to do so now. Refer to Chapter 1 for more details on the installation of drivers.

**Step 2:** The latest version of the Propeller chip IDE at the time of this printing is located in a single .EXE file on your CD here:

**CD\_ROOT:\HYDRA\TOOLS\PROPELLER\PROPELLER\_SETUP.EXE**

Once again, you should have already installed the IDE and set it up; if you haven't please do so now (referring to Chapter 1 for details).

**Step 3:** Get your HYDRA out, and plug in the power and the A/V cables to your TV set. Also, plug in the keyboard, mouse, and gamepad into Port 0 (left). Remove the game cartridge if there is one. And make sure the USB cable is plugged into the HYDRA's USB port.

**Step 4:** Power up the HYDRA and press reset. There "might" be a program on the on-board EEPROM depending on what you have been doing, if so, disregard it. Now, you are ready for the experiments.

**Experiment 1:** Load in the Parallaxaroids demo in the IDE ( <CTRL + O> ).

If you haven't played with the IDE, then here's your chance. You should have the IDE up and running. Under **File → Open**, browse for **ASTEROIDS\_DEMO\_013.SPIN** on your hard drive or CD. And load the program in. You should see the editing pane fill with code. Try scrolling around a bit and take a look.

**Experiment 2:** View information about program ( <F8> ).

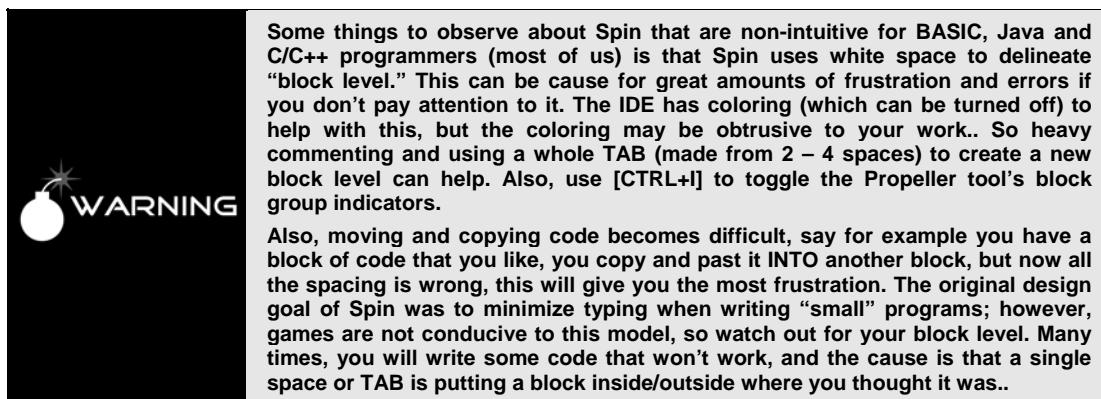
Now that we have a program in memory, let's try compiling it, but not uploading it to the system. On the main menu select **Run → Compile Current → View Info**. This compiles the program and shows you the binary image, etc. in the "Object Viewer." You can also load, and save binary images from this dialog and more. But, for now just look around. You can learn a lot by building really simple programs and looking at the images in the viewer. When you are done Close the window.

**Experiment 3:** Compile and load the program directly into the Propeller chip ( <F10> ).

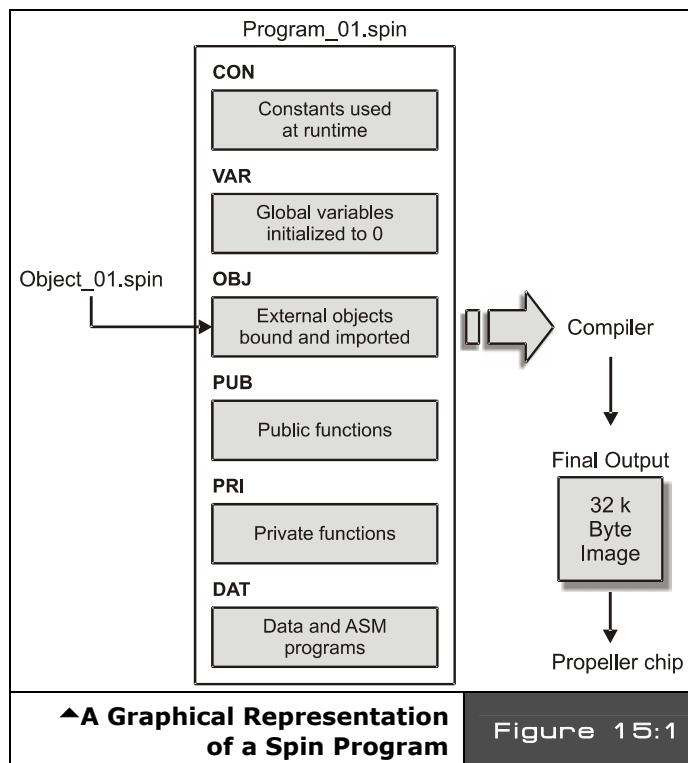
Now, we are going to compile and load the program into the Propeller chip. We are NOT going to re-program the EEPROM, so if you press reset after this experiment, then whatever was on the EEPROM will re-load. In any event, click **Run → Compile Current → Load RAM and Run** from the main menu bar. You will see the compilation take place and a quick upload, then you should see the game start up very quickly.

**Experiment 4:** Compile and load the program into the EEPROM and then run it ( <F11> ).

In this experiment, we are going to not only compile the program and load it, but first copy it to the EEPROM, so the hardware will "retain" the program even after a reset. Try clicking **Run → Compile Current → Load EEPROM and Run**. This selection will first load the EEPROM, and then the Propeller chip will reset, then retrieve the program from the EEPROM under the booter and run it.



### 15.3 Organization of a Spin Program



Spin is a functional language with object oriented encapsulation of functions at a file scope level. That is, you can create a Spin "object" which is a collection of subroutines, data, etc. that you can "include" in another program and then make calls to the functions within the object. Figure 15:1 shows this graphically. The language as mentioned before uses spacing to create block level designation and has no "begin", "end" symbols. The language is case insensitive as well. Variable and function names follow the same rules as most HLLs and can include alphanumeric characters as well as underscores.

A Spin program can contain **constants**, **variables** (globals), **objects** (pulled in from other files), **public functions** and variables, **private functions** and variables, and finally a **data** section(s) (usually at the end of the program). The block designators that indicate these sections are:

### 15.3.1 Spin Code Block Designators

The following is a list of code block designator keywords as well as some brief examples. Note that once you declare a block designator, that block type stays in flux until another block designator is encountered in the program. For example, once you type "CON" the compiler is in "constant" mode until you direct it otherwise.

**CON** — The CON block designator starts a "Constants" section; here is where you place your constants that are simply compiler-resolved symbols for convenience and take up no storage. Notice they have no type information.

**Example:** Some simple working constants for a graphics program.

```
CON
  ' size of graphics tile map
  X_TILES          = 16
  Y_TILES          = 12

  ' screen size
  SCREEN_WIDTH     = 256
  SCREEN_HEIGHT    = 192
```

**VAR** — The VAR block designator defines global object-wide variables, these take up space in main memory (the 32K region) not the cog memory of 512 LONGs, this is used to hold the interpreter running your Spin code when using high-level coding. You can define BYTEs (8 bits), WORDs (16 bits), or LONGs (32 bits).

**Example:** LONGs, WORDs, BYTEs, and array variables.

```
VAR
  long mouse_x, mouse_y      ' holds mouse x,y position
  word screen[x_tiles * y_tiles]   ' storage for screen tile map
  long colors[64]                ' color look up table

  ' active asteroids
  byte num_active_asteroids
```



#### NOTE

All VARS are initialized to 0 on program start, but local variables in functions are NOT!

**OBJ** — The OBJ block designator starts an “Object” import region, this is where you can import and name other objects that are located in external Spin files. These objects will be imported during compile time and merged with your program. Also, note no matter how many times you import an object, only one copy of the code is imported, so multiple objects are distilled into a single object with a copy of the unique data.

**Example:** Loads in TV, graphics, and mouse and objects.

```
OBJ
  tv      : "tv.spin"           ' instantiate a tv object
  gr      : "graphics.spin"     ' instantiate a graphics object
  mouse   : "mouse_iso.spin"    ' instantiate a mouse object
```



#### NOTE

The file extension “.spin” is unnecessary and can be omitted; however the Propeller IDE will only search for files with the “.spin” extension, thus you can’t import a file with the name “foo.dat” for example, even if its valid Spin code.

**PUB** — The PUB block designator is used to create a “Public” function which is accessible outside the scope of the file to other objects that might import the file containing the PUB. This is similar to defining a function in other HLLs and then exporting it.



#### NOTE

Execution of all Spin programs **always** starts at the first PUB encountered in the top level file, or if the program only has one file the first PUB encountered there.

**Example:** A simple function that computes the square of the sent value.

```
PUB Square (x) : ret_val
  ret_val := (x*x)
```

Later we will delve into the syntax of function declarations in much more detail. For now, note that functions may have zero or more parameters, may have a named return value (otherwise it’s aliased to RESULT always), and finally PUBs may have locals.

**PRI** — The PRI block designator is used to create a “Private” function which is not accessible outside the scope of the file to other objects; other than that, the syntax and use is identical to PUB.

**DAT** — The DAT block designator defines the beginning of a “Data” section and continues until another block designator is encountered. DAT sections are used in Spin to define data and tables; DAT sections are also used to write actual ASM code, that is, you must declare a DAT section then put your ASM code. The reason for this is that ASM code is like “data” to the compiler and it simply merges it into the final object and then you pass it to a cog at

some point. Note that ASM defined in a DAT section can never exceed 512 LONGs (technically 512 – 16 LONGs due to the register file at the end of each cogs memory).

**Example 1:** The declaration of some strings in a high-level Spin program.

```
DAT
score_string      byte  "Score",0          'text
hiscore_string    byte  "High",0           'text
ships_string      byte  "Ships",0          'text
start_string      byte  "PRESS START",0    'text
parallax_string   byte  "PaRaLLaXaRoiDs",0 'text
hex_table         byte  "0123456789ABCDEF" ' hex lookup table
```

Notice there is no “string” type in Spin, so we simply use standard ASCII-Z format and encode a string with a NULL (0) terminator at the end. However, if you wanted you could encode strings using a Pascal format where you insert the length of the string into the first character followed by the string characters themselves. The point is, any string processing you must do yourself. Nonetheless, the few string functions Spin does support assume ASCII-Z format.

**Example 2:** An ASM excerpt from the graphics driver, notice it starts with a DAT section.

```
DAT
' ****
'* Assembly language graphics driver *
' ****
        org
'
; Graphics driver - main loop

loop      rdlong t1,par      wz      'wait for command
        if_z      jmp #loop

        movd   :arg,#arg0      ' get 8 arguments
        mov    t2,t1
        mov    t3,#8
:arg     rdlong arg0,t2
        add   :arg,d0
        add   t2,#4
        djnz  t3,:arg
```



### NOTE

The code actually retrieves parameters from the caller. If you’re interested, there will be more on ASM programming techniques when we get to ASM examples later in the text.

DAT section variables can be accessed by Spin as if they were variables; the named DAT section is an address. Therefore, later when we discuss pointers and memory access, remember that DAT sections are where we can store data, tables, etc. and to access any element named in a DAT section, we simply use the named region. For example, in Example 1 above, if we wanted the starting address of the hex table, we would refer to it as "hex\_table" in the Spin code, more on this later.

## 15.4 Spin Language Elements

In the next sections we will briefly discuss the important various Spin language elements such as data types, conditionals, loop constructs, built-in functions, math operators and more. This is by no means an exhaustive description of the language (for a complete treatise on Spin please refer to the Propeller Manual). The Spin language itself is the native high-level code that the Propeller chip runs with. The interpreter for Spin is in pure ASM and fits into the 512 LONGs of a single cog; therefore whenever you use Spin on a cog what you are really doing is launching the cog, loading the interpreter into it and then the interpreter starts executing the BYTE code for your compiled Spin program out of RAM memory. You can mix ASM and Spin by launching a cog with a pointer to the ASM code, then the interpreter basically loads the cog up with the binary image of the ASM and starts executing.

The Spin language supports a crude form of object-oriented programming in as much as you can create a program/object with "**methods**," PUB functions, and then load the object into your main file and access these methods using a dot "." access notation (more on this later when we discuss objects). Other than that, there is no operator overloading, no polymorphism, no inheritance, no constructors, no data structures (other than arrays) etc., the language is really a "to the metal" stripped Pascal/BASIC/ASM for the most part that is designed to help you work with multiple processors and run code on them with the least amount of pain. However, as noted previously in the docs, the Spin language is a BYTE code interpreted language and thus 20–40x slower than ASM code due to its interpretation, so keep that in mind, you will still have to write time-critical code in ASM in many cases.

### 15.4.1 General Syntax of Spin

Spin has its roots in a Pascal, BASIC, and ASM. The syntax is somewhat non-orthogonal, but you will find that after a while its idiosyncrasies are minimal. The language was designed to be very easy to use, and as WYSIWYG as possible (unlike C++/JAVA where things happen without you knowing it). The only syntactic oddity of the language is that it relies on "**white space**" to define block nesting level, this is unlike any standard language such as C, C++, Pascal, Java, Javascript, Prolog, Modula, etc. However, you will find some "scripting" languages that subscribe to this concept such as **Python**. The reasoning behind this is simple, for very short programs (scripts), one usually only needs a few lines of code and extra "begin/end" statements waste typing; however, for a general programming language using white space to define blocks is a hindrance for a number of reasons, the most

important is that the alignment of code dictates its functionality, a single space in the wrong place can push something in and out of a block or scope. Additionally, file exporting/importing becomes an issue since if you like to edit with an external editor etc. the editor might change spacing and thus the program's meaning – things to consider.

The Propeller chip IDE is designed to help with this with syntax highlighting, but for those of us that don't want to look at a shaded rainbow when coding or if you are part of the 5–10% of men that are color blind, this is an issue, thus care should be taken when coding. I have had many rounds of debugging while pulling hair only to realize there was an extra space somewhere. Alas, then be VERY careful when coding and especially when copying and pasting blocks of code. Or, if you don't mind a visual aid, turn on the block group indicators <Ctrl+I> which show the logical structure of conditional or loop blocks. If you have some code you want to move, like a complex conditional statement if/else tree, copy and paste then re-align it all within the sub-block you wish using the block selection and block indenting and outdenting features. The best approach is to use 2-4 spaces to move into a block or a tab (which is converted to spaces) to move down into various nesting levels, so you can "see" the difference visually without coloring.

Spin is also case insensitive; other than the initial spacing of functions, and reserved words that must be spaced in to be nested, the language is free-flowing.



#### NOTE

There are no end-of-line delimiters in Spin. Lines end with a carriage return. For example, C/C++ uses ";" to end the line/statement.

#### 15.4.2 Comments in Spin

One of the most important things in any programming language is commenting! Spin uses a single quote to denote a normal comment like this:

```
x := x + 1 ' this increments x
```

Additionally, to help with documentation generation in the IDE, you can use a double single quote to pass the comment to the documentation formatter:

```
x := x + 1 '' this increments x and this comment will be in the documentation.
```

In general, you want to use single quote comments for your detailed comments about the inner workings of an algorithm and the double single quote comments on higher level functionality comments.

Lastly, there is a block comment that allows you to comment out entire blocks of code, this is useful for obvious reasons, but the most important one is there is no conditional assembly/compilation functionality, so if you want to turn a code block off to save size or target a certain piece of hardware, etc. the only way would be to remove the code or have a different file for all variations, not very effective, but with block comments you can at least include/exclude code in a primitive manner, the block comment starts with a left curly brace "{" and ends with a right curly brace "}". Here's an example:

```
{ ' start block comment

' initialize particles
repeat i from 0 to NUM_PARTICLES-1
  base := i*PARTICLES_DS_WORD_SIZE
  particles[base+PARTICLE_DS_TYPE_STATE_INDEX] := PARTICLE_TYPE_NULL | OBJECT_STATE_DEAD
  particles[base+PARTICLE_DS_X_INDEX] := 0
  particles[base+PARTICLE_DS_Y_INDEX] := 0
  particles[base+PARTICLE_DS_DX_INDEX] := 0
  particles[base+PARTICLE_DS_DY_INDEX] := 0
  particles[base+PARTICLE_DS_COUNTER_INDEX] := 0

} ' end block comment
```

Additionally, there is a documentation version of the block comment denoted by enclosing the text in double curly braces {{ and }}.

#### 15.4.3 Spin Reserved Words

Now let's look at the most important reserved words and functions in Spin as shown in Table 15:1 on the next page. (for a complete listing of all reserved words, please refer to the Propeller Manual).

As you can see there are almost no built in libraries, no math calls, no graphics, no sound, not much of anything. Spin is very small and has to be to fit into the 512 LONGs of a single cog, so any functionality you want, you must code with external libraries. This isn't bad since you can write just about anything you want, but of course the performance will be slower than native functions that are built in. However, you can always use ASM as well. Of course, Parallax as well as myself are going to build as many cool libraries as possible and include them with the products. Currently anything that might be considered "useful" and a library will be stored in a **LIBRARY\** directory where the Propeller IDE .EXE is located and installed. In any event, take a good look at the table and we will discuss each class in the next section.

<b>Table 15:1</b>		<b>Spin Reserved Words Organized by Category (abridged list)▼</b>	
<b>Block Designators</b>	<b>Table and Set Lookup</b>	<b>Cog Manipulation</b>	
CON VAR OBJ PUB PRI DAT	LOOKUP LOOKUPZ LOOKDOWN LOOKDOWNZ	RUN COGNEW COGINIT COGSTOP COGID	
<b>Conditional Blocks</b>	<b>Memory Movement &amp; Filling</b>	<b>HUB Synchronization</b>	
IF IFNOT ELSEIF ELSEIFNOT ELSE CASE OTHER	BYTEFILL WORDFILL LONGFILL BYTEMOVE WORDMOVE LONGMOVE	LOCKNEW LOCKRET LOCKSET LOCKCLR	
<b>Looping Constructs</b>	<b>String Functions</b>	<b>Cog Register Access</b>	
REPEAT WHILE UNTIL FROM/TO/STEP NEXT	STRSIZE STRCOMP	SPR PAR CNT INA INB OUTA OUTB DIRA DIRB CTRA CTRBR FRQA FRQB PHSA PHSB	
<b>Function Control &amp; Branching</b>	<b>Waiting Functions</b>		
QUIT RETURN ABORT RESULT	WAITPEQ WAITPNE WAITCNT WAITVID		
<b>Logical Values</b>	<b>Clocking</b>		
TRUE FALSE	CLKSET CLKMODE CLKFREQ CHIPVER		
<b>Data Types</b>	<b>Math</b>	<b>Video Configuration</b>	
BYTE WORD LONG	FLOAT ROUND TRUNC CONSTANT	VCFG VSCL	

In any event, take a good look at the table and we will discuss each class of statement/function/keyword in the paragraphs below.

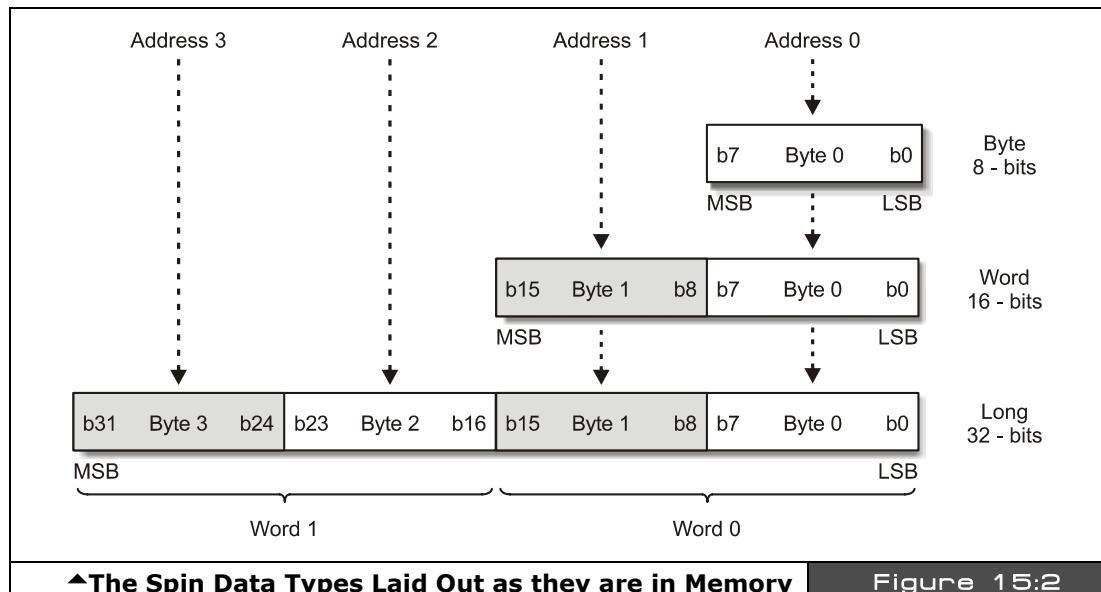
#### 15.4.4 Spin Data Types and Data Structures

The Spin language supports three basic data types, they are:

**BYTE** 8 bits

**WORD** 16 bits

**LONG** 32 bits



The Propeller chip is a “little endian” processor meaning memory is stored in low BYTE to high BYTE order as shown in Figure 15:2.

Here are some examples of defining variables in a VAR section:

```
VAR
  LONG position, angle' defines a couple 32-bit longs
  WORD energy' defines a 16-bit word
  BYTE character' defines an 8-bit byte
```

Notice that you can define more than one typed variable by separating them by commas. Also, there is no static initialization of variables, rather they are all initialized to zero on startup. This is somewhat of a pain, but simply means on entry to your main code, you simply need to initialize all your variables with constants or named constants from a CON section.

Other than the basic three types there are no other data types and there is no intrinsic support for records or structures of any kind (they can be simulated with arrays though). Also, there are no signed/unsigned variants of each type, therefore, BYTE and WORD are signed or unsigned depending how you use them. That is if you assign a negative constant value to a BYTE then you assign the BYTE to a WORD type there will be NO sign extension if you are doing your math in 2's complement. Now, on the other hand, 32-bit values when assigned to a smaller type will work out in 2's complement as long as the magnitude doesn't overflow. For example, given these two declarations:

```
VAR
  LONG x ' define a long
  BYTE y ' define a byte
```

...then somewhere in the body of a function we make these assignments:

```
x := -1 ' looks like $FFFF_FFFF in memory, 32-bit 2's complement -1
y := -1 ' looks like $FF in memory, 8-bit 2's complement -1
```

Now, if we were to assign the 8-bit value to the 32-bit value we would write this:

```
' example 1: assigning a smaller data type to a larger
x := y ' x = $0000_00FF which is 255! should be -1

' example 2: assigning a larger data type to a smaller
y := x ' y = $FF which is -1, correct!
```

As you can see, without sign extension the result in the larger data type is incorrect, thus care must be taken when making assignments if you are doing you math with mixed data types and using 2's complement math. Later, we will see the math operators that help remedy this with sign extension.

### 15.4.5 Data Structures in Spin

Byte A [8]			Word B [5]		
Index	b7	b0	Base Adder	Index	b15
0	\$FF		X	0	\$37
1	\$10		X + 1	1	45
2	\$E7		X + 2	2	\$92
3	\$AA		X + 3	3	17
4	\$32		X + 4	4	\$00
5	\$16		X + 5		15
6	\$39		X + 6		\$FF
7	\$67		X + 7		E0
8 - bits wide			HighByte      Low Byte		

A) Byte Array  
Starting at Base Address X

Long C [4]			
Index	b31	b0	Base Adder
0	\$00	00	X
1	\$F0	56	X + 4
2	\$00	00	X + 8
3	\$00	00	X + 12
	Byte 3	Byte 2	Byte 1
	High		Byte 0
Low			
32 - bits wide			

C) Long Array  
Starting at Base Address X

**▲Arrays in Spin**

Figure 15:3

Spin is very lean, so there is no support for records, structures, or any abstract data types; basically, the language only supports singletons and 1D arrays (which must be defined in a VAR section for globals, locals can be defined at the start of methods). The 1D array type is shown in Figure 15:3.

The syntax has been shown before, but formally to declare a 1D array use:

```
BYTE name[SIZEm]    : creates a byte array m bytes long
WORD name[SIZEm]   : creates a word array m words long or 2m bytes long
LONG name[SIZEm]   : creates a long array m longs or 4m bytes long
```

The syntax to access an array is simple, just use the array name and an index, the interpreter will take care of scaling and will always return the value with the proper size, for example:

```
VAR
  BYTE string[80]  ' define a string that holds 80 characters
  .
  .
  string[0] := 64  ' assign 64 to the first entry
  string[79] := 0  ' assign 0 (null) to the last entry
```



### NOTE

All arrays are ZERO based, that is an array with n elements is accessed 0 to n-1.

Since there is no data structure support, one trick is to use “simulated records.” For example, let’s assume we wanted to represent a record that has 3 BYTE fields: x,y,z, and we want 100 of these records, and we want to access any of them with some simple syntax. Then we can do this:

```
VAR
  BYTE point[3*100]      : allocate 100 records each 3 bytes long, assume
                           : format is x0,y0,z0, x1,y1,z1...
  .
  .
  : access element i
  x: = point[i*3+0]       : x is at offset 0 of triple
  y: = point[i*3+1]       : y is at offset 1 of triple
  z: = point[i*3+2]       : z is at offset 2 of triple
```

There are also some special memory access operators that are similar to “peek” and “poke” that allow direct memory access, their syntax uses the actual keywords/data types “BYTE,” “WORD,” and “LONG” but we will discuss these operators in the section on “Spin Data, Memory, and Pointer Manipulation” later in the document.

#### 15.4.6 Spin Constant, Math and Variable Expressions

Spin expressions can be composed of single numbers, constants, variables, unary operations and binary operations as well as function calls that are evaluated as part of an expression.

Literal constants can be written in decimal (default numeric mode), binary (with the prefix "%"), hexadecimal (with the prefix "\$"), and simple one- to four-character ASCII literals. Here are some examples:

### Literals

Decimal: 56, 202, 1919234, 405000, 100\_000\_000  
 Binary: %00011, %11101101, %1111\_1111\_1111\_0000  
 Hexadecimal: \$F4, \$a6, \$FFF8\_B800, \$AB005690

Notice the use of the underscore character "\_" to make numbers more readable, a really nice feature.

All ASCII literals stored in a 32-bit LONG (in little endian format)

ASCII "x" — In memory looks like \$00\_00\_00\_78, will work as single length ASCII-Z string.

### Boolean Constants

Additionally, there are two 32-bit system constants for **TRUE** and **FALSE**, they are:

"TRUE" — In binary, the value is 11111111\_11111111\_11111111\_11111111, "-1" in two's complement.

"FALSE" — In binary, the value is 00000000\_00000000\_00000000\_00000000, "0" in two's complement.

Be careful when using these values, since TRUE (all 1's) technically is (-1) in decimal two's complement. The reason for all 1's rather than TRUE being equal to binary "1" is that for binary operations all 1's makes more sense for masking operations since **every** single bit is TRUE.

### Variable and Function Names

Moving on, variable names in Spin for numeric data types as well as function names must start with letter and can contain letters, numbers and underscores. Here are some examples:

```
VAR
  long x, y1
  word POWER_LEVEL
  byte _data_port
  long _word0
```

Literals, variables, and functions can all be combined to create complex mathematical expressions involving both unary and binary operations. We will discuss these expressions in the next section.

### 15.4.7 Spin Mathematical, Logical, and Binary Operations

The first and most important part of an expressions is the ***assignment*** operator. The assignment operator in Spin is “:=” which you may recognize from Pascal. Let’s begin with the simpler unary operations that can be performed on variables, they are shown in Table 15:2.

Table 15:2	Variable Modifiers▼
Modifier	Description
?var	Rnd forward, LFSR 4-tap, 32 iteration, use a LONG
var?	Rnd reverse, LFSR 4-tap, 32 iteration, use a LONG
~var	Sign-extend from bit 7 (handy on BYTES)
~~var	Sign-extend from bit 15 (handy on WORDs)
var~	Post-clear to 0, read and reset
var~~	Post-set to -1 (all bits high), read and set
var++	Post-increment
++var	Pre-increment
var--	Post-decrement
--var	Pre-decrement

#### 15.4.7.1 Random Number Generation

The table is self-explanatory except for the first two entries which are used to generate random numbers. LFSR stands for “linear feedback shift register” and it’s a technique where a binary vector is shifted to the left or right in a circular feedback method, but certain bits are combined with logical operations such as XOR at certain points along the feedback path, these are called “taps”. In any event, these kinds of digital counters create binary patterns with pseudo-random behavior and thus can be used to create random numbers or white noise. The “?var” and “var?” operators facilitate this with a 32-bit, 4 tap, 32 iteration LFSR or in other words, you put a number into a variable var then apply the pre or post “?” operator and the 32-bit value in “var” will be shifted 32 times using a LFSR, this process is slow, but the result will be nearly random for any input value. Thus you can seed a variable with some number say 13, then LFSR it each time you want a new random number and just leave the old result. Here’s an example:

```
CON
  seed = 13    ' seed for the LFSR

VAR
  longrandom  ' holds the random number
```

```

.
.
random := seed  ' assign the seed
.

random := ?random' get next random number, assign it back to self

```

Of course, we are not writing complete working Spin programs with all the initialization code, but we will later in the chapter.

#### 15.4.7.2 Spin Math Operators

Next are the math operators for Spin. This is where Spin really shines and with just an operator or two you can get a lot of work done (although the code starts to look a little "perlesque!"). Table 15:4 on the next page lists all the operators.

Notice many of the operators have fairly redundant and cryptic syntax, so be careful when writing the operators out, I suggest putting a space on either side, so you can "see" the operator(s) and won't make typos! Given that there are so many operators, you might find yourself getting results that don't make sense when writing complex expressions, so make sure to parenthesis your expressions to make sure they are evaluated in the way you think they will be. Additionally, Table 15:3 is a guide to the operator precedence.

<b>Table 15:3</b>		<b>Operator Precedence Table▼</b>
<b>Operator</b>		<b>Precedence</b>
<b>0 (highest)</b>	( ), -, !,   , > ,  <, ^^ (unary)	
<b>1</b>	->, <-, >>, << ~>, ><	
<b>2</b>	&	
<b>3</b>	, ^	
<b>4</b>	*, **, /, //	
<b>5</b>	+, -	
<b>6</b>	>, <	
<b>7</b>	<, >, <>, ==, =<, =>	
<b>8</b>	NOT (unary)	
<b>9</b>	AND	
<b>10 (lowest)</b>	OR	

Table 15:4			Math Operators▼
Normal	Assign	Unary/ Binary	Description
	<code>: =</code>		Assignment
<code>-&gt;</code>	<code>-&gt;=</code>	<code>b</code>	Rotate right
<code>&lt;-</code>	<code>&lt;-=</code>	<code>b</code>	Rotate left
<code>&gt;&gt;</code>	<code>&gt;&gt;=</code>	<code>b</code>	Shift right
<code>&lt;&lt;</code>	<code>&lt;&lt;=</code>	<code>b</code>	Shift left
<code>#&gt;</code>	<code>#&gt;=</code>	<code>b</code>	Limit minimum (signed), ex: "x #>= y", equivalent to "if x < y then x = y"
<code>&lt;#</code>	<code>&lt;#=</code>	<code>b</code>	Limit maximum (signed) , ex: "x <#= y", equivalent to "if x > y then x = y"
<code>-</code>	<code>-</code>	<code>u</code>	Negate
<code>!</code>	<code>!</code>	<code>u</code>	Bitwise NOT
<code>&amp;</code>	<code>&amp;=</code>	<code>b</code>	Bitwise AND
<code>  </code>	<code>  </code>	<code>u</code>	Absolute value
<code> </code>	<code> =</code>	<code>b</code>	Bitwise OR
<code>^</code>	<code>^=</code>	<code>b</code>	bitwise XOR
<code>+</code>	<code>+=</code>	<code>b</code>	Add
<code>-</code>	<code>-=</code>	<code>b</code>	Subtract
<code>~&gt;</code>	<code>~&gt;=</code>	<code>b</code>	Shift arithmetic right, assumes 32-bit long (copies sign bit and shifts right)
<code>&gt;&lt;</code>	<code>&gt;&lt;=</code>	<code>b</code>	Reverse bits, ex: x >< y, reverses lowermost y bits, zero's all others
<code>AND</code>	<code>AND=</code>	<code>b</code>	Boolean/Logical AND (promotes non-0 to -1, that is all 1's).
<code>&gt; </code>	<code>&gt; </code>	<code>u</code>	Encode (0-32), ex. returns number of bits necessary to encode value or ( $\log 2 n$ )
<code>OR</code>	<code>OR=</code>	<code>b</code>	Boolean/Logical OR (promotes non-0 to -1, that is all 1's)
<code> &lt;</code>	<code> &lt;</code>	<code>u</code>	Decode
<code>*</code>	<code>*=</code>	<code>b</code>	Multiply, 32-bit x 32-bit, returns lower half of 64-bit result (signed)
<code>**</code>	<code>**=</code>	<code>b</code>	Multiply, 32-bit x 32-bit, returns upper half of 64-bit result (signed)
<code>/</code>	<code>/=</code>	<code>b</code>	Divide, return quotient (signed)
<code>//</code>	<code>//=</code>	<code>b</code>	Divide, return remainder (signed) (mod operator)
<code>^^</code>	<code>^^</code>	<code>u</code>	Square root
<code>&lt;</code>	<code>&lt;=</code>	<code>b</code>	Test - below (signed)
<code>&gt;</code>	<code>&gt;=</code>	<code>b</code>	Test - above (signed)
<code>&lt;&gt;</code>	<code>&lt;&gt;=</code>	<code>b</code>	Test - not equal
<code>==</code>	<code>==</code>	<code>b</code>	Test – equal
<code>=&lt;</code>	<code>=&lt;=</code>	<code>b</code>	Test - below or equal (signed)
<code>=&gt;</code>	<code>=&gt;=</code>	<code>b</code>	Test - above or equal (signed)
<code>NOT</code>	<code>NOT</code>	<code>u</code>	Boolean/Logical NOT (promotes non-0 to -1, that is all 1's)

### 15.4.7.3 Compile-Time Floating-Point Support

Recently, some floating-point support was added to the Spin compiler at ***compile time only***. In other words, there still is no intrinsic floating-point type or support, but the compiler's parser now has some helper code that allows you to create constant expressions at compile time and then use these at run time along with a run-time library object. More or less, the compiler's help could have been implemented in the library as well, but the designer Chip Gracey was able to "easily" add some conversion and expression evaluation functions in the parser without much trouble thus they were added. So the rules are that you can use these functions ***only*** in the CON section at compile time, they will compile the expressions and then convert them to single precision IEEE spec floating-point numbers, something like this:

```
S EEEEEEEE FFFFFFFFFFFFFFFFFFFFFF  
0 1      8 9          31
```

...where S is the sign bit, E is the exponent and F is the fraction (also known as the ***significand***), both in standard binary format. There are approximately 24 bits of fractional resolution and 7 bits of exponent.

Then once you have your floating-point constant you can use it in your code and assign it to a LONG and then the LONG will have a floating-point value in it as far as the bits are encoded, then you make calls to the floating-point library function to add, subtract, etc. during run time. Also, all floating-point expressions must be in either of these formats:

**Format 1:** Standard floating-point long hand.

whole\_part . decimal\_part

**Examples:** 0.4, -4.5, 12323.454

You must always have a decimal point and either a leading or trailing 0 even if there is no whole\_part or decimal\_part. Usually, compilers will "promote" all integers to floats in an expression and then do the math, but this compiler is simpler and doesn't do this, hence you must make everything a float yourself.

**Format 2:** IEEE scientific notation format (non-normalized).

mantissa E+/- multiplier = mantissa  $\times 10^{+/-\text{multiplier}}$

...where the mantissa must be a floating-point number itself, for example, these are all valid floating-point numbers to the compiler:

1.0E2 =  $1.0 \times 10^2$  (normalized)

456.23E5 =  $456.23 \times 10^5$  =  $4.5623 \times 10^7$  (normalized)

-56343.232E-3 =  $-56343.232 \times 10^{-3}$  =  $-5.6343232 \times 10^1$  (normalized)

Notice for fun I have normalized all the values so that there is only one significant digit leading each; however, when you write floating-point numbers using this exponential scientific notation you don't need to write them in normalized format.

Since the library isn't complete at the time of this writing, for now, we are simply going to cover the basic compile-time operations that are implemented. Table 15:5 shows the operations that are available at compile-time.

Table 15:5		Compile-Time Operators for Floating-Point	
Operator	Type	Meaning	Example
FLOAT( )	Function	Converts an integer into a single precision float	x = float(3)
TRUNC( )	Function	Converts a float to an integer via truncation	x = trunc(3.5), returns 3
ROUND( )	Function	Converts a float to an integer by rounding up	x = round(3.6), returns 4
+ , - , * , /	Binary	Standard add, subtract, multiply, divide	y = 3.4+9.0*4.5
-	Unary	Negation	z = -6.0
^^	Unary	Prefix square root	w = ^^69.0, returns 8.30662
	Binary	Prefix absolute value	a =   -45.0, returns 45.0
>	Binary	Boolean greater than, returns 0.0 or 1.0	c = (5.0 > 3.0), returns 1.0
<	Binary	Boolean less than, returns 0.0 or 1.0	c = (5.0 < 3.0), returns 0.0
=>	Binary	Boolean equal to or greater than, returns 0.0 or 1.0	c = (5.0 => 3.0), returns 1.0
=<	Binary	Boolean equal to or less than, returns 0.0 or 1.0	c = (5.0 = < 3.0), returns 0.0
<>	Binary	Boolean not equal, returns 0.0 or 1.0	c = (3 <> 9), returns 1.0
==	Binary	Boolean equal to, returns 0.0 or 1.0	c = (3 == 9), returns 0.0
<b>Note:</b> These three operators first promote the floating-point number to either 0.0 or 1.0; these are the "floating-point" Boolean values. The promotion rule is that 0.0 maps to 0.0; anything else maps to 1.0.			
AND	Binary	Promotes operands to floating point then ANDs	c = (3.0 AND -3.0), ret. 1.0
OR	Binary	Promotes operands to floating point then ANDs	c = (0.0 OR -5.6), ret. 1.0
NOT	Unary	Promotes to floating point then NOTs	c = NOT z, returns 0.0

Additionally, there is new function/operator that runs at compile time that supports both float and normal integer expressions called "Constant( )". Constant( ) evaluates compile time constant expressions and solves them, so that at run time this evaluation isn't done.

Normally, a compiler would do this automatically, but Spin currently is limited in its optimizations, thus **any** expression during run time that is even of simple constant nature such as:

```
x*4*5
```

...with a smart compiler would evaluate as  $x^{20}$ , but Spin actually does two operations at run time:

```
t = x*4, t = t*5
```

With the "Constant( )" operator we can force the compiler to evaluate this, so

```
Constant(x*4*5)
```

...results in BYTE code for:

```
x*20
```

...which is what is desired during run time.

### 15.4.8 Spin Statements

Statements typically include assignment, conditionals, control structures, loops and function calls. We have already seen the assignment statement, so now let's take a look at the various types of other statements Spin provides.

#### 15.4.8.1 Conditionals

The most basic form of condition is the "if" statement, Spin supports standard "if" as well as "elseif" and "else." Additionally, there are more exotic "ifnot" and "elseifnot" forms that are Spin-centric and not commonly found in other languages. The various forms of conditional syntax are:

**Example 1:** Basic "if" statement.

```
if conditional_expression
{code}
```

**Example 2:** More complex "if" followed by "elseif" statement.

```
if conditional_expression1
{code}
elseif conditional_expression2
{code}
.
.
elseif conditional_expression_n
{code}
```

**Example 3:** Next, adding the final “else” to catch all other possibilities...

```
if conditional_expression
  {code}
else
  {code}
```

...or with “elseif”:

```
if conditional_expression1
  {code}
elseif conditional_expression2
  {code}
.
.
elseif conditional_expression_n
  {code}
else
  {code}
```

**Example 4:** The “ifnot” statement.

```
if conditional_expression1
  {code}
ifnot conditional_expression2      ' code executes if "conditional_expression2"
                                  ' is FALSE.
  {code}
elseif conditional_expression3
  {code}
.
.
elseif conditional_expression_n
  {code}
else
  {code}
```

**Example 5:** The “elseifnot” statement.

```
if conditional_expression1
  {code}
ifnot conditional_expression2      ' code executes if "conditional_expression2"
                                  ' is FALSE.
  {code}
elseif conditional_expression3
  {code}
.
```

```

elseif conditional_expression_n-1
{code}
elseifnot conditional_expression_n      ' the "elseifnot" executes if the previous
                                         ' conditionals are FALSE and the "elseifnot"
                                         ' condition is FALSE as well
{code}
else
{code}

```

Of course you can nest these structures as you wish; however, keep in mind that the interior block is created by one or more spaces, so you have to space or tab once to get into the execution block for when the conditional is true. Also, the “conditional\_expression” can be any valid expression and unlike C/C++ etc. you don’t need to surround it by parens; however, its always a good idea to parenthesize your expressions to make sure they are evaluated in the order you think they are going to be, that is, the operator precedence might be different than what you think. Therefore, if you are unsure, parenthesize!

The last conditional control structure is the standard n-way switch or “case” statement. The syntax is reminiscent of C/C++/Java languages. There is a “case” followed by an expression, then each one of the evaluation blocks. There are three different types of ways of defining evaluation blocks; you can use a single constant expression, you can use a range of values that increment linearly from one constant expression to another using the “..” notation, and finally, you can separate various non-sequential values by commas. The syntax variants are shown below:

```

CASE expression
const_exp1.. const_exp2, cexp3:      ' a range followed by another single value
{code}
const_exp4, const_exp5:              ' two single ordinal value/expressions
{code}                                ' separated by commas (could be more)
const_exp6:                          ' a single ordinal value/expression
{code}
OTHER:                               ' the catch all or default case
{code}

```



### NOTE

Note that all “const\_exp” are constant expressions and must be based on constants or arithmetic expressions that can be evaluated at compile time.

### 15.4.8.2 Looping Constructs

There are a number of looping constructs in Spin, all of which are similar to what you are used to in C/C++, Java, and Pascal. There loops that repeat indefinitely, loops that evaluate the looping expression at the beginning of the loop, and others that evaluate it at the end of the loop. Additionally, there are for constructs that allow you to step though a loop starting from one value to another by a step value. Also, inside each loop you will see two optional statements denoted in the curly braces {NEXT} and {QUIT}, “NEXT” instructs the loop to return to the “REPEAT” clause or the top of the loop, and “QUIT” exits the loop body. The following is a list of all the looping constructs in Spin:

**Example 1:** Basic infinite loop.

```
REPEAT
  {code goes here}
  {NEXT}
  {QUIT}
```

**Example 2a:** “While” loop with pre-evaluation of condition.

This form executes the loop body zero or more times.

```
REPEAT WHILE condition
  {code goes here}
  {NEXT}
  {QUIT}
```

**Example 2b:** “While” loop with post-evaluation of condition.

This form executes the loop body at least once.

```
REPEAT
  {code goes here}
  {NEXT}
  {QUIT}
WHILE condition(...) note the WHILE must be at the same column as the REPEAT
```

**Example 3a:** “Until” loop with pre-evaluation.

This form executes the loop body zero or more times.

```
REPEAT UNTIL condition
  {code goes here}
  {NEXT}
  {QUIT}
```

**Example 3b:** "Until" loop with post-evaluation.

```
This form executes the loop body at least once.
REPEAT
  {code goes here}
  {NEXT}
  {QUIT}
UNTIL cond
```

**Example 4:** "Repeat" with countdown

The "count\_expression" is evaluated at the time of loop entry and this result is used as the counter for the loop, so if the "count\_expression" has variables, constants, and function calls this is fine, but "count\_expression" will only be evaluated once on entry to the loop. If the final evaluation of "count\_expression" is n, then the loop executes n times exactly (unless a NEXT or QUIT is encountered).

```
REPEAT count_expression
  {code goes here}
  {NEXT}
  {QUIT}
```

**Example 5:** Standard "FOR" loop with starting and ending expression.

This is a standard "FOR" loop with a starting and ending expression. Note, both expressions are evaluated only once at the start of the loop. Additionally, you can optionally add a "STEP" by a constant value if you don't want the loop to increment by the default value of 1.

```
REPEAT var FROM start_expr TO finish_expr {STEP delta}
  {code goes here}
  {NEXT}
  {QUIT}
```

**15.4.8.3 Function Declarations and Calls**

Spin is a functional language that supports a structured programming paradigm by allowing you to create functions that can be called locally or through an object (more on objects later). First, all functions return a single 32-bit value, this is passed back through the named return value or through the ***super-global*** named "RESULT." That is, every time a function is called "RESULT" is an alias to the return value (whether you have one or not) and when you use the "RETURN" statement to exit a function and send back a value this is written to RESULT as well as returned (also RESULT is always initialized to 0 on entry to the function). Thus, all functions have an implied return value named RESULT, it's always 0, on entry. If you don't explicitly return a value at the end of the function, then the function will evaluate to the default value of RESULT which is 0. There are a number of ways to return results from

a function, first note that the statement “RETURN” has two forms; “RETURN” by itself which simply returns from the function, and “RETURN expr” which returns from the function with a value of expr which is of course aliased to RESULT as well as will be passed out to the caller as the result of the function call. With that in mind, there are many ways to return results from a function, for example:

**Example 1:** Assign the default return value RESULT a value at the end of the function.

```
result := expression
```

But, this will NOT exit the function, unless it's the last line of the function; if you want to make sure the function exits then you would put a “return” after this, like this:

```
result := expression
return
```

Of course, this “return” is implied if it's the end of the function, but you might want to have the assignment and return in a conditional.

**Example 2:** Create a return value in the function declaration.

Assuming, you create a named return value, call it “ret\_val”, you can return it using either technique above as well as using “return expr” as an option as well:

```
ret_val := expr
```

...and then at some point the function would exit, but if we want to insure exit immediately with the return value then we can use this syntax:

```
return ret_val
```

Moving on, the syntax of functions allows you to have any number of parameters, a return value, and locals, the syntax is a bit tricky, so let's take a look at the general syntax of functions with some pseudo BNF notation examples where “{ thing }” means “thing” is optional, and “{“thing\*”} means 0 or more “things” which are optional.

### Function Declarations

All functions take and return 32-bit values therefore there is no need to declare a return type or parameter types. Additionally, all locals are 32-bit. The syntax of functions is a bit tricky, functions can have zero or more parameters, locals, as well as a named return value. Note “ws” stands for “white space” in the examples below:

**Example 1:** Public function with no return, no locals, no parameters:

```
PUB func_name ( )
  {code goes here}
  {RETURN expression}  this is optional
```

**Example 1 syntax:**

```
PUB Do_Nothing( )
  Return
```

**Example 2:** Private Function with return and locals:

```
PRI func_name1 (parm1, parm2, ..., parmn) ws  {: return_value} ws | ws
{local(s),}* 
  {code goes here}
  {RETURN expression}  this is optional
```

Notice the RETURN value is optional, that is if you don't want to return a value, maybe the function is more of a procedure – then you can omit the RETURN statement; however, note that RESULT, which is 0, will be returned on the stack and if you try to use the function call in an expression, it will evaluate to zero in this case. Also, the syntax is a little hard to decrypt, reading from left to right, there are 1 to n parameters in the parens after the function name, then there is white space followed by a ":" and the name of the return value variable which is optional itself, then if you want one or more locals you indicate the local list with the pipe character "|" then give the list of locals separated by commas.

**Example 2 syntax:** Two parameters, a return value named "ret\_val" and two locals.

```
PRI Distance(x, y) : ret_val | temp1, temp2
  {code goes here}
  return ret_val
```

**Example 3:** Public Function parameters and locals variables, but no named return value.

```
PUB func_name1 (parm1, parm2, ..., parmn) ws | {local(s),}*
```

**Example 3 syntax:** One parameter and one local...

```
PUB Square (x) | temp
  temp:=x*x
  return(temp)
```

....or this would work as well,

```
PUB Square (x) | temp  
    temp:=x*x  
    result := temp
```

As you can see, we can either “RETURN” the result, or we can assign the result to the return value either named or the super-global “RESULT” at the end of the function body. Or we can just do nothing and return the default of 0, if the function is more of a “procedure” and we aren’t interested in using the function in an expression.

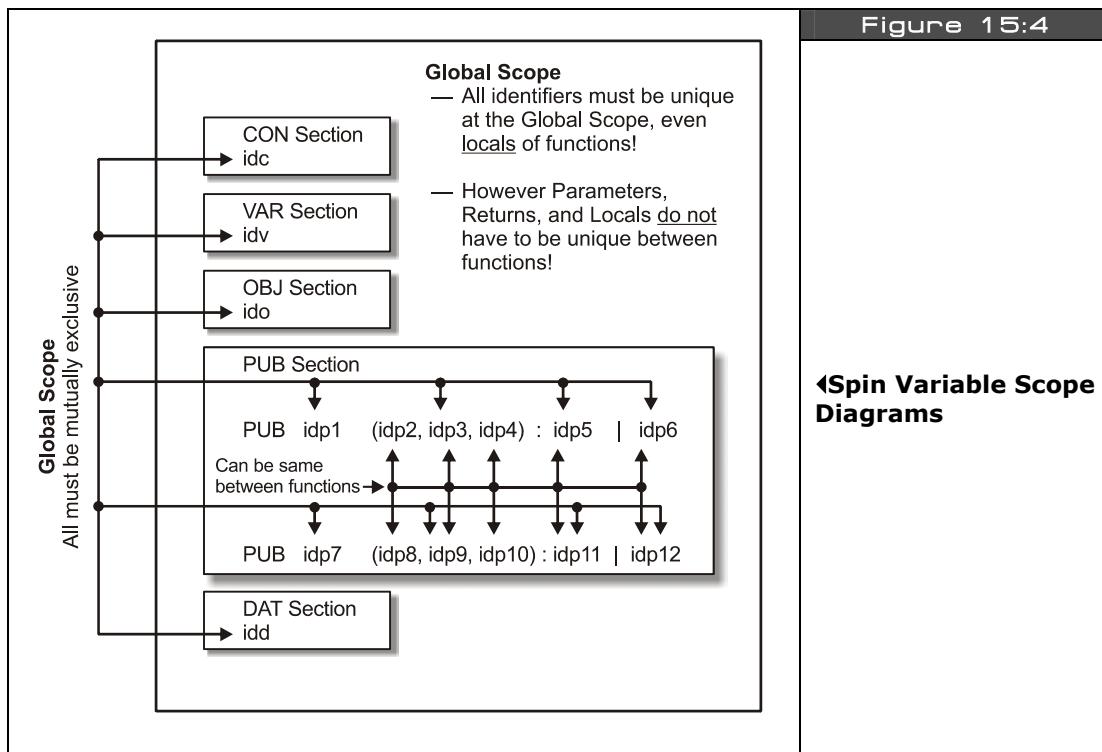
**Example 4:** Public function with no parameters, no return value, no locals.

If you want no parameters, no return value, no locals, use this syntax:

```
PUB foo  
    return
```

### Scoping Rules

The scoping rules for Spin functions are a bit unintuitive. In general, most programming languages allows “locals” to functions to have local “scope” meaning, these locals can’t be seen outside the function or procedure declaration. Therefore, one can use the variable “index” as a global and use “index” in every single function as a local as well without a problem. Figure 15:4 shows this graphically.



However, in Spin there are “funny” scoping rules. Locals can ***NOT*** have the same name as globals, BUT, locals between functions ***CAN*** have the same name. Additionally, parameters and return values can ***NOT*** have the same name as any global -- BUT, function to function ***CAN*** have the same name.

In this example:

```
PUB func_name1(var1, var2,, varn) : ret_val | local1, local2
```

...var1, var2, retvar, local1, and local2 all collide with global scope! So you can't have a global in a VAR section with any of these names! But, you can have two functions with the same parameters, return value, and local names like this:

```
PUB func_name1(var1, var2,, varn) : ret_val | local1, local2
```

```
PUB func_name2(var1, var2,, varn) : ret_val | local1, local2
```

### The Abort Keyword

"Abort" is like "return," but keeps on returning to the first caller with a leading "\\" in front of the function name. This leading backslash "tags" the function as the "exit" point for an "abort."

**Example 1:** Func1 is tagged as an exit point for aborting.

```
\Func1(parms...)
' function body for Func1 contains a call to Func2
Func2(parms...)
' end Func1

'///////////
\Func2(parms...)
' function body for Func2 contains a call to Func3
Func4(parms...)
' end Func2

'///////////

Func3( )
' function body for Func3 contains an Abort and Return

if (something)
    Return ' returns to Func2
else
    Abort ' returns to first "\\" abort tagged function, or Func1 in this case!
' end Bar
```

Reviewing the example, the call graph is Func1 → Func2 → Func3. Func3 then can either return to Func2, or if the Abort code is true then Func3 will return all the way back to Func1 and skip Func2 in the call return stack. Additionally, there are two forms of Abort:

**ABORT** — Returns to nearest most \ tagged call on stack like return.

**ABORTvalue** — Returns the value and OVERIDES the current return value in "return."

### 15.4.9 Spin Data, Memory and Pointer Manipulations

Spin supports pointers and pointer arithmetic; however, "pointers" aren't any special typed value, they are just vars that numerically are equal to memory addresses that we can perform mathematical operations on and additionally use them to dereference memory locations. Therefore, there is no "pointer" type per se. However, accessing memory is very easy and can be done in a number of ways.

First, to get the address of any variable the "@" operator is used. For example, if we have the following VAR section:

```
Byte a[10]  ' 10 bytes of space starting at memory location where "a" is stored
Long x[100] ' 100 longs of space starting at memory location where "x" is stored
Long y      ' 1 long of storage starts at memory location where "y" is stored
Long z      ' 1 long of storage starts at memory location where "z" is stored
Long lptr   ' 1 long of storage starts at memory location where "ptr" is stored
Word wptr   ' 1 word of storage starts at memory location where "wptr" is stored
```

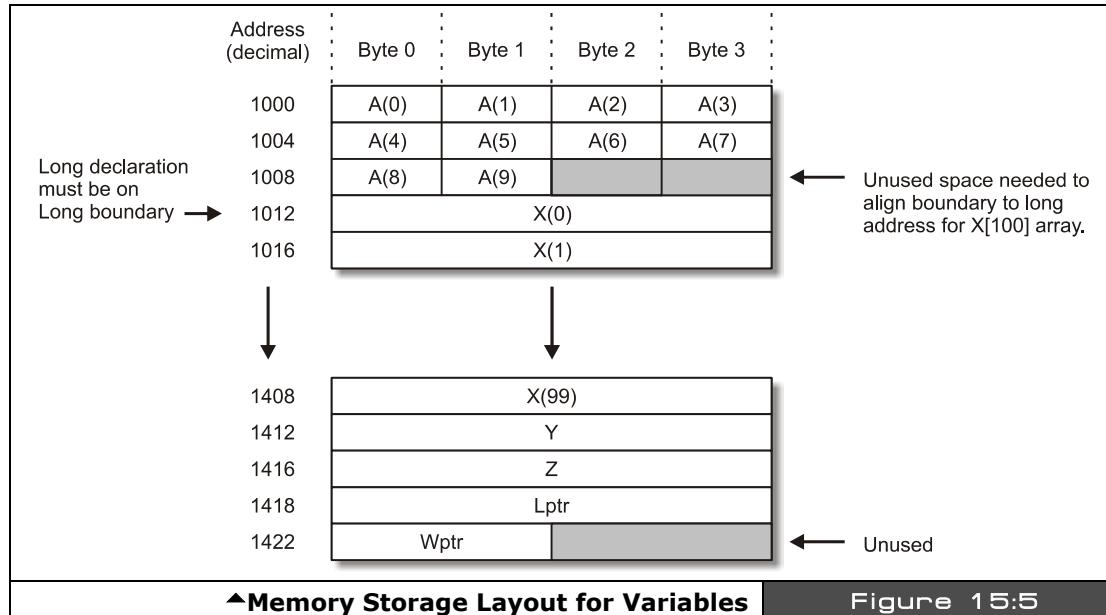


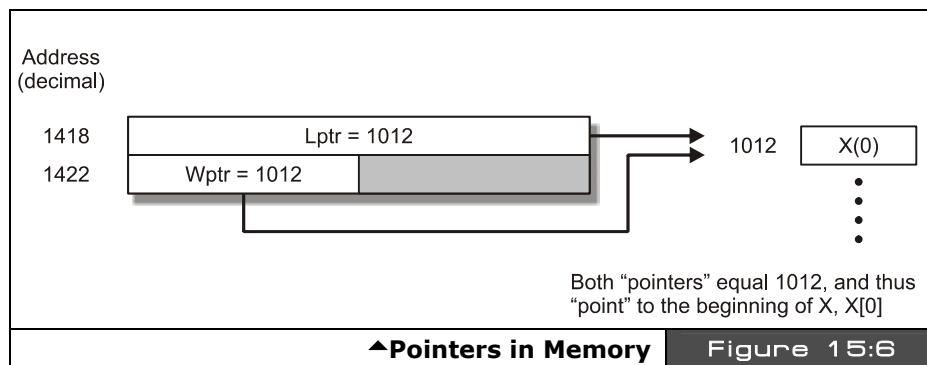
Figure 15:5 shows a hypothetical memory layout for the storage of the variable declarations, just for discussion purposes. Note that these addresses may not ever happen in a real program.

Then we can write something like this:

```
lptr := @x
wptr := @x
```

These statements compute the address where "x" is stored in memory and assigns this value to lptr and wptr, literally. This address/number will always fall between 0 – (64K-1), since that's the size in BYTES of the Propeller chip's internal memory. Therefore, if you want to use

a variable as a pointer then you must use a size of WORD or LONG, so that the address space can fit, a BYTE variable won't work since it only can address 0-255 (unless you know you are accessing the first 256 BYTES. Figure 15:6 shows the relationship between lptr, wptr, and x at this point.



In any event, both lptr and wptr now point to x. We can use a number of syntaxes to access the LONG array x[ ].

- `lptr[0]` - Accesses the long at x[0], or (@x + 0\*4)
- `lptr[1]` - Accesses the long at x[1] , or (@x + 1\*4)
- `lptr[n]` - Accesses the long at x[n] , or (@x + n\*4)

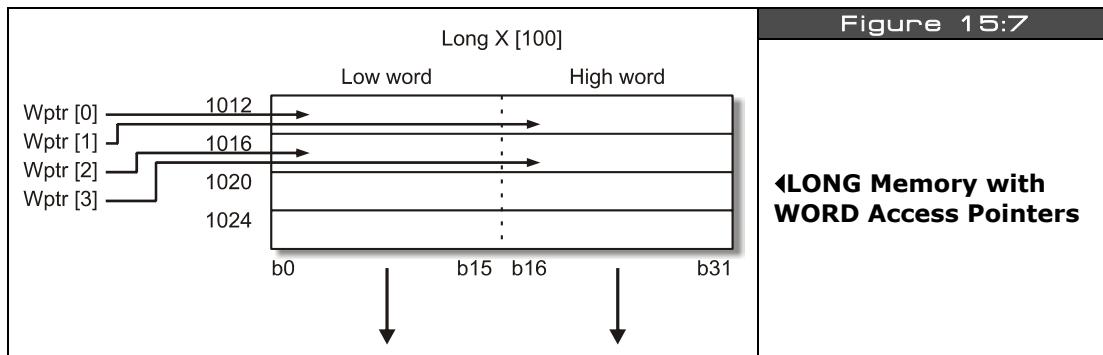
The interesting thing is that lptr is itself a LONG, therefore, whenever we access anything with the syntax "lptr[n]" then the access is always on a LONG boundary, that is, the indexing is smart enough to know that lptr is itself a LONG, and assumes that when used in this way it should index by LONGs. On the other hand, wptr is a WORD, therefore, when we assign the address of the LONG array x[ ] to wptr, we get a slightly different behavior. For example, take a look at these two lines of code:

```
wptr[0]  : Accesses the low word at x[0], or (@x + 0*2)
wptr[1]  : Accesses the high word at x[0] , or (@x + 1*2)
```

Notice that both accesses are within x[0]. To access the next two WORDs which reside in the next LONG or x[1], the following code can be used:

```
wptr[2]  : Accesses the low word at x[1], or (@x + 2*2)
wptr[3]  : Accesses the high word at x[1] , or (@x + 3*2)
```

Figure 15:7 shows the WORD and LONG accesses graphically. Moving on, there are some other forms of memory access based on “variable modifiers.”



#### 15.4.9.1 Accessing Memory with Variable Modifiers

In addition to using a variable name as a pointer with array index syntax, you can also use a type modifier with the dot “.” operator to access data with another WORD size. That is, say you have a variable or array that is based on LONGs, but you want to access it as if it were BYTES, or maybe you have an array that is WORDs and you want to access it as if it were BYTES, and so forth. However, the modifier syntax only allows “downcasting,” that is, you must always access memory in chunks as big or smaller than the size of the base.

The syntax is as follows:

- varname.LONG[i] – Accesses the memory starting at “varname” as LONGs, indexed by i.
- varname.WORD[i] – Accesses the memory starting at “varname” as WORDs, indexed by i.
- varname.BYTE[i] – Accesses the memory starting at “varname” as BYTES, indexed by i.

...where “varname” can be any of the following types and sizes:

- VAR BYTE/WORD/LONG
- DAT BYTE/WORD/LONG
- Local LONG such as subroutine parameters and locals

For example, let's say we have the following variables:

```
long  x[10]
word  y[10]
byte  z[10]
```

Then if we wanted to access them using the modifiers we simply use a dot followed by the size modifier. Here are some examples:

**Example 1:** Accessing the LONG array as LONGs, redundant example.

```
x.LONG[0]      ' accesses the first LONG of the array identical to x[0]
```

**Example 2:** Accessing the LONG array as WORDs.

```
x.WORD[3]      ' accesses the 3rd word in the LONG array of x, or technically the
                  ' low word of the 2nd LONG
```

**Example 3:** Accessing the WORD array as BYTEs.

```
y.BYTE[19]      ' accessed the very last BYTE of the entire WORD array defined by
                  ' y[10] = 10 words or 20 bytes.
```

**Example 4:** Accessing the BYTE array as BYTE.

```
z.BYTE[9]      ' accesses the last BYTE of the BYTE array
```

Example 4 is another redundant example since BYTE can only downcast to BYTE, therefore, the modifier doesn't do much, you could just say "z[9]" which is equivalent to z.BYTE[9], that is, in general if you access a variable of a given type using the SAME type as the modifier there is no difference in just accessing the memory as an indexed array.

Lastly, its interesting to note than in Spin there is **NO** bounds checking, everything is just memory and an address, so if you define a variable as a singleton, you can STILL access it as an array, for example:

```
long x
x[100] := 1      ' this is legal!
```

Additionally, you can use the variable name with modifier syntax like this:

```
x.WORD[20] := 2  ' this is legal as well
```

This of course is very dangerous if you're not careful! So remember the compiler doesn't know the difference between a singleton and an array, you can access both with any index. The only thing the array does for you is the compiler makes sure to allocate space in the memory map for you. However, this freedom is powerful since it allows you to index into anything you wish and create, self-modifying BYTE code even!

### 15.4.10 Spin and DAT Blocks

For a moment let's digress a bit and talk about DAT sections since they are special cases of memory that we can access. DAT sections are just like variables in that they are stored at a location in main memory, but unlike variables in a VAR section, we can pre-initialize DAT sections with real data statically and this data will always be present on BOOT, that is, it's stored statically in the binary image of the program. If you recall, in the VAR section we can't pre-initialize anything, but the compiler does guarantee that all VARs are initialized to 0 on start-up. With all that in mind, if we had a DAT section as shown below:

DAT

score_string	byte	"Score", 0	'text
hiscore_string	byte	"High", 0	'text
ships_string	byte	"Ships", 0	'text
start_string	byte	"PRESS START", 0	'text
parallax_string	byte	"PaRaLLaXaRoiDs", 0	'text
hex_table	byte	"0123456789ABCDEF"	'hex lookup table

...then @hex\_table would be the starting address of the hex table. Also, if we used array indexing syntax on hex\_table like this:

```
hex_table[n]
```

...then we would access the  $n^{\text{th}}$  BYTE of hex\_table[ ] always. This is because the DAT declaration has hex\_table "typed" as a BYTE. Similarly, WORD and LONG data would be indexed on WORD and LONG boundaries as well.

#### 15.4.10.1 Direct Memory Access with BYTE, WORD, and LONG Operators

As if having data types named BYTE, WORD, and LONG along with modifier BYTE, WORD, and LONG weren't enough there is yet ***another*** way to access memory directly! The idea is to use BYTE, WORD, and LONG as if they were peek/poke statements from BASIC and access memory directly at some base address. There are two forms:

- ▶ Base Address Direct
- ▶ Base Address Direct Plus Indexed

#### Base Address Direct

The base address direct form is simple, you simply give a base address and use BYTE, WORD, or LONG to indicate the size of the data you want to access there.

- BYTE[addr] — Accesses the BYTE at base address addr.
- WORD[addr] — Accesses the WORD at base address addr.
- LONG[addr] — Accesses the LONG at base address addr.

**Example 1:** Write a 53 into memory location 1000 assuming BYTE size data.

```
BYTE[1000] := 53
```

### Base Address Direct Plus Index

The base address plus index form allows you to “index” from the base address by the data size; BYTE, WORD, or LONG.

- BYTE[addr][index] — Accesses the BYTE at base address addr + index\*1
- WORD[addr][index] — Accesses the WORD at base address addr + index\*2
- LONG[addr][index] — Accesses the LONG at base address addr + index\*4

**Example 2:** Write a 211 into memory location 1004 assuming BYTE size data.

```
BYTE[1000][4] := 211
```

The indexed mode is useful when you want to think in terms of a single base address and then index from there. Here is another example that shows memory and the data stored in it as it's being accessed and modified:

**Example 3:** Memory manipulation showing memory each step of access.

```
long ptr      ' create a long variable, we will use this as a pointer
ptr := 1024   ' point ptr at address 1024 in RAM, the 256th LONG or
               ' BYTE 1024, or WORD 512
```

Now, to access the first **BYTE** we could write:

```
byte[ptr] := $01

Memory Address Data (after access)
1024  $01
1025  x
1026  x
1027  x
1028  x
```

Now, to access the first **WORD** we could write:

```
word[ptr] := $02

Memory Address Data (after access)
1024  $02
1025  $00
1026  x
1027  x
1028  x
```

Now, to access the first **LONG** we could write:

```
long[ptr] := $03

Memory Address Data (after access)
1024  $03
1025  $00
1026  $00
1027  $00
1028  x
```

Additionally, with the array index and **BYTE** modifier we can access the 3rd **BYTE** from the base address:

```
byte[ptr][3] := $05

Memory Address Data (after access)
1024  $03
1025  $00
1026  $00
1027  $05
1028  x
```

### 15.4.11 Spin Special Language Elements

In this next section we are going to cover the majority of the functional and system data access keywords from Table 15:1 on 256 that have special meaning. This will complete the language specification for the most part save the multiprocessing and object oriented aspects which we will discuss in the next sections respectively.

#### 15.4.11.1 System and Cog Registers

Each cog has a group of 16 registers, each 32-bit in size. We have discussed these registers before in numerous sections, refer to Table 15.6 on the next page. Spin allows you to access these registers with the following literal names listed in the "Name" column of the table.

Table 15:6		Cog Registers▼	
Address	Name	Access	Description
\$000-\$1EF	—	Read/Write	General Purpose RAM
\$1F0	PAR	Read-Only*	Boot Parameter
\$1F1	CNT	Read-Only*	System Counter
\$1F2	INA	Read-Only*	Input States for P31..P0
\$1F3	INB	Read-Only*	Input States for P63..P32 **
\$1F4	OUTA	Read/Write	Output States for P31..P0
\$1F5	OUTB	Read/Write	Output States for P63..P32 **
\$1F6	DIRA	Read/Write	Direction States for P31..P0
\$1F7	DIRB	Read/Write	Direction States for P63..P32 **
\$1F8	CTRA	Read/Write	Counter A Control
\$1F9	CTR B	Read/Write	Counter B Control
\$1FA	FRQA	Read/Write	Counter A Frequency
\$1FB	FRQB	Read/Write	Counter B Frequency
\$1FC	PHSA	Read/Write	Counter A Phase
\$1FD	PHSB	Read/Write	Counter B Phase
\$1FE	VCFG	Read/Write	Video Configuration
\$1FF	VSCL	Read/Write	Video Scale
<b>NOTES</b>	* Only accessible as a Source Register (i.e. MOV DEST,SOURCE) ** Allocated for future use, but not currently implemented.		
	<b>Remember all addresses are LONG or 4-BYTE addresses.</b>		

### Cog Register Access Notes

**SPR**      Special Purpose Register, allows access to all registers of the cog via an index syntax SPR[ index] , where:

SPR [ 0 ] accesses cog register \$1F0 (PAR)

SPR [ 15 ] accesses cog register \$1FF (VSCL)

.....etc. This way you can use numerical algorithms to access the registers rather than their names.

**PAR**      The parameter address from the cog boot, this indicated where the parameters are located.

<b>CNT</b>	The system wide 32-bit counter running at full speed, one clock per system cycle.
<b>INA</b>	The I/O Port A input buffer lower 32 bits, P31..P0.
<b>INB</b>	The I/O Port B input buffer, upper 32 bits, P63..P32, (future expansion).
<b>OUTA</b>	The I/O Port A output buffer, lower 32 bits, P31..P0.
<b>OUTB</b>	The I/O Port B output buffer, upper 32 bits, P63..P32, (future expansion).
<b>DIRA</b>	Direction states for Port A, P31..P0, 1=output, 0=input.
<b>DIRB</b>	Direction states for Port B, P63..P32, 1=output, 0=input.
<b>CTRA</b>	Counter A control bits, described earlier in document.
<b>CTRB</b>	Counter B control bits, described earlier in document.
<b>FRQA</b>	Counter A frequency bits, described earlier in document.
<b>FRQB</b>	Counter B frequency bits, described earlier in document.
<b>PHSA</b>	Counter A phase, described earlier in document.
<b>PHSB</b>	Counter B frequency bits, described earlier in document.

Obviously, some of this is review like the counter material, but it's useful to discuss the CNT keyword and all the I/O registers. The I/O material deserves its own section which is next, but let's see an example of the CNT register usage.

### The Global Counter CNT Register

The CNT register is a free-running 32-bit counter that is incremented once every system-wide clock cycle. Each cog accesses this register, gets the same value back at the same time, that is, there is a **single** global counter accessed by CNT, **not** multiple counters. In Spin, simply use the symbol "CNT" to access the register (read only of course):

To get the current count and store it:

```
curr_count := CNT
```

A crude wait loop that waits 10,000 clocks:

```
wait_cnt := CNT + 10_000
repeat while (CNT < wait_cnt)
```

### 15.4.11.2 Spin Input Output

The I/O model of the Propeller chip is simple and Spin makes it even easier, you simply set the **direction** of the I/O pin(s) with the **DIRA** register then **write** using the **OUTA** register or **read** using the **INA** register.


**NOTE**

The DIRB, INB, and OUTB registers are not used and are reserved for future expansion.

Now, the first thing that should come to mind about I/O on a multiprocessor chip is there is going to potentially be a lot of conflict! And this is true. The bottom line is that every cog can access the I/O pins and set the direction of them as well; this means that one instant a pin might be an input, the next an output. The bottom line is that as the programmer you have to set the pins in the right direction and not step on any toes yourself. The Propeller chip architecture uses an “I/O conflict resolution” design based on OR’ing and AND’ing things together as shown back in Figure 13:1, but this just helps, so there isn’t any hardware conflict internally. At the end of the day, if you set an I/O for an output with one cog and another cog sets it for an input and keeps doing this each cycle and your input cog only does it once, then you will never be able to communicate – therefore, be careful!

Thankfully, in the case of the HYDRA, there is really no concern about this for the most part since only one piece of hardware is connected to each I/O pin set, so usually the directions and use of the I/O are the same. But, it might be the case that you want two or more cogs both to talk to the same piece of hardware, maybe something like video for example; in this case, you better set the I/O the way you want it each time and then put it back the way it was or work out some global agreement with yourself – this all falls under “multiprocessing / parallel programming” techniques, you will learn them as you go. Now that we have had “**the talk**” about safe multiprocessor I/O, let’s see some examples.

**Example 1:** Set the I/O pins P7-P0 to outputs, and write a \$35 to the port.

```
DIRA := $FF          ' set the lower 8 bits to 1, which means "outputs",
                      ' all other bits will be 0 or "inputs".
```

Another syntax that would work is using the “..” range notation:

```
DIRA [ 7..0 ] := $FF  ' set the lower 8 bits to 1, which means "outputs",
                      ' notice the "..." bit range notation.
```

Once the direction is set, it’s simply a matter of writing to the OUTA register our value:

```
OUTA := $35
```

**Example 2:** Wait on I/O P0 (bit 0) for it to turn HIGH then exit loop.

```
' step 1: set I/O P0 to an input
DIRA[0] := 0      ; bit 0 set to 0, the bracket notation means which bit or bit(s)
                  ; with the range "... " notation.

' step 2: enter loop and wait
repeat while (!INA[0])
```



The bit range syntax only works on register access; you can't use it in any other cases.

#### 15.4.11.3 Table and Set Lookup

The following functions are useful for table lookups, conversions, translations, and mapping algorithms.

- LOOKUP** Looks up a value in a list, 1-based.
- LOOKUPZ** Looks up a value in a list, 0-based.
- LOOKDOWN** Scans for a value in a list and returns the index if the value is found, 1-based.
- LOOKDOWNZ** Scans for a value in a list and returns the index if the value is found, 0-based.

##### LOOKUP Functional Syntax:

LOOKUP(index: cexp0..cexp1, cexp2, etc.)

**Description:** Returns constant expression indexed by “index” (with 1 as first index), else 0 if out of range. Note “cexp?” is a “constant expression evaluated at execution time.”

##### LOOKUPZ Functional Syntax:

LOOKUPZ(index: cexp0..cexp1, cexp2, etc.)

**Description:** Returns constant expression indexed by “index” (with 1 as first index), else 0 if out of range. Note “cexp?” is a “constant expression evaluated at execution time.”

**Comments:** Both lookup functions are used to look up a value indexed by “index,” either 0-based indexing or 1-based indexing.

**Example 1:** Maps the integers 1,2,3,4,5 to 7,6,4,5,4.

```
repeat i from 1 to 5
  value := LOOKUP(i: 7,6,4,5,4)
```

**Example 2:** Maps the integers 0,1,2,3,4 to 7,6,4,5,4.

```
repeat j from 0 to 4
  value := LOOKUPZ(j: 7,6,4,5,4)
```

### LOOKDOWN Functional Syntax:

LOOKDOWN(value: cexp0..cexp1, cexp2, etc.)

**Description:** Returns the offset (1-based indexing) of the “value” if found in the list of constant expressions, 0 otherwise.

### LOOKDOWNZ Functional Syntax:

LOOKDOWNZ(value: cexp0..cexp1, cexp2, etc.)

**Description:** Returns the offset (0-based indexing) of the “value” if found in the list of constant expressions, 0 otherwise.

**Comments:** Both the lookdown functions basically look for the “value” in the list of constant expressions, if “value” is found, then the 0- or 1-based index of the location is returned.

**Example 1:** Look for location of 5 in list, 1-based lookdown.

```
index := LOOKDOWN(5: 10,3,19,90,4,-5,5,1,2,3) ' returns 7 since "5" is located 7th
                                                in the list.
```

**Example 2:** Look for location of 90 in list, 0-based lookdownz.

```
index := LOOKDOWNZ(90: 10,3,19,90,4,-5,5,1,2,3) ' returns 3 since "90" is located
                                                3rd in the list.
```

#### 15.4.11.4 Memory Movement and Filling

The following functions are used to move, copy, or fill memory. They all operate with memory addresses or pointers to main memory, thus all addresses must be in range from 0 to 64K-1 for source addresses, 0 to 32K-1 for destination addresses.

<b>BYTEFILL</b>	Fills a region of memory on BYTE boundaries a BYTE at a time.
<b>WORDFILL</b>	Fills a region of memory on WORD boundaries a WORD at a time.
<b>LONGFILL</b>	Fills a region of memory on LONG boundaries a LONG at a time.
<b>BYTEMOVE</b>	Moves BYTES from one location to another a BYTE at a time.
<b>WORDMOVE</b>	Moves WORDs from one location to another a WORD at a time.
<b>LONGMOVE</b>	Moves LONGs from one location to another a LONG at a time.

#### BYTEFILL/WORDFILL/LONGFILL Functional Syntax:

```
BYTEFILL(start_addr, value, count)
WORDFILL(start_addr, value, count)
LONGFILL(start_addr, value, count)
```

Where,

**start\_addr** = 16-bit starting address, must be BYTE, WORD, or LONG aligned depending on fill.  
**value** = Value to fill memory with; must be BYTE, WORD or LONG depending on fill.  
**count** = Number of "words" to fill of appropriate size.

**Description:** The functions all simply fill memory starting at the given address (0 to 32K -1). Each respective function fills on either BYTE, WORD, or LONG boundaries, one BYTE, WORD, or LONG at a time. Also, "count" always refers to the "word" size, so "count" in BYTEFILL( ) means how many BYTES to fill, "count" in LONGFILL( ) means how many LONGs to fill, etc.

**Example 1:** Fill a string with ASCII "A"

```
BYTEFILL(string_ptr, "A", 80)
```

**Example 2:** Zero out a region of 1024 BYTES, which we know to be on a LONG boundary, as fast as possible.

```
LONGFILL(mem_ptr, $00_00_00_00, 256) ' notes count = 256 LONGs which is 1024 BYTES
```

**BYTE/WORD/LONGMOVE Functional Syntax:**

```
BYTEMOVE(dest_addr, source_addr, count)
WORDMOVE(dest_addr, source_addr, count)
LONGMOVE(dest_addr, source_addr, count)
```

Where,

**source\_addr** = 16-bit source address of memory to move from, must be BYTE, WORD, or LONG aligned depending on fill.

**dest\_addr** = 16-bit destination address of memory to move to, must be BYTE, WORD, or LONG aligned depending on fill.

**count** = Number of "words" to move of appropriate size.

**Description:** The functions all simply move memory from a source address (in the range of 0 to 64K-1) to a destination address (in the range of 0- to 32K-1). Each respective function moves either BYTEs, WORDs, or LONGs one BYTE, WORD, or LONG at a time. Also, "count" always refers to the "word" size, so "count" in BYTEMOVE( ) means how many BYTEs to move, "count" in LONGMOVE( ) means how many LONGs to move, etc.

**Example:** Copy stringA to stringB assuming the length of stringA is 25 characters

```
BYTEFILL(@stringB, @stringA, 25+1) ' this +1 is to copy the NULL terminator
```

**15.4.11.5 String Functions**

The next set of functions are string "helper" functions. For more complex string handling, you must write an object or library yourself.

**STRSIZE**      Computes the length of an ASCII-Z (NULL-terminated string).

**STRCOMP**      Compares two strings together alphanumerically and returns result.

**STRSIZE Functional Syntax:**

```
STRSIZE(string_ptr)
```

**Description:** Computes the length of a string by scanning for a NULL (0) terminator then returns the length of the string (not counting the NULL terminator).

**STRCOMP Functional Syntax:**

```
STRCOMP(stringa_ptr, stringb_ptr)
```

**Description:** Compares **same size** NULL-terminated strings and returns if they are equal or not, TRUE or FALSE respectively.

**Comments:** The strings must be pointers or addresses of the actual strings, remember there is no "string" type.

**Example 1:** Compute the length of the string.

```
length := STRSIZE(@andre_string) ' length will equal 5 after call  
DAT  
  andre_string BYTE "ANDRE", 0
```

**Example 2:** Compares input string to "STOP"

```
VAR  
  BYTE input_string[80] ' used to hold input  
. .  
if (STRCOMP (@input_string, @stop_string)==TRUE)  
  {do work}  
. .  
DAT  
  stop_string BYTE "STOP", 0
```

**15.4.11.6 Waiting Functions**

The next class of functions are the "**waiting**" functions that are used to wait for external **or** internal events, either I/O events or timer/clock events.

<b>WAITPEQ</b>	Waits for the I/O port pins to equal a specific pattern.
<b>WAITPNE</b>	Waits for the I/O port pins to not be equal to a specific pattern.
<b>WAITCNT</b>	Waits for the global counter.
<b>WAITVID</b>	Waits for the video streaming hardware to pick up next block of colors and pixels.

**WAITPEQ/WAITPNE Functional Syntax:**

```
WAITPEQ(value, bit_mask, port)
WAITPNE(value, bit_mask, port)
```

Where,

- Value** = 32-bit value to compare port inputs to.
- bit\_mask** = 32-bit mask to AND value with.
- Port** = Indicates which port to use; 0=Port A, 1=Port B.

**Description:** The WAITPEQ( ) and WAITPNE( ) functions respectively are used to “wait” for a specific value at the I/O port input P31..P0. Currently, the port must always equal 0, or Port A since Port B is for the 64-bit I/O part.

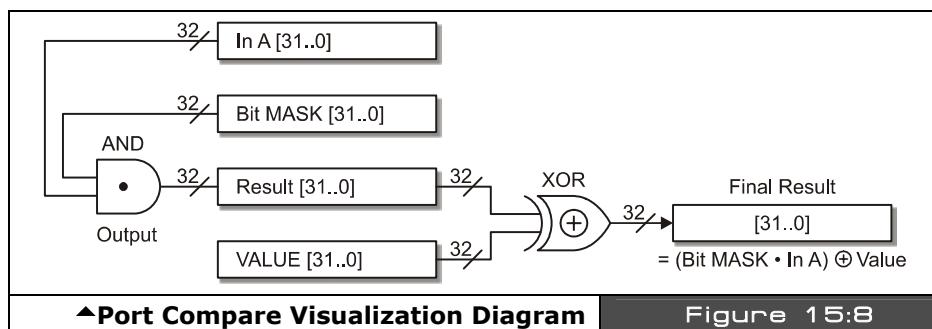


Figure 15:8

Figure 15:8 illustrates the mechanics of the wait function's masking and comparison. In essence, first the bitmask is AND'ed with the input Port A bits, this masks the bits of interest, then this result is compared to value using an XOR operation, the result of this operation is wherever the bits are the **same** the result of the XOR will be 0's, wherever the bits are different, the results are 1's, thus the outcome of all this **is 0** then WAITPEQ( ) exits while WAITPNE( ) waits until the result is **non-0**. Therefore, WAITPEQ( ) is programmatically equivalent to:

```
repeat while ((value ^ INA) & bit_mask)      ' where ^ is XOR and & is bitwise AND
```

...and WAITPNE() is equivalent to:

```
repeat while !((bit_mask & INA) ^ value)    ' where ^ is XOR and & is bitwise AND
```

**WAITCNT Functional Syntax:**

WAITCNT(count)

**Description:** The WAITCNT( ) function *waits* until the counter *reaches* the value of "count," it **does not** count down from "count."

**WAITVID Functional Syntax:**

WAITVID(colors, pixels)

Where,

**colors** = Is a 32-bit number that represents the 2 or 4 "color" BYTES as described in the text earlier, these might be NTSC/PAL values or VGA values, etc. It's **these** "colors" that are referenced by "pixels." In 2-color mode, pixels represents 32-pixels and accesses the first 2 "color" BYTES in the "colors" parameter, in 4-color mode, each pair of 2 pixels in the "pixels" parameter represents one the 4 color "BYTES" in the 32-bit "colors" parameter.

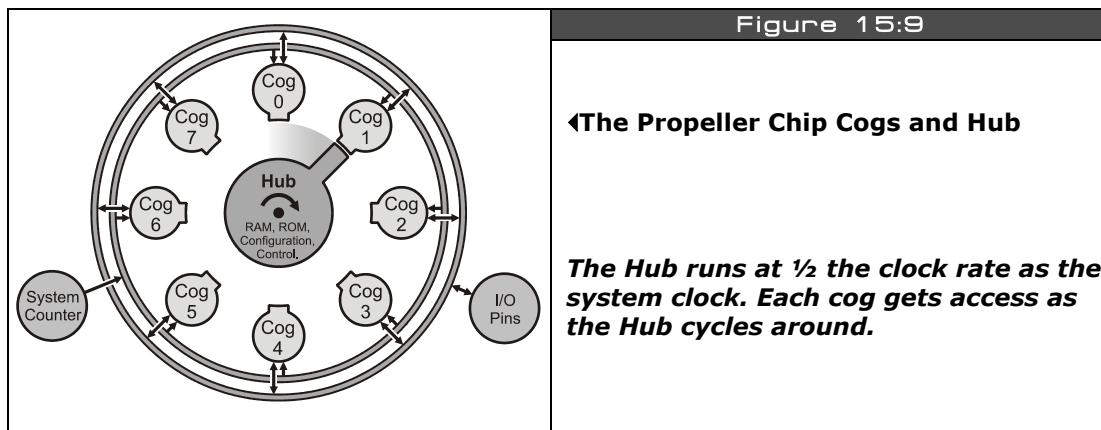
**pixels** = 32 bits that represent the pixels to be streamed out by the VSU to either the NTSC port or the VGA port. The streaming occurs at a rate set up in the VSCL (video scale register) and VCFG (video configuration register) and depending on the mode of operation set in the VCFG registers, either 1 bit at a time or 2 bits at a time represent a "pixel," in either 2 or 4 color mode respectively, and these "pixels" index into the "colors" parameter for the final color BYTE to be streamed.

**Description:** The WAITVID( ) function waits/blocks until the VSU (video streaming unit) needs more colors and pixels, takes them and then returns. The function is nearly useless in Spin since Spin is too slow to "feed" the VSU, but technically the function does work and will wait the first time, chances are by the next time you go and get ready for another pass, the VSU will be many lines down the screen!

**Example:** Wait until Port bits P3..P0 are equal to 9.

```
WAITPEQ ($00_00_00_09, $00_00_00_0F, 0)      ; enable lower 4-bits only with mask
                                                ; $F, compare to $9
```

## 15.5 Spin and Multiprocessing



Multiprocessing and parallel programming are a huge subject and something for you to research on your own. There are numerous books about the subject and internet is full of information. I suggest the following reading on the subject (one is a general college text, one is a more Windows-specific text):

**"Introduction to Parallel Programming"** by Steven Brawer

**"Multithreading Applications in Win32, The Complete Guide to Threads"**  
by Jim Beveridge & Robert Weiner

And here are a few links on internet to some interesting articles (read the last one and that's pretty much all you need):

[http://www.mhpcc.edu/training/workshop/parallel\\_intro/MAIN.html](http://www.mhpcc.edu/training/workshop/parallel_intro/MAIN.html)

<http://library.lanl.gov/numerical/bookf90pdf/chap222f9.pdf>

[http://www.llnl.gov/computing/tutorials/parallel\\_comp/](http://www.llnl.gov/computing/tutorials/parallel_comp/)

In any case, I want to briefly discuss the multiprocessing on the Propeller chip and what you need to consider when programming it. The rest you will learn as you go, or you will die and be crushed by enormous gravitational anomalies, the choice is yours. However, I strongly suggest you re-modulate the deflector output to 23.54653434 Tera-Hz and divert power from the impulse drive to the forward shields.

As shown in Figure 15:9, the Propeller chip has 8 processing cores called “cogs,” each cog is identical and has 512 LONGs of local storage (where 16 LONGs are internal registers used by the cog). Each cog can run completely independently on its own data and program, thus the Propeller chip is what’s called a MIMD machine (**M**ultiple **I**nstruction **M**ultiple **D**ata), which is the most flexible and most common parallel processing architecture. Additionally, there are SIMD (**S**ingle **I**nstruction **M**ultiple **D**ata) as well as other bizarre variants. The idea of parallel processing on the Propeller chip is to keep things “simple” and not get into or to avoid altogether the problems of parallel processing in general. To that end, we are going to use the cogs in more of a “task” based parallel processing, in other words, one cog is going to do sound, one is going to do video, another might handle I/O and so forth. We are NOT going to try and “parallelize” single algorithms, this is for high-end parallel computing and something for you to explore on your own.

What we are concerned with is how to “approach” running multiple tasks on a Propeller chip and communication between them. As noted, the Propeller chip has a total of 64K of shared memory, 32K of it is ROM and the other 32K of it is RAM (loaded on boot) from the IDE or a EEPROM with a 32K image of the programs to load into the Propeller chip. On boot, Cog 0 always gets control, loads the Spin interpreter, and then execution starts there. \

Now, here is the important part: on boot, Cog 0 gets control, that is, Cog 0 **always** loads the Spin interpreter into its 512 LONGs of local memory space and **then** starts executing your program’s 1st line of code which is **always** Spin code – always. Now, from this point your main program can always call on “objects” which are simple external files that contain programs; these programs may or may not spawn more cogs, so don’t equate “objects” with multiprocessing. Objects are simply containers for programs, nothing more. In any case, we will see exactly how to start other cogs and run either Spin or ASM with them, but for now let’s talk about how cogs talk.

### 15.5.1 Communication between Cogs

There is no communication API for inner-cog communications per se, communication between cogs is handled by you, the programmer using a “**shared memory**” paradigm. However, there is a resource “locking” mechanism that will help you build programs that have “critical sections” and create parallel tasks that must wait for each other.

Both ASM and Spin support these locking instructions, they are:

- LOCKNEW** Checks out the next available lock from the HUB and returns the ID 0-7, if there is no available lock then the function returns -1.
- LOCKRET(id)** Returns the lock referred to by ID to the HUB's inventory, returns nothing.
- LOCKSET(id)** Sets the lock referred to by ID to 1, and returns the lock's prior state 0 or 1.
- LOCKCLR(id)** Clears the lock referred to by ID, and returns the lock's prior state 0 or 1.

**Note:** On startup all locks are checked in, and cleared to 0.

In brief, to refresh you memory locks are single bits (8 of them) that can only be accessed by one cog at a time, therefore, the hardware guarantees that no two cogs can access a lock at once, thus locks can be used by cog programs to create various resource synchronization schemes. A lock is basically a "*binary semaphore*."



#### NOTE

The assembly language versions are listed in the ASM instruction table and have the same functionality. An in-depth discussion of the functionality is in the Hub Instruction / Lock Usage section, please refer to that.

Locks can help you synchronize multiple cogs with any resource. For example, you might have a device connected to some I/O port, then you have 4 different cogs that are all running various I/O programs that want this resource. You come up with the convention that all 4 cogs are going to use Lock 0, the moment Lock 0 becomes "set" then the resource is in "use" and the other cogs must "wait" for it, they can continue working and try and again later for the resource or just sit and wait. Algorithmically, all the cogs would have nearly identical code, something like:

**Example 1:** Using Lock 0 to synchronize access to some resource, low-level method.

```
' wait until resource is available
repeat while (LOCKSET(0)==1)

' at this point LOCKSET(0) returned 0, so the last cog using the resource has
' released it. Additionally, the actual call to LOCKSET(0) set Lock 0 to 1, thus
' we do NOT need to set it ourselves.

' do work with shared resource...
```

```
.
;
; now release the lock
LOCKCLR(0)
```

Most of you will never use locks in a game program, since each cog is going to be doing something completely different (video, audio, input, logic) and they rarely will need to share an outside resource. The only "resource" you might find necessary to share is main memory itself. This can be very complex in a parallel programming system, but the Propeller chip uses a "round robin" hub as discussed before which cycles around every 16 clocks to each cog and gives it access to main memory, thus there is no possibility for any two cogs to ever access memory at the same time. However, the downside to this is that that maximum bandwidth to access main memory is one read/write per 16 system clocks; since you only get one read/write operation per turn and then the hub moves on, the 32K shared memory has 1/16<sup>th</sup> the speed of your local 512 LONGs of cog program memory.

### **15.5.1.1 Sidebar Discussion: Using Locks, Two Methodologies**

In the example above we didn't "check out" a lock, we simply "agreed" to use Lock 0 and coded our tasks to all assume this. This is the low-level way of doing things or more advanced method for programmers that want to handle all the details. However, the high-level way of doing things is to use the LOCKNEW( ) and LOCKRET( ) functions to "check out" and "check in" locks. The idea here is that at the start of your master task you will check out a lock with LOCKNEW( ) then pass the returned lock to all the tasks that start new processes as a parameter, or maybe you might store it in a global.

The idea is to either pick one methodology or the other, do not mix them. Either do all the lock selection yourself or use the LOCKNEW( ) / LOCKRET( ) functions. The reason of course is if you use a lock there is no way to tell the lock system that it's in use, thus if another task makes a call to LOCKNEW( ), it's possible that your manually allocated lock might be given to the caller as a free lock and disaster would strike!

### **15.5.2 Accessing Shared Memory**

In Spin, accessing shared memory occurs whenever you define any VARs, DATs, LOCALs, or PARAMETERS (greater than 7), in general all Spin program memory is in the shared memory, thus very slow, so watch out!

Summing up, the idea of the Propeller chip is to do coarse-grained multiprocessing in a really simple way, not in a complex way, so you can't read/write memory at the same time by the simple fact the hub won't allow it. Moreover, if you do find you need to synchronize all cogs to some event or share a resource then you can employ locks.

### 15.5.3 Starting Cog Tasks

In both ASM and Spin there are a similar set of cog task control instructions. We are going to focus on the Spin-related syntax for now. The cog manipulation functions allow you to start new cogs and have them run Spin functions or ASM programs, it's all pretty cool, and relatively simple for the most part. First, here are the primary functions themselves.

<b>COGNEW(addr, ptr)</b>	Selects the next available cog and runs the code located at addr with parameters located at address ptr; there are two variants of this function. Returns cog new task runs on, -1 otherwise.
<b>COGINIT(cog_id, addr, ptr)</b>	Same as COGNEW, but forces the cog selected with cog_id (0..7) to stop and start with the new code described by addr and ptr.
<b>COGSTOP(cog_id)</b>	Stops the cog identified by cog_id.
<b>COGID</b>	Returns the ID (0..7) of the cog running where the call was made.

#### COGNEW Functional Syntax:

**Variant One:** When launching a cog with a Spin function from Spin itself:

COGNEW(function\_name(parm1, parm2,...,parmn), stack\_ptr)

**Variant Two:** When launching an ASM program from Spin:

COGNEW(entry\_addr, par\_ptr)

Where,

**function\_name(parm1, parm2,..., parmn)** = The function that you want the launched cog to start executing from.

**stack\_ptr** = A pointer to start of the "stack" space in main memory to be used by the task launched on the new cog.

**entry\_addr** = Points to the ASM language program's entry point in main memory load into the cog and execute.

**par\_ptr** = Points to the address of the parameter area that you want to relay to the ASM program launched on the cog and accessed in ASM via the PAR symbol.

The COGNEW( ) function is a bit complex since it has two "forms." In general COGNEW( ) is always used to start up a new cog with a task of some sort (either Spin or ASM code). However, the task might be a Spin function or some ASM. If the task is Spin code then what happens is the cog is launched, the Spin interpreter is loaded into the cog, then the cog starts running your code. So if its desired to run more Spin code on another cog then what you do is literally place the name of the function you want to run on the other cog as the first parameter to the COGNEW( ) function (function name, parens, and parameters, the whole thing) along with a pointer to the "stack" the cog will use. The stack space is more or less a pointer to memory that you set aside for that cog. Every cog no matter what needs some unique stack space to store the activation records for each function call, along with all math temporary variables needed during expression analysis. For example, if you launch another cog with some Spin function, and you know that that Spin function is going to make 8 calls deep and each call is going to have a total of 8 parameters and 8 local variables, then that means that each function call will need 16 LONGs, at worst case it will go 8 deep for a total of 128 LONGs, and then throw in a few LONGs for math expression analysis and you might come up with a stack of 136 LONGs. This is an extreme case, but the point is that EVERY single cog needs its own stack, large or small, but it still needs it, and you MUST pass the address to this stack, we will see how to do this later though.

If you use the COGNEW( ) function to start a cog with an assembly language program then something entirely differently happens. The COGNEW( ) function is passed the entry address of the assembly code in entry\_addr, along with the location in main memory of the parameters for the ASM function in par\_ptr which is then accessible in ASM with the PAR symbol. Now, there are a number of subtle differences when starting a cog with ASM. First, unlike starting a cog with Spin, there is no interpreter loaded when you run ASM on a cog, the COGNEW( ) function simply copies the ASM code right out of main memory into the 512 LONGs of register space for the cog that gets the task, that's it, there is no interpreter etc. Therefore, the first constraint is that all ASM tasks must be 512 LONGs or less, in fact, they must be 512–16 LONGs since the last 16 LONGs in a cog's address space are for the cog registers, so all ASM programs must be relatively small.

The second thing is that typically you want to access some Spin code's variables or parameters from ASM; this is what the par\_ptr is for. When you use COGNEW( ) to launch your ASM task, you send the address of parameters you want to communicate through, which are typically defined in a VAR section of Spin code in the program file that launches the cog with the ASM. This way, the ASM knows where to place results in the main memory. It is a bit tricky how this mechanism works, so we will look at it later in the example programs, but for now the bottom line is that when launching ASM code from Spin, we use the entry point address along with a pointer to the parameter passing area in main memory as the parameters to the COGNEW( ) function call.

**COGINIT Functional Syntax:**

**Variant One:** When launching a cog with a Spin function from Spin itself:

```
COGINIT(id, function_name(parm1, parm2,...,parmn), stack_ptr)
```

**Variant Two:** When launching an ASM program from Spin.

```
COGINIT(cog_id, entry_addr, par_ptr)
```

Where,

**function\_name(parm1, parm2,..., parmn)** = The function that you want the launched cog to start executing from.

**stack\_ptr** = A pointer to the start of the “stack” space in main memory to be used by the task launched on the new cog.

**entry\_addr** = Points to the ASM language program’s entry point in main memory load into the cog and execute.

**par\_ptr** = Points to the address of the parameter area that you want to relay to the ASM program launched on the cog and accessed in ASM via the PAR symbol.

**cog\_id** = The ID of the cog to run the task on, overrides any task running on the cog with the same ID.

The COGINIT( ) function is identical to the COGNEW( ) function, has both variants, but COGINIT( ) has one more leading parameter – the cog ID cog\_id (0..7). Also note sending a -1 will select the new available cog, that is, the function then has the same behavior as COGNEW. COGINIT( ), rather than finding the next available cog to run your task on, allows you, the caller, to define the ID of the cog you want the task started on. Moreover, if something is running on the requested cog, then it’s terminated and left to “hang in the wind,” so watch out!

**COGSTOP Functional Syntax:**

```
COGSTOP(cog_id)
```

**Description:** COGSTOP( ) terminates the task running on the cog with cog\_id (if there is one), return nothing.

**COGID Functional Syntax:**

```
COGID
```

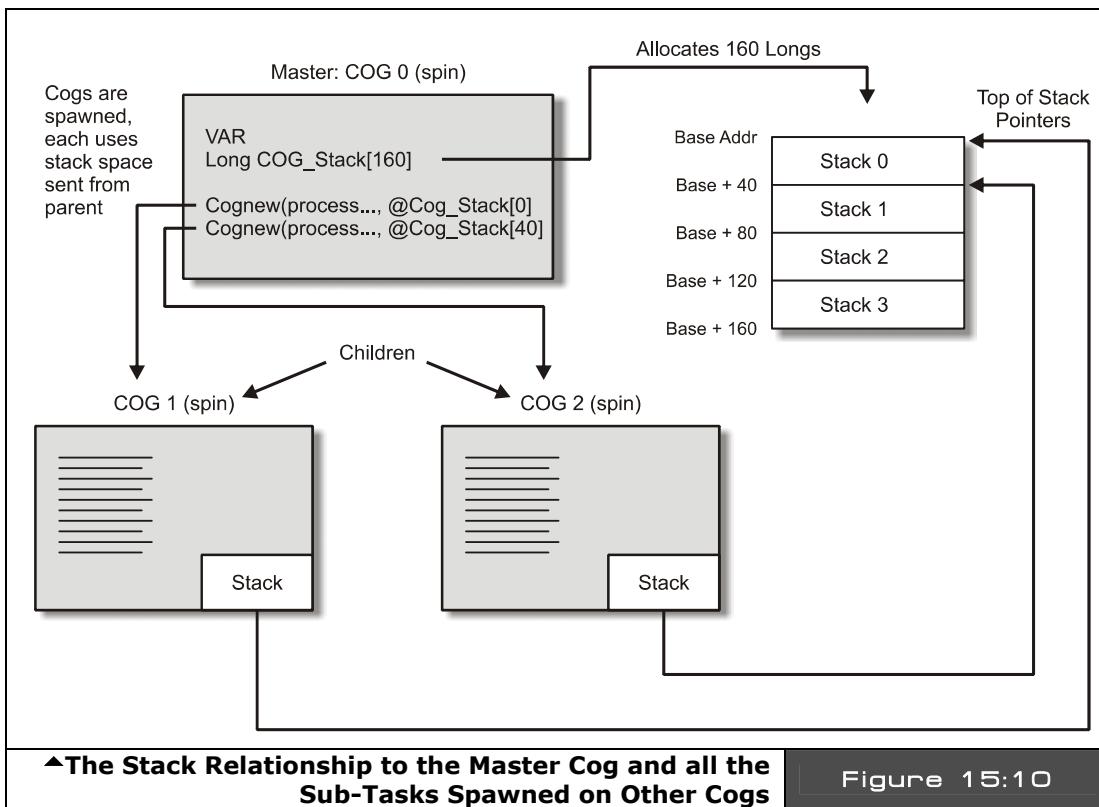
This is a “self” identification function, when running in a multiprocessor system, a task might want to know its own ID; use this function to determine this, it returns 0..7 (the ID of the cog it’s called on).

When launching another cog that is going to run Spin code, you must give the new task some stack space. This stack space must be in a region that you know is safe, there are a number of ways to do this, but in general you can create some stack space in the VAR section and then reference it when you launch the cog. For example, say from your master process you were going to launch 4 more tasks that are going to run Spin code. Also say that you have done some rough calculations and there will never be more than 8 locals or params per function call, and the depth of function calls per task won’t exceed 4. Therefore, you might need  $4 \times 8 = 32$  LONGs to handle function calls and activation records, then throw in another 8 LONGs assuming some of your math expressions might need up to 8 temps. This makes for a total of 40 LONGs per task on each cog, thus you might create this stack in the VAR section like this:

```
VAR
cog_stack[40*4]      ' set aside 40 LONGs per each task running on each new cog
```

Then when you launch each cog task, you use a function and an address to the stack space you have set aside, for example, say the function that you are going to run on each cog starts at “Parallel\_Process” and has no parameters, then you might write:

```
' from master cog spawn each new task on a new cog
COGNEW(Parallel_Process, @cog_stack[0] )      ' launch cog running "Parallel Process"
                                                ' and 40 LONGs of stack
COGNEW(Parallel_Process, @cog_stack[40] )      ' launch cog running "Parallel Process"
                                                ' and 40 LONGs of stack
COGNEW(Parallel_Process, @cog_stack[80] )      ' launch cog running "Parallel Process"
                                                ' and 40 LONGs of stack
COGNEW(Parallel_Process, @cog_stack[120] )     ' launch cog running "Parallel Process"
                                                ' and 40 LONGs of stack
```



▲The Stack Relationship to the Master Cog and all the Sub-Tasks Spawning on Other Cogs

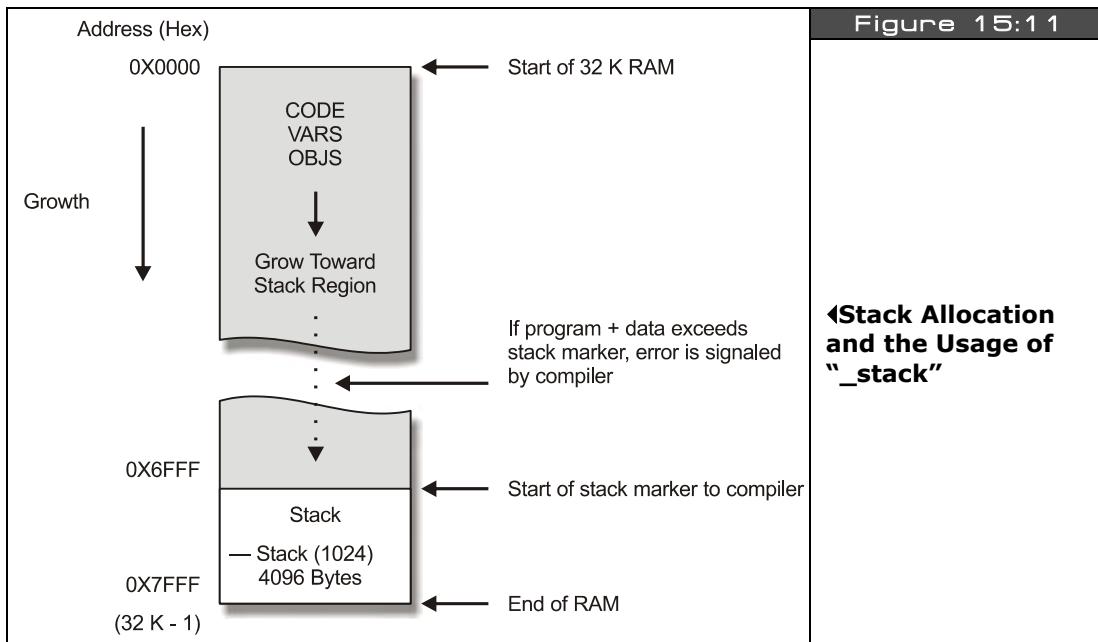
Figure 15:10

Figure 15:10 illustrates the relationships between the stack space pre-allocated in the VAR section of the master cog along with the tasks that are started on the other cogs. Some things to remember: each cog runs the same function in this case, starting at the address "Parallel\_Process," note that we do not need to put the "@" operator in front of the function name as the compiler knows to do this. Secondly, the VAR section allocation of cog\_stack[ ] is absolute, that is, the address of it is the same for all cogs since they all use a shared memory, this makes things easier. The master process allocates the memory so nothing else will step on it, then each of the cogs is given a region of this as "stack." We could also do a more low-level stack allocation by using the "\_stack" keyword, let's discuss this a moment.

#### 15.5.4 Allocating Stack Space

Although we haven't discussed this at all, and it's somewhat appropriate to discuss in the "objects" section, we might as well cover it here as well. In Spin, you need a stack just like any other HLL; additionally, just like any other compiler you can tell the compiler how much to allocate to stack space and if the compiled code and data exceed this value the compiler

throws an error. If you don't indicate any hints to the compiler about stack space then the compiler will grow the code and data potentially too large without warning you.



In Spin, the stack always starts after the entire binary image of all the Spin, ASM, DAT, and VAR data and then grows toward the end of RAM memory at address 32K-1 or \$7FFF. The stack is always LONG-aligned and each element of the stack is a LONG. Now, let's say that you know you are going to do some heavy recursion or whatever and you need a stack of 1024 LONGs, then you tell the compiler this in the CON section with the `"_stack"` keyword, note the value always refers to the number of LONGs not BYTES:

```
CON
  _stack = (1024)      ' tell compiler to set aside 1024 longs
                      ' (4096 bytes) minimum for stack
```

Now, all this does really is set a lower limit from the top of memory, that is, at  $(32K - 4096)$  there is a marker. If the total memory allocation for all your compiled program plus data is greater than this number  $(32K - 4096)$  then the compiler flags an error. Figure 15:11 shows the stack allocation and compiler directive `"_stack"` in action. Alright, now let's see a couple examples of spawning tasks on other cogs in Spin.

### 15.5.5 Execution Dynamics

Although we haven't spent a lot of time writing complete programs, there are a couple of cog-related items I want to review before getting to the example demos. The first is that all Spin programs start at the first PUB encountered in the program. If there are multiple files involved (a program with objects) then the first PUB encountered in the "top level" file is executed. Now, that being said, there are a couple of interesting details to discuss now that we are talking about cogs and parallel programming. The first interesting fact is that if you have a Spin program running on a cog that consists of something like this:

```
PUB Start  
' .. do work  
  
repeat while TRUE ' this is an infinite loop
```

...the interpreter will run this code on a cog, do whatever "work" there is; I/O, etc. and then hit that last line which is an infinite loop for all intents and purposes, thus the interpreter will continue interpreting code and the cog will stay online consuming power and maintaining any counters, I/O states, etc. that you set up. On the other hand, what if you have a program like this?

```
PUB Start  
' .. do work  
  
PUB Foo  
' ..do work
```

In this case execution will start at "Start" and the work will be done, but then when the interpreter gets to the end of the body of "Start" it will not start executing "Foo," no one called "Foo," thus the interpreter will shut down the cog, power it down, and all internal working including counters and I/O will turn off! Therefore, if you don't put some code at the end of the main line and just let it end, the cog will turn off. This may be absolutely the intent, that is, the startup cog runs some initialization code, then launches some other cogs, then you want it to shut down and become available for other tasks OR you might want the cog to continue to stay running since you have some I/O states that are important, thus you will need an infinite loop at the end of the main line or some other looping construct to keep the cog alive. With that all said, let's finally see some examples! As a demo of parallel programming, I have created a demo that spins two cogs; each blinks the LED at its own rate, this results in a "fluttering" effect. The code for the demo is located on the CD here:

**CD\_ROOT:\HYDRA\SOURCES\PARALLEL\_BLINK\_010.SPIN**

**Example 1:** Start code on Cog 0 by default then launch 2 more cogs with blinking light tasks.

```

CON

    _clkmode = xtal1 + pll4x          ' enable external clock and pll times 4
    _xinfreq = 10_000_000             ' set frequency to 10 MHZ
    _stack   = 40                   ' accomodate display memory and stack

VAR

    long  blink_stack[20]           ' allocate 20 longs for the task stack

'/////////////////////////////////////////////////////////////////
PUB Start
{ this is the first entry point the system will see when the Propeller chip
starts, execution ALWAYS starts on the first PUB in the source code for the top
level file }

' spawn 2 cogs each with the Blink function and some stack space
COGNEW (Blink(5_000_000), @blink_stack[0])
COGNEW (Blink(1_500_000), @blink_stack[10])

'sit in infinite loop, that is do not release COG 0
repeat while TRUE

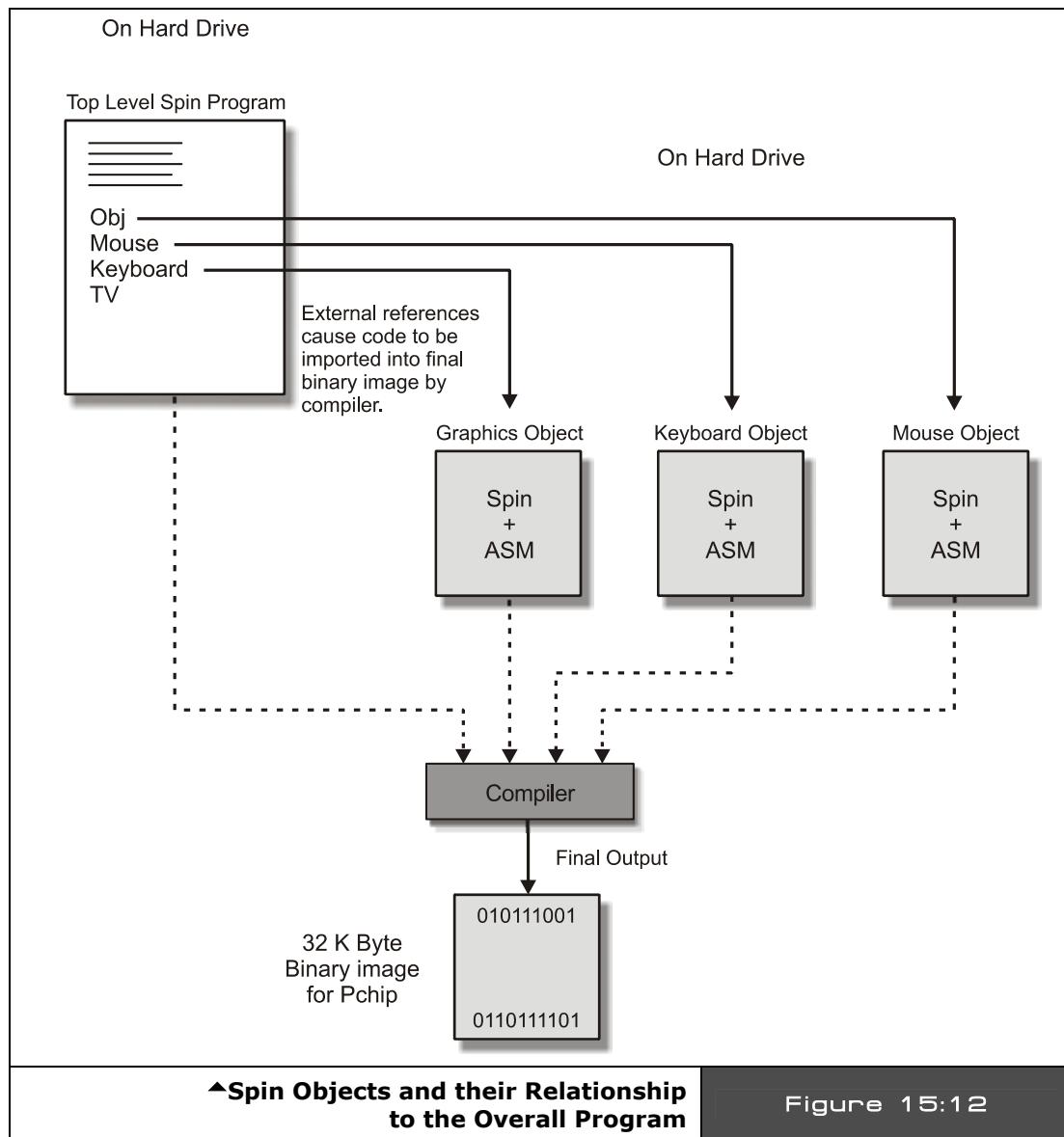
'/////////////////////////////////////////////////////////////////
PUB Blink(rate)
{ this is the parallel function, it simple blinks the debug LED on the HYDRA, note
is must set the direction output and then falls into an infinite loop and turns
the LED on / off with a delay count. The interesting thing to realize is that the
"rate" is sent as a param when we launch the cog, so there will be 2 cogs running
this SAME infinite loop, but each with a different blink rate, the results will be
a blinking light that has both one constant blink rate with another super-imposed
on it }

DIRA[0] := 1

repeat while TRUE
    OUTA[0] := !OUTA[0]
    waitcnt(CNT + rate)

```

## 15.6 Spin Objects



Spin is not an object-oriented language in the usual sense of the word. But, Spin allows some "OO" techniques in as much as we can simulate some OO behaviors such as some organizational techniques at very least. Spin does have the ability to bring in code from other modules named "objects," execute the object's functions using a dot "." Operator as well as access the objects CON section using a "#" operator. You could think of the object name as a namespace and the dot operator "." calls the function from that namespace while the "#" operator allows access to CONstants defined in that sub-object. Figure 15:12 shows a simplified visualization of this. In this case, we have a main program called **GAME.SPIN** and **GAME.SPIN** relies on 4 other objects:

<b>MOUSE_ISO_010.SPIN</b>	– Version 1.0 of the isolated mouse driver
<b>KEYBOARD_ISO_010.SPIN</b>	– Version 1.0 of the isolated keyboard driver
<b>GRAPHICS_DRV_010.SPIN</b>	– Version 1.0 of the graphics engine driver
<b>TV_DRV_010.</b>	– Version 1.0 of the NTSC/PAL TV driver



#### NOTE

To refresh your memory from earlier discussions, the versioning convention for Spin system files is very simple: the last 3 digits refer to the major and minor version, 2 digits for major, one digit for minor; thus version 0.0 to 99.9 can be referred to. For example, version 3.4 would be 034, version 12.9 would be 129, and so forth.

Referring to Figure 15:12 and seeing the file's names, our main program file would include these external files as "objects" and this is done in the OBJ section of your program. An object is defined with the following syntax:

```
object_name : "object file name.spin"    ; the ".spin" file extension is assumed
                                                and not required.
```

So you simply create a name for the object, follow it by a colon ":" then by the actual filename of the object that contains the code, this must be in quotes. This creates an "instantiation" of the object; if you create another instantiation of the object with a different object\_name, they are completely unrelated, they will both have their own VAR sections, but they will share the same code. That is, the compiler is smart enough to distill redundant code into one copy of it, so there is some "smart linking" of objects that are instantiated more than once so that only one copy of the code is present and multiple copies of the data, just like in Windows. In any event, declaring the object brings in the object for use in your main program. Here's an example of bringing in multiple objects into your program, one instantiation of each:

OBJ

```
Mouse : "MOUSE_ISO_010.SPIN" ' Version 1.0 of the isolated mouse driver
Keyboard : "KEYBOARD_ISO_010.SPIN" ' Version 1.0 of the isolated keyboard driver
Graphics : "GRAPHICS_DRV_010.SPIN" ' Version 1.0 of the graphics engine driver
tv : "TV_DRV_010.SPIN" Version 1.0 of the NTSC/PAL TV driver
```

Given the code above, we have 4 objects declared in our main program with the names mouse, keyboard, graphics, and tv respectively. Now, each of these files has code in them, potentially Spin and ASM, or just Spin. However, there is one important necessity: all objects MUST have at least one Spin PUB function to "connect" with the caller. You can't just have an object with pure ASM, it wouldn't make sense, the transition from object to object occurs at the interpreter level, the interpreter is running Spin on your cog then a call to function in another object is made, thus it too must be Spin, but then once in the Spin of the other object, you can always spawn another cog with some ASM. In fact, this is what all the objects above do, if you look at the code for them on the CD here:

**CD\_ROOT:\HYDRA\SOURCES\\*.\***

You will notice that all of them enter with a "START( )" function of sorts in Spin that does some housekeeping, spawns another cog that runs the ASM driver (ASM is needed for high speed) and then returns to the caller. In any event, when you call an object's sub-function you use the syntax:

object\_name.sub\_function(parm1, parm2,...,parmn)

All that happens from the compiler's point of view is that the code for the object is compiled into the final program, and with the "." operator you can make calls to it from one file to another as long as you declare an object with the proper filename to the object you want to communicate with. There is no parallel processing, no cogs involved, nothing, the SAME cog that is running your code before the call to the object's sub-function is the same cog that executed the object's sub-function call. But here's the interesting thing: if you do want to have ASM in your object then typically what you do is have a "Start" function in the object, this start function might take a parameter or two from your main program, then you call the object's Start sub-function with the syntax (and maybe some parms):

object\_name.Start(parm1,...,parmn)

Then the cog interpreter transfers control to the Start( ) function in the object and executes whatever code is there:

```
PUB Start(parm1,..., parmn)
```

```
' ... do work
```

```
'...spawn some ASM or more Spin possibly on another cog, maybe not...
' return to caller, potentially after starting another task on a CIG
return
```

I highly recommend you study in detail the 4 driver objects listed above in the examples. See how they work. In all of them you will see the same pattern of architecture, there is a Start, Stop, Present (sometimes), and then typically a parameter is sent to the Start( ) function from the caller – this might be a pingroup or a memory address, etc. – to tell the object important information. For example, the mouse driver is relatively straightforward, let's take a look at it. These drivers are official Parallax drivers and very clean.

### 15.6.1 Example: Understanding the Mouse Driver Object

The mouse driver base version is included as an object in a main program as follows:

```
OBJ
mouse : "MOUSE_ISO_010.SPIN"           ' Version 1.0 of the isolated mouse driver.
```

Then to call sub-functions of the mouse driver, this syntax used is:

```
mouse.sub_function(parms...)
```

In our case, let's just try a couple things to get going. If you have reviewed the mouse driver code in **MOUSE\_ISO\_010.SPIN** then you see the "start( )" function, this takes a single parameter: the pingroup to communicate with the mouse on. In the design of the HYDRA the mouse pins are fixed at pingroup 2 (the keyboard on 3), but this allows the object to be used in general, thus the first rule of objects is try and make them flexible. In any event, to use the mouse the first thing we would do in our main GAME program's initialization function is to start the mouse driver by calling the object's sub-function "start" like this:

```
mouse.start(2)  ' start the mouse driver on pingroup 2 I/O's compatible with HYDRA
```

Ok, at this point, let's take a look at the actual mouse driver VAR section and the "start" and "stop" functions. I am going to cut most of the comments out, and just keep the content along with my notes; refer to the program on CD for all the original comments:

```
' Include this from the mouse driver, so you can see some of the data structures
VAR
    long  cogen, cog
```

```

long oldx, oldy, oldz      ' must be followed by parameters (9 contiguous longs)

long par_x          ' absolute x      read-only      (6 contiguous longs)
long par_y          ' absolute y      read-only
long par_z          ' absolute z      read-only
long par_buttons    ' button states   read-only
long par_present    ' mouse present   read-only
long par_pingroup  ' pin group       write-only

' //////////////////////////////// //////////////////////////////// ////////////////////////////////

PUB start(pingroup) : okay

' call stop to stop the driver it was already started previously
stop

{ Now assign the local var par_pingroup the sent parm pingroup value, this is done
so any ASM spawned from here on another cog can access it, notice all the "par"
pre-fixed vars in the VAR section? These are the parameter section that at some
point will be passed to the ASM as the address for the PAR register so the ASM can
communicate with the Spin code's VAR area, remember this is what PAR is for in the
16 registers of each cog, to communicate some address that relates to the
"parameter" area or common memory region to pass information between Spin to ASM }

par_pingroup := pingroup

{ This line of code is contrived, but more or less, what it does is start a cog
running with the ASM code located at entry point "entry" with the parameter
passing area located at @par_x. This triple assignment serves a number of
purposes, the inner most function call to COGNEW() returns a Boolean TRUE or
FALSE if a cog 0..7 came back, if a -1 came back then we are out of cogs! The
Boolean is redundantly assigned to okay and cogon for kicks. }

okay := cogon := (cog := cognew(@entry,@par_x)) >= 0

' return to caller by default

' //////////////////////////////// //////////////////////////////// ////////////////////////////////

PUB stop

' Stop mouse driver - frees a cog

' test if cogon was already set, post clear either way with the "~" operator
if cogon~
  cogstop(cog) ' stop the cog

longfill(@oldx, 0, 9) ' clear out some memory that was used, prepare for restart

```

```

' more code, then finally another DAT section with the actual ASM mouse driver

DAT

'*****
'* Assembly language PS/2 mouse driver *
'*****

        org

.

' Entry

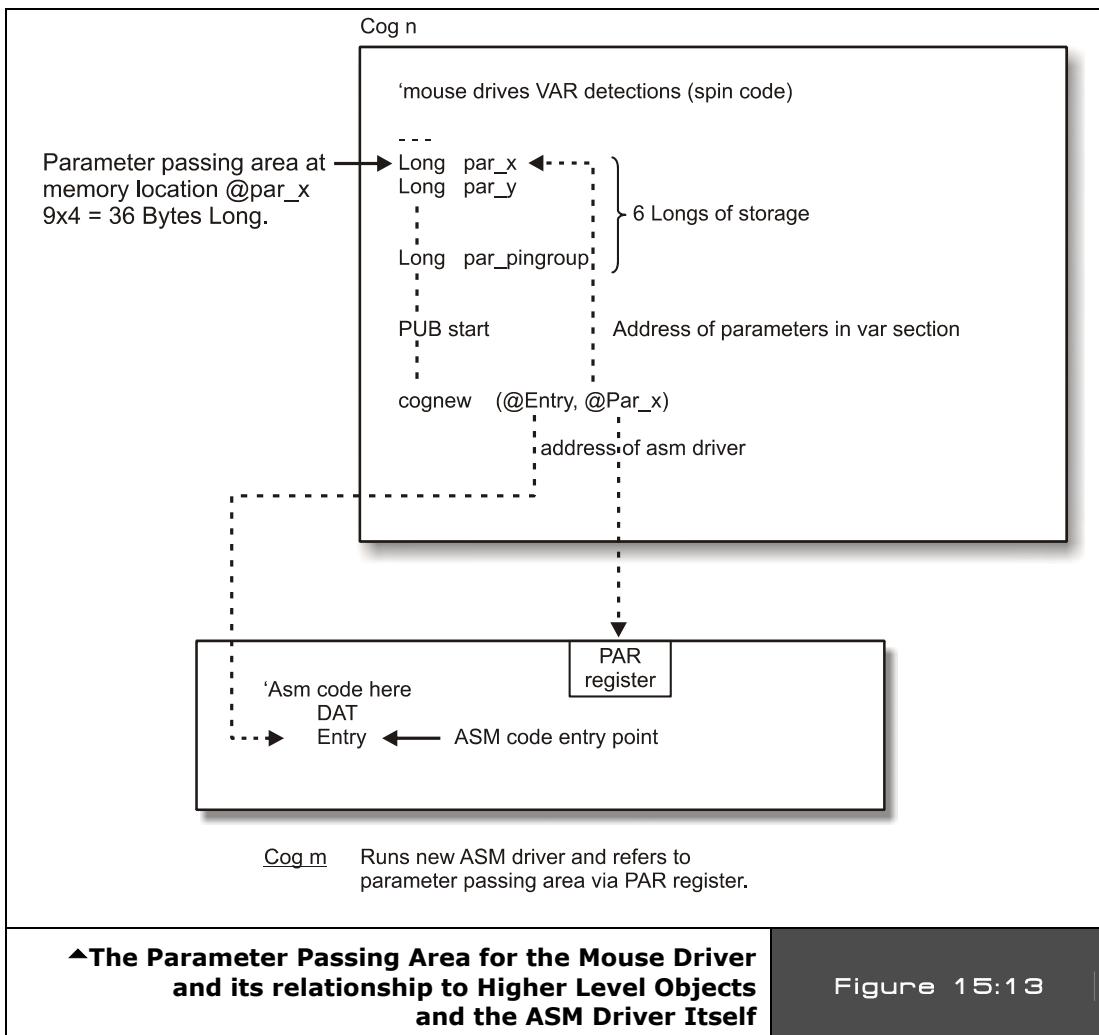
entry          mov      x,par           'load _pingroup input
parameter
                add      x,#5*4
                rdlong _pingroup,x

                shl      _pingroup,#2       'set pin masks
                mov      mask_dw,#%0001
                shl      mask_dw,_pingroup

' more asm . . .

```

The important thing to understand here is that from our main GAME program we call the mouse sub-function "start," it continues running on the current cog, then tests if the mouse driver is already running. If so, then the variable **cog** in the **MOUSE\_ISO\_010.SPIN** object file is holding the ID of the cog, so this task is terminated with a call to "stop" from the "start" sub-function, then once this housecleaning is handled then a call is made to launch a new cog with the ASM code mouse driver itself located at "@entry." Additionally, COGNEW's 2nd parm is the address of the parameter passing area that the ASM program can access with the PAR keyword, this is sent as "@par\_x" which is the first LONG in the list of parameters in the object's VAR section representing the parameter passing area. This is shown in Figure 15:13.



So to review, we import the mouse driver in our OBJ section with a named import of the filename. Then we call the "start" sub-function with the pingroup, "start" resets the driver if it's already running on another cog, then it restarts the ASM mouse driver on another cog, remembers the cog number, and then returns to the caller, the main GAME program.

Now the interesting part: as the ASM mouse driver is running on another cog, it is passing results of the mouse movements into the parameter passing area all the time (as shown in

Figure 15:13) asynchronously to what we are doing. Then, when we want to know the mouse state, we call the mouse object with a sub-function like "mouse.abs\_x" or "mouse.abs\_y" to get the absolute state of the mouse position. These functions are called from our original cog that our main GAME program was running on, and all they do is access the common parameter passing area and return the variable of interest that the ASM program is continually writing to. For example, here's the "abs\_x" sub-function in the mouse driver file:

```
PUB abs_x : ax
  '' Get absolute-x

  ax := par_x
```

Note that the assignment of par\_x to ax implies return from the function. Anyway, look at the body – there is no code! Of course not, since the work is being done on another cog that was spawned earlier, so this is really an accessor function that just bridges the gap from the calling and the ASM running on another cog via the parameter passing area.

**You can also access CONstants from your objects using this syntax:**  
**"objectname"#"constant\_name"**

For example, say that you had an object file name "weapons\_object.spin" with the following CON section:

```
CON
  ENERGY = 100
```

...and you create an object in your main program called weapon like this:

```
OBJ
  weapon : "weapons_object.spin"
```

...then to access the constant "ENERGY" you would use the following syntax from your main program:

```
weapon#ENERGY
```

In conclusion, if you are going to make objects that you want others to use they should have some kind of "start" or "init." Also if they do spawn other cogs, they should be "well behaved" and track and terminate multiple calls, so you don't restart the same driver multiple times when only one is needed.

### 15.6.2 Setting the Clock Modes

The Propeller chip can be clocked in three different ways:

- ▶ An external crystal.
- ▶ An external clock generator.
- ▶ The internal 12 MHz and 20 kHz RC clock.

To set the clock mode you use the keyword “\_clkmode” in the CON section of your program to “add” the various flag bits together to form the final clock mode control WORD; however, some control bits only make sense in some modes. For example, if you select one of the RC modes then you can’t use the PLL multiplier rates. Once you have set the clock mode up correct for external oscillator or external crystal with PLL, then you must let the Propeller chip know the actual input frequency with the “\_xinfreq” keyword. Table 15:7 shows all the mode option bits for “\_clkmode.” This is repeated from the Propeller chip discussions earlier, but more simplified for the Spin language.

Table 15:7		Clock Mode Selection Constants▼
_CLKMODE(s)	Descriptions	
<b>RCFAST</b>	Selects internal 12 MHz RC clock (used at startup until switch over to external clocking is made)	
<b>RCSLOW</b>	Select internal 20 kHz RC clock (very low power)	
<b>XINPUT</b>	Selects clock input via XI pin, used for external oscillators (the most accurate)	
<b>XTAL1</b>	Used for <b>slow</b> crystal via XI and XO pins (2 kΩ drive, 35 pF caps)	
<b>XTAL2</b>	Used for <b>medium</b> crystal via XI and XO pins (1 kΩ drive, 25 pF caps)	
<b>XTAL3</b>	Used for <b>fast</b> crystal via XI and XO pins (500 Ω drive, 15 pF caps)	
<b>PLL1X</b>	Uses PLL clock 1x (may be used with XINPUT / XTAL1 / XTAL2 / XTAL3)	
<b>PLL2X</b>	Uses PLL clock 2x (may be used with XINPUT / XTAL1 / XTAL2 / XTAL3)	
<b>PLL4X</b>	Uses PLL clock 4x (may be used with XINPUT / XTAL1 / XTAL2 / XTAL3)	
<b>PLL8X</b>	Uses PLL clock 8x (may be used with XINPUT / XTAL1 / XTAL2 / XTAL3)	
<b>PLL16X</b>	Uses PLL clock 16x (may be used with XINPUT / XTAL1 / XTAL2 / XTAL3)	

In general, we are going to use the HYDRA system which has an external crystal (XTAL), in most cases we will use the XTAL1 or XTAL2 modes for slow and medium speed crystals from 1-10MHz. Additionally, we will always scale this input speed with the PLLxx modes to arrive at our final processing clock – usually 40, 80, or 100 MHz or thereabouts.

**Example 1:** Set the clocking for an external 10 MHz oscillator, but we want a system clock of 40 MHz.

```
CON
    _clkmode = XINPUT + pll4x  ' enable external clock and pll times 4
    _xinfreq = 10_000_000      ' set frequency to 10 MHz, final clock will be 40 MHz
```

**Example 2:** Set the clocking for an external 5 MHz crystal, but we want a system clock of 80 MHz.

```
CON
    _clkmode = XTAL1 + pll16x  ' enable external clock slow and pll times 16
    _xinfreq = 5_000_000        ' set frequency to 5 MHz, final clock will be 80 MHz
```

## 15.7 A Minimal Spin Program Template

Now that we have covered much of the Spin language, its syntax, and the hardware itself, it's time to digress for a moment and talk about a minimum Spin program. That is, what at very least do you need to do something in Spin? Well, this depends!

First, if you want to use objects then you have to import them, but if you just want a "template" to start with so your programs will have structure, use something like this:

```
CON
    ' constants potentially

    ' also in this section you will define your clock mode something like this

    ' additionally you may want to define a stack, so the compiler can flag a
        ' warning if the code+data bump into it

VAR
    ' here you might have any globals that you want your program to use

OBJ
    ' here's where you import your objects and bind them to variable names

PUB
    ' you need at least ONE single PUB in your top level program

PRI
    ' you might want to have one or more private functions

DAT
    ' if you need data or ASM this is where you put it
```

Considering all this, here's the simplest program you can make on the HYDRA that does something useful, it's the LED blinker stripped to nothing:

```
CON
  _clkmode = xtall + pll8x      ' enable external clock and pll times 8
  _xinfreq = 10_000_000          ' set frequency to 10 MHZ, final clock will be 80 MHz

PUB Start
{ This is the first entry point the system will see when the Propeller chip
starts. Execution ALWAYS starts on the first PUB in the source code for the top
level file. }

' set output direction for debug LED
DIRA[0] := 1

repeat
  OUTA[0] := !OUTA[0]          ' set LED to opposite of what it was
  waitcnt(CNT + 5_000_000)     ' wait 5,000,000 clocks and continue
```

In this program, the only important thing that is a must is that the `_clkmode` and `_xinfreq` constants are set. In this case, we select the clock mode `"_clkmode"` to take the input crystal (mode 2, medium speed crystal) and then we add in PLL8X to tell the PLL to spin the clock 8x its frequency. Then the next line `"_xinfreq"` indicates the actual crystal we have plugged into the HYDRA (10 MHz most of the time).

## 15.8 Spin Tricks and Tips

The following is a list of tricks and tips that you can use when coding in Spin, they are not in any particular order.

### Trick - Default CON Section

The compiler defaults to a CON section at the start of a program, so you don't have to say CON at the top of your program if your first block is going to be constants.

### Trick - Constant Evaluation

The compiler doesn't do expression optimization or aliasing, in fact, even a simple run-time expression like:

```
x := x * 5 * 4
```

...will not be simplified by the compiler to:

```
x := x * 20
```

The compiler will actually generate BYTE code to do the following operations:

```
temp := x*5
```

```
x := temp*4
```

Therefore, as an optimization you can pre-solve constant expressions yourself or you can use the manual evaluator to "help" the compiler evaluate expressions with the CONSTANT( ) operator. The CONSTANT( ) operator will simplify any "compile time" solvable expression into a single term. So, you can write:

```
x := x *CONSTANT(4*5)
```

...and the compiler will replace "CONSTANT(4\*5)" with 20. Of course this is an oversimplified expression, but you get the idea. CONSTANT( ) also works with floating-point expressions that can be resolved at compile time as well.

### **Trick - Simulating BYTE, WORD, and LONG Pointers**

Many times when programming, you want to use the data size of BYTE, WORD, or LONG, that is 8, 16, or 32-bit data size, but you also want to use a pointer to some memory block that is "indexed" by similar size chunks. In Spin this isn't obvious how to do this when you have a simple variable that is being used as a "pointer." For example, say you have defined a pointer variable as:

```
WORD ptr;
```

Now, you can assign ptr anything you want, but if you want it to "act" like a BYTE, WORD, or LONG pointer it's a little tricky, here's the syntax to do it:

Use ptr as a LONG pointer which indexes to memory location  $\text{ptr}^*4$

```
LONG[0][ptr]
```

Use ptr as a WORD pointer which indexes to memory location  $\text{ptr}^*2$

```
WORD[0][ptr]
```

Use ptr as a BYTE pointer which indexes to memory location  $\text{ptr}^*1$

```
BYTE[0][ptr]
```

The trick here to this syntax is that we use the “base plus index” memory access mode, but put the base as 0, this way the index is always “scaled” by the type setting: BYTE, WORD, or LONG. In essence we have simulated the behavior as a BYTE, WORD, or LONG pointer, in as much as when you index it you would expect the indexing to occur on data widths equal to the type of pointer itself. In this case, though, we artificially select the scaling with LONG, WORD, or BYTE syntax.

## 15.9 Summary

This chapter has been probably the most tedious thus far, lots of information to remember, but use this chapter more as a reference, no point in memorizing all the language constructs since typically programmers only use 5-10% of a language’s syntax anyway. The main idea is to know features “exist,” you can always go back and find the exact details or syntax relating to them. Well, we are almost done with the fundamentals, next chapter we are going to run some demos, and finally its time for Part III or game programming – it’s about time!

## Chapter 16:

### Programming Examples on the Propeller Chip / HYDRA

Well, that's it, hopefully at this point you have some overall idea of what the Propeller chip does and its relationship to the HYDRA's hardware support around it. Next, we are going to look at a number of demo programs to get you started and give you something to work with. Hopefully, within hours you will have reverse engineered them all and will start making your own crazy demos. At first as noted, you should start with Spin demos only then later try some ASM, then even later try modifying the graphics driver itself and making variants of it along with the tv driver. Just make sure to use my file naming and software conventions, otherwise, you will quickly lose control of everything and start overwriting files. This chapter is more of a hands-on chapter rather than a lot of theory. Here's the general demos and code bases we are going to play with:

- ▶ Basic graphics programming
- ▶ Game controller interfacing
- ▶ Sound programming
- ▶ EEPROM primer
- ▶ Hybrid ASM/Spin programming and parameter passing

To begin with, here's is a listing of all the basic Parallax Spin drivers and files that come with the system that we will base our work on (all of these files are located in the SOURCES\ sub-directory):

<b>MOUSE_ISO_010.SPIN</b>	PS/2 Mouse driver, uses another cog when launched
<b>KEYBOARD_ISO_010.SPIN</b>	PS/2 Keyboard driver, uses another cog when launched
<b>TV_DRV_010.SPIN</b>	NTSC/PAL TV driver, uses another cog when launched
<b>VGA_DRV_010.SPIN</b>	VGA 640×480 driver, uses another cog when launched
<b>GRAPHICS_DRV_010.SPIN</b>	Graphics engine driver, is coupled to the TV driver, but still uses another cog when launched

Considering that most drivers run separately on their own cog, you can very quickly run out of cogs! So keep this in mind – it might not be wise to run everything on a separate cog. In fact, you may find it better to merge like operations into a “smart” driver, for example, a single cog driver that does keyboard, mouse, and gamepad to save processing power, etc.

You will typically include both the graphics and tv drivers with each program along with the mouse, gamepad, and keyboard drivers potentially. The following demos are simply to get you started, there is going to be a fair amount of “reverse engineering” and code analysis on your part to really understand things. I am going to give you a demo of everything important and you can use these as a starting point. Later in Part III of the book we will develop more demos, and skeleton drivers to perform higher performance graphics, sounds, and I/O. But, the drivers illustrated in this chapter are more generic and based on Parallax’s original drivers, thus we will refer to them as “reference” drivers and use them to model more specific high-performance drivers later as needed.

## 16.1 Running the Demos

For each demo there will be one or more files that make up the demo. Typically there will be a single “top level” file that might include other objects; simply run the demo from the /SOURCES directory and any other files will be loaded by the Propeller IDE that are called out in the top level file. Make sure to have your USB cable connected to your HYDRA and have the Propeller IDE up and running with all drivers installed and functioning.

## 16.2 Programming Conventions and Filenaming

The following short rules and conventions were used by myself and the various “demo” coders that developed for the HYDRA. Reviewing them will help you understand the naming conventions as well as give you a set of conventions to follow (or not) that will help you keep everything organized. Typically, you are going to develop only a few types of applications and files:

- ▶ Source code for games/demos in Spin/ASM usually
- ▶ Drivers for the Propeller chip/HYDRA
- ▶ PC Tools written in some RAD tool or C/C++/BASIC etc
- ▶ Data files

The main goal of my programming conventions is that if all the files from EVERYONE on the planet were dumped into a single directory not a single name collision would occur; this is trivial if the correct measures are taken. For example, the following are bad ideas for file names:

```
game.spin      ' terrible!
driver2.asm    ' crap!
```

```
gamestuff.dat  ' you gotta be kidding!
myobj.src      ' ya right!
```

...and so on. These names are useless in large scale software development with more than one person in the team. So we are going to use three simple tactics to create intelligent, useful, informative names:

- ▶ **Tactic 1:** All files must have a version suffix at the very end of the file name.
- ▶ **Tactic 2:** All files must have a 2-4 letter "developer/library" prefix pre-pended to them.
- ▶ **Tactic 3:** All files must have intelligent (short) names, no spaces, but underscores are okay.

### Version Suffix

We have discussed this already, but there will be a 3 digit version code on EVERY single source file. The format is:

**MMm**

The first two digits are the Major version number, the last digit is the Minor number, zeros are used if there is no digit. This format allows us to version 0.1 to 99.9, some examples are:

```
version 1.3 = 013
version 1.0 = 010
version 0.5 = 005
version 10.8 = 108
```

...and so forth. You should append the version field to the end of all file names, example:

```
tv_driver_010.spin      ' tv driver version 1.0
graphics_api_020.asm    ' graphics api version 2.0
music_files_003.dat     ' music data files version 0.3
```

...and so on.

In most cases, you will probably just use major version numbers, since minor version numbers are useless really, but they are there if you need them. Typically, all your programs will simply start with version 1.0.

### Developer "Tagging" with Code/Library Names

There are so many programmers working on so many projects that people are inevitably going to think of the same names, thus to protect your code a great idea is to "code" a unique sequence of characters into every single file name, typically at the front or end of the file name works best. This will identify the coder/library and will make collisions nearly impossible. For example, OpenGL uses "GL" in front of every function call; we are going to do the same. For example, say you want to use "Bob Brown's Game Engine" then you might use BBGE or BGE for your code, and your files would look like this:

```
BGE_asteroids_demo_011.spin ' some spin game source
BGE_tv_driver_fast_texturing_001.spin ' a spin/asm driver
BGE_table_generator_021.CPP ' some external C++ for a tool
```

These are beautiful names, they indicate the developer/library "BGE" which we know is good old Bob. Then the file names themselves are descriptive, finally there is a version code, so these will never be confused or collided with. Of course, I hope everyone can find more interesting names for the libraries. For example, "HEL" for the HYDRA Extreme Library – which is mine, so that's now taken!!!!

So every file you make has your developer prefix pre-pended to it along with the version code. This includes all HYDRA stuff as well as your PC tools, data files, whatever. We want to immediately be able to say "Bob" made that, it does this, and it's version xxx.

### Modifying Drivers

As far as core names for your games, tools, drivers, it's up to you. However, if you do decide to modify one of the "system" drivers written by Parallax, me, or Chip Gracey then please use a name that is similar since it might end up on internet and will help people figure out its origins. Additionally, in the source itself comment at the top of your source what driver it was originally based on and what general modifications you made. For example, let's say we want to modify the graphics driver **graphics\_drv\_010.spin** and remove all the text stuff, add better clipping, and support for textured triangles, then we might call the new driver:

**HEL\_FAST\_GRAPHICS\_DRV\_010.SPIN**

In this case, the name still indicates this is some kind of graphics driver, and this is the "HEL" library (which we know whose that is!) and its version 1.0 of the driver. Then in the top of the source we might find something like this:

```
{ {HEL_FAST_GRAPHICS_DRV_010.SPIN - Written by Andre' LaMothe
Last modified 1.20.06, version 1.0}
```

This new graphics driver was originally based on Parallax's default graphics driver GRAPHICS\_DRV\_010.SPIN.

I modified it to work faster, removed text support, and added texture mapping and better object space clipping.}}



**UNDER NO CIRCUMSTANCES** should you modify an original driver then release it with the same name on internet, it will cause confusion! Please make another version of a default driver and update the version name with your own tag, these files are like "original DNA" and only Parallax or myself will modify these officially.

## Deployment and Packaging

When you have completed a game or demo, another good idea is to always ZIP it up along with a README.TXT file. Also, every single file for the demo should be in the ZIP. The reason for this is the concept of a "**package**" – no one wants to hunt for a file, a version, etc. So if you always deploy your demos/games as a ZIP with everything in there that the user needs then he/she will be very happy. I almost have a hatred for open source projects since they are so unorganized, nothing ever compiles, files are missing, etc. It's like someone does all this work and then no one else can appreciate it, so take time to "package" your projects, the world will thank you. Here are some examples of how I do it:

### Example 1: Single File

Say you made a game called **HEL\_centipede\_023.SPIN** and this is the only file. Then you would create a zip and place the file in there:

**HEL\_centipede\_game\_01\_20\_06.ZIP**

The ZIP does NOT necessarily have to have the same name as the file, since you might have 100 files in there, but you do want to put the developer tag on the zip as well as a DATE code this time. Thus, when you upload another version maybe 2 days later then on the FTP we would find:

**HEL\_centipede\_game\_01\_20\_06.ZIP**  
**HEL\_centipede\_game\_01\_22\_06.ZIP**

This way we have backups and a record of all the work as well, and we can always see other previous versions. Of course, you do NOT need to include standard drivers supplied by me or Parallax, these are assumed, but anything you make must be in there.

**Example 2: Multiple Files**

Let's say that you have a game that is composed of a number of source files, a driver object, a data file, and a C++ console application:

```
HEL_raycastor_034.spin
HEL_raycastor_data_010.spin
HEL_graphics_engine3D_021.spin
HEL_data_generator_ray_010.CPP
HEL_data_generator_ray_010.EXE
readme.txt
```

Then we would take all this and package it into a single ZIP with today's date:

**HEL\_Raycaster\_demo\_01\_20\_06.ZIP**

Now, there is a lot going on in this example, we have lots of files, and things are so complex that we need a README.TXT to explain what's what. Obviously, the readme is simple enough where it doesn't need a version or date, but it should explain things a bit, so someone that opens this package doesn't have to "reverse engineer" it and immediately can read what the C++ files are for etc.

Now, let's make a single change and see what happens. So 3 days from now, I decide to rewrite the C++ code, and update the ray caster itself, so we change 2 files, once again, we package all of them!

```
HEL_raycastor_035.spin
HEL_raycastor_data_010.spin
HEL_graphics_engine3D_021.spin
HEL_data_generator_ray_020.CPP
HEL_data_generator_ray_020.EXE
readme.txt
```

Now, we take it all and make a zip and if deployed on internet or on FTP we might see:

**HEL\_Raycaster\_demo\_01\_20\_06.ZIP**  
**HEL\_Raycaster\_demo\_01\_23\_06.ZIP**

### 16.3 Graphics Programming

Basic graphics programming on the HYDRA is facilitated via the Parallax drivers **TV\_DRV\_010.SPIN** and **GRAPHICS\_DRV\_010.SPIN**. The TV driver more or less continually sends data out from the bitmap memory via the VSU unit and keeps the timing

correct for the TV display. The graphics driver on the other hand is just a generic set of graphics routines, not really tuned for speed or game programming, but more general graphics and business rendering. You will immediately find the use of polar coordinates for everything for example very slow and non-standard, but polar coordinates allow easier rotation of simple circularly symmetrical objects, drawing of pie charts, etc. However, don't worry, you are free to write your own graphics drivers and or modify the current drivers. With all that in mind, what I am going to do is show you a master demo that does all kinds of stuff, and then briefly cover some of the details of this implementation of **GRAPHICS\_DRV\_010.SPIN**. Although, we don't want to spend too much time on the generic reference drivers since you will inevitably re-write the drivers completely, or strip them down since they not really designed for "game/graphics" rendering, but they are great to get some demos up and running and use to develop demo programs quickly. Later in Part III of the book we will develop a number of tile engines and other graphics drivers that are more specific, but it's very important that you follow the underlying principles of the Parallax reference drivers since they are indicative of the kinds of issues and design decisions that must be made when designing TV and graphics drivers in general, thus they are a good "model" to begin with.

### 16.3.1 Master Graphics Demo – **Graphics\_Demo\_010.SPIN**

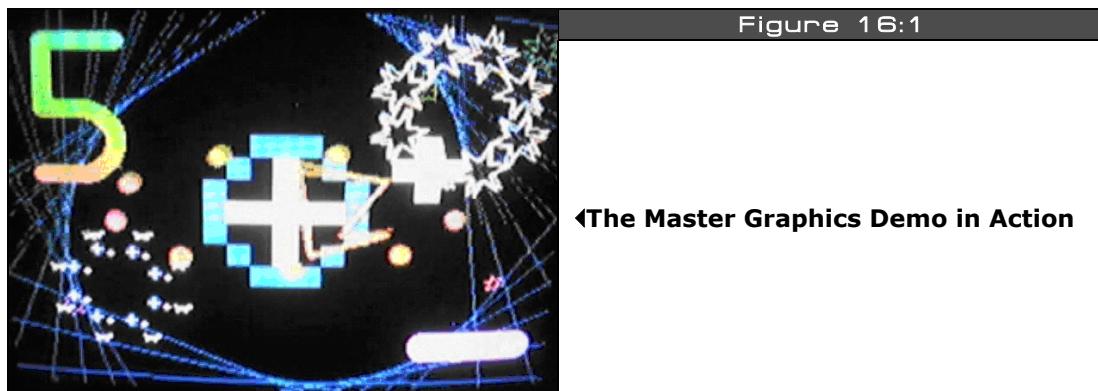


Figure 16:1 is a screen shot of the master graphics demo in action (written by Chip Gracey). It doesn't show every single function that the graphics driver **GRAPHICS\_DRV\_010.SPIN** supports, but it gives you an idea of what the driver can do. To run the demo, follow these steps:

**Step 1:** Load the file "**GRAPHICS\_DEMO\_010.SPIN**" into the Propeller IDE from the directory **CD\_ROOT:\HYDRA\SOURCES\**.

**Step 2:** Press the F10 or F11 button to program the Propeller chip and start the demo.

The demo shows off rotation, sprites, use of multiple colors, text, scaling, rotation, and numerous other effects.

### 16.3.2 TV and Graphics Drivers

There are two primary reference drivers that make all the graphics happen on the Propeller chip and the HYDRA respectively, they are the NTSC/PAL TV driver) and the Graphics driver itself, both of which are purely software and you don't have to use if you do not wish to, but give us a way to get something on the screen quickly. However, for now I suggest using these for your first demos and games and then later you can re-write the Graphics driver and potentially the NTSC/PAL driver yourself.

The NTSC/PAL driver is very low-level and primarily responsible for feeding TV with video data via the VSU, thus the NTSC/PAL driver **TV\_DRV\_010.SPIN** is primarily a timing chain state machine that drives the NTSC/PAL TV display. If you review the code you will find all kinds of interesting things, the first is that at the top of the file there is a number of constants and parameters:

```
CON
fntsc      = 3_579_545      'NTSC color frequency
lntsc      = 3640          'NTSC color cycles per line * 16
sntsc      = 624           'NTSC color cycles per sync * 16

fpal        = 4_433_618      'PAL color frequency
lpal        = 4540          'PAL color cycles per line * 16
spal        = 848           'PAL color cycles per sync * 16

paramcount  = 14
colortable   = $180          'Start of colortable inside cog
```

The driver code continues on for many pages, then at the end there is a listing that describes the "TV Parameters" list. This is a list of 14 LONGs that you pass to the TV driver when you initialize it (the driver is totally programmable); through these parameters you tell the driver where video RAM is, the color table, the character table, the screen size, the origin, and a number of other settings. For your convenience here's the TV parameters explanations pulled from the source file for your review (take a few moments and peruse the listing):

```
''VAR                      'TV parameters - 14 contiguous longs
..
''  long  tv_status       '0/1/2 = off/invisible/visible      read-only
''  long  tv_enable        '0/non-0 = off/on                  write-only
''  long  tv_pins          '%pppmmmm = pin group, pin group mode  write-only
```

```

'' long tv_mode      '%ccip = chroma, interlace, ntsc/pal      write-only
'' long tv_screen    'pointer to screen (words)           write-only
'' long tv_colors    'pointer to colors (longs)          write-only
'' long tv_ht        'horizontal tiles                  write-only
'' long tv_vt        'vertical tiles                   write-only
'' long tv_hx        'horizontal tile expansion       write-only
'' long tv_vx        'vertical tile expansion        write-only
'' long tv_ho        'horizontal offset                 write-only
'' long tv_vo        'vertical offset                  write-only
'' long tv_broadcast 'broadcast frequency (Hz)        write-only
'' long tv_auralcog 'aural fm cog                   write-only

'' The preceding VAR section may be copied into your code.
'' After setting variables, do start(@tv_status) to start driver.

'' All parameters are reloaded each superframe, allowing you to make live
'' changes. To minimize flicker, correlate changes with tv_status.

'' Experimentation may be required to optimize some parameters.

'' Parameter descriptions:

'' _____
'' tv_status

''     driver sets this to indicate status:
''         0: driver disabled (tv_enable = 0 or CLKFREQ < requirement)
''         1: currently outputting invisible sync data
''         2: currently outputting visible screen data
'' 

'' _____
'' tv_enable

''     0: disable (pins will be driven low, reduces power)
''     non-0: enable
'' 

'' _____
'' tv_pins

''     bits 6..4 select pin group:
''         %000: pins 7..0
''         %001: pins 15..8
''         %010: pins 23..16
''         %011: pins 31..24
''         %100: pins 39..32
''         %101: pins 47..40
''         %110: pins 55..48
''         %111: pins 63..56
'' 

''     bits 3..0 select pin group mode:
''         %0000: %0000_0111 -                                baseband

```

```

'': %0001: %0000_0111 - broadcast
'': %0010: %0000_1111 - baseband + chroma
'': %0011: %0000_1111 - broadcast + aural
'': %0100: %0111_0000 baseband -
'': %0101: %0111_0000 broadcast -
'': %0110: %1111_0000 baseband + chroma -
'': %0111: %1111_0000 broadcast + aural -
'': %1000: %0111_0111 broadcast baseband
'': %1001: %0111_0111 baseband broadcast
'': %1010: %0111_1111 broadcast baseband + chroma
'': %1011: %0111_1111 baseband broadcast + aural
'': %1100: %1111_0111 broadcast + aural baseband
'': %1101: %1111_0111 baseband + chroma broadcast
'': %1110: %1111_1111 broadcast + aural baseband + chroma
'': %1111: %1111_1111 baseband + chroma broadcast + aural
-----
'': active pins top nibble bottom nibble

the baseband signal nibble is arranged as:
bit 3: chroma signal for s-video (attach via 560-ohm resistor)
bits 2..0: baseband video (sum 270/560/1100-ohm resistors to form 75-ohm
1V signal)

the broadcast signal nibble is arranged as:
bit 3: aural subcarrier (sum 560-ohm resistor into network below)
bits 2..0: visual carrier (sum 270/560/1100-ohm resistors to form 75-ohm
1V signal)

tv_mode
bit 3 controls chroma mixing into broadcast:
0: mix chroma into broadcast (color)
1: strip chroma from broadcast (black/white)

bit 2 controls chroma mixing into baseband:
0: mix chroma into baseband (composite color)
1: strip chroma from baseband (black/white or s-video)

bit 1 controls interlace:
0: progressive scan (243 display lines for NTSC, 286 for PAL)
    less flicker, good for motion
1: interlaced scan (486 display lines for NTSC, 572 for PAL)
    doubles the vertical display lines, good for text

bit 0 selects NTSC or PAL format
0: NTSC
    3016 horizontal display ticks
    243 or 486 (interlaced) vertical display lines

```

```

```
    CLKFREQ must be at least 14_318_180 (4 * 3_579_545 Hz) *
1: PAL
```
    3692 horizontal display ticks
```
    286 or 572 (interlaced) vertical display lines
    CLKFREQ must be at least 17_734_472 (4 * 4_433_618 Hz) *
```
    * driver will disable itself while CLKFREQ is below requirement
```
_____
tv_screen

```
    pointer to words which define screen contents (left-to-right, top-to-bottom)
    number of words must be tv_ht * tv_vt
    each word has two bitfields: a 6-bit colorset ptr and a 10-bit pixelgroup
    ptr
        bits 15..10: select the colorset* for the associated 16 * 16 pixel tile
        bits 9..0: select the pixelgroup** address %oooooooooooo00
        (p=address, c=0..15)
```
    * colorsets are longs which each define four 8-bit colors
```
    ** pixelgroups are 16 longs which define (left-to-right, top-to-bottom)
    the 2-bit (four color) pixels that make up a 16 * 16 pixel tile
```
_____
tv_colors

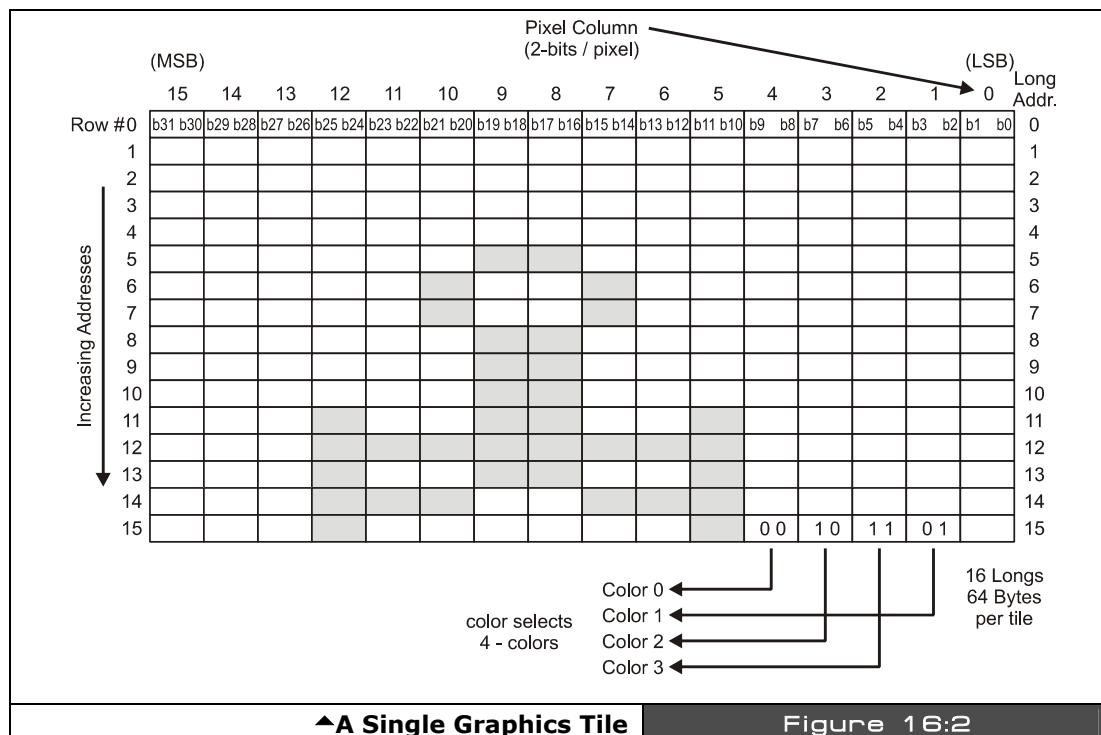
```
    pointer to longs which define colorsets
    number of longs must be 1..64
    each long has four 8-bit fields which define colors for 2-bit
    (four color) pixels
    first long's bottom color is also used as the screen background color
    8-bit color fields are as follows:
        bits 7..4: chroma data (0..15 = blue..green..red..)*
        bit 3: controls chroma modulation (0=off, 1=on)
        bits 2..0: 3-bit luminance level:
            values 0..1: reserved for sync - don't use
            values 2..7: valid luminance range, modulation adds/subtracts 1
            (beware of 7)
```
    * because of TV's limitations, it doesn't look good when chroma changes
    abruptly - rather, use luminance - change chroma only against a black or
    white background for best appearance
```
_____
tv_ht

```
    horizontal number of 16 * 16 pixel tiles - must be at least 1
    practical limit is 40 for NTSC, 50 for PAL
```
_____
tv_vt

```

```
''  
''    vertical number of 16 * 16 pixel tiles - must be at least 1  
''    practical limit is 13 for NTSC, 15 for PAL (26/30 max for interlaced  
''    NTSC/PAL)  
''  
''    tv_hx  
''  
''    horizontal tile expansion factor - must be at least 3 for NTSC, 4 for PAL  
''  
''    make sure 16 * tv_ht * tv_hx + ||tv_ho + 32 is less than the horizontal  
''    display ticks  
''  
''    tv_vx  
''  
''    vertical tile expansion factor - must be at least 1  
''  
''    make sure 16 * tv_vt * tv_vx + ||tv_vo + 1 is less than the display lines  
''  
''    tv_ho  
''  
''    horizontal offset in ticks - pos/neg value (0 for centered image)  
''    shifts the display right/left  
''  
''    tv_vo  
''  
''    vertical offset in lines - pos/neg value (0 for centered image)  
''    shifts the display up/down  
''  
''    tv_broadcast  
''  
''    broadcast frequency expressed in Hz (ie channel 2 is 55_250_000)  
''    if 0, modulator is turned off - saves power  
''  
''    broadcasting requires CLKFREQ to be at least 16_000_000  
''    while CLKFREQ is below 16_000_000, modulator will be turned off  
''  
''    tv_auralcog  
''  
''    selects cog to supply aural fm signal - 0..7  
''    uses ctra pll output from selected cog  
''  
''    in NTSC, the offset frequency must be 4.5MHz and the max bandwidth +-25kHz  
''    in PAL, the offset frequency is and max bandwidth vary by PAL type
```

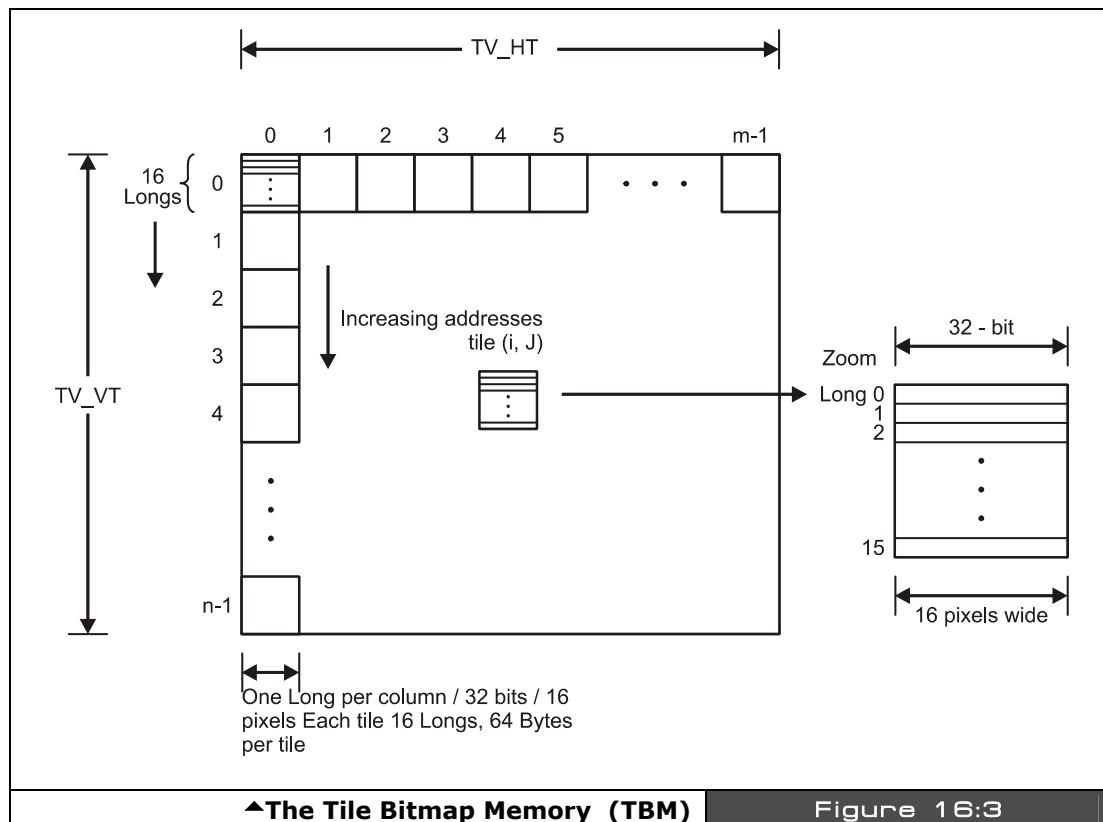
Considering this massive list of possibilities there is a lot this driver can do and probably why you do not want to re-write it at first, but use it as-is then later potentially re-write if you need to free up memory and or have it work in other ways with memory or something that are more conducive to your games' architecture. However, that being said, I think that in most cases we probably can use this driver for 50% of our games and demos. Still, the **GRAPHICS\_DRV\_010.SPIN** definitely will need customizing for more advanced games and at very least to cut out all the business graphics and generalization it has that we don't need for games. Alas, when it comes time to start making changes you will start with the **GRAPHICS\_DRV\_010.SPIN** driver at first, but at first just use them as-is to get things going!

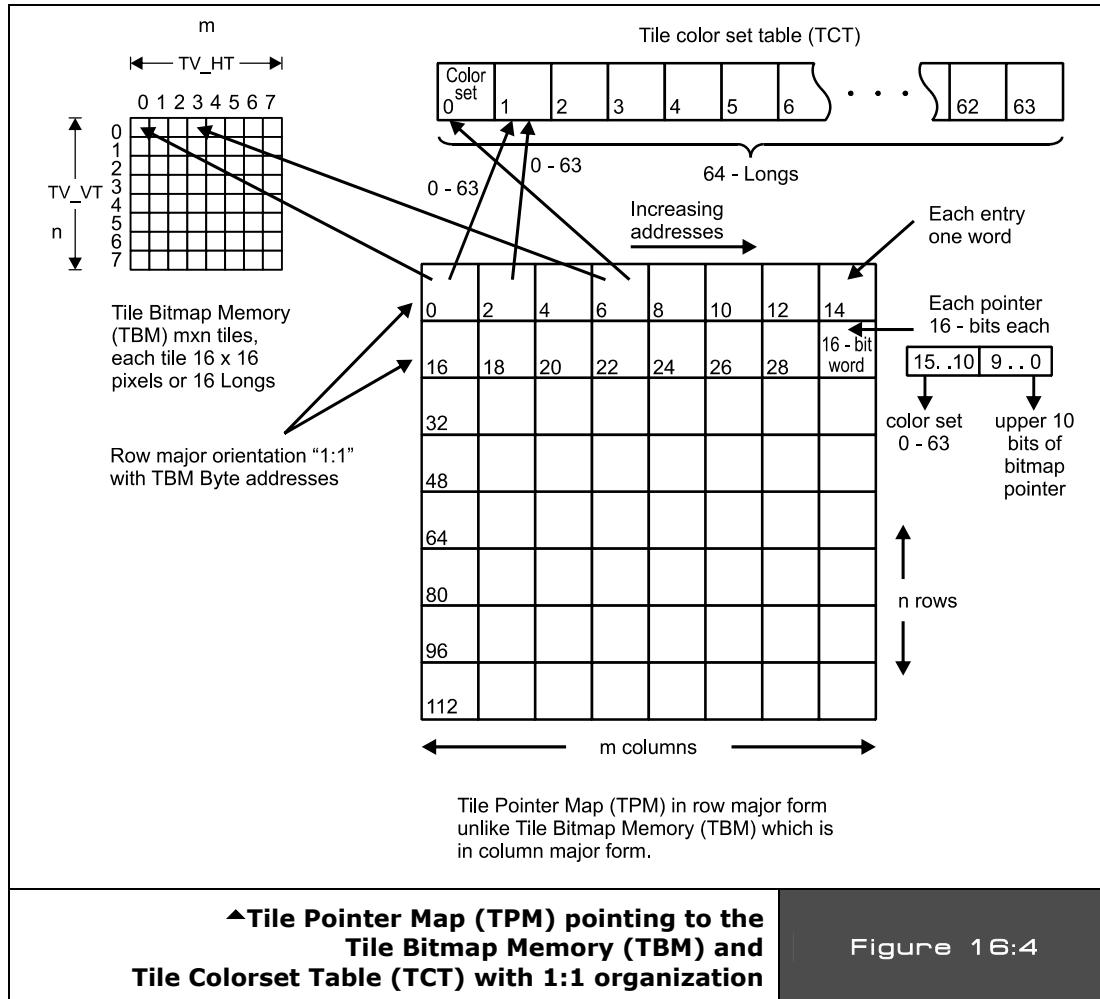


In any event, the TV driver runs on a cog by itself and simply feeds the TV display with video data. The video data comes from an "on-screen" bitmap buffer in the shared 32K memory that is 2 bits per pixel, supports 4 colors, and is contiguous, but has a very strange memory mapping which we will get to shortly. The size of the bitmap buffer is related to the number of **tiles** you decide to run the TV in horizontally and vertically. The size of a tile is **always**

**16×16** pixels, that is, a single tile is constructed of 16 LONGs where each LONG is 32 bits and supports 16 pixels at 2 bits per pixel, so this works out nicely. This is shown in Figure 16:2.

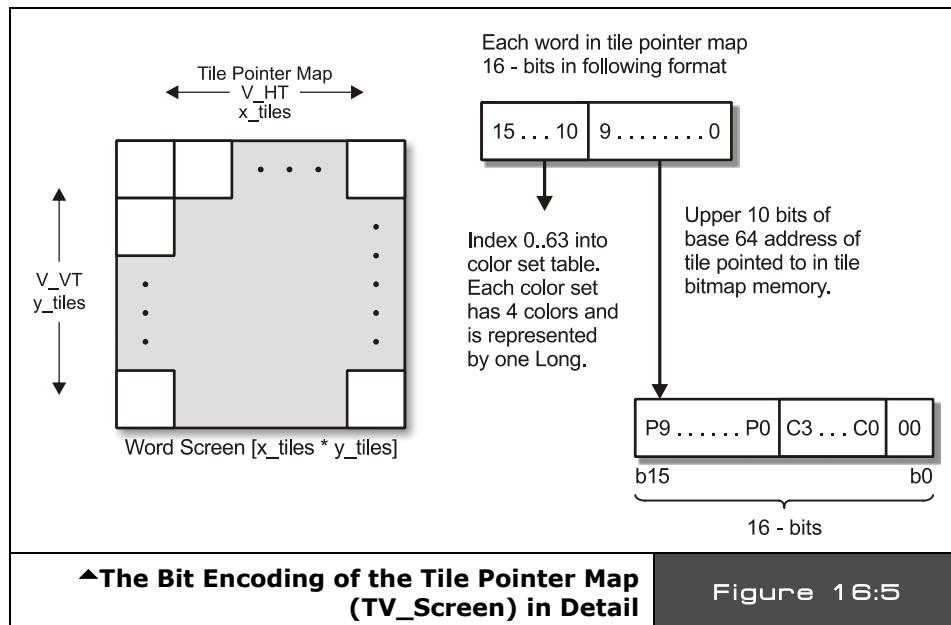
Therefore, the TV driver really is a tile-mapped system consisting **of M-tiles horizontally (columns, referred to as TV\_HT in the TV driver)**, and **N-tiles vertically (rows, referred to as TV\_VT in the TV driver)** where each tile is 16×16 pixels, this is the actual memory for the bitmap and referred to as the "**Tile Bitmap Memory**" or "**TBM**." This is shown in Figure 16:3.





However, there is one more level of indirection! The memory is tile mapped like this and referenced as described, but there is a "**Tile Pointer Map**" or "**TPM**" which is a 2D array with the same  $M \times N$  dimensions as shown in Figure 16:4. Each entry in the TPM is a single 16-bit WORD which contains both a pointer to the tile's bits in bitmap memory along with an index into the "**Tile Colorset Table**" or "**TCT**." The Tile Colorset Table is an array of 64 LONGs, where each 32-bit LONG represents 4 colors each (8 bits per color), these colors are used for the tile in question. Thus each tile can have 4 colors each out of a set of 64

potential **"Color Sets."** The organization of each Tile Pointer Map entry is shown below in Figure 16:5 (paraphrased from the driver listing above):

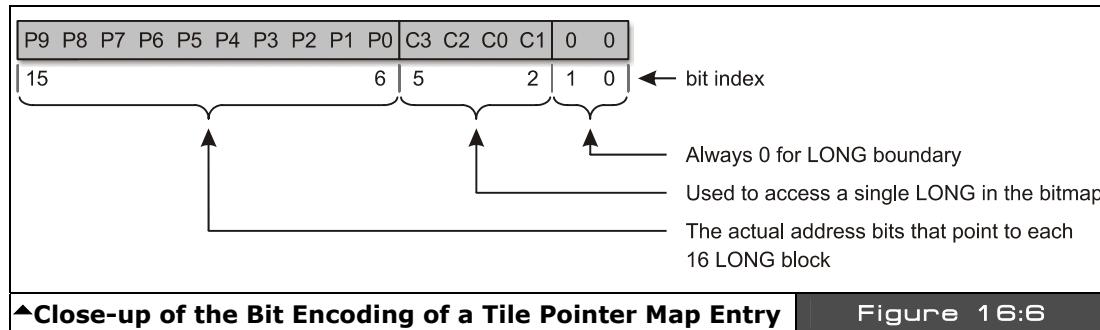


Each 16-bit WORD from the Tile Pointer Map (TV\_Screen in the TV driver) array has two bitfields:

- ▶ A **6-bit index** (0..63) into the Tile Colorset Table that indicates which Color Set (a single LONG) of 4 colors to use for the tile.
  - ▶ A **10-bit pointer** into the Tile Bitmap Memory which must be on a 64-LONG boundary, this 10-bit value is augmented in the actual addressing and is turned into a 16-bit address as shown below.

**Bits 15..10:** Select the Color Set for the associated  $16 \times 16$  bitmap tile to use. Remember each tile is build of  $16 \times 16$  pixels, where each pixel is 2 bits, each 2 bits refers to 4 colors, these colors (Color Set) are actually a single LONG pointed to by this 6-bit index. The format of the Color Set is 4 BYTES, each is one color, each is in the standard color format discussed in the VSU discussions.

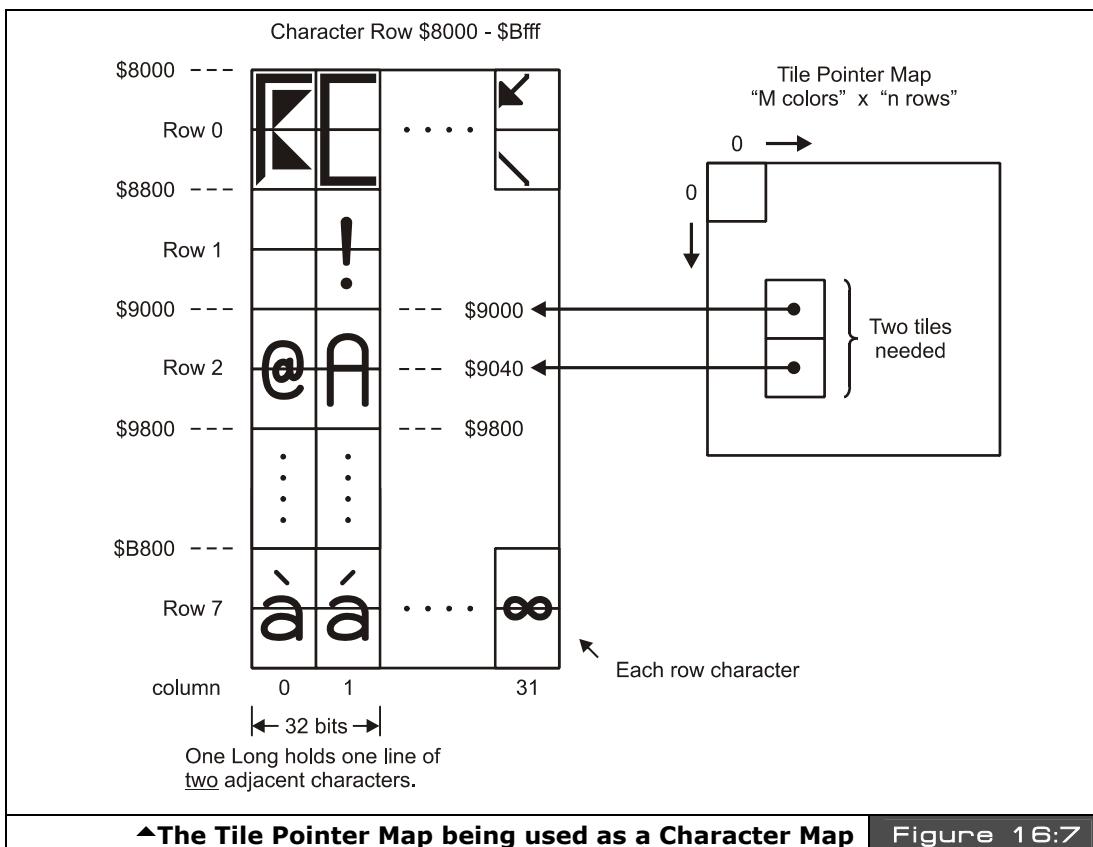
**Bits 9..0:** Pointer bits to the Tile Bitmap data where these 10 bits form the upper 10 bits of the final 16-bit address augmented as shown in Figure 16:6.



Referring to the encoding above and Figure 16:5 as well, the bottom line is that each Tile Pointer Map entry (TV\_Screen WORD) points to the bitmap data and the color data for each tile. The color part is easy: the upper 6 bits are an index into the Tile Colorset Table, simple as that. But the lower 10 bits that form the pointer to the bitmap data are a little more complex: you don't give the actual address in these 10 bits, but you give the address to the 16-LONG block or 64-BYTE block, thus you can think of these 10 bits as the upper 10 bits of a 16-bit address where the lower 6 bits MUST be 0. That is, they will always refer to a block of 64 BYTES or 16 LONGs since the addressing in the TV driver simply shifts these bits 6 places to the left and then manipulates the lower 6 bits during its addressing, but the "base" address you supply as the 10 bits is a 64 BYTE or 16 LONG block where the bitmap is.

This is a very cool feature and allows you to either write directly into the bitmap tile memory with each tile pointer pointing into its respective tile bitmap OR you can use the tile pointer memory to point to the SAME bitmap. This way you can implement either full bitmap or character graphics. For example, if you just want to do graphics, sprites, lines, etc. then you need a standard bitmap set up, so what you would do is decide on the size and number of tiles of your bitmap screen, say 16×12 tiles (256×192 pixels), then in the tile pointer map you would point each pointer directly to its 1:1 representative tile in memory and that would be the last time you mess with the tile pointer map. Then all you do is update the tile graphics memory map. This is shown in Figure 16:7, where the Tile Pointer Map is being used as a Character Map and each pointer points to the start of a character in memory facilitating character modes.

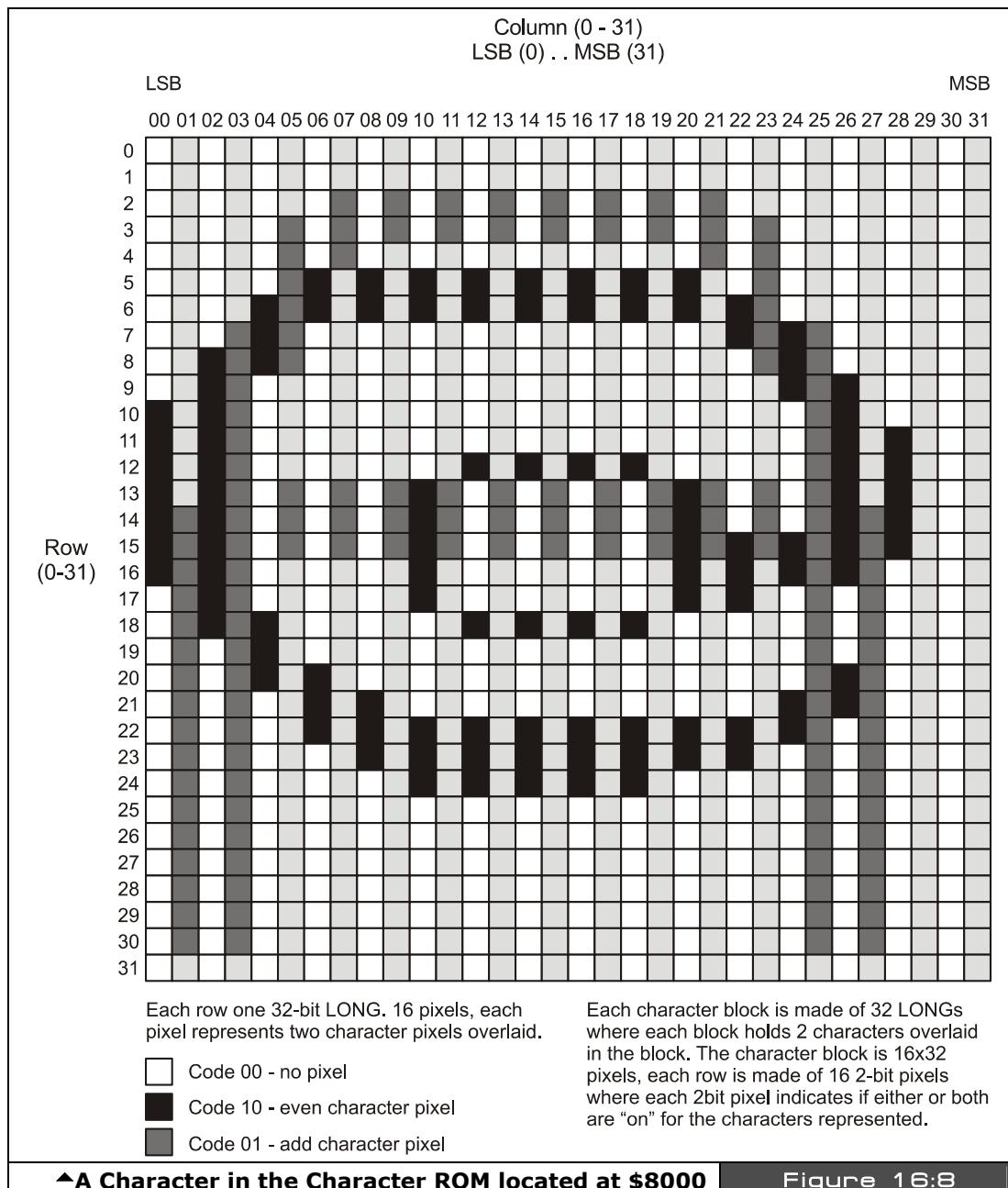
On the other hand, if you are going to primarily be doing "**classic**" tile graphics, then you can have your "tiles" in memory wherever you wish.



▲The Tile Pointer Map being used as a Character Map

Figure 16:7

Tiles don't need to be contiguous in any way since you aren't going to use any of the raster graphics routines for lines, etc., the only constraint is that the tile bitmaps are  $16 \times 16$  in the proper format (16 LONGs per bitmap, each LONG represents 16 pixels of 2 bits per pixel). Then you simply point your tile pointer map entries to these tile entries. This way you need only update the tile pointer map and instantly the bitmaps would change on screen! For example, to implement a character mode you would point each entry in the tile pointer map to the SPACE character in the ROM (character 32) and you would see a blank screen, then if you wanted an "A" to show up in the top left corner of the screen you would point the tile pointer map entries to the "A" bitmap entry in the character set in the ROM at \$8000 – this is why each character is made of 16 LONGs, where each LONG represents (16) 2-bit pixels. Then the trick is to only turn on certain colors in the "color table" so that only the "A" shows up. If you recall there are TWO characters compressed into each ROM character location (more on this later).



▲ A Character in the Character ROM located at \$8000

**Figure 16:8**

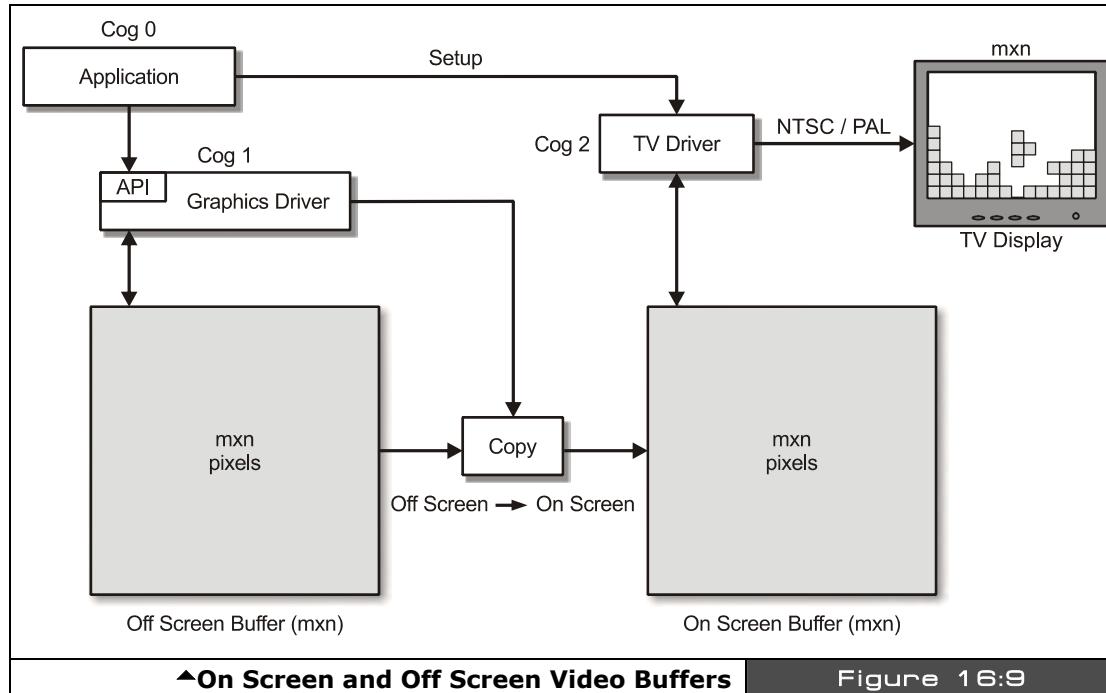
The only problem with pointing the tile pointer map to a **character** in the character ROM is that we need to "**stack**" two standard bitmap tiles since the characters in the ROM are 16 pixels wide by **32 pixels tall**, but the TV driver assumes 16×16 pixel tiles. Therefore we need to bitmap tiles to point to a single character definition in ROM, this is shown in Figure 16:8 (the "A" and "@" characters are overlaid/encoded as a pair in this example). This is a bit of a bummer, since it's nice to have one character per one tile, but the character set was made tall to support some extra drawing and schematic characters, so if you want to use it then you must use two tile pointer map entries to point to the top and bottom of the tile pointer map to the character definition LONGs in the ROM lookup at \$8000.

Therefore, at the end of the day, if you set up a tile map of 16×12 tiles where each tile is 16×16 pixels (by definition) then if you want to use the built-in ROM character set (which is very tall at 16×32), you are going to only be able to draw 16 columns by 6 rows since it takes 2 characters stacked to display the super-tall 16×32 character, and this cuts your rows down by half. Therefore, you might want to make your own 8×8 character sets etc. Of course, the graphics driver actually has a bitmap character engine that can draw very small characters, but it is 100× slower literally than just pointing the tile point map to a character definition in ROM.

#### 16.3.2.1 Video Memory Mapping and Organization

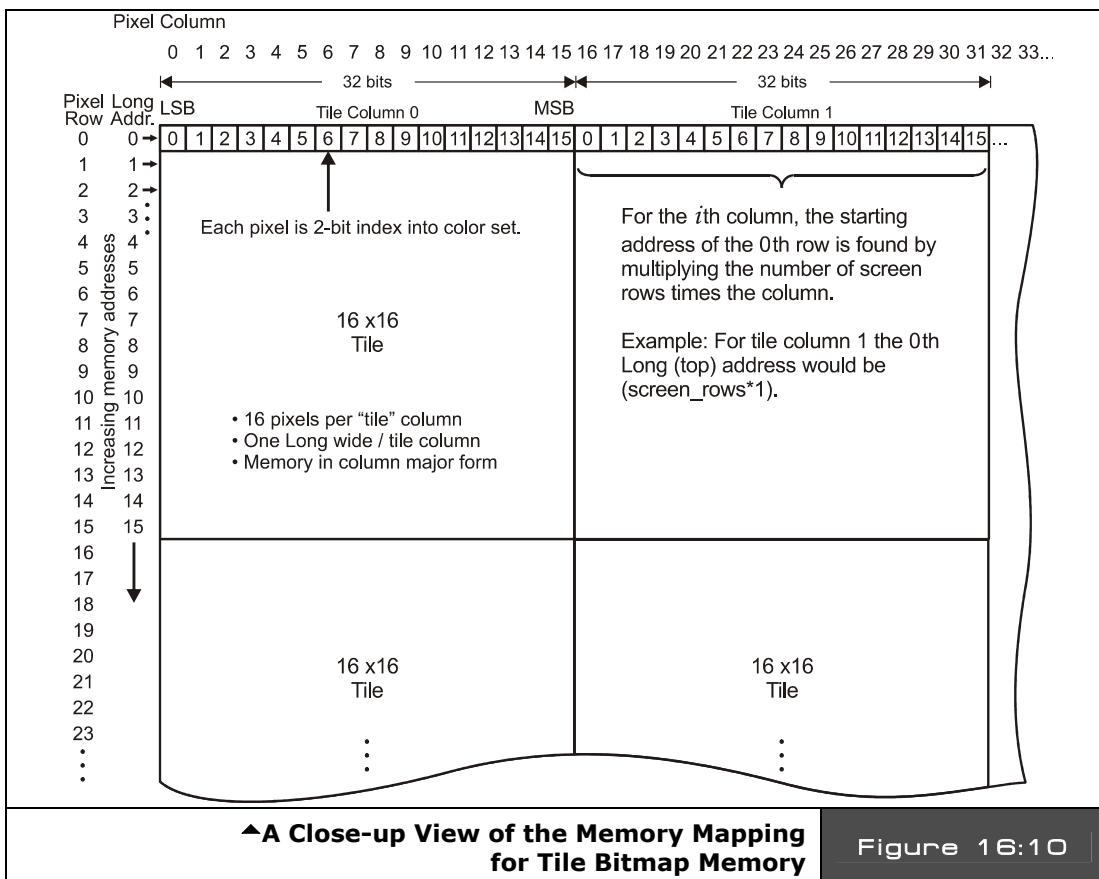
The actual organization of the **Tile Bitmap Memory** and the **Tile Pointer Map** are a bit tricky, so we are going to discuss that in a moment, but first let's talk about animation and double buffering. The TV driver supports a "**double buffered**" architecture, that is you draw on an "**off-screen**" buffer and the TV driver renders an "**on-screen**" buffer. Therefore, on start-up you tell the TV driver the address of the on-screen buffer only (actually you do this indirectly through the Tile Pointer Map), the off-screen buffer is manipulated by the Graphics driver and it's the job of the Graphics driver to "copy" the contents of the **off-screen** buffer to the **on-screen** buffer. Therefore, there is no coupling between the TV and Graphics drivers other than if you want to see something then you need to copy it into the on-screen buffer since this is the only thing the TV driver renders. The relationship between the buffers and the drivers is shown in Figure 16:9.

The cool thing about this is that you can write your own "graphics" driver fairly easily, you just have to remember that to "see" anything you have to have a function that copies the contents of your off-screen bitmap data into the on-screen bitmap data which the TV driver is always rendering. Thus, with the off-screen and on-screen buffers you can implement standard double-buffered flicker-free animation.



### Plot Pixel Algorithm LONG Based Version

The memory organization of the Tile Memory Map isn't standard left-to-right, top-to-bottom. It's primarily top-to-bottom (column major), left-to-right within a single LONG of 16 pixels for the width of each span, but within each bitmap tile, it is left-to-right, top-to-bottom. Refer to Figure 16:10 to see this graphically. So the bottom line is this: the bitmap memory for a single tile is always  $16 \times 16$  pixels which consists of 16 LONGs that represent 16 pixels (2 bits per pixel for a total of 32 bits per 16-pixel span) per line and 16 lines. The TV driver always draws like this. Now, when you couple the TV driver with the Graphics driver, the Graphics driver assumes you have organized your bitmap pointers in the Tile Pointer Map such that they point to Tile Bitmap Memory in the way shown in Figure 16:10, that is, each tile bitmap in memory of 16 LONGs is contiguous from top-to-bottom, left-to-right.



Referring to Figure 16:10, take a look at the memory calculations to access a single pixel in the bitmap. Let's discuss how I arrived at the calculations to locate a single pixel and then how to access the pixel and write to it. First off, we can either think in terms of BYTES or LONGs. LONGs are better overall since the architecture is 32-bit and we don't get a performance hit for using LONGs, also, each pixel row in a single tile bitmap is a single LONG which represents 16 pixels. So this makes LONGs ultimately the best choice. On the other hand later, you might want to write a bit blitter and think in terms of BYTES and/or something else that is more "BYTE friendly" and accessing the Tile Bitmap Memory as BYTES is better. Therefore, we are going to see the code both ways. First, let's write a LONG access algorithm that plots pixels. Here's the algorithm outline:

Assume we want to plot a pixel located at  $(x,y)$  in color 0,1,2,3 with the upper left hand corner being  $(0,0)$ , and the lower right being  $(191, 191)$  – a  $12 \times 12$  tile map of  $16 \times 16$  tiles.

**Step 1:** Locate the memory address of the LONG that the pixel is located in.

**Step 2:** Read the LONG out of memory that we are going to write the pixel into.

**Step 3:** Shift our pixel into the correct bit position and logically mask and OR our data with the pixel data in the read LONG.

**Step 4:** Write the LONG value back to the Tile Bitmap Memory.

Some things to remember are that there are 16 pixels per LONG, also, each LONG is rendered from left to right on the screen within a tile bitmap, it is organized in memory from low bit to high bit. That is, bits 0 and 1 represent pixel 0 and it is drawn as the first (left-most) pixel. Bits 2 and 3 represent pixel 1 and it is drawn as the 2nd pixel from the left of the tile bitmap's current pixel row.

In a moment, we will see a listing of the code that performs all the steps, but briefly let's discuss the address calculation and the pixel preparation step. To calculate the address, we start by realizing that the TV/Graphics drivers are accessing the bitmaps, each consisting of 16 LONGs (representing  $16 \times 16$  pixels) in a top-to-bottom fashion, then once each column is defined then the next column continues in memory. With this in mind, there are a lot of ways to approach this, but I started with calculating which "column" the  $(x,y)$  pixel is located in. To do this we need to divide the  $x$  by 16, since there are 16 pixels per tile or per LONG:

$$\text{tile\_column} = x/16$$

Now, if we are assuming that we are going to use "LONG" math and that all addresses are LONG based, that is 0 would be physical address 0, 1 would be physical address 4, and so on, then we can figure out how many LONGs there are per column pretty easily at a  $12 \times 12$  tile screen:

$$\text{longs\_per\_column} = 16 \times 12 = 192$$

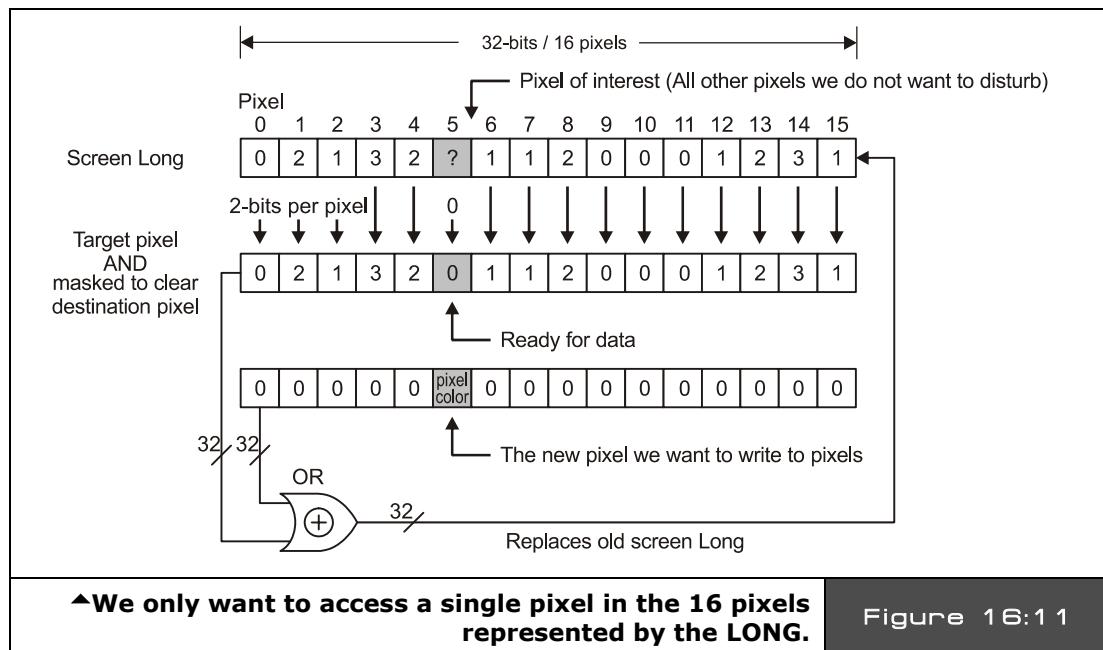
That was easy, so to index from column to column with LONG addressing we simply multiply 192 to our index to locate the top of the column address. Alright, getting there, now within a column, to index vertically from top to bottom, we know that there is one LONG per pixel group (16 pixels), so all we need to do is ADD the  $y$  coordinate. Summing up, we have:

$$\text{long\_memory\_index} = (x/16 \times 192) + y$$

Now, assuming that the "base" of the video RAM (off-screen or on-screen) buffer is located at physical address `vram_base`, we need to convert this to a LONG address by dividing by 4, the final LONG address to the LONG that contains our target pixel is:

$$\text{final\_physical\_long\_address} = \text{vram\_base}/4 + (x/16 \times 192) + y$$

Ok, almost there, we have the LONG we need to work with, but which of the 16-pixels in the LONG do we want to access? Well, first who cares, we just read the entire LONG out and store it in `read_pixel_value` for example, then once we have the pixels from the screen we are free to mask in our pixel.



There are 16 pixels to choose from in the LONG, and we only want to modify one of them. So typically we need to read the data, then mask the pixels on the screen and zero out the target bits then OR in our color value. Figure 16:11 shows this operation. All of you are graphics guys, so this is a common operation. You can also, XOR the bits or perform other logical operations etc. Anyway, to either mask or OR the final color bits in, we need to compute the location in the LONG where we want to write the 2 bits that compose the pixel (with the real pixel data or a mask). Thus, we need to compute which “pixel” in the block of 16 that each LONG represents to shift our 2-bit pixel data:

$$\text{pixel\_shift} = (\text{x mod } 16) * 2$$

And that is the last piece of the puzzle, putting it all together with a simple function that plots pixels on the sent buffer located at `x,y` with a color from 0-3. Here's a function (Note I have pre-pended line numbers to make the following discussion easier):

Page 342 ◀ Game Programming for the Propeller Powered HYDRA

```

1: PUB Plot_Pixel2(x, y, video_buffer, color) | video_offset, pixel_value
2:   ' plot pixel calculation using LONG aligned calcs 192x192 bitmap, 12x12 tiles
3:   video_offset := (video_buffer >> 2) + (x >> 4) * (192) + y
4:
5:   ' read pixel group from memory
6:   pixel_value := long[0][video_offset]
7:
8:   ' mask AND out target bits, so color mixing doesn't occur
9:   pixel_value := pixel_value & !(%11 << ((x & %1111) << 1))
10:
11:  ' OR color with pixel value
12:  pixel_value := pixel_value | (color << ((x & %1111) << 1))
13:
14:  ' write pixel back to memory
15:  long[0][video_offset] := pixel_value

```

To call the function, you simply would pass it the BYTE address to the video buffer along with the x,y and color you want to plot with:

Plot\_Pixel(video\_ram, x,y, color)

And that's it! Now, one of the main reasons I went through all this discussion is so that I could finally show you some of the memory access tricks in use. Take a look at line 6, see the syntax "long[0][video\_offset]"? This means go to the memory location BYTE address 0, then using LONG indexing using "video\_offset" add the LONG index into memory and access a LONG at that final location, or in other words the final BYTE address is:

byte address = 0 + video\_offset × 4

But, using the memory accessor technique is less clunky than multiplying manually. In any event, that is the LONG version of accessing the Tile Bitmap Memory and plotting a pixel.

### **Plot Pixel Algorithm BYTE-Based Version**

The BYTE-based version is nearly identical to the LONG version except that we are going to use BYTE math and indexing instead of LONG math and indexing. Plus, each pixel row is a single LONG that represents 16 pixels, but now we are going to think of each pixel row as a set of 4 BYTES, where each BYTE represents 4 pixels (each still consisting of 2 bits). Ok, the steps are the same, so I am going to just show the highlights, since this is probably all boring you guys. First, we are going to compute the final BYTE address of the BYTE that contains our pixel of interest, but in this BYTE there will be 4 pixels, 3 of which we do not want to disturb.

We start once again by realizing that we want a column major calculation, the tile column is still:

tile\_column = x/16

Then to compute the address of the top of each column, we realize there are 192 LONGs per column or in BYTES, we have:

$$\text{bytes\_per\_column} = 192 * 4$$

But, we have the final LONG starting address, but not the BYTE within, we need to work a little harder now and find the BYTE offset with the LONG, this is computed as:

$$\text{byte\_index} = (\text{x mod } 16) >> 2$$

...which will be from 0-3. Last, but not least this gets us to the right BYTE in a row of pixels, but to get to the correct row of pixels, we need to add the y into the calculation. This is simple – now there are 4 BYTES per tile bitmap row, thus from any row n to n+1, the difference in memory is just  $y \times 4$ , or in this case  $192 * 4 = 768$  BYTES. Doing a common sense check this is correct since we said we are doing a  $12 \times 12$  tile setup with  $16 \times 16$  pixel tiles, thus each tile bitmap is 4 BYTES per row times 16 rows is 64 BYTES, and there are 12 tiles vertically per column for a total of  $64 * 12 = 768$  BYTES. Now, putting this all together into a final physical BYTE address we have:

$$\text{final\_physical\_byte\_address} = (\text{x}/16) * (192 \times 4) + ((\text{x mod } 16) >> 2) + (\text{y} \times 4)$$

Lastly, we have the same read pixel, masking and shifting operations to perform, but now instead of computing which pixel in 16, there are only 4 pixels per BYTE, so the mask and shifting change to reflect this. Taking all this into consideration here's the pixel plot function that works with BYTES and BYTE addressing:

```

1: PUB Plot_Pixel(x, y, video_buffer, color) | video_offset, pixel_value
2:   ' plot pixel calculation using BYTE aligned calcs 192x192 bitmap, 12x12 tiles
3:   video_offset := video_buffer + (x >> 4) * (192*4) + ((x & %1111) >> 2) + (y << 2)
4:
5:   ' read pixel group from memory
6:   pixel_value := byte[video_offset]
7:
8:   ' mask AND out target bits, so color mixing doesn't occur
9:   pixel_value := pixel_value & !(%00000011 << ((x & %11) << 1))
10:
11:  ' OR color with pixel value
12:  pixel_value := pixel_value | (color << ((x & %11) << 1))
13:
14:  ' write pixel back to memory
15:  byte[video_offset] := pixel_value

```

Again, I have numbered the lines, so we can discuss the code (they aren't part of the code).

Everything follows our algorithmic construction to the letter, the only interesting thing about this function is the memory operation. Notice we are using the syntax "byte[offset]" – this accesses the BYTE at video\_offset. The important thing to realize is that the value in the

brackets is ***always*** a BYTE address or base address. The type operator only tells Spin how large of a chunk of memory to access at this location, so since we are working with BYTES this works out for us; we could have also achieved the same thing with this syntax:

```
byte[0][video_offset]
```

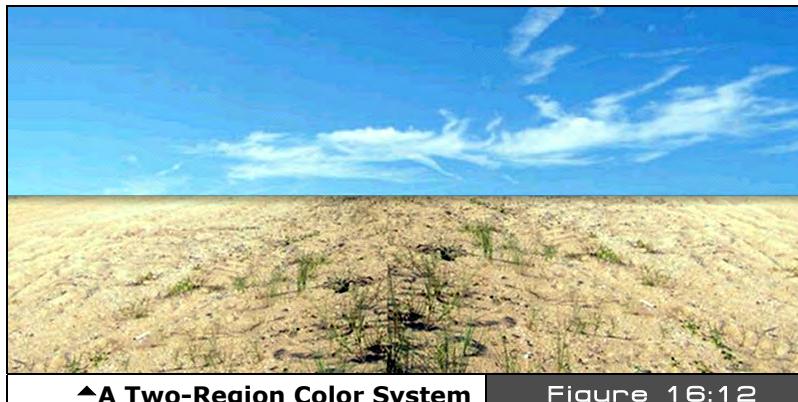
This would have been redundant since it basically computes the final address as: "0 + video\_offset."

So that wraps it up for the memory mapping and the tile bitmap organization. But, remember this is only a side effect of how the Parallax TV and Graphics drivers like things, later when you have exhausted their capabilities you can re-write them. Also, the Graphics driver itself **GRAPHICS\_DRV\_010.SPIN** has all kinds of functionality as mentioned before including a plot pixel function, but I wanted to show you how to access the video memory as seen by the TV driver so you can experiment and/or make special graphics functions that might not be supported by the graphics driver currently. We are going to get to some working demos soon, but bear with me, we still need to discuss the color indirection the TV driver uses.

### 16.3.2.2 Setting up the TV Driver Example

To set up the TV driver we have to set up all the parameters and pass it both a "TV\_Screen" and "TV\_Colors" array that we have generated. The TV\_Screen array is what we are generalizing to Tile Pointer Map and the TV\_Colors array is more or less a 1-D array of LONGs where each LONG represents a palette of 4 colors.

Each of these LONGs are indexed by a 6-bit index in the Tile Pointer Map and allow each tile to have its own set of 4 colors. So what we need to do is build these two arrays up. The color array is arbitrary and more of a "creative" thing since you can have 64 color sets and each set has 4 colors that are applied to a single tile; therefore, there is no "correct" way to do this, just the way that makes sense for your colors for your game. For example, if you wanted to use the SAME 4 colors on the top of the screen and the SAME 4 colors on the bottom of the screen, then you would only need TWO entries in the TV\_Colors array or two LONGs, since all your Tile Pointer Map color entries would all point to either the first or second entry in the TV\_Colors array which in this case consists of only two entries.



▲A Two-Region Color System

Figure 16:12

Figure 16:12 shows this graphically (exaggerated albeit), in the top region we might have "sky" colors like blues and whites, and in the bottom region we might have "ground" colors like browns, greens, grays, and blacks, and in the interface we might have a blend of the two color schemes to make the transition smooth. Every tile in the top and bottom would use the same set of 4 colors, this way when we move bitmap objects through the tile space, their colors are consistent. On the other hand, if you were making a very colorful game and objects stayed on tile boundaries then every tile could have its own set of 4 colors and you could use the max allotted color sets of 64, and 64 different indexes in the Tile Pointer Map. Therefore, you must have from 1 to 64 color sets, but it's not necessary to have all 64 if you do not need them!

In any case, to start the TV driver code we need to create some CONs and VARs:

```

CON
  ' size of graphics tile map
  X_TILES      = 16
  Y_TILES      = 12

  SCREEN_WIDTH    = 256
  SCREEN_HEIGHT   = 192

  ' graphics driver and screen constants
  PARAMCOUNT     = 14
  OFFSCREEN_BUFFER = $2000          ' offscreen buffer
  ONSCREEN_BUFFER  = $5000          ' onscreen buffer

VAR
  ' these parameters are going to be passed by address to the TV driver
  long tv_status    '0/1/2 = off/visible/invisible      read-only
  long tv_enable     '0/? = off/on                         write-only

```

```

long tv_pins      '%ppmmm = pins           write-only
long tv_mode      '%ccinp = chroma,interlace,ntsc/pal,swap write-only
long tv_screen    'pointer to screen (words)   write-only
long tv_colors    'pointer to colors (longs)   write-only
long tv_hc        'horizontal cells       write-only
long tv_vc        'vertical cells        write-only
long tv_hx        'horizontal cell expansion write-only
long tv_vx        'vertical cell expansion write-only
long tv_ho        'horizontal offset      write-only
long tv_vo        'vertical offset       write-only
long tv_broadcast 'broadcast frequency (Hz) write-only
long tv_auralcog 'aural fm cog        write-only

word  screen[x_tiles * y_tiles] : storage for screen tile map
long  colors[64]          : color look up table

```

The CONstant section creates some named constants that help use refer to the size of the tile map and the size of the screen. The VARiable section builds all the VARs that the TV driver needs access to. The next thing you need to do is include the TV driver itself as an object and bind it to a variable name:

```

OBJ
tv   : "tv_drv_010.spin"           ' instantiate a tv object

```

This instantiates a single object. Remember we could instantiate more TV objects if we wanted to and drive multiple TVs, each with its own cog and pingroup, but the HYDRA only has one TV output, so this will do fine.

Next, in the body of your code, you “start” the TV driver up and tell it where the parameters are along with the TV\_Screen and TV\_Colors data structures:

```

0: 'start tv
1: longmove(@tv_status, @tvparams, paramcount)
2: tv_screen := @screen
3: tv_colors := @colors
4: tv.start(@tv_status)

```

Notice that we never initialized the values in the parameters we declared in the VAR section? Well, there is a little trick: in the DAT section we create a list of initializers and then “copy” these values with the LONGMOVE( ) function from the data section to the memory in the VAR section. These initializations must be one to one and in sequence. This is similar to individually initializing each value, thus we also need these initial values declared in the DAT section like this:

```

DAT

' TV PARAMETERS FOR DRIVER /////////////////////////////////
tvparsms      long 0           :status
               long 1           :enable
               long %011_0000   :pins
               long %0000        :mode
               long 0           :screen
               long 0           :colors
               long x_tiles     :hc
               long y_tiles     :vc
               long 10          :hx timing stretch
               long 1           :vx
               long 0           :ho
               long 0           :vo
               long 55_250_000  :broadcast
               long 0           :auralcog

```

Analyzing the bits takes some time, but it's a good exercise; refer to the TV driver parameter listing above a few pages. Briefly, though let's take a look at the four lines of code that start the TV driver, they are labeled above. Let's look at each line:

**Line 1** – copies our static initializers into the parameter passing area defined in our VAR section with the “longmove(@tv\_status, @tvparsms, paramcount)” instruction.

**Line 2** – assigns the address of the memory used to hold the “TV\_Screen” or what we call the “Tile Pointer Map” to “tv\_screen,” this is going to be passed momentarily.

**Line 3** – assigns the address of the color lookup table or “Tile Colorset Table” (where each LONG entry represents 4 color) to “tv\_colors.”

**Line 4** – starts the tv driver up by calling the sub-function “start” with the beginning of the parameters from our program’s VAR section.

Moving on, the next thing we need to do (actually you can do this before you start the TV driver) is build the TV\_Color and TV\_Screen data structures; these are the Colorset Table and the Tile Pointer Map respectively.

```

' init colors
repeat i from 0 to 64
    colors[i] := $00001010 * (i+4) & $F + $2B060C02

' init tile screen
repeat dx from 0 to tv_hc - 1
    repeat dy from 0 to tv_vc - 1
        screen[dy * tv_hc+dx] := onscreen_buffer >> 6+dy+dx*tv_vc+((dy & $3F) << 10)

```

Forgive the cryptic use of constants in the setup, they are “fudged” in the color initialization to give a “rainbow” color effect vertically down the screen. The initialization of the tile pointer map though is consistent, so that starting from “onscreen\_buffer” in memory wherever that is, the pointers are initialized to point to 64 BYTE blocks (16 LONG blocks) that each represent a tile in such a way that the Tile Bitmap Memory is organized in the column major form required by the Graphics driver algorithms (we will learn about that next).

At this point, the TV driver is up and running and video will display. Now, we can either delve into the bitmap memory directly or use the Parallax Graphics driver to draw graphics

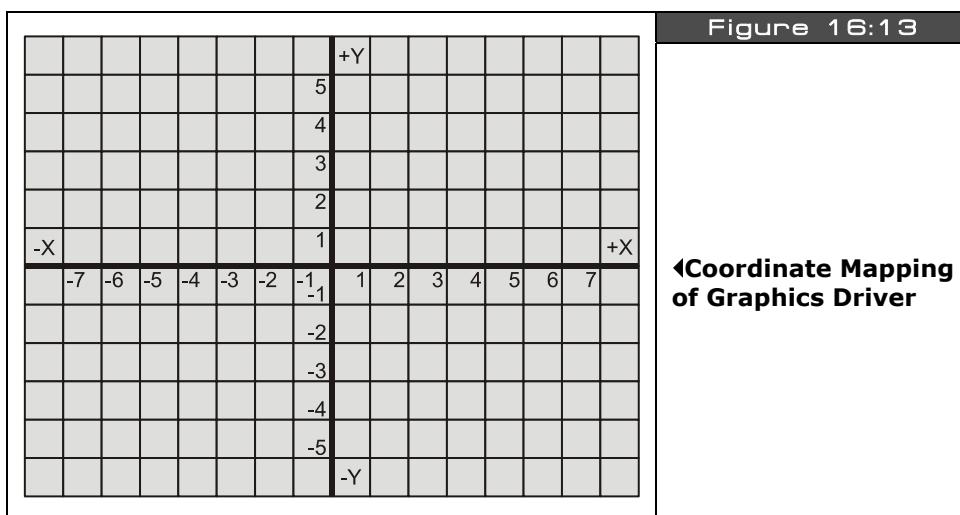
### 16.3.3 The Graphics Driver Details

The reference Graphics driver is named **GRAPHICS\_DRV\_010.SPIN** and was designed to give the best performance for a number of applications, not necessarily games. Nonetheless, it has a lot of cool features, supports rotation, sprites, polygons, pixels, lines, filled triangles, text and much more.

The only weirdness you are going to find is the use of polar coordinates to define polygons. For example, in every graphics engine you have ever used or written, I am sure you used standard Cartesian cords to represent vertices of a polygon or shape. This driver uses polar cords to simplify rotation. The problem is of course to make a simple square you have to compute the distance from the origin to each vertex using the Pythagorean theorem and then compute the angle for each polar point ( $r$ , theta). This is a huge pain and for complex objects you must resort to using inverse tangents to compute angles based on the vertex (x,y). A tool could be written to convert, but definitely not an intuitive architecture, however, rotation is sped up by this since it turns into addition!

In any event, other than the weird polar cords used to define polygons and shapes, everything else is pretty much what you would expect. I am not going to go over every function since there are too many to review and you can figure them out for yourself by reviewing the driver.

However, do review the graphics demo **GRAPHICS\_DEMO\_010.SPIN** since it uses much of the functionality. Nevertheless, a handful of demos will be shown that perform basic operations to get you started with the least amount of code. And as mentioned, all your initial experimentation should use the reference graphics driver, then you should start modifying it and optimizing it as need be.



The graphics driver uses a double-buffered architecture, that is, it renders into an “off-screen buffer” then has a function call that copies the “offscreen buffer” into the “on-screen buffer” that the TV driver or other driver is rendering. So during initialization, we pass the Graphics driver the offscreen\_buffer along with some other parameters and that’s it. Also, unlike most graphics systems, this graphics driver uses coordinates that are like standard graph paper or a Cartesian coordinate system. That is, positive X is to the right, but unlike normal graphics systems that have positive Y going down, this driver has positive Y going up. Therefore, the origin (0,0) of the driver is normally at the **bottom left hand corner** (rather than the top left hand corner of most graphics drivers). Also, you can translate this origin by passing values to the Graphics driver via the “setup” calls and center it just as a 2D Cartesian system; this mapping is shown in Figure 16:13 above. Let’s take a look at all this in detail now...

### 16.3.3.1 Initializing and Using the Graphics Driver

The first step in using the Graphics driver is to of course include it as an object and bind it to a variable name like this:

OBJ

```
gr : "graphics_drv_010.spin"      ' instantiate a graphics object
```

Of course, you would have a TV object in there as well, but I omitted it for simplicity. Now, the Graphics driver doesn’t need a parameter table, you simply pass all the important information as parameters. The “setup” function is shown next:

**Functional Syntax:**

```
PUB setup(x_tiles, y_tiles, x_origin, y_origin, base_ptr)
```

Where,

**x\_tiles** = Number of x tiles (tiles are always 16×16 pixels each).

**y\_tiles** = Number of y tiles.

**x\_origin** = Relative-x center pixel.

**y\_origin** = Relative-y center pixel.

**base\_ptr** = Base address of bitmap.

**Discussion:** The setup( ) function is rather straightforward: the x\_tiles and y\_tiles indicate the size of the screen overall since each tile is 16×16. Also, the x\_origin and y\_origin allow you to move the (0,0) point to anywhere you wish: for example, if the final screen size was 256×128 and you wanted to move the origin from the bottom left corner to the center of the screen, then the x\_origin and y\_origin would be set to 128,64 respectively which translates the origin to the center of the screen. Also, another nice feature of the Graphics driver is that it does all clipping for you! So when drawing pixels, lines, polygons, whatever, you don't have to worry about pre-clipping anything, they will be clipped for you. However, be warned the clipping is done at the pixel-plotting level, so it's not the fastest thing in the world! Lastly, you pass the starting address of video memory to be used as the off-screen buffer. All rendering will be done here and for the most part is invisible until you copy the off-screen buffer to the visible on-screen buffer than the TV Driver is rendering. The Graphics driver has a function call to do this as well.

**Example:** Set up a 256×192 pixel screen consisting of 16×12 tiles with the origin at the bottom left corner and an offscreen rendering area at \$4000.

```
gr.setup(16, 12, 0, 0, $4000)
```

Next, let's briefly take a quick look at the function list in the Graphics driver, we aren't going to cover each since there are too many and you can simply look at the driver source itself for more insight.

**Remaining Graphics Driver Function List**

The following is a list of the remaining graphics drivers functions and their prototypes and parameters, please review the source in **GRAPHICS\_DRV\_010.SPIN** for a more details since this list doesn't have complete discussions or examples of each function.

**Functional Syntax:**

PUB start : okay  
" Start graphics driver - starts a cog.

**Functional Syntax:**

PUB stop  
" Stop graphics driver - frees a cog.

**Functional Syntax:**

PUB clear  
" Clear bitmap.

**Functional Syntax:**

PUB copy(dest\_ptr)  
" Copy bitmap, use for double-buffered display (flicker-free).

**Functional Syntax:**

PUB color(c)  
" Set pixel color to two-bit pattern where c is color code in bits[1..0].

**Functional Syntax:**

PUB width(w)  
" Set pixel width, actual width is w[3..0] + 1, w is 0..15 for round  
" pixels, 16..31 for square pixels.

**Functional Syntax:**

PUB colorwidth(c, w)  
" Set pixel color and width c and w respectively.

**Functional Syntax:**

PUB plot(x, y)  
" Plot point at x,y.

**Functional Syntax:**

```
PUB line(x, y)
" Draw a line from the last endpoint to x,y
PUB arc(x, y, xr, yr, angle, anglestep, steps, arcmode)
" Draw an arc.
"   x,y      - center of arc.
"   xr,yr    - radii of arc.
"   angle     - initial angle in bits[12..0] (0..$1FFF = 0°..359.956°).
"   anglestep - angle step in bits[12..0].
"   steps      - number of steps (0 just leaves (x,y) at initial arc position).
"   arcmode    - 0: plot point(s), 1: line to point(s), 2: line between points,
"                 3: line from point(s) to center.
```

**Functional Syntax:**

```
PUB vec(x, y, vecscale, vecangle, vecdef_ptr)
" Draw a vector sprite.
"   x,y      - center of vector sprite.
"   vecscale - scale of vector sprite ($100 = 1x).
"   vecangle  - rotation angle of vector sprite in bits[12..0].
"   vecdef_ptr - address of vector sprite definition.
```

**Functional Syntax:**

```
PUB vecarc(x, y, xr, yr, angle, vecscale, vecangle, vecdef_ptr)
" Draw a vector sprite at an arc position.
"   x,y      - center of arc.
"   xr,yr    - radii of arc.
"   angle     - angle in bits[12..0] (0..$1FFF = 0°..359.956°).
"   vecscale - scale of vector sprite ($100 = 1x).
"   vecangle  - rotation angle of vector sprite in bits[12..0].
"   vecdef_ptr - address of vector sprite definition.
```

**Functional Syntax:**

```
PUB pix(x, y, pixrot, pixdef_ptr)
" Draw a pixel sprite.
"   x,y      - center of vector sprite.
"   pixrot   - 0: 0°, 1: 90°, 2: 180°, 3: 270°, +4: mirror.
"   pixdef_ptr - address of pixel sprite definition.
```

**Functional Syntax:**

```
PUB pixarc(x, y, xr, yr, angle, pixrot, pixdef_ptr)
" Draw a pixel sprite at an arc position.
"   x,y      - center of arc.
"   xr,yr    - radii of arc.
"   angle     - angle in bits[12..0] (0..$1FFF = 0°..359.956°).
"   pixrot    - 0: 0°, 1: 90°, 2: 180°, 3: 270°, +4: mirror.
"   pixdef_ptr - address of pixel sprite definition.
```

**Functional Syntax:**

```
PUB text(x, y, string_ptr) | justx, justy
" Draw text
"   x,y      - text position (see textmode for sizing and justification).
"   string_ptr - address of zero-terminated string (it may be necessary to call
"                  finish immediately afterwards to prevent subsequent code from
"                  clobbering the string as it is being drawn.
```

**Functional Syntax:**

```
PUB textarc(x, y, xr, yr, angle, string_ptr) | justx, justy
" Draw text at an arc position.
"   x,y      - center of arc.
"   xr,yr    - radii of arc.
"   angle     - angle in bits[12..0] (0..$1FFF = 0°..359.956°).
"   string_ptr - address of zero-terminated string (it may be necessary to call
"                  finish immediately afterwards to prevent subsequent code from
"                  clobbering the string as it is being drawn.
```

**Functional Syntax:**

```
PUB textmode(x_scale, y_scale, spacing, justification)
" Set text size and justification.
"   x_scale   - x character scale, should be 1+.
"   y_scale   - y character scale, should be 1+.
"   spacing   - character spacing, 6 is normal.
"   justification- bits[1..0]: 0..3 = left, center, right, left.
"                      bits[3..2]: 0..3 = bottom, center, top, bottom.
```

**Functional Syntax:**

```
PUB box(x, y, box_width, box_height) | x2, y2, pmin, pmax
" Draw a box with round/square corners, according to pixel width.
"   x,y      - box left, box bottom.
```

**Functional Syntax:**

```
PUB quad(x1, y1, x2, y2, x3, y3, x4, y4)
" Draw a solid quadrilateral.
" vertices must be ordered clockwise or counter-clockwise.
```

**Functional Syntax:**

```
PUB tri(x1, y1, x2, y2, x3, y3)
" Draw a solid triangle.
```

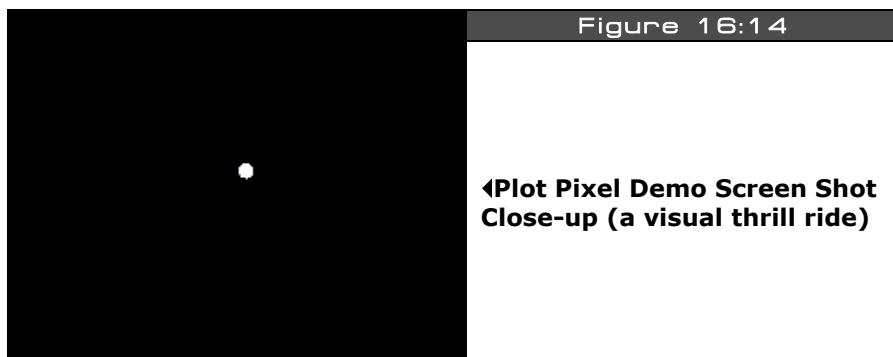
**Functional Syntax:**

```
PUB finish
" Wait for any current graphics command to finish.
" use this to insure that it is safe to manually manipulate the bitmap.
```

As you can see the Graphics driver is quite extensive. Use it as a model to write your own graphics drivers in the future. For example, one immediate optimization that can be done is to cut all the functions that you don't use in your demo(s) and then to optimize the rendering functions, so it's a good base to start with. Of course, the actual "code" that does most of the work is in assembly language in the DAT section of the **GRAPHICS\_DRV\_010.SPIN** source, so you are going to have to code in ASM to optimize the driver and redo it when the time comes and you have pushed it to its limits.

Now, that you have a firm foundation and have a picture (no pun intended) of how the TV and Graphics drivers related to each other, let's see a few quick demos of some of the more basic functions. Of course, you could just crack open any of the game demos or the **GRAPHICS\_DEMO\_010.SPIN** itself, but they have a lot of other stuff in them, so sometimes it's nice to see the bare minimum for a demo. Alas, in the next sections will be a collection of rudimentary demos that do very little other than what they are intended, this way you can see what's what and not have to deal with a bunch of ancillary code.

### 16.3.3.2 Plot Pixel Demo



We have already seen how to access video RAM directly and plot pixels as organized by the TV driver, **TV\_DRV\_010.SPIN**. However, in this demo and all those remaining we are going to see how to perform basic graphics functions using the Graphics driver itself. The first demo plots a single dot on the screen and moves it from left to right as shown in Figure 16:14. The code for the demo is located on the CD in the path below and is listed below for reference:

**CD\_ROOT:\HYDRA\SOURCES\PLOT\_PIXEL\_010.SPIN**

```
' /////////////////////////////////
' Plot Pixel Demo - plot a single pixel on screen and animates it by
' moving it from left to right
' AUTHOR: Andre' LaMothe
' LAST MODIFIED: 1.3.06
' VERSION 1.0
'
' /////////////////////////////////
' CONSTANTS SECTION /////////////////////////////////
'
CON
_clkmode = xtal2 + pll4x           : enable external clock and pll times 4
_xinfreq = 10_000_000 + 3000        : set frequency to 10 MHZ plus some error
_stack = ($3000 + $3000 + 64) >> 2 : accomodate display memory and stack
```

```

' graphics driver and screen constants
PARAMCOUNT      = 14
OFFSCREEN_BUFFER = $2000          ' offscreen buffer
ONSCREEN_BUFFER  = $5000          ' onscreen buffer

' size of graphics tile map
X_TILES          = 16
Y_TILES          = 12

SCREEN_WIDTH     = 256
SCREEN_HEIGHT    = 192

'/////////////////////////////////////////////////////////////////
' VARIABLES SECTION /////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////

VAR
  long tv_status      '0/1/2 = off/visible/invisible           read-only
  long tv_enable       '0/? = off/on                           write-only
  long tv_pins         '%ppmmm = pins                          write-only
  long tv_mode         '%ccinp = chroma,interlace,ntsc/pal,swap   write-only
  long tv_screen       'pointer to screen (words)                   write-only
  long tv_colors       'pointer to colors (longs)                  write-only
  long tv_hc           'horizontal cells                         write-only
  long tv_vc           'vertical cells                          write-only
  long tv_hx           'horizontal cell expansion                 write-only
  long tv_vx           'vertical cell expansion                  write-only
  long tv_ho           'horizontal offset                        write-only
  long tv_vo           'vertical offset                         write-only
  long tv_broadcast    'broadcast frequency (Hz)                  write-only
  long tv_auralcog    'aural fm cog                           write-only

  word screen[X_TILES * Y_TILES]  ' storage for screen tile map
  long colors[64]             ' color look up table

'/////////////////////////////////////////////////////////////////
' OBJECT DECLARATION SECTION ///////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////

OBJ
  tv    : "tv_drv_010.spin"      ' instantiate a tv object
  gr    : "graphics_drv_010.spin" ' instantiate a graphics object

'/////////////////////////////////////////////////////////////////
' PUBLIC FUNCTIONS ///////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////


PUB start | i, dx, dy, x, y

```

```

'start tv
longmove(@tv_status, @tvparams, paramcount)
tv_screen := @screen
tv_colors := @colors
tv.start(@tv_status)

'init colors
repeat i from 0 to 64
    colors[i] := $00001010 * (i+4) & $F + $FB060C02

'init tile screen
repeat dx from 0 to tv_hc - 1
    repeat dy from 0 to tv_vc - 1
        screen[dy*tv_hc+dx] := onscreen_buffer >> 6+dy+dx*tv_vc+((dy & $3F) << 10)

'start and setup graphics 256x192, with origin (0,0) at center of screen
gr.start
gr.setup(X_TILES, Y_TILES, SCREEN_WIDTH/2, SCREEN_HEIGHT/2, offscreen_buffer)

' BEGIN GAME LOOP /////////////////////////////////
' infinite loop
repeat while TRUE

    'clear the offscreen buffer
    gr.clear

    ' RENDERING SECTION (render to offscreen buffer always/////////////////
    ' set pen attributes, color 1, size 0
    gr.colorwidth(1,0)

    ' plot the pixel
    gr.plot(x, 0)

    ' move the pixel
    if (++x > SCREEN_WIDTH/2)
        x := -SCREEN_WIDTH/2

    'copy bitmap to display offscreen -> onscreen
    gr.copy(onscreen_buffer)

    ' synchronize to frame rate would go here...

    ' END RENDERING SECTION /////////////////////////////////
    ' END MAIN GAME LOOP REPEAT BLOCK ///////////////////////////////

```

```

'/////////////////////////////////////////////////////////////////
' DATA SECTION ///////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////

DAT

' TV PARAMETERS FOR DRIVER /////////////////////////////////

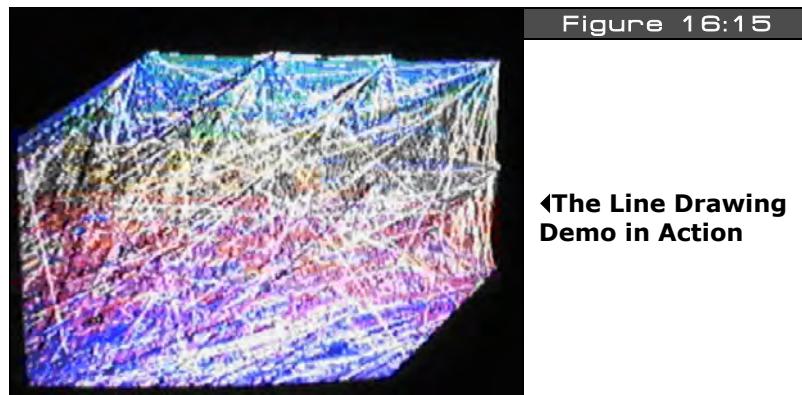
tvparams long 0           'status
          long 1           'enable
          long %011_0000   'pins
          long %0000        'mode
          long 0            'screen
          long 0            'colors
          long x_tiles     'hc
          long y_tiles     'vc
          long 10           'hx timing stretch
          long 1            'vx
          long 0            'ho
          long 0            'vo
          long 55_250_000   'broadcast on channel 2 VHF, each channel is
                           ' 6 MHz above the previous
          long 0            'auralcog

```

The code is fairly straightforward: the TV driver parameters are defined in the VAR section then the TV driver and Graphics driver are included in the OBJ section. The code continues into the initialization section where the TV driver and Graphics driver are initialized. Then we fall into the main loop, set the pen color and width, plot a single pixel, and move it checking for bounds overflow. This is more or less the smallest program you can write to do all this. Also, notice the program clears the off-screen buffer, then renders, then copies the off-screen buffer to the on-screen buffer. Even though there is hardly any animation happening other than the pixel walking across the screen, this is a complete “game loop” with double-buffered animation.

Therefore, the pixel plotting aside, you can use this program as a “template” for your other graphics programs to get things started. Also, notice I am running the chip at 40 MHz even though it will go 80 MHz.

### 16.3.3.3 Line Drawing Demo



To draw lines, you must use the Line( ) function, but to “seed” the starting point, you must use the Plot( ) function. Therefore, whenever you draw a line, the line is drawn from the last “plot” or the endpoint of the last line drawn. Figure 16:15 shows the line drawing demo in action. The code for the demo is located on the CD in the path below and is listed below for reference:

**CD\_ROOT:\HYDRA\SOURCES\DRAW\_LINES\_010.SPIN**

```
' /////////////////////////////////
' Line Drawing Demo - Draw lines randomly on screen
' AUTHOR: Andre' LaMothe
' LAST MODIFIED: 1.4.06
' VERSION 1.0
'
' ///////////////////////////////
'
' /////////////////////////////// CONSTANTS SECTION ///////////////////////////////
'
CON
    _clkmode = xtal2 + pll4x          ' enable external clock and pll times 4
    _xinfreq = 10_000_000 + 3000      ' set frequency to 10 MHZ plus some error
    _stack = ($3000 + $3000 + 64) >> 2 ' accomodate display memory and stack
    '
    ' graphics driver and screen constants
    PARAMCOUNT = 14
```

```

OFFSCREEN_BUFFER = $2000          ' offscreen buffer
ONSCREEN_BUFFER = $5000           ' onscreen buffer

' size of graphics tile map
X_TILES          = 16
Y_TILES          = 12

SCREEN_WIDTH     = 256
SCREEN_HEIGHT    = 192

'/////////////////////////////////////////////////////////////////
' VARIABLES SECTION /////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////

VAR
  long tv_status      '0/1/2 = off/visible/invisible      read-only
  long tv_enable       '0/? = off/on                         write-only
  long tv_pins         '%ppmmm = pins                      write-only
  long tv_mode         '%ccinp = chroma,interlace,ntsc/pal,swap write-only
  long tv_screen        pointer to screen (words)           write-only
  long tv_colors        pointer to colors (longs)          write-only
  long tv_hc            horizontal cells                   write-only
  long tv_vc            vertical cells                     write-only
  long tv_hx            horizontal cell expansion        write-only
  long tv_vx            vertical cell expansion        write-only
  long tv_ho            horizontal offset                 write-only
  long tv_vo            vertical offset                  write-only
  long tv_broadcast     broadcast frequency (Hz)        write-only
  long tv_auralcog     aural fm cog                    write-only

  word  screen[X_TILES * Y_TILES]   ' storage for screen tile map
  long colors[64]                ' color look up table

'/////////////////////////////////////////////////////////////////
' OBJECT DECLARATION SECTION ///////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////

OBJ
  tv    : "tv_drv_010.spin"      ' instantiate a tv object
  gr    : "graphics_drv_010.spin" ' instantiate a graphics object

'/////////////////////////////////////////////////////////////////
' PUBLIC FUNCTIONS /////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////

PUB start | i, dx, dy, x, y, color

  'start tv
  longmove(@tv_status, @tvparams, paramcount)

```

```

tv_screen := @screen
tv_colors := @colors
tv.start(@tv_status)

'init colors
repeat i from 0 to 64
    colors[i] := $00001010 * (i+4) & $F + $FB060C02

'init tile screen
repeat dx from 0 to tv_hc - 1
    repeat dy from 0 to tv_vc - 1
        screen[dy*tv_hc+dx] := onscreen_buffer >> 6+dy+dx*tv_vc+((dy & $3F) << 10)

'start and setup graphics 256x192, with origin (0,0) at bottom left of screen
gr.start
gr.setup(X_TILES, Y_TILES, 0, 0, onscreen_buffer)

' BEGIN GAME LOOP /////////////////////////////////
' initialize some vars
x := 0
y := 0
color := 1

'clear the onscreen buffer
gr.clear

' plot the pixel at origin to seed starting point for line draw
gr.plot(0, 0)

' infinite loop
repeat while TRUE

    ' RENDERING SECTION (render to offscreen buffer always/////////////////
    ' set pen attributes, color (1..3), size 0
    gr.colorwidth(1 + (?color) // 3,0)

    ' draw the next line segment to a pseudo-random location onscreen
    ' notice the update of x,y pseudo-randomly with LFSR operator "?"
    ' "//" is the modulus operator which keeps are values on screen
    gr.line(?x // 256, ?y // 192)

    ' synchronize to frame rate would go here...

    ' END RENDERING SECTION /////////////////////////////////
    ' END MAIN GAME LOOP REPEAT BLOCK ///////////////////////////////

```

```

'/////////////////////////////////////////////////////////////////
' DATA SECTION /////////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////

DAT

' TV PARAMETERS FOR DRIVER /////////////////////////////////

tvparams long 0           'status
           long 1           'enable
           long %011_0000   'pins
           long %0000        'mode
           long 0            'screen
           long 0            'colors
           long x_tiles     'hc
           long y_tiles     'vc
           long 10           'hx timing stretch
           long 1            'vx
           long 0            'ho
           long 0            'vo
           long 55_250_000   'broadcast on channel 2 VHF, each channel is
                           '6 MHz above the previous
           long 0            'auralcog

```

The demo has nearly the same initialization as the pixel plotting demo, but calls the Graphic's driver's Setup( ) function is a bit different. In the line demo, the origin is set to (0,0) at the bottom left of the screen for fun. Also, since I don't want any animation this time, the Graphics driver is told to render directly on the visible on-screen buffer, this way the line rendering is "accumulated" and we see lots of lines. Some things to note about the line drawing is the clever use of the LFSR (linear feedback shift register) operator to generate pseudo-random numbers for the endpoint of the lines. Notice the geometrical pattern they generate, they cover most of the screen, but there are "holes" in the coverage, these holes are numerical values that never occur in the sequence which is interesting. In any event, let's move on to something more complex and render some triangles and polygons.

### 16.3.3.4 Triangle Demo



The Graphics driver can draw open or closed line-based polygons, filled triangles as well as quads. In most cases, you will use triangles or polygon contours to draw your graphics, so we are going to take a look at these two functions. Again, there are variants of these functions, so look through the Graphics driver source to really get the low-down. The triangle demo simply draws a collection of random triangles on the screen, 100 at a time, and then refreshes the page (running at 80 MHz); the demo is shown running Figure 16:16. The code for the demo is located on the CD in the path below and is listed below for reference:

**CD\_ROOT:\HYDRA\SOURCES\DRAW\_TRIANGLES\_010.SPIN**

```
' /////////////////////////////////
' Triangle Drawing Demo - Draws sets of 100 triangles per frame
' AUTHOR: Andre' LaMothe
' LAST MODIFIED: 1.4.06
' VERSION 1.0
'
' ///////////////////////////////
'
' ///////////////////////////////
' CONSTANTS SECTION ///////////////
' ///////////////////////////////
CON
_clkmode = xtal12 + pll8x           : enable external clock and pll times 8
_xinfreq = 10_000_000 + 3000         : set frequency to 10 MHZ plus some error
_stack = ($3000 + $3000 + 64) >> 2  : accommodate display memory and stack
'
' graphics driver and screen constants
```

```

PARAMCOUNT      = 14
OFFSCREEN_BUFFER = $2000          ' offscreen buffer
ONSCREEN_BUFFER = $5000          ' onscreen buffer

' size of graphics tile map
X_TILES         = 16
Y_TILES         = 12

SCREEN_WIDTH    = 256
SCREEN_HEIGHT   = 192

'/////////////////////////////////////////////////////////////////
' VARIABLES SECTION /////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////

VAR
  long tv_status      '0/1/2 = off/visible/invisible           read-only
  long tv_enable       '0/? = off/on                           write-only
  long tv_pins         '%ppmmm = pins                         write-only
  long tv_mode         '%ccinp = chroma,interlace,ntsc/pal,swap   write-only
  long tv_screen       'pointer to screen (words)                   write-only
  long tv_colors       'pointer to colors (longs)                  write-only
  long tv_hc           'horizontal cells                      write-only
  long tv_vc           'vertical cells                        write-only
  long tv_hx           'horizontal cell expansion                 write-only
  long tv_vx           'vertical cell expansion                  write-only
  long tv_ho           'horizontal offset                     write-only
  long tv_vo           'vertical offset                      write-only
  long tv_broadcast    'broadcast frequency (Hz)                write-only
  long tv_auralcog    'aural fm cog                         write-only

  word  screen[X_TILES * Y_TILES]  ' storage for screen tile map
  long colors[64]           ' color look up table

'/////////////////////////////////////////////////////////////////
' OBJECT DECLARATION SECTION ///////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////
OBJ
  tv    : "tv_drv_010.spin"      ' instantiate a tv object
  gr    : "graphics_drv_010.spin" ' instantiate a graphics object

'/////////////////////////////////////////////////////////////////
' PUBLIC FUNCTIONS ///////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////


PUB start | i, dx, dy, x, y, color, x0, y0, x1, y1, x2, y2
  'start tv

```

```

longmove(@tv_status, @tvparams, paramcount)
tv_screen := @screen
tv_colors := @colors
tv.start(@tv_status)

'init colors
repeat i from 0 to 64
    colors[i] := $00001010 * (i+4) & $F + $FB060C02

'init tile screen
repeat dx from 0 to tv_hc - 1
    repeat dy from 0 to tv_vc - 1
        screen[dy*tv_hc+dx] := onscreen_buffer >> 6+dy+dx*tv_vc + ((dy & $3F) << 10)

'start and setup graphics 256x192, with origin (0,0) at center of screen
gr.start
gr.setup(X_TILES, Y_TILES, SCREEN_WIDTH/2, SCREEN_HEIGHT/2, offscreen_buffer)

' BEGIN GAME LOOP /////////////////////////////////
' seed x,y with some arbitrary #'s
x := 13
y := 177

' infinite loop
repeat while TRUE

    'clear the offscreen buffer
    gr.clear

    ' RENDERING SECTION (render to offscreen buffer always///////////
    ' draw 1000 triangles per frame
    repeat i from 0 to 100
        ' generate the vertices seperately for fun
        x0 := -SCREEN_WIDTH/2 + ?x // SCREEN_WIDTH
        y0 := -SCREEN_HEIGHT/2 + ?y // SCREEN_HEIGHT

        x1 := -SCREEN_WIDTH/2 + ?x // SCREEN_WIDTH
        y1 := -SCREEN_HEIGHT/2 + ?y // SCREEN_HEIGHT

        x2 := -SCREEN_WIDTH/2 + ?x // SCREEN_WIDTH
        y2 := -SCREEN_HEIGHT/2 + ?y // SCREEN_HEIGHT

        ' draw the triangle with the generated vertex list
        gr.tri (x0, y0, x1, y1, x2, y2)

        ' set pen attributes to cycling color, size 0

```

```

gr.colorwidth(++color // 4,0)

' copy bitmap to display offscreen -> onscreen
gr.copy(onscreen_buffer)

' synchronize to frame rate would go here...

' END RENDERING SECTION /////////////////////////////////
' END MAIN GAME LOOP REPEAT BLOCK /////////////////////////////////

'/////////////////////////////////////////////////////////////////
' DATA SECTION /////////////////////////////////
'/////////////////////////////////////////////////////////////////

DAT

' TV PARAMETERS FOR DRIVER /////////////////////////////////

tvparams long    0           'status
           long    1           'enable
           long   %011_0000   'pins
           long   %0000       'mode
           long    0           'screen
           long    0           'colors
           long   x_tiles     'hc
           long   y_tiles     'vc
           long    10          'hx timing stretch
           long    1           'vx
           long    0           'ho
           long    0           'vo
           long 55_250_000   'broadcast on channel 2 VHF, each channel is
                           '6 MHz above the previous
           long    0           'auralcog

```

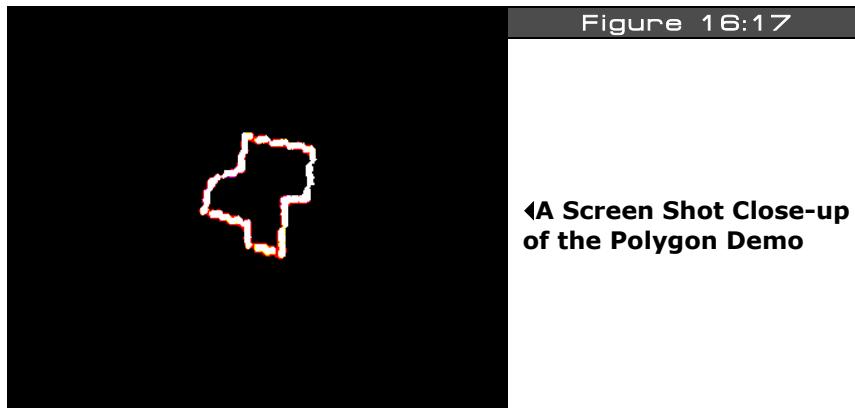
The triangle demo doesn't do anything new, but makes the call to the Tri( ) function which takes 3 sets of x,y cords and renders the filled triangle. As you can see, even at 80 MHz, when you run the demo even 100 polys a frame is really taxing the graphics engine. Here's where some of the non-performance design issues are going to really pop up. For example, the clipping is per pixel, and when rendering triangles you would always clip the top and bottom and then clip only the endpoints of spans, the Graphics engine doesn't do this and simply clips every pixel. This slows it down by a factor of 5 to 10, so don't count on making Quake with it ☺. However, for some simple 3D demos, this triangle rasterizer should be good to get some solid cubes on the screen.



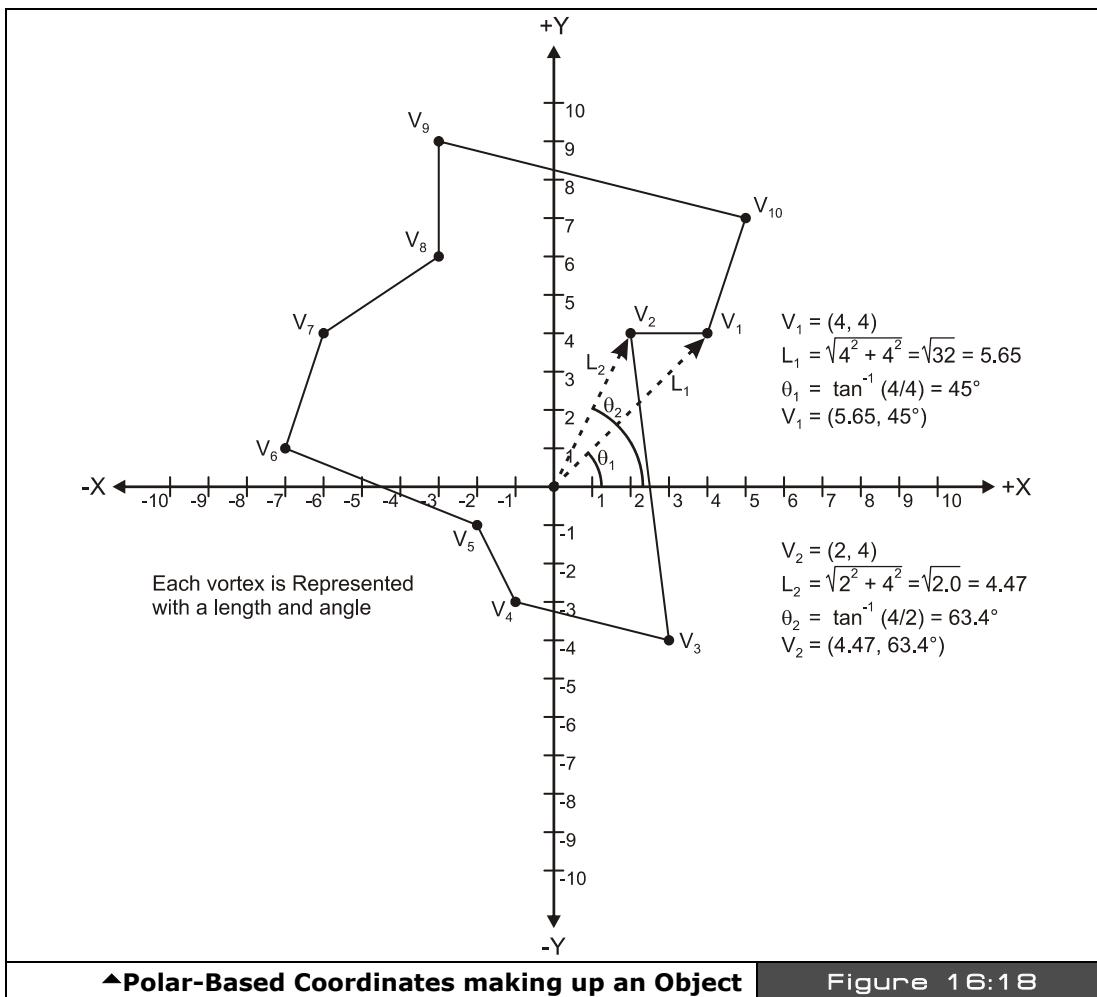
TIP

The code for all the demos is meant to be clear not clever; however, the compiler is not optimizing, thus what you see is what you get. See if by syntax changes alone you can speed the rendering up any?

#### 16.3.3.5 Polygon Demo



The polygon support in the Graphics engine allows you to draw unfilled polygons made of lines where the polygon can be open or closed. A screen shot of the demo program we will look at shortly is shown in Figure 16:17. In fact, its not really a “polygon” demo per se, but a collection of vectors that make up the polygon, thus you can draw polygons, but what you are really doing is drawing what the engine refers to as a **“Vector Sprite.”** A vector:sprite is a collection of vectors that make up the contour of the object where each vector is a Polar coordinate based vector in the format of (r, theta) rather than (x,y) vertices, this is shown in Figure 16:18.



▲Polar-Based Coordinates making up an Object

Figure 16:18

Now, what the cool part is that vector sprites are really data structures that define the sprite and then are passed to the vector sprite rendering function named `Vec()` which does all the work and the function supports "on the fly" rotation and scaling, so its very powerful!

The prototype and data structure for the Vector Sprite is shown below pulled right from the Graphics driver **GRAPHICS\_DRV\_010.SPIN**:

```
PUB vec(x, y, vecscale, vecangle, vecdef_ptr)
  `` Draw a vector sprite
```

```

```
``` x,y           - center of vector sprite
``` vecscale      - scale of vector sprite ($100 = 1x)
``` vecangle       - rotation angle of vector sprite in bits[12..0]
``` vecdef_ptr     - address of vector sprite definition
```

``` Vector sprite definition:
``

``` word      $8000 | 4000 + angle   ' vector mode + 13-bit angle
```                           ' (mode: $4000=plot, $8000=line)
```                           ' where angle is a 13 bit value bits[12..0]
```                           ' mapping (0..$1FFF = 0°..359.956°)
``` word      length            ' vector length
``` ...
``` ...
``` word      0                ' end of definition

``` ' angular constants to make object declarations easier
``` ANG_0      = $0000
``` ANG_360    = $2000
``` ANG_240    = ($2000*2/3)
``` ANG_180    = ($2000/2)
``` ANG_120    = ($2000/3)
``` ANG_90     = ($2000/4)
``` ANG_60     = ($2000/6)
``` ANG_45     = ($2000/8)
``` ANG_30     = ($2000/12)
``` ANG_22_5   = ($2000/16)
``` ANG_15     = ($2000/24)
``` ANG_10     = ($2000/36)
``` ANG_5      = ($2000/72)
```

```

Reviewing the parameters, we need to pass to the function the screen position to draw the vector sprite (this is always the center of the sprite), along with the scale (notice \$100 is 1×) and rotation angle (more on this in a moment), finally a pointer to the actual vector sprite data which is in the format shown above in the "Vector Sprite Definition." So each vector consists of:

1. A **vector mode angle** WORD which defines polar angle of the vector as well as indicates if only a point should be plotted (\$4000) at the endpoint or if a line (\$8000) should be drawn from the last endpoint.

$$\text{angle} = (\$8000 \mid \$4000) + \$2000 * \theta/360$$

There is a table I have generated with some common angles in the listing above as well. But, basically 0-360 maps to \$0000 to \$2000.

2. The **length** of the vector in pixels – this is equivalent to r in the polar coord (r,theta), simply compute the length with the standard Pythagorean formula:

$$r = \sqrt{x^2 + y^2}$$

...where x,y is the point of the vertex assuming a center of (0,0).

To end the vector sprite definition place a \$0000 at the end and this stops the sequence.

Figure 16:18 above shows a polar sprite asteroid graphed on graph paper and here's the data structure for it from the demo we will see shortly:

```
DAT
asteroid_large
    word    $4000+$2000*45/360      ' vertex 0, start as a point
    word    8*8

    word    $8000+$2000*63/360      ' vertex 1
    word    4*8

    word    $8000+$2000*108/360     ' vertex 2
    word    6*8

    word    $8000+$2000*147/360     ' vertex 3
    word    7*8

    word    $8000+$2000*206/360     ' vertex 4
    word    4*8

    word    $8000+$2000*213/360     ' vertex 5
    word    7*8

    word    $8000+$2000*243/360     ' vertex 6
    word    9*8

    word    $8000+$2000*296/360     ' vertex 7
    word    4*8

    word    $8000+$2000*303/360     ' vertex 8
    word    7*8

    word    $8000+$2000*348/360     ' vertex 9
    word    10*8

    word    $8000+$2000*45/360      ' vertex 0
    word    8*8
    word    0                         ' terminates vector sprite
```

There are 10 vertices that make the asteroids and then the last vertex is connected to the first. Also, notice the first vertex uses the mode \$4000 pattern which indicates "point," and from then on we use \$8000 which means draw a line from the last vertex. As a demo, I have created a program that draws a single asteroids polygon and rotates it around slowly as it moves around. The code for the demo is located on the CD in the path below and is listed below for reference:

#### **CD\_ROOT:\HYDRA\SOURCES\POLYGON\_VECTOR\_010.SPIN**

```
' /////////////////////////////////'
' Polygon Drawing Demo - Draws a single polygon based on the vector sprite
' and moves it around on the screen
' AUTHOR: Andre' LaMothe
' LAST MODIFIED: 1.4.06
' VERSION 1.0
'

' /////////////////////////////////'
' CONSTANTS SECTION /////////////////////////////////
' /////////////////////////////////'

CON

_clkmode = xtal12 + pll4x           ' enable external clock and pll times 8
_xinfreq = 10_000_000 + 3000        ' set frequency to 10 MHZ plus some error
_stack = ($3000 + $3000 + 64) >> 2 ' accomodate display memory and stack

' graphics driver and screen constants
PARAMCOUNT      = 14
OFFSCREEN_BUFFER = $2000           ' offscreen buffer
ONSCREEN_BUFFER  = $5000           ' onscreen buffer

' size of graphics tile map
X_TILES          = 16
Y_TILES          = 12

SCREEN_WIDTH     = 256
SCREEN_HEIGHT    = 192

' angular constants to make object declarations easier
ANG_0            = $0000
ANG_360           = $2000
ANG_240           = ($2000*2/3)
ANG_180           = ($2000/2)
ANG_120           = ($2000/3)
```

```

ANG_90    = ($2000/4)
ANG_60    = ($2000/6)
ANG_45    = ($2000/8)
ANG_30    = ($2000/12)
ANG_22_5  = ($2000/16)
ANG_15    = ($2000/24)
ANG_10    = ($2000/36)
ANG_5     = ($2000/72)

'/////////////////////////////////////////////////////////////////
' VARIABLES SECTION ///////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////

VAR
  long tv_status      '0/1/2 = off/visible/invisible          read-only
  long tv_enable       '0/? = off/on                                write-only
  long tv_pins         '%ppmmm = pins                               write-only
  long tv_mode         '%ccinp = chroma,interlace,ntsc/pal,swap   write-only
  long tv_screen        pointer to screen (words)                write-only
  long tv_colors        pointer to colors (longs)                 write-only
  long tv_hc           'horizontal cells                         write-only
  long tv_vc           'vertical cells                          write-only
  long tv_hx           'horizontal cell expansion                  write-only
  long tv_vx           'vertical cell expansion                  write-only
  long tv_ho           'horizontal offset                         write-only
  long tv_vo           'vertical offset                           write-only
  long tv_broadcast    'broadcast frequency (Hz)                   write-only
  long tv_auralcog    'aural fm cog                            write-only

  word screen[X_TILES * Y_TILES] ' storage for screen tile map
  long colors[64]           ' color look up table

'/////////////////////////////////////////////////////////////////
' OBJECT DECLARATION SECTION ///////////////////////////////////
'/////////////////////////////////////////////////////////////////
OBJ
  tv    : "tv_drv_010.spin"      ' instantiate a tv object
  gr    : "graphics_drv_010.spin" ' instantiate a graphics object

'/////////////////////////////////////////////////////////////////
' PUBLIC FUNCTIONS ///////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////


PUB start | i, dx, dy, x, y, color, rotation

  'start tv
  longmove(@tv_status, @tvparams, paramcount)
  tv_screen := @screen

```

```

tv_colors := @colors
tv.start(@tv_status)

'init colors
repeat i from 0 to 64
  colors[i] := $00001010 * (i+4) & $F + $FB060C02

'init tile screen
repeat dx from 0 to tv_hc - 1
  repeat dy from 0 to tv_vc - 1
    screen[dy*tv_hc+dx] := onscreen_buffer >> 6+dy+dx*tv_vc+((dy & $3F) << 10)

'start and setup graphics 256x192, with origin (0,0) at bottom left of screen
gr.start
gr.setup(X_TILES, Y_TILES, SCREEN_WIDTH/2, SCREEN_HEIGHT/2, offscreen_buffer)

' BEGIN GAME LOOP /////////////////////////////////
' initialize position of asteroid
x := 0
y := 0

' set pen attributes
gr.colorwidth(1, 0)

' infinite loop
repeat while TRUE

  'clear the offscreen buffer
  gr.clear

  ' RENDERING SECTION (render to offscreen buffer always///////////
  ' draw asteroid polygon at $100 = 1x scale with slowly incrementing
  ' rotation angle
  gr.vec(x, y, $100, rotation, @asteroid_large)

  ' animate asteroid
  rotation := (rotation+=4 // ANG_360)

  ' translate asteroid
  if (++x > SCREEN_WIDTH/2)
    x -= SCREEN_WIDTH

  'copy bitmap to display offscreen -> onscreen
  gr.copy(onscreen_buffer)

  ' synchronize to frame rate would go here...

```

```

' END RENDERING SECTION /////////////////////////////////
' END MAIN GAME LOOP REPEAT BLOCK ///////////////////////////////
////////////////////////////// DATA SECTION ///////////////////////////////
////////////////////////////// ///////////////////////////////
DAT
' TV PARAMETERS FOR DRIVER /////////////////////////////////

tvparams long    0           ' status
            long   1           ' enable
            long %011_0000     ' pins
            long %0000          ' mode
            long 0              ' screen
            long 0              ' colors
            long x_tiles        ' hc
            long y_tiles        ' vc
            long 10             ' hx timing stretch
            long 1              ' vx
            long 0              ' ho
            long 0              ' vo
            long 55_250_000      ' broadcast on channel 2 VHF, each channel is
                                ' 6 MHz above the previous
            long 0              ' auralcog

asteroid_large
            word   $4000+$2000*45/360      ' vertex 0
            word   8*2

            word   $8000+$2000*63/360      ' vertex 1
            word   4*2

            word   $8000+$2000*108/360     ' vertex 2
            word   6*2

            word   $8000+$2000*147/360     ' vertex 3
            word   7*2

            word   $8000+$2000*206/360     ' vertex 4
            word   4*2

            word   $8000+$2000*213/360     ' vertex 5

```

```

word    7*2
word    $8000+$2000*243/360      ' vertex 6
word    9*2
word    $8000+$2000*296/360      ' vertex 7
word    4*2
word    $8000+$2000*303/360      ' vertex 8
word    7*2
word    $8000+$2000*348/360      ' vertex 9
word    10*2
word    $8000+$2000*45/360       ' vertex 0
word    8*2
word    0                         ' terminates vector sprite

```

The demo uses the double-buffer display since we need animation to smoothly draw the asteroid. Also, notice that after the asteroid is drawn with the call to `Vec()`, we animate its angle and position. One note, the angle is not cumulative, that is the rendering rotates the vector sprite every single time. Typically this would be a tragedy performance wise, but since the internal format is polar, the rotation ends up being a single addition per vertex, so not much of a performance hit. Lastly, the scaling factor might be a little confusing at first glance since \$100 means 1x size, but this is understandable since \$100 (hex) is 256 decimal which is "1.0" in fixed point 24.8 format which the `Vec()` function uses in some calculations. Next, let's move on to text.

#### 16.3.3.6 Text Demo



Figure 16:19 is a screen shot of the text demo running. The Graphics driver really shines in the area of text. This is one of the worst implemented features in any graphics engine (especially Windows GDI), typically all you have is a bitmap font and that's that. Of course in many cases that's all you want, but the Graphics driver here allows all kinds of scaling and even arc text to be drawn, so it's pretty cool if you have a text-heavy interface you want to do. The only bad news is that you only have a single font choice, which is the built-in vector font, but it's pretty good and fairly legible. But, no one said that you can't modify it! Remember, anything you change you must RE-SAVE as another graphics driver, document it and call it something intelligent if you want to deploy it on the internet.

In any case, to draw text we are concerned with two basic functions: Textmode( ) and Text( ). Their definitions are listed once again for reference below; Texmode( ) sets up the rendering of the text and Text( ) does the actual drawing:

```
PUB textmode(x_scale, y_scale, spacing, justification)
  `` Set text size and justification
  ..
  ``  x_scale      - x character scale, should be 1+
  ``  y_scale      - y character scale, should be 1+
  ``  spacing       - character spacing, 6 is normal
  ``  justification - bits[1..0]: 0..3 = 0=left, 1=center, 2=right, 3=left
  ``                  bits[3..2]: 0..3 = 0=bottom, 1=center, 2=top, 3=bottom

PUB text(x, y, string_ptr)
  `` Draw text
  ..
  ``  x,y          - text position (see textmode for sizing and justification)
  ``  string_ptr    - address of zero-terminated string (it may be necessary to
  ``                  call finish immediately afterwards to prevent subsequent
  ``                  code from clobbering the string as it is being drawn
```

The Textmode( ) parameters should be obvious from inspection, basically they describe the scale, spacing and justification you wish. I suggest experimenting to see what works and what doesn't, remember depending on what your colors are, resolution, etc. you have to find the "sweet spot" for text rendering that looks best. Also, you must of course set the pen up with the Colorwidth( ) function to see anything.

The Text( ) rendering function itself is very simple, you just pass the x,y position and a pointer to a standard ASCII-Z string and that's it. Thus you will typically define your strings statically in a DAT section or you might put them in a VAR section if you want to alter them on the fly.

As an example, **SCROLLING\_TEXT\_010.SPIN** draws a scrolling marquee. The code for the demo is located on the CD in the path below and is listed as well for reference:

**CD\_ROOT:\HYDRA\SOURCES\SCROLLING\_TEXT\_010.SPIN**

```
' /////////////////////////////////  
' Scrolling Text Drawing Demo - Draws a scrolling marquee of text  
' AUTHOR: Andre' LaMothe  
' LAST MODIFIED: 1.5.06  
' VERSION 1.0  
'  
' /////////////////////////////////  
' CONSTANTS SECTION /////////////////////////////////  
' /////////////////////////////////  
  
CON  
  
_clkmode = xtal2 + pll8x           : enable external clock and pll times 8  
_xinfreq = 10_000_000 + 3000        : set frequency to 10 MHZ plus some error  
_stack = ($3000 + $3000 + 64) >> 2  : accomodate display memory and stack  
  
' graphics driver and screen constants  
PARAMCOUNT      = 14  
OFFSCREEN_BUFFER = $2000          : offscreen buffer  
ONSCREEN_BUFFER  = $5000          : onscreen buffer  
  
' size of graphics tile map  
X_TILES          = 16  
Y_TILES          = 12  
  
SCREEN_WIDTH     = 256  
SCREEN_HEIGHT    = 192  
  
' /////////////////////////////////  
' VARIABLES SECTION /////////////////////////////////  
' /////////////////////////////////  
  
VAR  
  long tv_status      '0/1/2 = off/visible/invisible      read-only  
  long tv_enable       '0/? = off/on                         write-only  
  long tv_pins         '%ppmmmm = pins                      write-only  
  long tv_mode         '%ccinp = chroma,interlace,ntsc/pal,swap write-only  
  long tv_screen       pointer to screen (words)            write-only  
  long tv_colors       pointer to colors (longs)           write-only  
  long tv_hc           horizontal cells                     write-only
```

```

long  tv_vc          'vertical cells                      write-only
long  tv_hx          'horizontal cell expansion        write-only
long  tv_vx          'vertical cell expansion        write-only
long  tv_ho          'horizontal offset                 write-only
long  tv_vo          'vertical offset                  write-only
long  tv_broadcast   'broadcast frequency (Hz)      write-only
long  tv_auralcog   'aural fm cog                   write-only

word  screen[X_TILES * Y_TILES]  ' storage for screen tile map
long  colors[64]         ' color look up table

byte  sbuffer[128]       ' string buffer holds the string

'/////////////////////////////////////////////////////////////////
' OBJECT DECLARATION SECTION /////////////////////////////////
'/////////////////////////////////////////////////////////////////
OBJ
  tv    : "tv_drv_010.spin"      ' instantiate a tv object
  gr    : "graphics_drv_010.spin" ' instantiate a graphics object

'/////////////////////////////////////////////////////////////////
' PUBLIC FUNCTIONS /////////////////////////////////
'/////////////////////////////////////////////////////////////////

PUB start | i, dx, dy, x, y, color, x0, y0, x1, y1, x2, y2, scroll, scroll_counter
  'start tv
  longmove(@tv_status, @tvparams, paramcount)
  tv_screen := @screen
  tv_colors := @colors
  tv.start(@tv_status)

  'init colors
  repeat i from 0 to 64
    colors[i] := $000001010 * (i+4) & $F + $FB060C02

  'init tile screen
  repeat dx from 0 to tv_hc - 1
    repeat dy from 0 to tv_vc - 1
      screen[dy*tv_hc+dx] := onscreen_buffer >> 6+dy+dx * tv_vc+((dy & $3F) << 10)

  'start and setup graphics 256x192, with origin (0,0) at bottom left of screen
  gr.start
  gr.setup(X_TILES, Y_TILES, 0,0, offscreen_buffer)

  ' BEGIN GAME LOOP /////////////////////////////////
  ' set up the text mode and color information

```

```

gr.textmode(2,1,5,3) ' scale 2x1, 5 for spacing, justification left-bottom
gr.colorwidth(color,0) ' color 2, smallest pixel width

' infinite loop
repeat while TRUE

' clear the offscreen buffer
gr.clear

' RENDERING SECTION (render to offscreen buffer always///////////
' copy a screen worth of the static string into the working string sbuffer
BYTMOVE(@sbuffer, @text_string + scroll, 26)
' terminate the string
sbuffer[26] := 0

' draw the text
gr.text(0,SCREEN_HEIGHT/2, @sbuffer)

if (++scroll_counter > 7)
  scroll the text for next frame
  scroll := ++scroll // 58
  ' reset counter
  scroll_counter := 0
  ' update color
  gr.colorwidth(1 + (++color//3) ,0) ' force color to be from 1..3

' copy bitmap to display offscreen -> onscreen
gr.copy(onscreen_buffer)

' synchronize to frame rate would go here...

' END RENDERING SECTION /////////////
' END MAIN GAME LOOP REPEAT BLOCK /////////////

' DATA SECTION /////////////
' /////////////

DAT

' TV PARAMETERS FOR DRIVER /////////////

tvparams long    0          'status
            long    1          'enable
            long    %011_0000   'pins
            long    %0000       'mode

```

```

long    0           'screen
long    0           'colors
long    x_tiles     'hc
long    y_tiles     'vc
long    10          'hx timing stretch
long    1           'vx
long    0           'ho
long    0           'vo
long    55_250_000   'broadcast on channel 2 VHF, each channel is
                     '6 MHz above the previous
long    0           'auralcog

text_string byte "...I'm sorry Dave, I can't do
that.....",0

' NOTE: the two lines above belong on the SAME line in the IDE.

```

The demo is fairly straightforward. You will notice constants in the program are simply the length of the string and the length of the “...” segment which is when we can do a reset and restart the scrolling without any visual disruptions. Anyway, try experimenting with the Textmode( ) function and see what kind of weird things you can make it do.


**NOTE**

Notice how slow the text rendering is? When the dots are on the screen it speeds up, then when there is text you see it slow down! Text is slow on GDI and it's slow here too – slow text seems to be a universal constant ☺.

Well, that's it for basic graphics. Next, let's take a look at the mouse, keyboard, and gamepad interfacing.

## 16.4 Mouse, Keyboard and Gamepad Programming

Well, we are almost done, now for the boring stuff – Input/Output! The HYDRA supports three input devices:

- ▶ PS/2 mouse
- ▶ PS/2 keyboard
- ▶ Nintendo-compatible Gamepad

All three can be plugged in at once and communicated to at once. Currently, there are cog object based drivers for all three devices. Actually, later you will find that there is no need to run the mouse, keyboard, and gamepad scanning on multiple cogs; in fact, once you start coding games and graphics you will quickly find yourself running out of cogs. Thus, once you

get into more serious coding you will want to make a stripped-down “I/O Object” that runs on a single cog and does all the reading of the keyboard, mouse, and gamepad and packs these into DirectX or SDL-like chunks. Additionally, this object might do output on the little debug LED, maybe allow patterns or something, or some PWM modulation to make it “glow” with games – there’s a cool idea! In any event, let’s take a quick look at some simple examples of each input device.

#### 16.4.1 Mouse Demo

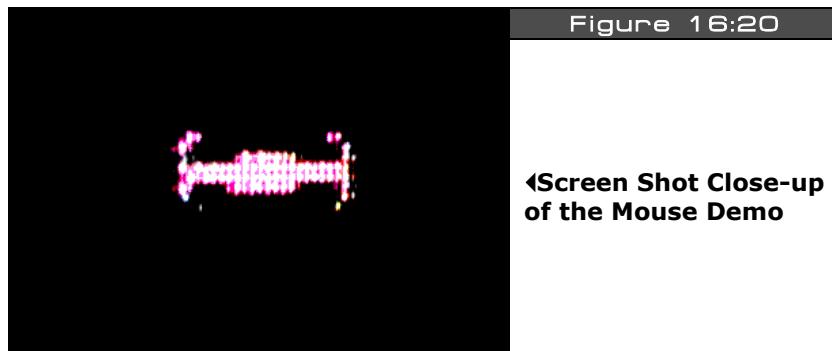


Figure 16:20 shows a simple demo of the mouse in action. The Mouse driver object is named **MOUSE\_ISO\_010.SPIN** as mentioned before. It is instantiated by declaring an object in the OBJ section like this:

```
OBJ
  mouse : "mouse_iso_010.spin"      ' instantiate a mouse object
```

Once the mouse is instantiated it must be “started” by making a call to the start( ) sub-function of the mouse object with the pingroup that the mouse should use to communicate with. On the HYDRA the pingroup is always 2, thus to start the mouse you need to make this call:

```
mouse.start(2) ' start mouse and bind it to pingroup 2
```

The mouse driver, like the graphics driver, has a lot of functionality, in fact, a lot of overkill for our purposes, so at some point you will want to merge all the input drivers into one and run them on a single cog with bare-bones functionality. However, starting from the robust and complete mouse driver is always best. The mouse send packets whenever there is an event, the driver handles this for us, and returns the mouse position and button state for querying. The functions that retrieve the mouse deltas and buttons are shown below:

**Functional Syntax:**

```
PUB button(b) : state
" returns the state of a particular button, see bit encoding below
" returns TRUE or FALSE if the button is down
```

**Functional Syntax:**

```
PUB buttons : states
" returns the states of all buttons encoded as follows:
" bit4 = right-side button
" bit3 = left-side button
" bit2 = center/scrollwheel button
" bit1 = right button
" bit0 = left button
```

**Functional Syntax:**

```
PUB delta_x : dx
" Returns mouse delta-x
```

**Functional Syntax:**

```
PUB delta_y : dy
" Returns mouse delta-y
```

Of course there are functions to retrieve pretty much everything else the mouse has to offer, so make sure to review the mouse driver itself in **MOUSE\_ISO\_010.SPIN**. As an example, **MOUSE\_DEMO\_010.SPIN** draws a little Tie fighter on the screen and lets you mouse it around and change its wing configuration with the buttons. The code for the demo is located on the CD in the path below and is listed below for reference:

**CD\_ROOT:\HYDRA\SOURCES\MOUSE\_DEMO\_010.SPIN**

```
' /////////////////////////////////
' Mouse Demo - Demos the mouse and moves a little tie fighter cursor
' AUTHOR: Andre' LaMothe
' LAST MODIFIED: 1.5.06
' VERSION 1.0
'
' /////////////////////////////////
'
' /////////////////////////////////
' CONSTANTS SECTION /////////////////////////////////
' /////////////////////////////////
```

```

CON

_clkmode = xtal2 + pll8x          ' enable external clock and pll times 8
_xinfreq = 10_000_000 + 3000      ' set frequency to 10 MHZ plus some error
_stack = ($3000 + $3000 + 64) >> 2 ' accomodate display memory and stack

' graphics driver and screen constants
PARAMCOUNT      = 14
OFFSCREEN_BUFFER = $2000          ' offscreen buffer
ONSCREEN_BUFFER  = $5000          ' onscreen buffer

' size of graphics tile map
X_TILES          = 16
Y_TILES          = 12

SCREEN_WIDTH     = 256
SCREEN_HEIGHT    = 192

'/////////////////////////////////////////////////////////////////
' VARIABLES SECTION /////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////

VAR
  long tv_status      '0/1/2 = off/visible/invisible      read-only
  long tv_enable       '0/? = off/on                           write-only
  long tv_pins         '%ppmmm = pins                         write-only
  long tv_mode         '%ccinp = chroma,interlace,ntsc/pal,swap write-only
  long tv_screen        'pointer to screen (words)           write-only
  long tv_colors        'pointer to colors (longs)            write-only
  long tv_hc           'horizontal cells                      write-only
  long tv_vc           'vertical cells                       write-only
  long tv_hx           'horizontal cell expansion           write-only
  long tv_vx           'vertical cell expansion             write-only
  long tv_ho           'horizontal offset                     write-only
  long tv_vo           'vertical offset                      write-only
  long tv_broadcast     'broadcast frequency (Hz)           write-only
  long tv_auralcog     aural fm cog                         write-only

  word  screen[X_TILES * Y_TILES] ' storage for screen tile map
  long colors[64]                ' color look up table

  long mousex, mousey          ' holds mouse x,y absolute position

'/////////////////////////////////////////////////////////////////
' OBJECT DECLARATION SECTION ///////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////

OBJ
  tv   : "tv_drv_010.spin"      ' instantiate a tv object

```

```

gr      : "graphics_drv_010.spin"      ' instantiate a graphics object
mouse   : "mouse_iso_010.spin"        ' instantiate a mouse object

'/////////////////////////////////////////////////////////////////
' PUBLIC FUNCTIONS ///////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////

PUB start | i, dx, dy, x, y

    'start tv
    longmove(@tv_status, @tvparams, paramcount)
    tv_screen := @screen
    tv_colors := @colors
    tv.start(@tv_status)

    'init colors
    repeat i from 0 to 64
        colors[i] := $00001010 * (i+4) & $F + $FB060C02

    'init tile screen
    repeat dx from 0 to tv_hc - 1
        repeat dy from 0 to tv_vc - 1
            screen[dy*tv_hc+dx] := onscreen_buffer >> 6+dy+dx*tv_vc+((dy & $3F) << 10)

    'start and setup graphics 256x192, with origin (0,0) at center of screen
    gr.start
    gr.setup(X_TILES, Y_TILES, SCREEN_WIDTH/2, SCREEN_HEIGHT/2, offscreen_buffer)

    'start mouse on pingroup 2 (HYDRA mouse port)
    mouse.start(2)
    ' initialize mouse position
    mousex := 0
    mousey := 0

    ' BEGIN GAME LOOP ///////////////////////////////////////////////////
    ' infinite loop
    repeat while TRUE

        'clear the offscreen buffer
        gr.clear

        ' INPUT SECTION ///////////////////////////////////////////////////
        ' update mouse position with current delta (remember mouse works in deltas)
        ' for fun notice the creepy syntax at the end?
        ' These are the "bounds" operators!
        mousex := mousex + mouse.delta_x |> -128 <| 127
        mousey := mousey + mouse.delta_y |> -96 <| 95

```

```

' RENDERING SECTION (render to offscreen buffer always//////////)

'draw mouse cursor
gr.colorwidth(1,0)

'test for mouse buttons to change bitmap rendered
if mouse.button(0) ' left button
    ' draw tie fighter with left wing retracted at x,y with rotation angle 0
    gr.pix(mousex, mousey, 0, @tie_left_bitmap)
elseif mouse.button(1) ' right button
    ' draw tie fighter with right wing retracted at x,y with rotation angle 0
    gr.pix(mousex, mousey, 0, @tie_right_bitmap)
else
    ' draw tie fighter w/ normal wing configuration at x,y w/ rotation angle 0
    gr.pix(mousex, mousey, 0, @tie_normal_bitmap)

'copy bitmap to display offscreen -> onscreen
gr.copy(onscreen_buffer)

'synchronize to frame rate would go here...

' END RENDERING SECTION //////////

' END MAIN GAME LOOP REPEAT BLOCK //////////

'///////////////
' DATA SECTION ///////////////
'///////////////

DAT

' TV PARAMETERS FOR DRIVER //////////

tvparams long 0           'status
          long 1           'enable
          long %011_0000   'pins
          long %0000        'mode
          long 0            'screen
          long 0            'colors
          long x_tiles      'hc
          long y_tiles      'vc
          long 10           'hx timing stretch
          long 1            'vx
          long 0            'ho
          long 0            'vo
          long 55_250_000   'broadcast on channel 2 VHF, each channel is
                           ' 6 MHz above the previous

```

```

        long    0          ' auralcog

'` Pixel sprite definition:

'` word           ' This aligns the WORD data structure
'` byte   xwords, ywords  ' x,y dimensions expressed as WORDs express
'` byte   xorigin, yorigin  ' dimensions and center, define pixels
'` word   %%xxxxxxxx,%%xxxxxxxx  ' Center of pixel sprite
'` word   %%xxxxxxxx,%%xxxxxxxx  ' Now comes the data in row major WORD form...
'` word   %%xxxxxxxx,%%xxxxxxxx

' bitmaps for mouse cursor

tie_normal_bitmap   word          ' tie fighter in normal wing
                                ' configuration
                                ' 2 words wide (8 pixels) x 8
                                ' words high (8 lines),
                                ' 8x8 sprite
                                word %%01000000,%%00000010
                                word %%10000000,%%00000001
                                word %%10000111,%%11100001
                                word %%11111111,%%11111111
                                word %%11111111,%%11111111
                                word %%10000111,%%11100001
                                word %%10000000,%%00000001
                                word %%01000000,%%00000010

tie_left_bitmap     word          ' tie fighter with left wing
                                ' retracted configuration
                                ' 2 words wide (8 pixels) x 8
                                ' words high (8 lines),
                                ' 8x8 sprite
                                word %%00000000,%%00000010
                                word %%01100000,%%00000001
                                word %%10000111,%%11100001
                                word %%11111111,%%11111111
                                word %%11111111,%%11111111
                                word %%10000111,%%11100001
                                word %%01100000,%%00000001
                                word %%00000000,%%00000010

tie_right_bitmap    word          ' tie fighter with right wing
                                ' retracted configuration
                                ' 2 words wide (8 pixels) x 8
                                ' words high (8 lines),
                                ' 8x8 sprite
                                word %%00000000,%%00000010
                                word %%01100000,%%00000001
                                word %%10000111,%%11100001
                                word %%11111111,%%11111111
                                word %%11111111,%%11111111
                                word %%10000111,%%11100001
                                word %%01100000,%%00000001
                                word %%00000000,%%00000010

```

```
word  %%01000000,%%00000000  
word  %%10000000,%%000000110  
word  %%10000111,%%11100001  
word  %%11111111,%%11111111  
word  %%11111111,%%11111111  
word  %%10000111,%%11100001  
word  %%10000000,%%000000110  
word  %%01000000,%%00000000
```

The demo consists of the standard infinite rendering loop with a double buffer, the off-screen buffer is cleared, the mouse position is updated, and depending on the mouse button pressed a different mouse sprite is drawn. This leads me to the bonus part of the demo and that is the use of "pixel sprites." Take a look at the end of the source and you will see some bitmaps defined for the Tie fighters (try bluring your eyes to seem them). The bitmaps are encoded as an array of WORDs, where each WORD makes up 8 pixels. The data structure has a little header where you tell it the number of WORDs and the number of rows, etc. then there is a Graphics driver function called **Pix( )** that renders the sprite, so check it out in the demo. Try scaling the sprite, and drawing many of them to get an idea of the performance.

## 16.4.2 Keyboard Demo



The keyboard demo is shown in Figure 16:21 – it's a little more exciting than the mouse – it is actually a little key echo and terminal program. The name of the demo is **KEYBOARD\_DEMO\_010.SPIN**. The demo is based on the keyboard driver object named **KEYBOARD\_ISO\_010.SPIN** which is a fully implemented PS/2 keyboard driver. This driver is much more complex than the mouse driver and supports nearly all the functionality and key maps for PS/2 keyboards. Of course, this means there is a lot of overhead and wasted code on features you don't need, but once again it's a good starting point.

To get the keyboard up and running, you must instantiate the keyboard object in the OBJ section like so:

```
OBJ
```

```
key : "keyboard_iso_010.spin"      ' instantiate a keyboard object
```

Next you must “start” the keyboard up with the Start( ) sub-function, once again, it takes the pingroup you want to bind to the keyboard serial stream lines, on the HYDRA this is pingroup 3. Here’s how you start the keyboard up:

```
'start keyboard on pingroup 3
key.start(3)
```

Then you are ready to receive keys. The keyboard driver will buffer 16 keycodes and then throw away the first keycode. There are numerous functions, but three of them can do most the work; one to test if a key is pressed, one to get the next key, and finally, one that reads the entire key state at once. They are listed below:

#### **Functional Syntax:**

```
PUB gotkey : truefalse
" Checks if there is a key in the circular buffer
" Returns TRUE or FALSE
```

#### **Functional Syntax:**

```
PUB getkey : keycode
" Get next key (will wait for keypress)
" Returns key
```

#### **Functional Syntax:**

```
PUB keystate(k) : state
" Get the state of a particular key
" Returns TRUE or FALSE
```

With these three functions you can do pretty much anything you want and read the keyboard in real-time without blocking, you simply need to test for a key press with **gotkey** then retrieve the key with **getkey**.

For a demo, I thought we would get a little more interesting, so I made a little screen terminal that echoes the keyboard to the screen like a typewriter. Simply plug in your keyboard, load the demo and try pressing keys. <**Return**> skips a line and <**ESC**> clears

the screen. The code for the demo is located on the CD in the path below and is listed below for reference:

**CD\_ROOT:\HYDRA\SOURCES\KEYBOARD\_DEMO\_010.SPIN**

```
' /////////////////////////////////
' Keyboard Demo - This demo allows keys to be pressed and echoes them to
' the screen.
'

' AUTHOR: Andre' LaMothe
' LAST MODIFIED: 1.6.06
' VERSION 1.0
' COMMENTS:
'

' CONTROLS: keyboard
' ESC - Clear Screen
'

' /////////////////////////////////
' CONSTANTS SECTION /////////////////////////////////
' /////////////////////////////////

CON

_clkmode = xtall + pll8x           : enable external clock and pll times 8
_xinfreq = 10_000_000 + 3000        : set frequency to 10 MHZ plus some error
_stack = ($2400 + $2400 + $100) >> 2   : accommodate display memory and stack

' graphics driver and screen constants
PARAMCOUNT      = 14

OFFSCREEN_BUFFER = $3800           : offscreen buffer
ONSCREEN_BUFFER  = $5C00           : onscreen buffer

' size of graphics tile map
X_TILES          = 12
Y_TILES          = 12

SCREEN_WIDTH     = 192
SCREEN_HEIGHT    = 192

BYTES_PER_LINE   = (192/4)

KEYCODE_ESC      = $CB
KEYCODE_ENTER    = $0D
KEYCODE_BACKSPACE = $C8
```

```

'/////////////////////////////////////////////////////////////////
' VARIABLES SECTION ///////////////////////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////

VAR

    long tv_status      '0/1/2 = off/visible/invisible          read-only
    long tv_enable       '0/? = off/on                           write-only
    long tv_pins         '%ppmmm = pins                          write-only
    long tv_mode         '%ccinp = chroma,interlace,ntsc/pal,swap   write-only
    long tv_screen        pointer to screen (words)                  write-only
    long tv_colors        pointer to colors (longs)                 write-only
    long tv_hc            horizontal cells                         write-only
    long tv_vc            vertical cells                          write-only
    long tv_hx            horizontal cell expansion                write-only
    long tv_vx            vertical cell expansion                 write-only
    long tv_ho            horizontal offset                      write-only
    long tv_vo            vertical offset                       write-only
    long tv_broadcast     broadcast frequency (Hz)                 write-only
    long tv_auralcog     aural fm cog                           write-only

    word screen[x_tiles * y_tiles] ' storage for screen tile map
    long colors[64]           ' color look up table

    ' string/key stuff
    byte sbuffer[9]
    byte curr_key
    byte temp_key
    long data

    ' terminal vars
    long row, column

    ' counter vars
    long curr_cnt, end_cnt

'/////////////////////////////////////////////////////////////////
' OBJECT DECLARATION SECTION ///////////////////////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////
OBJ

    tv    : "tv_drv_010.spin"      ' instantiate a tv object
    gr    : "graphics_drv_010.spin" ' instantiate a graphics object
    key   : "keyboard_iso_010.spin" ' instantiate a keyboard object

'/////////////////////////////////////////////////////////////////
' EXPORT PUBLICS ///////////////////////////////////////////////////////////////////

```

```
' /////////////////////////////////////////////////
PUB start | i, j, base, base2, dx, dy, x, y, x2, y2, last_cos, last_sin
' ///////////////////////////////////////////////
' GLOBAL INITIALIZATION /////////////////////////
' ///////////////////////////////////////////////

'start keyboard on pingroup 3
key.start(3)

'start tv
longmove(@tv_status, @tvparams, paramcount)
tv_screen := @screen
tv_colors := @colors
tv.start(@tv_status)

'init colors
repeat i from 0 to 64
  colors[i] := $00001010 * (i+4) & $F + $FB060C02

'init tile screen
repeat dx from 0 to tv_hc - 1
  repeat dy from 0 to tv_vc - 1
    screen[dy*tv_hc+dx] := onscreen_buffer >> 6+dy+dx*tv_vc+((dy & $3F) << 10)

'start and setup graphics
gr.start
gr.setup(X_TILES, Y_TILES, SCREEN_WIDTH/2, SCREEN_HEIGHT/2, onscreen_buffer)

' initialize terminal cursor position
column := 0
row := 0

' put up title screen
' set text mode
gr.textmode(2,1,5,3)
gr.colorwidth(1,0)
gr.text(-SCREEN_WIDTH/2,SCREEN_HEIGHT/2 - 16, @title_string)
gr.colorwidth(3,0)
gr.plot(-192/2, 192/2 - 16)
gr.line(192/2, 192/2 - 16)
gr.colorwidth(2,0)

' BEGIN GAME LOOP /////////////////////////////////
repeat

  ' get key
```

```

if (key.gotkey==TRUE)
    curr_key := key.getkey
    print character to screen
    Print_To_Term(curr_key)
else ' gotkey
    curr_key := 0

' ////////////////////////////////



PUB Print_To_Term(char_code)
' prints sent character to terminal or performs control code
' supports, line wrap, and return, esc clears screen

' test for new line
if (char_code == KEYCODE_ENTER)
    column :=0
    if (++row > 13)
        row := 13
elseif (char_code == KEYCODE_ESC)
    gr.clear
    gr.textmode(2,1,5,3)
    gr.colorwidth(1,0)
    gr.text(-SCREEN_WIDTH/2,SCREEN_HEIGHT/2 - 16, @title_string)
    gr.colorwidth(3,0)
    gr.plot(-SCREEN_WIDTH/2, SCREEN_HEIGHT/2 - 16)
    gr.line(SCREEN_WIDTH/2, SCREEN_HEIGHT/2 - 16)
    gr.colorwidth(2,0)
    column := row := 0
else ' not a carriage return
    ' set the printing buffer up
    sbuffer[0] := char_code
    sbuffer[1] := 0
    gr.text(-SCREEN_WIDTH/2 + column*12,SCREEN_HEIGHT/2 - 32 - row*12, @sbuffer)

    ' test for text wrapping and new line
if (++column > 15)
    column := 0
    if (++row > 13)
        row := 13
        ' scroll text window

' ////////////////////////////////



' DATA SECTION ////////////////////////////////


DAT

' TV PARAMETERS FOR DRIVER ////////////////////////////////




```

```
tvparams
    long  0          'status
    long  1          'enable
    long %011_0000   'pins
    long %0000       'mode
    long 0          'screen
    long 0          'colors
    long x_tiles    'hc
    long y_tiles    'vc
    long 10         'hx timing stretch
    long 1          'vx
    long 0          'ho
    long 0          'vo
    long 55_250_000 'broadcast
    long 0          'auralcog

' STRING STORAGE /////////////////////////////////
title_string byte  "HYDRA Keyboard Demo",0      'text
blank_string  byte  "",0
```

I think that's about the most exciting demo thus far ☺. Anyway, the **Print\_To\_Term( )** function might be useful for debugging, so you might want to steal it.

### 16.4.3 Gamepad Demo



As discussed in the hardware section of this guide the HYDRA Gamepads are NES-compatible, that is, based on Nintendo Entertainment System's controllers. These are readily available, simple to interface to and found in abundance. Moreover, there are numerous third-party manufacturers of these controllers to this day.

Figure 16:22 shows the gamepad demo running, basically it shows the state of either gamepad and can detect if they are plugged in or not. The algorithm to read the gamepads simply latches the state of the controllers and then clocks in the button state bits. Thus, each controller is interfaced via a latch, clock, and data pin. The latch and clock are in parallel, but the data pin(s) are separate. The I/O pins once again are shown in Table 16:1 below:

| Table 16:1                          |                |              |
|-------------------------------------|----------------|--------------|
| The Gamepad Interface on the HYDRA▼ |                |              |
| Propeller Chip Pin Name             | HYDRA Function | Physical Pin |
| P3                                  | JOY_CLK        | 4            |
| P4                                  | JOY_SH/LDn     | 5            |
| P5                                  | JOY_DATAOUT0   | 6            |
| P6                                  | JOY_DATAOUT1   | 7            |

Below is a crude high-level Spin-based function that reads both game controllers and encodes them into a single WORD with the lower 8 bits representing the button states of Gamepad 0 (left) and the upper 8 bits representing the button states of Gamepad 1 (right) respectively. The encoding of the bits is shown below (excerpted from the demo):

```
' NES Bit Encoding
' RIGHT  = %00000001
' LEFT   = %00000010
' DOWN   = %00000100
' UP     = %00001000
' START  = %00010000
' SELECT = %00100000
' B      = %01000000
' A      = %10000000
```

The Gamepads do have a maximum clocking rate of anywhere from 5-10 MHz, but Spin is slow enough where we can run the Spin code at full speed at 80 MHz system clock and not have any delay code. However, once you convert the function to ASM, you must take timing into consideration and make sure that you give the little NES controller enough time to clock and settle when you read it. The function that reads the controllers is shown below:

```
PUB NES_Read_Gamepad : nes_bits | i

' /////////////////////////////////
' NES Game Paddle Read
' /////////////////////////////////
' reads both gamepads in parallel encodes 8-bits for each in format
' right game pad #1 [15..8] : left game pad #0 [7..0]
'

' set I/O ports to proper direction
' P3 = JOY_CLK      (4)
' P4 = JOY_SH/LDn   (5)
' P5 = JOY_DATAOUT0 (6)
' P6 = JOY_DATAOUT1 (7)
' NES Bit Encoding

' RIGHT  = %00000001
' LEFT   = %00000010
' DOWN   = %00000100
' UP     = %00001000
' START  = %00010000
' SELECT = %00100000
' B      = %01000000
' A      = %10000000

' step 1: set I/Os
DIRA [3] := 1 ' output
DIRA [4] := 1 ' output
DIRA [5] := 0 ' input
DIRA [6] := 0 ' input
```

```

' step 2: set clock and latch to 0
OUTA[3] := 0 ' JOY_CLK = 0
OUTA[4] := 0 ' JOY_SH/LDn = 0
'Delay(1)

' step 3: set latch to 1
OUTA[4] := 1 ' JOY_SH/LDn = 1
'Delay(1)

' step 4: set latch to 0
OUTA[4] := 0 ' JOY_SH/LDn = 0

' step 5: read first bit of each game pad

' data is now ready to shift out
' first bit is ready
nes_bits := 0

' step 6: read first bits

' left controller
nes_bits := INA[5] | (INA[6] << 8)

' step 7: read next 7 bits
repeat i from 0 to 6
  OUTA[3] := 1 ' JOY_CLK = 1
  'Delay(1)
  OUTA[3] := 0 ' JOY_CLK = 0
  nes_bits := (nes_bits << 1)
  nes_bits := nes_bits | INA[5] | (INA[6] << 8)

  'Delay(1)
  ' invert bits to make positive logic
  nes_bits := (!nes_bits & $FFFF)

' /////////////////////////////////
' End NES Game Paddle Read
' ///////////////////////////////

```

Notice I invert the bits on exit; normally when a button is down it returns a 0, up returns a 1. This is cool, I prefer positive logic myself. In any event, the function is straightforward and simply performs the clocking and bit shifting into the final holding data WORD "nes\_bits"

which is returned on exit. Also, notice the calls to Delay( ) are commented out; as mentioned, Spin was slow enough that they weren't needed.

Based on this function, I have created a demo that shows the state of both controllers on the screen and can determine if a controller is plugged in or not. This is ascertained by looking at the bits and if they are all 1's then no controller is in, this is true since when the controller isn't in and you try to read it, you will be reading "air" on the data line, but this line is pulled up so it ends up giving you a stream of 1's when the controller is unplugged. The code for the demo is located on the CD in the path below and is listed below for reference:

#### **CD\_ROOT:\HYDRA\SOURCES\GAMEPAD\_DEMO\_010.SPIN**

```
' /////////////////////////////////
' Nintendo Gamepad Demo Program - Reads the nintendo gamepads and prints
' the state out on the screen, reads both gamepads at once into a 16-bit
' vector, each gamepad is encoded as 8-bits in the following format:
'
' RIGHT   = %00000001 (lsb)
' LEFT    = %00000010
' DOWN   = %00000100
' UP     = %00001000
' START   = %00010000
' SELECT  = %00100000
' B       = %01000000
' A       = %10000000 (msb)
'
' Gamepad 0 is the left gamepad, gamepad 1 is the right game pad
'
' AUTHOR: Andre' LaMothe
' LAST MODIFIED: 1.07.06
' VERSION 1.0
' COMMENTS: Use gamepads, note that when a controller is NOT plugged in
' the value returned is $FF, this can be used to "detect" if the game
' controller is present or not.
'
' ///////////////////////////////
'
' ///////////////////////////////
' CONSTANTS SECTION ///////////////////////////////
' ///////////////////////////////
'
CON
_clkmode = xtall + pll8x           ' enable external clock and pll times 8
_xinfreq = 10_000_000 + 3000        ' set frequency to 10 MHZ plus some error
_stack = ($3000 + $3000 + 64) >> 2  ' accomodate display memory and stack
```

```

' graphics driver and screen constants
PARAMCOUNT      = 14
OFFSCREEN_BUFFER = $2000          ' offscreen buffer
ONSCREEN_BUFFER  = $5000          ' onscreen buffer

' size of graphics tile map
X_TILES          = 16
Y_TILES          = 12

' size of screen
SCREEN_WIDTH     = 256
SCREEN_HEIGHT    = 192

' position of state readouts for the left and right gamepads
GAMEPAD0_TEXT_X0 = 10
GAMEPAD0_TEXT_Y0 = 172

GAMEPAD1_TEXT_X0 = 128
GAMEPAD1_TEXT_Y0 = 172

' NES bit encodings
NES_RIGHT        = %00000001
NES_LEFT          = %00000010
NES_DOWN          = %00000100
NES_UP            = %00001000
NES_START         = %00010000
NES_SELECT        = %00100000
NES_B             = %01000000
NES_A             = %10000000

'/////////////////////////////////////////////////////////////////
' VARIABLES SECTION
'/////////////////////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////
```

**VAR**

|                |  |            |
|----------------|--|------------|
| long tv_status | '0/1/2 = off/visible/invisible           | read-only  |
| long tv_enable | '0/? = off/on                            | write-only |
| long tv_pins   | '%ppmmm = pins                           | write-only |
| long tv_mode   | '%ccinp = chroma,interlace,ntsc/pal,swap | write-only |
| long tv_screen | 'pointer to screen (words)               | write-only |
| long tv_colors | 'pointer to colors (longs)               | write-only |
| long tv_hc     | 'horizontal cells                        | write-only |
| long tv_vc     | 'vertical cells                          | write-only |
| long tv_hx     | 'horizontal cell expansion               | write-only |
| long tv_vx     | 'vertical cell expansion                 | write-only |
| long tv_ho     | 'horizontal offset                       | write-only |

```

long tv_vo          'vertical offset                  write-only
long tv_broadcast   'broadcast frequency (Hz)      write-only
long tv_auralcog   'aural fm cog                 write-only

word screen[x_tiles * y_tiles] ' storage for screen tile map
long colors[64]           ' color look up table

' string/key stuff
byte sbuffer[9]
long data

' nes gamepad vars
long nes_buttons

'/////////////////////////////////////////////////////////////////////////
' OBJECT DECLARATION SECTION /////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////////////
OBJ

tv    : "tv_drv_010.spin"      ' instantiate a tv object
gr   : "graphics_drv_010.spin" ' instantiate a graphics object

'/////////////////////////////////////////////////////////////////////////
' EXPORT PUBLICS /////////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////////////

PUB start | i, j, base, base2, dx, dy, x, y, x2, y2, mask

'/////////////////////////////////////////////////////////////////////////
' GLOBAL INITIALIZATION /////////////////////////////////////////////////////
'/////////////////////////////////////////////////////////////////////////

'start tv
longmove(@tv_status, @tvparams, paramcount)
tv_screen := @screen
tv_colors := @colors
tv.start(@tv_status)

'init colors
repeat i from 0 to 64
  colors[i] := $00001010 * (i+4) & $F + $FB060C02

'init tile screen
repeat dx from 0 to tv_hc - 1
  repeat dy from 0 to tv_vc - 1
    screen[dy*tv_hc+dx] := onscreen_buffer >> 6+dy+dx*tv_vc+((dy & $3F) << 10)

'start and setup graphics

```

```

gr.start
gr.setup(16, 12,0,0, offscreen_buffer)

' BEGIN GAME LOOP //////////////////////////////// //////////////////////////////// ////////////////////////////////

repeat
  'clear bitmap
  gr.clear

  ' INPUT SECTION //////////////////////////////// //////////////////////////////// ////////////////////////////////

  ' get nes controller buttons (right stick)
  nes_buttons := NES_Read_Gamepad

  ' END INPUT SECTION //////////////////////////////// //////////////////////////////// ////////////////////////////////

  ' RENDERING SECTION //////////////////////////////// //////////////////////////////// ////////////////////////////////

  'draw text
  gr.textmode(2,1,5,3)

  ' print out total gamepad states vector as 2 hex digits each
  ' each controller printing could be merged into a single loop, but
  ' too confusing, rather be long and legible than too clever!

  ' gamepad 0 first, lower 8-bits //////////////////////////////// ////////////////////////////////
  gr.colorwidth(2,0)
  gr.text(GAMEPAD0_TEXT_X0,GAMEPAD0_TEXT_Y0, @gamepad0_string)

  ' insert the hex digits right into output string!
  bits_string[5] := hex_table[ (nes_buttons & $00F0) >> 4 ]
  bits_string[6] := hex_table[ (nes_buttons & $000F) >> 0]
  gr.colorwidth(1,0)
  gr.text(GAMEPAD0_TEXT_X0,GAMEPAD0_TEXT_Y0-12, @bits_string)

  ' print of gamepad is plugged in?
  if (( nes_buttons & $00FF) <> $00FF)
    gr.colorwidth(1,0)
    gr.text(GAMEPAD0_TEXT_X0,GAMEPAD1_TEXT_Y0-12*2, @plugged_string)
  else
    gr.colorwidth(3,0)
    gr.text(GAMEPAD0_TEXT_X0,GAMEPAD1_TEXT_Y0-12*2, @unplugged_string)

  gr.colorwidth(2,0)
  gr.text(GAMEPAD0_TEXT_X0,GAMEPAD0_TEXT_Y0, @gamepad0_string)

  ' print out the button states in unencoded strings
  ' step one extract the bit for each button and insert it into

```

```

' the display strings "in place" then we just print the strings
' out!
mask := $01
repeat i from 0 to 7
    ' test if button is down represented by the bit in mask
    ' updated the 6th character in the next description string with a 0 or 1,
    ' each string is fixed length, so we can look at the bit and then index into
    ' the strings and update the character in place and then print them all out
    gr.colorwidth(2,0)

    ' test for bit set or not, update string with ASCII "1" or "0"
    if (mask & nes_buttons)
        button_string_start_address[i*9+7] := $31
    else
        button_string_start_address[i*9+7] := $30

    ' print the string out with the embedded "1" or "0"
    gr.text(GAMEPAD0_TEXT_X0,GAMEPAD0_TEXT_Y0-12*i-40,
@button_string_start_address + 9*i)

    ' move to next bit
    mask := mask << 1
    ' end repeat loop

' gamepad 1 next, upper 8-bits /////////////////////////////////
gr.colorwidth(2,0)
gr.text(GAMEPAD1_TEXT_X0,GAMEPAD1_TEXT_Y0, @gamepad1_string)

' insert the hex digits right into output string!
bits_string[5] := hex_table[ (nes_buttons & $F000) >> 12 ]
bits_string[6] := hex_table[ (nes_buttons & $0F00) >> 8 ]
gr.colorwidth(1,0)
gr.text(GAMEPAD1_TEXT_X0,GAMEPAD1_TEXT_Y0-12, @bits_string)
    ' end print data

' print of gamepad is plugged in?
if (( nes_buttons & $FF00) <> $FF00)
    gr.colorwidth(1,0)
    gr.text(GAMEPAD1_TEXT_X0,GAMEPAD1_TEXT_Y0-12*2, @plugged_string)
else
    gr.colorwidth(3,0)
    gr.text(GAMEPAD1_TEXT_X0,GAMEPAD1_TEXT_Y0-12*2, @unplugged_string)

' print out the button states in unencoded strings
' step one extract the bit for each button and insert it into
' the display strings "in place" then we just print the strings
' out!
mask := $0100

```

```

repeat i from 0 to 7
    ' test if button is down represented by the bit in mask
    ' updated the 6th character in the next description string with a 0 or 1,
    ' each string is fixed length, so we can look at the bit and then index into
    ' the strings and update the character in place and then print them all out
    gr.colorwidth(2,0)

    ' test for bit set or not, update string with ASCII "1" or "0"
    if (mask & nes_buttons)
        button_string_start_address[i*9+7] := $31
    else
        button_string_start_address[i*9+7] := $30

    ' print the string out with the embedded "1" or "0"
    gr.text(GAMEPAD1_TEXT_X0,GAMEPAD0_TEXT_Y0-12*i-40,
@button_string_start_address + 9*i)

    ' move to next bit
    mask := mask << 1
    ' end repeat loop

    'copy bitmap to display
    gr.copy(onscreen_buffer)

    ' END RENDERING SECTION /////////////////////////////////
    ' END MAIN GAME LOOP REPEAT BLOCK ///////////////////////
    ///////////////////////////////// | i

PUB NES_Read_Gamepad : nes_bits      | i
: //////////////////////////////////////////////////////////////////
: NES Game Paddle Read
: //////////////////////////////////////////////////////////////////
: reads both gamepads in parallel encodes 8-bits for each in format
: right game pad #1 [15..8] : left game pad #0 [7..0]
: //////////////////////////////////////////////////////////////////

: set I/O ports to proper direction
: P3 = JOY_CLK      (4)
: P4 = JOY_SH/LDn   (5)
: P5 = JOY_DATAOUT0 (6)
: P6 = JOY_DATAOUT1 (7)
: NES Bit Encoding
:

: RIGHT  = %00000001
: LEFT   = %00000010
: DOWN   = %00000100

```

```

' UP      = %00001000
' START   = %00010000
' SELECT  = %00100000
' B       = %01000000
' A       = %10000000

' step 1: set I/Os
DIRA [3] := 1 ' output
DIRA [4] := 1 ' output
DIRA [5] := 0 ' input
DIRA [6] := 0 ' input

' step 2: set clock and latch to 0
OUTA [3] := 0 ' JOY_CLK = 0
OUTA [4] := 0 ' JOY_SH/LDn = 0
'Delay(1)

' step 3: set latch to 1
OUTA [4] := 1 ' JOY_SH/LDn = 1
'Delay(1)

' step 4: set latch to 0
OUTA [4] := 0 ' JOY_SH/LDn = 0

' step 5: read first bit of each game pad

' data is now ready to shift out
' first bit is ready
nes_bits := 0

' left controller
nes_bits := INA[5] | (INA[6] << 8)

' step 7: read next 7 bits
repeat i from 0 to 6
  OUTA [3] := 1 ' JOY_CLK = 1
  'Delay(1)
  OUTA [3] := 0 ' JOY_CLK = 0
  nes_bits := (nes_bits << 1)
  nes_bits := nes_bits | INA[5] | (INA[6] << 8)

  'Delay(1)
  ' invert bits to make positive logic
  nes_bits := (!nes_bits & $FFFF)

' /////////////////////////////////
' End NES Game Paddle Read
' ///////////////////////////////

```

```

' //////////////////////////////////////////////////////////////////
PUB Delay (count)      | i, x, y, z
  ' delay count times inner loop length
  repeat i from 0 to count

' //////////////////////////////////////////////////////////////////
' DATA SECTION //////////////////////////////////////////////////////////////////
' //////////////////////////////////////////////////////////////////

DAT

' TV PARAMETERS FOR DRIVER //////////////////////////////////////////////////////////////////

tvparams      long    0          ' status
               long    1          ' enable
               long %011_0000   ' pins
               long %0000       ' mode
               long 0           ' screen
               long 0           ' colors
               long x_tiles     ' hc
               long y_tiles     ' vc
               long 10          ' hx timing stretch
               long 1           ' vx
               long 0           ' ho
               long 0           ' vo
               long 55_250_000  ' broadcast
               long 0           ' auralcog

' STRING STORAGE //////////////////////////////////////////////////////////////////

hex_table      byte "0123456789ABCDEF"
gamepad0_string byte "Gamepad 0:",0      ' text
gamepad1_string byte "Gamepad 1:",0      ' text
bits_string     byte "Bits: ",0
plugged_string  byte "Plugged",0
unplugged_string byte "Unplugged",0

button_string_start_address
RIGHT_button_string  byte "Right: ",0
LEFT_button_string   byte "Left: ",0
DOWN_button_string   byte "Down: ",0
UP_button_string     byte "Up: ",0
START_button_string  byte "Start: ",0
SELECT_button_string byte "Select: ",0
B_button_string      byte "B: ",0
A_button_string      byte "A: ",0

```

This is probably the longest listing I have placed in this book, so forgive me, but I think it's a good example of a lot of programming techniques with Spin including some string tricks, like modifying strings in memory with small changes then re-using them, since there is very little support for string manipulation in Spin and nothing like `sprint()` for example to build up strings from various params. In any case, try plugging in your controller, pulling it out and placing it in the other port, etc. and playing with the buttons to make sure it all works!

Additionally, there is an ASM version of the driver and a demo program around it, all within a single file. This is a good example of not using a separate object, but you still want to use ASM for something:

**CD\_ROOT:\HYDRA\SOURCES\GAMEPAD\_DEMO\_011.SPIN**

Lastly, there is a object for the gamepad, but we will discuss it later when doing more game programming in Part III, but for reference, the file is:

**CD\_ROOT:\HYDRA\SOURCES\GAMEPAD\_DRV\_001.SPIN**

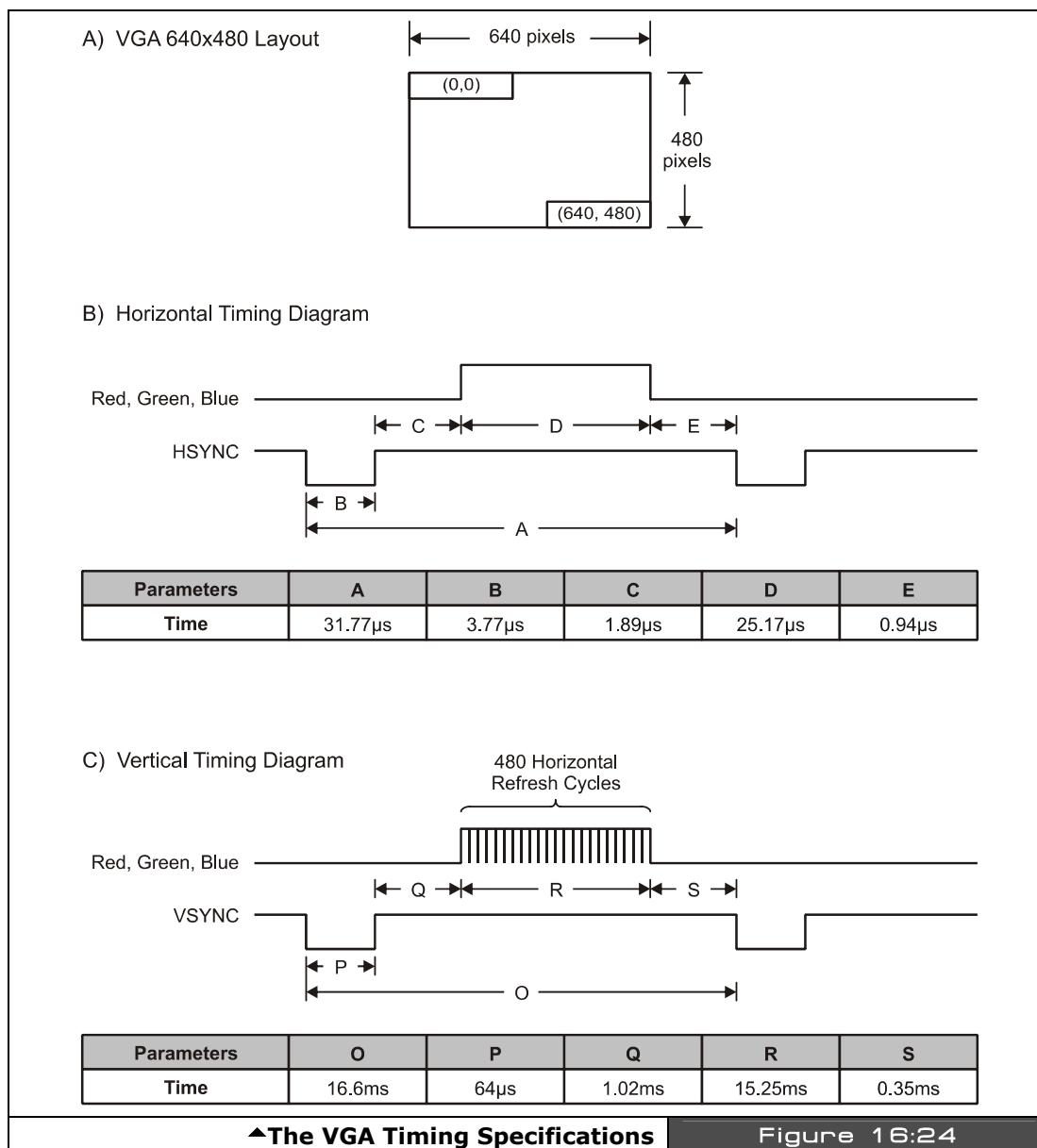
## 16.5 VGA Demo



The VGA is programmed by the direct BYTE mode of the VSU, 8 bits at a time are sent out from the final pin group each clock. These outputs are directly connected to R(2 bits), G(2 bits), B(2 bits) along with Hsync, and Vsync. Thus, the "colors" streamed out represent not only RGB values, but also sync to build up the VGA image. The VGA signal specification is shown once again in Figure 16:24 for reference.

Just as with NTSC/PAL you must generate the VGA signal with the VSU and then stream the data for the pixels to the RGB lines when appropriate. Currently, there is a basic VGA driver that you can work with in a tile/character mode to get started. The name of the driver is **VGA\_DRV\_010.SPIN** and its located on the CD here:

**CD\_ROOT:\HYDRA\SOURCES\VGA\_DRV\_010.SPIN**



The driver is too long to list, but it basically drives the VGA similarly to how the **TV\_DRV\_010.SPIN** drives the NTSC/PAL composite video, but the VGA driver is considerably simplified due to the lack of fields, complex sync, etc. In any event, as an example of VGA usage there are two programs: a terminal, and a demo that prints on the terminal. The terminal program named VGATERM\_013.SPIN emulates a simple text terminal, then a demo program **VGACHRS\_010.SPIN** prints to the terminal. The programs are located on the CD here:

```
CD_ROOT:\HYDRA\SOURCES\VGATERM_013.SPIN
CD_ROOT:\HYDRA\SOURCES\VGACHRS_010.SPIN
```

Figure 16:23 showed the **VGACHRS\_010.SPIN** program in action. The top level **VGACHRS\_010.SPIN** program that calls the terminal program and prints to the terminal is shown below:

```
CON
_xinfreq = 10_000_000
_clkmode = xtall + pll8x

OBJ
, term : "vgaterm_013.spin"
, Start monitor3

PUB start: I
    term.start(%10111)
    term.print($110)
    repeat 4
        repeat i from 0 to $FF
            term.print(i)
```

As you can see there's not much to it. The major problem with the VGA is speed: the VGA dot clock is 25.175 MHz roughly which is 7× faster than NTSC roughly, and this is hard to keep up with and do much. Thus, the challenge is to use tile modes rather than bitmapped modes to save memory as well as combining processors where possible to divide the workload.

## 16.6 Sound Programming

There aren't any reference sound drivers from Parallax for sound similar to the graphics and TV driver, but later in Part III I will provide you with a very complex sound engine that supports multiple channels, envelope control and more. However, for now, let's take a look at some simple single-channel examples to get you started on generating sound yourself. Please review the material in PWM and the counters from the various parts of the book thus far.

To begin with, the first "problem" is that we have a single pin that outputs sound on the HYDRA, thus everything has to happen at the output of that pin. For example, if we could drive 4 pins and then sum them with a resistor network then we could do "poor man's" multi-channel mixing. Of course, each channel would be a square wave always, and always toggle between 0 and 3.3 V, but this would be more than enough to do basic sound, music, and even noise. However, we are not this lucky, the HYDRA only has a single pin (I/O P7) that outputs sound, thus we have to use tricks to get a varying analog output such as PWM techniques. The way to think of sound is that as long as you can generate an analog voltage output from a numerical input, then you can off-load the sound mixing in the numerical processing section. So ultimately writing a very complex sound engine is very easy once you know how to approach it, you simply write the software driver so that an analog voltage can be generated on the sound output P7. Once this is done, you "feed" the driver with numbers that represent the "sound" you want, it might be a sine wave, square wave, noise, or the sum of 100 wave forms! Its all up to you, so with that in mind let's take a look at some samples.

### 16.6.1 Simple Square Wave

The simplest sound we can possibly generate is a square wave of some frequency  $f$ . We can do this two ways: directly with a software loop and sending the output to P7, or we can use one of the internal counters to do it. The pseudo-code for manually toggling the sound output pin in Spin would be something like:

```
DIRA[7] := 1 ' set P7 to output
Repeat
  OUTA[7] := 0      ' set output pin to LOW
  Repeat delay_low ' wait a moment
    OUTA[7] := 1    ' set output pin to HIGH
  Repeat delay_high ' wait a moment
    ' repeat process
```

Given the above code, you would hear a square wave on the output. Of course, you would have to select "delay\_low" and "delay\_high" to give enough time for the audio signal frequency to be audible and of course the duty cycle would be:

$$100\% * \text{delay\_high} / (\text{delay\_low} + \text{delay\_high})$$

The above method works fine, but of course you have to perform this processing all the time in a tight loop, better to take advantage of the built-in counters in each cog. The best mode to use to generate a pure square wave is NCO or PLL mode, but the PLL mode has no advantage, so the NCO (numerically controlled oscillator) is the best mode = "00100," refer to Table 13:12 on page 219 for more information.

Refreshing your memory, in the NCO modes, the value in register FRQx is added to PHSx every system clock, then the 31 bits of PHSx are gated to the "output" selected in the CTRx register. So we are going to use this counter mode, and assign the output pin to P7 which is connected to the HYDRA's sound output hardware. The complete demo that encapsulates all we just discussed can be found on the CD here:

### **CD\_ROOT:\HYDRA\SOURCES\sound\_demo\_010.spin**

...and the source is shown below:

```

CON
  _clkmode = xtal2 + pll8x      ' set PLL to x8
  _xinfreq = 10_000_000          ' set input XTAL to 10MHz, thus final freq = 80MHz

VAR
  long mousex, mousey           ' track mouse position
  long sd_freq                  ' frequency of sound (related to frequency actually)

OBJ
  mouse : "mouse_iso_010.spin"  ' import the generic mouse driver

PUB start
  'start mouse on pingroup 2
  mouse.start(2)

  'set up parms and start sound engine playing
  sd_freq := $00000200          ' anything lower is hard to hear

  ' step 1: set CTRA mode to NCO single mode "00100", Pin B 0, Pin A = 7
  CTRA := %0_00100_000_00000_00000000_00000011
  '               mode          Pin B    Pin A

  ' step 2: set the frequency value to be added to the PHSA register each clock
  FRQA := sd_freq

```

```

' step 3: set pin 7 to output
DIRA := %00000000_00000000_00000000_10000000

' sit in loop and update frequency with mouse movement
repeat
    sd_freq += mouse.delta_x << 8

    ' don't allow frequency to go lower than a rumble
    if (sd_freq < $00000200)
        sd_freq := $00000200

    ' and finally update frequency
    FRQA := sd_freq

```

The program more or less sets up Counter A and connects it to P7 (the sound pin) and then uses the mouse movement to modulate the frequency of the square wave. If you have an o-scope you might want to look at the final waveform audio output to confirm it is a square wave. The only loss of functionality when using the counter to generate a simple square wave is that we have no control on the duty cycle, it's always 50%, but in most cases this is fine.

### 16.6.2 PWM Demo Sine Wave

If all you need is a single channel of sound then manual square wave generation or using the counter to drive the sound pin will do, but for games, music, etc. you are going to need at least 2-3 channels and the ability to play more complex wave forms than square waves. Using PWM techniques allows you to generate any analog voltage from 0 to 3.3 V roughly, which in turn means you can synthesize any wave form you want. Of course, there are limits to the frequency you can synthesize with PWM since the PWM frequency has to be 10–100× that of the frequency you are synthesizing to get a “clean” signal, but that aside, with PWM on the HYDRA we can create any sound we want.

As a first example, we are going to use a pseudo-PWM technique using the “duty cycle” mode discussed in Chapter 13. The duty cycle mode outputs the carry bit from the counter’s operation, and this carry is “1” proportional to the value in FRQx, that is, the larger the value in FRQx, the more that PHSx overflows and thus the more the carry is “1.” If we output the carry into a RC integrator circuit, the result is an analog voltage and viola! we have a 1-bit output acting as a D/A converter.

Using the duty cycle mode we can generate any wave form by simply placing into FRQx the magnitude of the value we want to synthesize (scaled by a constant) and updating this value at some constant audio rate, say 11, 22, or 44 kHz. Thus, to generate a sine wave, all we need is a table of sine values and then we index into the sine table at some rate, take the output, scale it by a magic number and then plug it into the FRQx value of the counter we

are using to generate the signal and that's it. For a concrete example of this, I have created a demo that uses a top level program to load in the synthesizer object and direct it to generate the sine wave and output it to the HYDRA's sound pin. To try the demo simply load in this file from the CD:

**CD\_ROOT:\HYDRA\SOURCES\sound\_demo\_020.spin**

...which then will in turn load the sine wave sound generation object named **SOUND\_SINE\_DRV\_011.SPIN** which is in ASM. Trying running the top level program, and be sure to have the audio output of the HYDRA plugged into your TV. Also, the demo needs the mouse, so have that plugged in. Once the demo runs, slide the mouse left to right to change the frequency of the sine wave (also if you have an o-scope, try scoping the sound output to see how clean the sine wave is).

The top level file code is very simple and more or less just calls the sound driver object, so we aren't going to waste space with it, but the sine driver is important, so let's take a look at it below (with some of the comments and header source removed in the listing, refer to the copy on CD for the full listing):

```
.org
' Entry

entry mov     cntacc,cnt  ' init cntacc
        add     cntacc,cntadd ' add to counter number of cycles such that
        ' this loop executes at a rate of 22050 Hz

:loop
    mov     t2, par  ' retrieve parameter values from caller
    rdlong _pin, t2  ' pin # to output signal
    add     t2, #4
    rdlong _freq, t2 ' frequency to play
    add     t2, #4
    rdlong _volume, t2 ' volume (unused in this demo)

    mov     t1, #1  ' convert pin # into bit position
    shl     t1, _pin

    or      dira, t1  ' set general direction of I/O to output
    ' without disturbing other settings
    movs   ctra, _pin  ' set cntr A pin to the HYDRA's output pin
    movi   ctra, #%0_00110_000' duty cycle mode "00110", single ended

    mov     t1, phase ' calculate samples
    shr     t1, #32-13
    mov     t2, _volume
    call   #polar
```

```

    mov     output_amp, t1

    waitcnt cntacc, cntadd ' wait for count sync

    add     phase, _freq  ' update phases

    mov     frqa, output_amp ' update channel output

    jmp     #:loop      ' loop

' //////////////////////////////////////////////////////////////////

' Polar to cartesian conversion function, computes y = t2*sine(t1)

' in:       t1 = 13-bit angle
'           t2 = 16-bit length

' out:      t1 = x|y

polar test   t1,sine_180    wz   ,      ' get sine quadrant 3|4 into nz
        test   t1,sine_90     wc   ,      ' get sine quadrant 2|4 into c
        negc  t1,t1           ,      ' if sine quadrant 2|4, negate table offset
        or    t1,sine_table   ,      ' or in sine table address >> 1
        shl   t1,#1            ,      ' shift left to get final word address
        rdword t1,t1           ,      ' read sine/cosine word
        call   #multiply      ,      ' multiply sine/cosine by length to get x|y
        shr   t1,#2            ,      ' justify x|y integer
        add    t1,h800000000   ,      ' convert to duty cycle
        negnz t1,t1           ,      ' if sine quadrant 3|4, negate x|y
polar_ret ret

' local literal pool
sine_90          long   $0800          '90° bit
sine_180         long   $1000          '180° bit
sine_table        long   $E000 >> 1      'sine table address
shifted_right    long   $80000000

' //////////////////////////////////////////////////////////////////

' 16x16 Multiply function (unrolled), simply performs a "shift-add" multiply

' input:      t1 = 16-bit multiplicand (t1[31..16] must be 0)
'           t2 = 16-bit multiplier

' output:     t1 = 32-bit product (t1*t2)

```



```
t3 long    $0

' PWM variables
phase long    $00000000' phase accumulator for fundamental
output_amp long   $00000000' final summed output amplitude

' parameters from caller
_pin long    $0' 0 - 31
_freq long    $0' any 32-bit value, but only a small range of values
' will be audible
_volume long   $0      '$0000-FFFF, unused in this version of drivers,
' always FULL volume
```

All the action happens between the label “:loop” and “jmp #:loop.” The program begins by retrieving the latest copies of the parameters from the caller, this way the caller can change the parameters at any time and they will update in the driver. Next, the counter is set up including the output pin, mode, and direction. This must be done always. Then the main synthesis algorithm begins where you see “compute samples,” the value in “phase” is used as the angle of the sine wave, and “\_volume” is used to scale the sinewave. The angle and volume or amplitude are sent to a sine function that uses the built-in sine table from 0-90 degrees and computes the results then scales them appropriately. The results are returned in “t1” and then passed into the final output variable “output\_amp” which is written to the FRQA register. This value is proportional to the final voltage output.

Lastly, you will notice the use of the system counter CNT. The algorithm recomputes the signal at a rate of 22050 Hz, or roughly every 3628 clocks given a 80 MHz system clock; hence at the top of the loop this value (3628) is added to the current CNT value and stored, and then at the end of the loop a waitcnt call is made to keep the synthesis locked at 22050. Thus, we are outputting a new data point 22050 times a second, or in other words, the highest frequency signal we can generate is 11025 Hz, but this will NOT look like a sine wave, it will look distorted, since we should have at least a few sample points to make up each sine wave. Thus 2.2 kHz (1/10<sup>th</sup>) the synthesis rate is where things start to look funny if you want to get technical.

### 16.6.3 PWM Demo “Engine” Sound

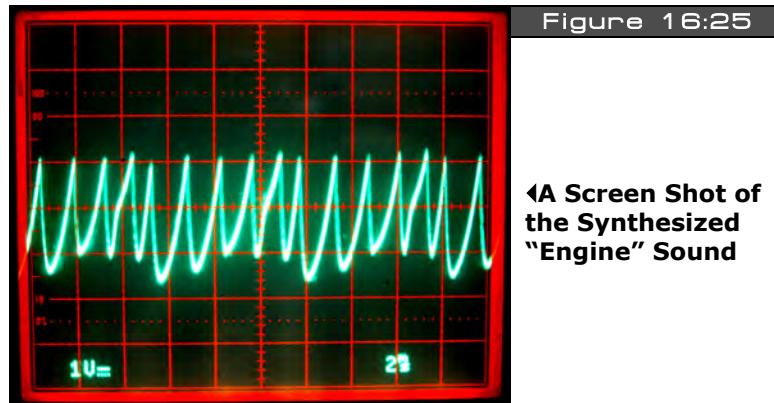
In the last example, we generated a sound that was a function of the sine wave or something like:

$$Y = a \sin(t)$$

We can plug anything we wish into the synthesis function, for example, I know that if you output an exponential curve waveform, it will sound like an engine as you change the frequency. Since we can't generate a true exponential curve, we can do the next best thing:

use a power to exponentiate the signal. Cubing works best, but a simple square will suffice. All we need to do is synthesis something like:

$$Y = a * t^2$$



Take a look at Figure 16:25 to see the results of summing these signals (you can't see it on the static figure, but there are two signals superimposed, both with the same shape, but they are harmonics and each have slightly different amplitudes). I have generated another demo using this technique which is on the CD:

**CD\_ROOT:\HYDRA\SOURCES\sound\_demo\_030.spin**

Again, the driver itself is in ASM and called from the demo top level file, the driver for the "engine" sound is called **SOUND\_ENGINE\_DRV\_011.SPIN** and is on the CD in the same place. So try loading up the top level file and running the demo and moving the mouse around. I think you will find the sound pretty authentic. Also, "sound engineering" takes a lot of trial and error, you start with what you know and then experiment until it sounds "right." In the real world, sounds are never simple, they usually have many harmonics, distortions, etc. that give them "texture" and "personality," thus I found by adding a slightly attenuated harmonic of the squared term the engine sounded "better." So when you check out the driver **SOUND\_ENGINE\_DRV\_011.SPIN** be sure to look for this added functionality. The core of the code in the "engine" sound driver is shown below for reference:

```

    ' the idea is to square the phase accumulator
mov    t1, phase           ' calculate samples
shr    t1, #32-16          ' scale the phase down to fit into 16 bits
mov    t2, t1
call   #multiply
mov    output_amp, t1      ' final output = scale*(phase*phase)

```

```

' same thing with phase2 accumulator which is a harmonic
mov    t1, phase2           ' calculate samples
shr    t1, #32-16          ' scale the phase down to fit into 16 bits
mov    t2, t1
call   #multiply

add    output_amp, t1       ' sum both harmonics
' final output = scale * [ (phase*phase) + (phase2*phase2) ]

waitcnt cntacc, cntadd      ' wait for count sync

add    phase, _freq         ' update phase (fundamental)

mov    t1, _freq             ' compute 1/2 harmonic
shr    t1, #2
add    phase2, t1            ' update phase2 (harmonic)

mov    frqa, output_amp     ' update channel output counter
jmp    #:loop                ' loop infinitely

```

As you can see, the code has two blocks at the top, each responsible for generating a squared term. Then the outputs are summed, scaled, and sent to the FRQA register, and that's it! Pretty cool huh? The neat thing is that anything you can imagine mathematically, including digitized audio data, you can play back. So, given that the HYDRA has a large EEPROM memory, you could theoretically store a lot of audio data in the EEPROM, decompress on the fly, and synthesize out using the techniques outlined here.

## 16.7 Accessing the EEPROM

As discussed numerous times, the Propeller chip has an on-chip 32 Kbytes of RAM, this RAM holds every single program code and data asset. The compiler builds the 32K "image" for you and no matter how large or how small your actual program(s) + data are, the image will always be 32 Kbytes so that the loader, IDE, and everybody else simply has to load 32K directly into the Propeller chip, or 32K from EEPROM in to the Propeller chip. So, the question is raised: "Can we extend this memory?" The answer is yes and no. Currently, the Propeller chip and IDE have no concept of anything greater than 32 Kbytes, in fact. The 32K EEPROM on the HYDRA is all that is necessary for operation. But, nonetheless the HYDRA has a 128K EEPROM (as do the game cartridges); this extra memory is to facilitate two things: expansion later on potentially of the Propeller chip, but more importantly for you to use for extra programming to store assets in the 96K above the base 32K needed by the Propeller chip.

No matter what, the IDE is going to build a 32K image and dump it to the Propeller chip or the EEPROM, so this means that if we are clever not only can we simply access the EEPROM from our programs to read/write game data on the fly, like scores, etc. but we can also build

tools on the PC that use a “host” program we write on the HYDRA/Propeller chip that allows us to talk to the EEPROM through the serial port on the PC. Before we take a look at both of these possibilities, let’s take a look at how the EEPROM works for now and discuss some ideas. Later in the Part III we will see some code/drivers that communicate with it and do something useful.

### 16.7.1 EEPROM Operation

The EEPROM used in the HYDRA is an Atmel 24C1024 (or equivalent) 128 Kbyte serial EEPROM, there are other models that are smaller and larger. The key word in the description is “serial,” this means that we access data, read and write via a serial protocol which is rather slow as far as game speeds are concerned. But, with proper caching and common sense you can definitely use the EEPROM to hold assets and cache them into the primary 32K into a small region of memory using a demand page memory access scheme etc. So the first thing you need to do is understand how to program this EEPROM and the underlying serial protocol, thus you need to start by reading the datasheets for the EEPROM which are located on the CD here:

[CD\\_ROOT:\HYDRA\DOCS\atmel\\_24c1024\\_datasheet.pdf](#)  
[CD\\_ROOT:\HYDRA\DOCS\atmel\\_24c256\\_datasheet.pdf](#)

It may take a few times to understand, but basically you simply need to learn to read and write to the EEPROM. The trick of course is that you are going to read and write only AFTER the first 32K since that is where the run-time image is always stored. Of course, if you know what you’re doing you can alter the 32K image on the EEPROM as well. For example, say you write a program, and you know exactly where a data structure is located in the final binary 32K image. To determine this you can use the IDE’s memory view or even a sentinel to target the memory. Whatever you do, once you know where this is, when you run a game, you can go to that memory location and store the player’s score for example, and the game would update and next time it booted this new score would be in the EEPROM, this way you could store a high score table or whatever.

However, at first it’s probably best to access memory after the first 32K, so you don’t step on anything. Assuming that you understand the protocol now, all you need to know is the actual I/O pins that connect to the EEPROM’s data and clock lines; they are shown in Table 16:2.

| <b>Table 16:2</b>   |                                   |                 |                   |
|---|-----------------------------------|-----------------|-------------------|
| <b>The Pinouts and Assignments for the Serial EEPROM Interface▼</b> |                                   |                 |                   |
| <b>General Name</b>   | <b>Exported Name on Cartridge</b> | <b>Pin Name</b> | <b>Pin Number</b> |
| <b>Serial Clock</b>   | (SCK_CART)                        | P28             | 37                |
| <b>Serial Data</b>  | (SDA_CART)                        | P29             | 38                |

There are two things to remember: first there is an EEPROM on the board, and potentially one on the game cart if it is inserted. Either way, from your perspective there is only ONE EEPROM in, thus, you can't use both of them! The hardware swaps out the base EEPROM the moment it detects an insertion, so only one EEPROM is addressable at once, and the priority is CARTRIDGE (if inserted), then BASE secondarily. Now, let's discuss the access scenarios.

### **16.7.2 Accessing the EEPROM for Simple Memory Operations in Game**

You will first want to write a driver that can access the EEPROM via pins P28/P29 and support a subset of the communication protocol that at least allows BYTE writes and reads, later you might want to add the page and sequential access modes for higher speeds. Later I will write a more robust function or object that allows EEPROM access.

In any event, once you have your driver then it's as simple as using it to talk to the EEPROM that is active. Remember though, do not access the EEPROM's first 32 Kbytes unless you are absolutely sure where you are writing to since you can frag the execution image. But, feel free to access the 96K above. A first app might be something that "remembers" a simple piece of data, then something that is more interesting might be an app that is like a word processor based on the little terminal I made, as the person types it's stored in the EEPROM and later you can load the document(s) into the program! That would be cool!

### **16.7.3 Accessing the EEPROM for Asset Storage via the PC/HYDRA**

The more interesting use of the EEPROM's extra 96 Kbytes of storage is of course for asset storage or implementation of a "virtual machine." Let's discuss the asset storage first.

#### **16.7.3.1 Asset Storage**

The EEPROM is of course too slow to be used as any kind of real-time memory, but with caching and some memory management, you can definitely make a crude memory system out of it using the RAM on the Propeller chip for the high-speed memory and the EEPROM as the slow storage. Along these lines, there are all kinds of possibilities to store extra assets like image data, sprites, tables, and sound data on the EEPROM and then bring them in or access them on the fly in slow EEPROM memory if speed isn't a concern. In either case, you need a "workflow" to do this. Currently, there is no support in the IDE for extra assets to be written to the EEPROM memory above 32K and there are no tools either. Thus, we have to write our own.

So here's how you do it: first we need a "client" program on the PC that allows us to talk to the HYDRA over the serial communications port. This is the easy part, you can write a Windows app with Builder, Delphi, or VB that basically shows you a graphical image of the EEPROM and then lets you drag-and-drop binary files into the image. Then when you are done, it writes the upper 96K of memory (or reads as well). This is all done over the serial port you have connected to the HYDRA with, let's say Com3 for fun. So you write this app on the PC that can do all this importing and file building and it's going to talk to the HYDRA over

a com port such as Com3 (Com 1 and 2 are usually taken by the mouse and keyboard on older machines).

Anyway, now for the hard part – now you have to write an app that “sits” on the HYDRA (the Propeller chip) and is a “host” or “server” that listens to the com port (via the USB connection) and waits for commands, then when it receives commands this host program takes data you send from the PC over the cable and then writes it to the EEPROM above the 32K mark. So we use the HYDRA and the Propeller chip to host this communication since we can't access pins P28/P29 from the PC directly, if we **could** then we could read/write the EEPROM from the PC and not need the surrogate of the Propeller chip/HYDRA to help us out.

This is not a hard thing to do, but must be well thought-out. You basically want a really easy app to “build assets” on the PC then a good protocol that allows reading/writing BYTES on the EEPROM via a host program running on the HYDRA. Then when you are done building the EEPROM, you would erase this host program running on the HYDRA, of course it could be made as an object and even part of a larger game program.

#### **16.7.3.2 Virtual Machine Implementation**

The next cool idea that you might want to try is to implement a virtual machine or emulator. For example, Spin is just a virtual machine, but simply happens to be built-in, but no one said you can't write another assembly language virtual machine and then have it run code you generate from a compiler yourself. You could simply write a virtual machine that is less than 512 LONGs, fits into a single cog (like Spin) that then runs code out of main memory. You could set this up from a main program with some Spin to start things off, load your virtual machine and then a DAT section to hold your code. Or maybe you could write another tool that you can code in FORTH, or 6502, or whatever, then it's compiled into BYTE codes or whatever and converted into Spin DAT statements which you import manually.

But, the cool opportunity is to write a virtual machine and then free up the 32K memory on the Propeller chip for video memory, etc. and then run your code out of the EEPROM with a memory paging and caching scheme to keep things moving quickly, that is, every time you get down to 256 virtual instructions, the memory management software brings in another 1-2K of instructions off the EEPROM for your virtual machine. This way, large programs can be executed.

### **16.8 Assembly Language Parameter Passing**

Last but not least, I want to discuss interfacing Spin/ASM code. This is typically a “trouble area” for many people similar to recursion, so I think it's worth discussing in brief, so you can take advantage of it and not limit yourself.

As mentioned before, when you make a call to start up a cog with an ASM program you start the cog up like so:

```
cognew(@asm_entry_point , parameter_ptr)
```

...where "asm\_entry\_point" is the address of your actual ASM code, and "parameter\_ptr" is usually a pointer to the base of your parameter list in main memory (0-64K byte addressed). I say, "usually" since parameter\_ptr can be anything you wish! It could be a single value, it could be a pointer, it could be a pointer to a pointer, whatever – the point is that it is passed by "value" and when your ASM code starts, the value passed will be accessible in the PAR register.

Thus, if you make the call from Spin:

```
cognew(@asm_entry_point , 0)
```

...then PAR on entry to your ASM code would be 0, for example, given the code below:

```
DAT
ORG

asm_entry_point  ' this is where the cog starts execution

    mov r0, PAR  ' copy VALUE in PAR to r0, so we can modify it
    .
    .
    .

' temporary 32-bit registers in "cog memory"

r0 long $0
r1 long $0
r2 long $0
```

Then after the "mov" instruction, r0 would be equal to 0. The reason why I copy PAR into r0 is because PAR is read-only, you can't "bump" it; you can use it to read from, etc. but if you want to pull parms from the caller, you can't modify PAR, thus it's a good idea to copy it into a temporary variable that is local and in cog memory.

Now, once you have PAR or a copy of it, then you can do whatever you want with it. For example, use it as a pointer to read from main memory (or write to main memory), or just use it as a parameter (if that was the intent of the caller). So, let's take a look at a few examples to solidify these concepts with some pseudo-code.

### 16.8.1 Reading Parameters from Spin

Many times you want to send a set of "start-up" parameters to your ASM program running on another cog. For example, the TV driver does exactly this, you send it the base address of a dozen or so LONG-sized parms then the ASM code indexes from the first parameter pointed to by PAR by increasing PAR by 4 each time to move to the next LONG. Remember PAR is always main memory relative addressing, thus BYTE-based, NOT LONG-based like the cog addressing. This is VERY important – when talking about addresses in main memory, we are always talking about BYTE addresses, when talking about cog addresses, we are always talking about LONG addresses 0-511, so keeping that in mind it will save you a lot of headaches.

As an example, let's say we want to write a graphics driver and we want to send the driver the width, height, and bits per pixel for the mode. Also, let's keep it simple and say that every parameter will be stored in a LONG, so we have both our Spin program and the ASM we are going to launch into another cog that we want to "pass" the base address of our parameter list, here's how all that would work (note this is pseudo-code, I am omitting the usual start-up Spin stuff, etc.):

```

VAR
LONG width, height, bpp ' these are the parameters we want to "pass" to ASM

PUB start
    ' start another cog with the asm driver, and send the address of "width"
    ' this assumes that height and bpp follow in memory, that is they are this order:
    ' addr x width
    ' addr x+4 height
    ' addr x+8 bpp
    ' which they always are unless the compiler messed up !
    cognew(@asm_entry_point, @width)

    ' do stuff...
repeat ' main loop would go here...

    ' and now we switch to a DAT section & put our ASM at the end of our Spin program
DAT
    ORG

    asm_entry_point
    ' on entry PAR points to width, height, bpp, in that order, each 1 LONG in size.

    mov r0, PAR      ' copy PAR to R0 local, so we can alter it
    rdlong _width, r0 ' r0 points to "width" in main memory, read it

```

```

        ' out and copy to local "_width"

add r0, #4      ' next parm is 4 BYTES down, add 4 to copy of PAR in r0
rdlong _height, r0 ' r0 points to "height" in main memory, read
                   it out and copy to local "_height"

add r0, #4      ' next parm is 4 BYTES down, add 4 to copy of PAR in r0
rdlong _bpp, r0   ' r0 points to "bpp" in main memory, read it
                   out and copy to local "_bpp"

' now, _width, _height and _bpp have the parms sent by caller.

' local copies of width, height, bpp, common tactic is to use a "_" in front
' of the parameter name
_width LONG$0
_heightLONG$0
_bppLONG$0

' local registers and working vars for fun
r0 LONG$0
r1 LONG$0
r2 LONG$0

```

So, the trick is to set up a parameter block in your high-level Spin code, and simply pass the base address of the parameters to the ASM code via the PAR register by means of the cognew( ) function's 2nd parameter. Also, notice the use of "\_" to indicate local copies of parms, this is just an idea, and you can do whatever you like. Sometimes, I use "L" for local, sometimes "\_" and other techniques, the idea is to help the reader of your code later track what were parms and what are the local copies of them.

### 16.8.2 Writing Values to Spin

If you followed the previous example, then it should be a snap to write values back to Spin. There are a billion reasons you would want to do this: anything from watching a real-time value, to using a memory location as a return value for some ASM process or even parallel processing message passing. The point is it's very easy to do. Let's say that you want to "watch" a memory location that an ASM program sends back some kind of status information. For example, later in the book you will see a number of video drivers that I create and they all send back various "raster state" information to the caller than started that cog running them. For example, a LONG that encodes the state of the sync, the current video line, the number of sprites doing something, whatever. Here's how you would write some generic "status" value back to the caller that starts up a cog with some ASM code:

VAR

LONG status' the ASM cog program is going to write back to this location

```

PUB start

cognew(@asm_entry_point, @status)

' do stuff...
repeat ' main loop would go here...

' and now we switch to a DAT section & put our ASM at the end of our Spin program
DAT
ORG

asm_entry_point
' on entry PAR is pointing to status

    mov r0, PAR ' copy PAR to R0 local, so we can alter it if needed
        ' now r0 -> status, so we can write anything we want to it, let's write $ff
    wrlong r0, #$FF ' r0 <- $ff, in other words main_memory[PAR=@status] := $FF

' local registers and working vars for fun
r0 LONG $0
r1 LONG $0
r2 LONG $0

```

The ASM code starts up in more or less the same way, we need a copy of the PAR register (so we can change it if we need to), then we simply use the "wrlong" instruction rather than the "rdlong" instruction, and write a value out to the main memory. Then anyone listening to the memory location will see it change, this is how you can pass back one or more values.



**TIP**

I have been using LONGs for the parameter passing discussion, but you are free to use BYTES or WORDs as well along with the RDWORD, RDBYTE, WRWORD, WRBYTE ASM instructions. Just make sure to advance your PAR pointer by 1, 2, or 4 for BYTE, WORD, or LONG addresses respectively.

## 16.9 Summary

This chapter has finally put some of the theory to practice and we have covered numerous demos and examples using the various drivers for graphics, I/O, sound, and more. I suggest if you already haven't done so, you take some time to get familiar with the IDE and try compiling, altering, and experimenting with the demos I have provided. When we begin Part III, I will assume that you are familiar with the hardware and the IDE and I won't take the time to explain in detail every little step. My goal isn't to turn you into the next John Carmack, but if you have never written a game before, you should walk away with being able to develop some reasonably sophisticated 2D games from Pong to Pac-Man, so let's get started!

### **PART III: GAME PROGRAMMING ON THE HYDRA**

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- Chapter 19: Tile Engines and Sprites, p. 509.**
- Chapter 20: Getting Input from the “User” World, p. 559.**
- Chapter 21: Sound Design for Games, p. 593.**
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- Chapter 25: HYDRA Demo Showcase, p. 779.**

## Chapter 17: Introduction to Game Development

This chapter begins the primary game development coverage of the book. The previous chapters were all foundation materials needed to give us a common framework, language, and vocabulary for the Propeller and HYDRA, so that we can start to discuss how to make games. From here on out, I am going to try and keep things as practical as possible without too much theory. Additionally, the previous chapters had to do with the Propeller chip, ASM, the instruction set, the hardware, really important things that you want to refer to in the book. The remainder of the book has a LOT of code, that is really big, so rather than show you huge listings and kill trees, I am going to explain algorithms and the architecture and main points of a program and leave listings (for the most part) on the CD, so you can refer to them later. This will save precious pages and give us more time to discuss game development rather than look at code.

Also, you will notice that the chapters from here on out have very specific titles and outlines; however, I always take any opportunity I can to show some game code, thus if we are talking about the mouse, I will make a little game demo that uses it, and so forth, so you will learn game development not in any specific location in these chapters, but throughout them, so read between the lines. In this chapter, we are going to discuss some of the creative and artistic aspects of game development then finish off with technical material and our first collaborative game. With that in mind, we are going to discuss the following topics primarily:

- ▶ What exactly is a game?
- ▶ Introduction to game development and the creative process
- ▶ Tools used to create games
- ▶ Game loops and organization
- ▶ Data structures used in games
- ▶ Mars Lander

### 17.1 What Exactly is a Game?

I get asked this question all the time. A game has a very loose definition, but more or less (when talking about computer games), a game is an interactive application, usually graphical, that users use to entertain themselves with – period.

Games can be separated into hundreds of categories these days, but typically for any game you can assign them loosely to one or more of the following categories:

- ▶ Arcade games
- ▶ Role-playing games
- ▶ Platform games
- ▶ Board games
- ▶ First-person shooter games
- ▶ Simulations

**Arcade games** tend to refer to games that used to be found only in arcades such as *Pacman*, *Centipede*, *Galaxians*, and other “twitch” games that are more action and shoot-em-up related. Figure 17:1 shows some classic arcade games in action. There isn’t much story line going on in an arcade game, you usually just blow things up, chase things, or run away, they are pure action and hand-eye coordination games usually.

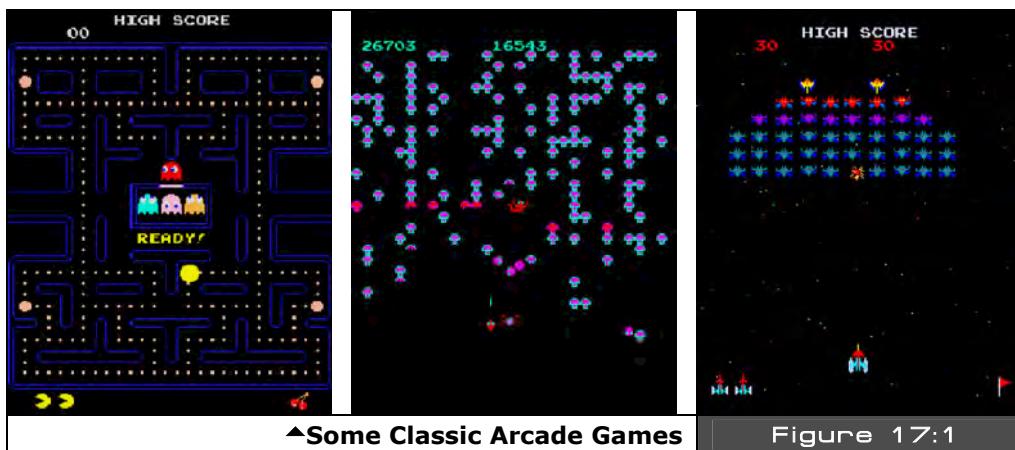
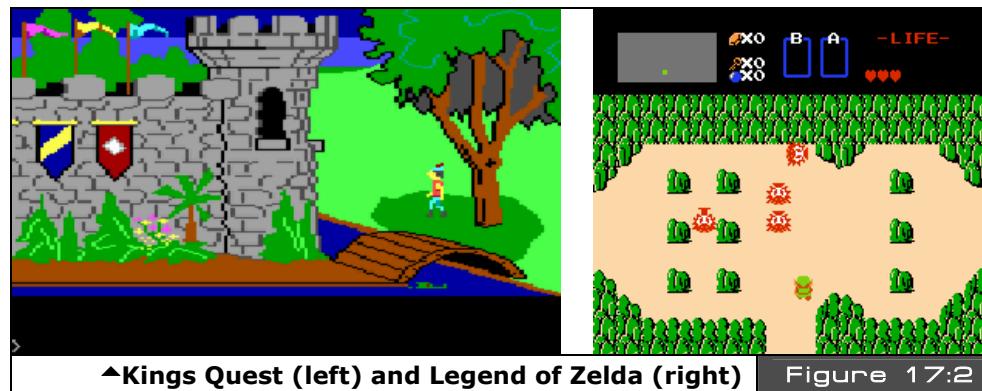


Figure 17:1

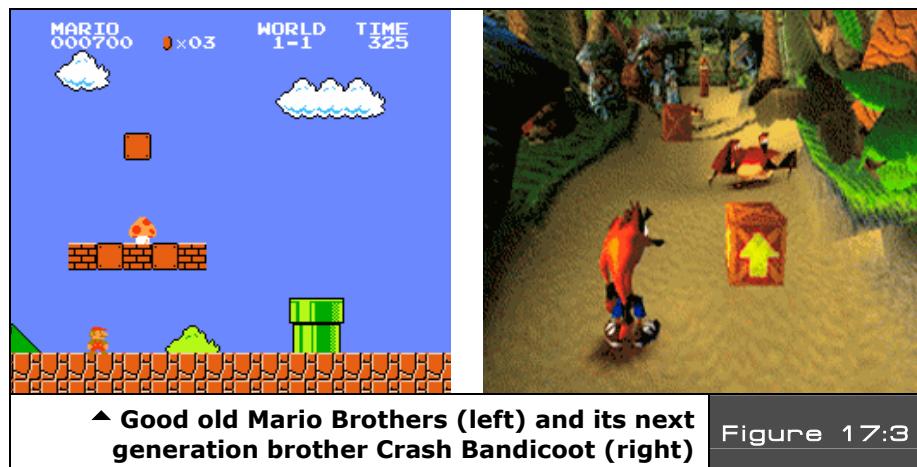
**Role-playing games** (also known as RPGs) are less action-oriented and might even have a minimal graphics and sound and sometimes “turn” based game play, meaning you do not interact in real-time, but tell the computer what you want to do and take turns with the computer or other players. In the late 80’s and early 90’s is when role playing games or “RPG’s really picked up momentum and fan base with classics such as *Kings Quest*, along with console-based variations such as the *Legend of Zelda*, both shown in Figure 17:2. Now, some might argue that Zelda is not a pure RPG, some may argue that Kings Quest has arcade elements to it and so forth. Thus, what people define as “pure” is often argued!



▲ Kings Quest (left) and Legend of Zelda (right)

Figure 17:2

**Platform games** really are a sub-genre of arcade games, but became so popular that they came to be known as "**platformers**." Both games in the arcade, and on PCs and consoles helped to make this designation stick. Platformer games can be 2D or 3D (early on games here all 2D, but later even 3D games had 2D game play and thus are called platformers). A platformer game is simply one where the game character tends to do a lot of jumping around on "platforms" – simple as that! For example, two classic platformer games from two different generations are **Super Mario Brothers** (8-bit era) and **Crash Bandicoot** (from the PSX 3D era). Both are shown in Figure 17:3.



▲ Good old Mario Brothers (left) and its next generation brother Crash Bandicoot (right)

Figure 17:3

**Board games** are video game implementations of “physical” board games. For example, chess on the computer, or Scrabble and so forth. You might ask, “What’s the point of playing a board game on the computer screen?” – well, other than the \$500M in revenues each year these games make, the other main reason is that many times it’s inconvenient to set up a physical board, the players are geographically in different locations, or the players want to play a “variation” of the board game that is based on the rules of the game (say checkers), but played with giant alien dinosaurs instead! Thus, video board games both identical to real board games as well as variations are very popular. Moreover, board games are easier to play since most of the population has played cards, chess, checkers, and Monopoly, so they can usually pick the games up very quickly. Lastly, sometimes you might want to play strip poker, but can’t find 5 supermodels to do it with, but the computer can easily accommodate you with 5 artificial players!

**First-person shooter** games need no introduction. They were more or less invented in the early 90’s as well as the term coined “**first-person shooter**” or **FPS** (not to be confused with “frames per second”) to refer to this kind of game. FPS games are typically technological demos as well as “push the envelope” kinds of games. In 1990 roughly, no one had seen a high-speed 3D game on the PC, then **Wolfenstein 3D** came out by **id Software** and the age of FPS games was upon us. FPS games take the highest amount of skill and technology to develop. Today, some of the more popular FPS games are the **Halo** series, the **DOOM** and **QUAKE** series as well as others that have followed suit. Figure 17:4 shows the evolution from Wolfenstein 3D (left) to DOOM 3 (right).



**Simulations** have been around for a long time; however, they never really looked that good. A simulation game is a game where the idea is to copy or simulate something in the real world such as flying an airplane, driving a car or boat, or even experiencing a war or

playing paint ball! In the 80's and 90's computers didn't have the processing power to make really good simulations, but all you have to do is take a look at the latest simulation games on the XBOX 360 or PSX 3 and you can see we have come a long way.

Figure 17:5 shows three prime examples of just how real simulations have become with a driving game **Burnout Revenge** (top), a flying game **Over G Fighters** (center), and finally a jet-skiing game **Splash Down!** (bottom). Amazing aren't they? The reality of simulations these days has come from two different directions; **graphics** and **physics modeling**. Game programmers have always been interested in graphics, but, they'd never had the computing power to even think about modeling real-world physics. But with today's game machines putting out trillions of operations a second, it's a snap to perform real-time physics modeling.

That about wraps it up for the main types of games, of course there are many sub-genres, games that fit in more than one genre, and so forth, but the point is these are a good starting point. In this book, we are going to focus on category one: the arcade games. Arcade games are "relatively" easy to make, they are 10,000 lines of code in comparison to 1-10 million lines of code for a state-of-the-art FPS game. Plus, most people have played them and know what they look and feel like, so it's a good reference point. Lastly, the HYDRA / Propeller have a limited amount of memory and computational power, so we have to choose our battles and not bite off too much!

The last comment I want to make before we start into the technical matter of this chapter is that there is no "way" to make a game. A game is a program just like any other program, but someone, somewhere, has



▲Simulation Games

Figure 17:5

convinced the world there is a “make game” button on some magical tool that takes “English” descriptions and translates them to millions of lines of code and hundreds of billions of bytes of assets – this is not the case. A game is a fusion of a number of engineering and artistic disciplines and a lot of work, but as long as we all start with Pong, anyone can work their way up to HALO given enough time. It’s always amusing to me when someone reads a game development book cover to cover and then asks, “yes, but how do you make HALO?” Obviously, they didn’t comprehend the book, and secondly they have oversimplified the process about 10 orders of magnitude. So the thing to remember about game development is this:

***“Every single pixel, every color, every sound, behavior, character of text, all of it – the game programmer designed, created, and thought about.”***

Keep that in mind, respect it, and making games will make sense to you.

## **17.2 Introduction to Game Development and the Creative Process**

Large games today are made by hundreds of artists and developers and take anywhere from 2 to 10 years to develop and many millions of dollars. The development cycle is very similar to a Hollywood movie. Luckily, we aren’t doing games of that scope, so we can forget about something that complicated and start off simple. But, herein lies the paradox – 99/100 programmers can NOT successfully negotiate a Pong or Pacman game from start to end. Games are so complex that they quickly get out of control if not programmed correctly and in an organized manner. Other types of programming are much more relaxed than game development. For example, I would say that over 50% of websites on internet are “incorrect” and have dozens if not thousands of serious bugs; however, all we do is view websites, the occasional glitch, lock up, or refresh is acceptable, but games do *not* give us this latitude. When was the last time you were in an arcade and a video game locked up? Ever remember your Nintendo locking up? Even once? I don’t. The point is games have to be very solid; if you design them too loosely they will spin out of control into spaghetti code oblivion faster than your typical application.

In addition, games are ultra high-performance so, unlike 99% of other applications you might use including word processors, paint programs, editors, etc. slow-down isn’t that important. But in a game, if all the action stopped on the screen and you saw a little hour glass pop up that would be unacceptable, thus the action has to continue at full speed and this is yet another challenge. So in a nutshell games have to be fast, small, correct, and fun! That’s a lot of things to worry about.

Taking all that in, the best way I can describe how to write games after 25+ years of doing it, is that you should start with a simple idea, sketch out your idea, and just think about it. When people design games they go way over board on hundreds of features and details that are irrelevant (like the motivation of the dead character’s father, who cares, it’s a pixel on the

screen!) When you start coding a game, it's going to be enough work getting a cross-hair on the screen let alone saving the princess and playing orchestral music! So for now, come up with really simple ideas, then decide what things will generally look like, the size of the imagery and characters (8×8, 16×16, 32×32 etc.), the game play, flow, or "story line." Story line in our context is going to be "blue ship blows up red ship." Then once you have all this down, you need to start coding the game.

Games are very special kinds of applications and do have a software pattern which we will discuss in a moment, but as long as you start with a good framework to write your game then you will have a lot of fun and you will finish it. If you start with a bad code base, the game will get harder and harder to modify and very soon you will reach the point where you can't add anything, since changing anything makes the rest of the game break. A properly written game is easy to add onto and fun to program.



There is a program called **MAME** – "Multi Arcade Machine Emulator." It's one of the most advanced and impressive pieces of collaborative software ever created. Basically, programmers from all over the world have reverse engineered every single game system on the planet both computer and arcade based, then with the ROMs of these games, you can play them. I suggest downloading MAME, getting some free ROMs and trying it out and playing games from the 70's and 80's to get ideas for directions to go with your early games on the HYDRA. You can Google for "MAME" but here's a place to start: <http://www.mame.net/>.

### 17.3 Tools Used to Create Games

For the kinds of games we are going to make, we are going to use "old school" techniques since the Propeller has a limited amount of RAM (32K) and there isn't a large asset tool chain in the IDE to get assets into the programs (we will talk about ways around this later), so we are going to use old techniques like graph paper and manual data entry for the most part. But, at some point you are going to want to use more advanced tools to develop the art assets for your games. There are a number of tools that are typically employed by game developers:

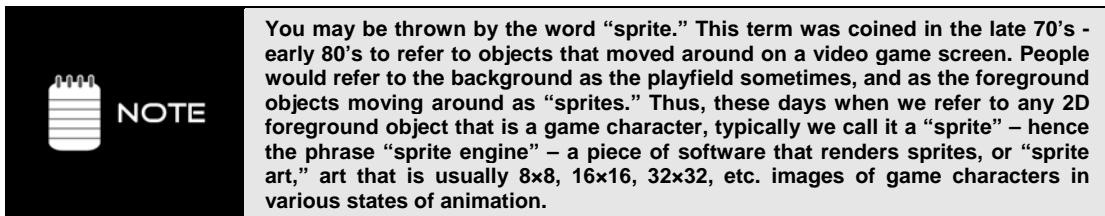
- ▶ 2D Paint programs
- ▶ Level editing programs
- ▶ 3D Modeling programs
- ▶ Sound editing programs
- ▶ Full motion video editing and compositing software
- ▶ Custom tools

**2D paint programs** are used to create 2D imagery, backgrounds, and sprites for games. Some of the more popular 2D painting programs are **Photoshop**, **Paint Shop Pro** and **Corel Paint**. Some old school products you can still get ahold of, such as **Fractal Paint** for

example. Painting programs can take a lot of work to learn, I usually suggest for beginners that aren't art savvy to start with something like Paint Shop Pro. There are evaluation versions of all these programs that you can download online, many of them work for at least 30 days without registration. In our case, the most art we are ever going to do is simple background, tile, and sprite artwork. However, as said most of the art we will do with graph paper and manually encode the data, but as you get more advanced you will want to use better-looking art. Even if you're not artistic you can start with some "stock" media that looks very good, and with a paint program tweak the art to your suiting. One such library than many newbie game developers use is called "**SpriteLib**" which I have included on the CD here:

**CD\_ROOT:\HYDRA\MEDIA\GRAPHICS\SPRITELIB**

SpriteLib is a GNU licensed sprite library that more or less allows you to do anything with it, other than sell it. However, you can use it in your games both personal and commercial.

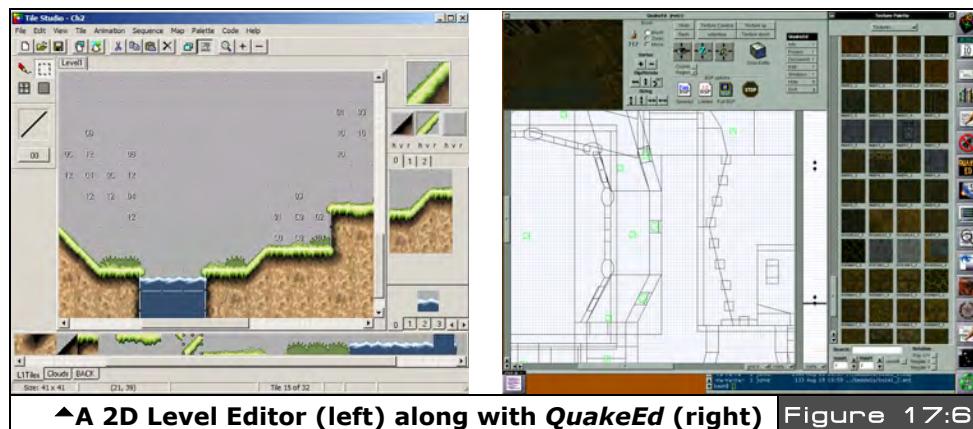


Of course, these sprites are in a .BMP format which means that somehow we need to get them into a game. On a PC that means simply opening a .BMP file with C/C++ etc. and reading, parsing, and extracting the pixel data based on the .BMP file format. But, when dealing with embedded systems and the HYDRA and Propeller, there are a lot of steps to get the sprite data from the .BMP file. First, we have to make a tool chain that can extract the .BMP images, then convert it to either Spin code, or data statements, or if possible just binary information that is uploaded in another step to the EEPROM as "assets" after the program. But, the bottom line is that a lot of work has to be done when dealing with embedded system game development and assets.

**Level editing programs** are very common in most modern games since anything more advanced than Asteroids. Level editors are more or less custom built tools that allow a "game designer" the latitude to place game play objects on a 2D screen (usually) and assign attributes. Then the level editor outputs a file that the game engine reads and with zero programming there is a new level! There are hundreds of level editors, if not thousands. Typically, for any popular game, someone will dissect the engine and build a level editor. Some common examples are the DOOM editor and QUAKE editors. But, "generic" level editors are a lot harder to make, since no two games are alike nor is their data.

So, you won't find many "level editing" tools since your game will typically be so different than anyone else's that what someone thinks is a good representation of level data will be useless to you. However, considering 2D games have been around for 30 years more or less people have a reasonable idea of what basic 2D level editing a programmer might want and from time to time create level editors. Two such programs are **Mappy** and **Tile Studio**. Both are very capable; Tile Studio has a slightly slicker interface, but is a little more complicated to use. However, Mappy works well for very simple tile worlds (which we will learn about later) and is the tool of choice in my book for very simple map editors if you don't want to make one. As a comparision to show what a 2D and 3D map editors looks like, check out Figure 17:6; it depicts Tile Studio on the left and the QUAKE editor on the right. Both Mappy and Tile studio can be found on the CD here:

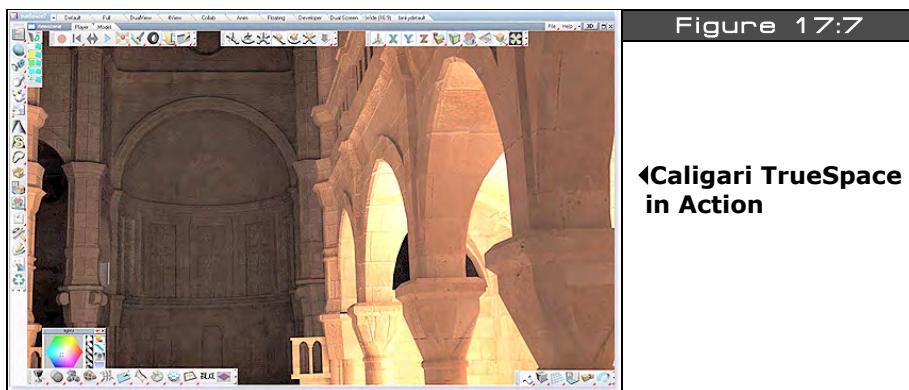
**CD\_ROOT:\HYDRA\TOOLS\MAPPY**  
**CD\_ROOT:\HYDRA\TOOLS\TILE\_STUDIO**



▲A 2D Level Editor (left) along with QuakeEd (right) Figure 17:6

**3D modeling programs** are very advanced tools typically used in 3D game character or environment creation. However, 3D modelers are also used to create hyper-realistic characters and backgrounds for 2D games to give them a more realistic look than an artist can. Some commonly used 3D modelers for game and movies are **Maya** (Alias) and **3D Studio Max** (Autodesk/Discreet). A lower-end for the more cost conscious (but still very powerful) modeler is **Truespace** (Caligari). Expect to pay anywhere from \$2500 – \$5,000 for MAX or Maya and about \$650 for TrueSpace. No matter what, these are serious programs for serious work. Typically, a "modeler" will model a game object in 3D space out of polygons, curves, and surfaces, then this mathematical description can be exported for direct use by a game engine, or the image and/or animation can be "rendered" to video as the final product. For example, Maya was used for "**Lord of the Rings**" and 3D Studio Max for "**Lost in**

**Space”** as examples. 3D modeling is not something you will learn overnight, it takes months to get the hang of and year to completely master, but the results are breathtaking. You can create absolutely photoreal imagery and render it out or export the data out for use in your game engines. Of course, this isn’t going to affect us too much considering a single model in a next generation game might be 4-32 megs of data. But, the idea is 3D modelers can be used to create sprites, backgrounds, etc. that look really cool and have proper lighting; an example done in Truspace is shown in Figure 17:7.



**Sound editing programs** are used by game developers to create sounds for games. Typically games have two kinds of sounds: digital sounds used for explosions, sounds effects, dialog, and music which is usually synthesized, but these days is always digitized usually in MPx format for playback. Of course, on small embedded systems you usually won’t have the memory to play digital sound effects, but if they are short you can get away with it. For example, on the HYDRA the EEPROM is 128K bytes, the program always uses 32K, so that leaves 96K bytes. Ok, with compression, let’s say that we can get 2K bytes per second compressed digital sound. That means 48 seconds of digital sound, hardly enough for a song, but more than enough for a few explosions, sound effects, and even some quick voice samples. So digital sound on the HYDRA is definitely in the “doable” range. And in fact, the piano keyboard demo starts up by saying “HYDRA” if you listen carefully. The top level source file is here on the CD:

**CD\_ROOT:\HYDRA\SOURCES\NS\_sound\_demo\_052.spin**

Anyway, there are lots of sound programs on the market, but some of the more common ones used for simpler games are *Cool Edit Pro* (which is now Adobe Audition), and *Sound Forge Audio Studio* (Sony). Both are downloadable off the internet and I recommend both of them. Sound Forge is my favorite though. Figure 17:8 shows Sound Forge in action. More or

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less, you can import sounds in numerous formats, edit them, compress them, experiment with them, and apply numerous filters to them to get what you want. Additionally, there are many sound libraries on internet, some are free, some are paid. One that is very popular is by a company called Sound Ideas located on the web at <http://www.sound-ideas.com/>.

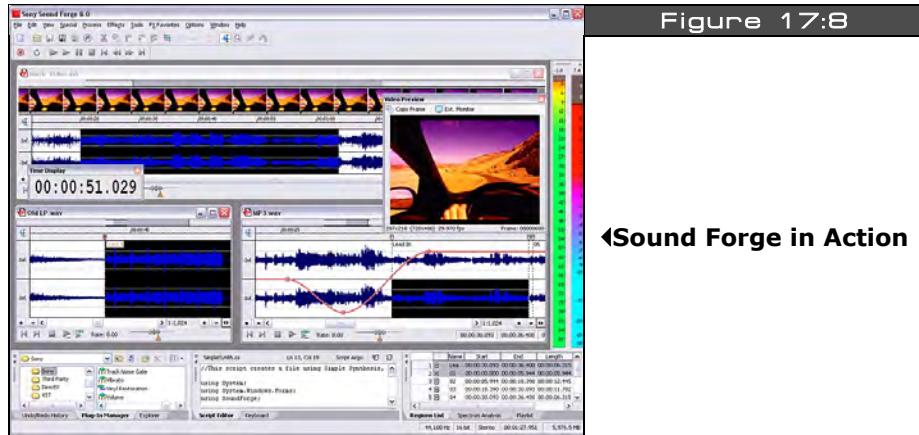


Figure 17:8

#### ◀ Sound Forge in Action

However, sound editing is a huge pain, so I have included a free library of sounds that I have created over the years for various games royalty free (just don't sell them), they are located on the CD here:

#### **CD\_ROOT:\HYDRA\MEDIA\SOUNDS\**

So if you want to experiment with sound effects and the HYDRA, you will have some source material to start with. Again, there will be a lot of work getting the sound data “out” of the PC and into the Propeller chip, since you will have to write a tool that reads a sound file in a common format such as .WAV, .RAW, etc. and then convert it to Spin code (or some other custom format/tool you create that downloads directly to the EEPROM).

**Full motion video editing and compositing software** are used mostly to take video generated by rendering, the game engine, or real actors, and composite and/or merge it together. This is the type of tool that is used to make “cut scenes” in games. Again, we don’t have enough memory to play video clips, but if someone hooked a HYDRA to an IDE then we would, thus, its good to know a little about it. So if you want to merge video, edit, composite, and manipulate, one of the most popular programs is **Adobe Premier**. You can probably make an entire movie with it. Also, you might want to check out **Adobe After Effects** which is a titling and video effects suite that gives you movie-style transitions and effects to add to your video.

**Custom tools** are the most common tools used by game developers. All of the tools we have discussed up till now are more or less used to manipulate very common data formats: graphics, video, audio. But, game data has no "format" since you make it up as you go. Thus, a game developer tends to write a lot of custom tools to do things to data. For example, you might want to use some .BMP files in your game, and you want to convert them to a Spin DAT section with the format where one LONG is on each line and represents 16 pixels, so your .BMP file might be 16×16 or maybe an array of 16×16 bitmaps, and you would have to write a tool that would do the following:

1. Open the .BMP file on the PC.
2. Parse the .BMP file.
3. Locate and extract the desired bitmaps from the file.
4. Convert them to another colorspace (the one used on the HYDRA).
5. Write a .TXT file with Spin-compliant code that you can import into your Spin program later.

Wow, that's a lot of work! But, the trick is to use a "tool" language to develop tools and quickly. I prefer C/C++ console applications, but **PERL**, **PHP** and **Python** are also good choices (I suggest the ActiveState implementations, you can find them at <http://www.activestate.com/>). Additionally, if you need to develop any GUI-based tools then I suggest **Microsoft Visual BASIC**, **Delphi**, or **Builder** as they are all excellent, easy to learn, drag and drop. In fact, many of the coders that developed tools and demos for the HYDRA created numerous tools and they typically used C/C++ and PERL more or less. So either is a good choice.



At this point, what you might want to do for fun is simply download all these applications (demo or eval versions) and play with them a bit, just to see what they are all about. I have never seen a person that isn't 10x more artistic using a computer than on paper, that is, even if you can't draw a stick figure on paper, with the computer and a good tool you can do pretty well, so it's worthwhile to try some of the tools out and see what they do.

So, you should have an idea of how games are thought up, what kinds of games are out there, and the tools used in games, so now it's finally time to get technical and start talking about coding games. We are going to start with basic code organization and work our way on from there. The thing to remember is there are no hard, fast rules, only heuristic techniques when it comes to game development. Typically, if you can write 3-5 working games, you will get the hang of it and be able to visualize any game (even HALO) and how to do it. The low-level details still always have to be worked out of course, but the structure of Pacman and HALO share a lot in common.

## 17.4 Game Loops, Design Patterns and Code Organization

When coding games there are some “tactics” used that help make the process easier. Some tactics have to do with the actual layout and syntax of the code, and some have to do with the structure of the code itself. Games are real-time, event-driven applications, thus they have to be written in the proper way.

### 17.4.1 Clean, Fast, and Simple

If you learned to program in the 90's or the 21st century then chances are you have never written any assembly language, your own compiler, or coded on a small, highly constrained system. If you have, then what I am going to say doesn't apply to you. Today's computers and compilers do so much for the programmer, programmers have forgotten how to do anything themselves. Web programming is a perfect example: with a few lines of code you can make an application that does something and millions of people can use! That sounds great, but most web programmers could never write the web browser, the TCP/IP stack, the HTML server, etc. but a game programmer could. So the point is that programming techniques you might be comfortable with for making other applications have to be thrown out of the window in most cases in order to make games. Games push the machine to its absolute limits in all ways, thus, you can't waste memory, time, or other resources. Games like DOOM used to fit on a single floppy disk! An .ini file for a Windows applications barely fits on a floppy disk these days! Thus, the point is that to make games you are going to have to think way out of the box; if you try to apply the same programming style, syntax, and organizational skills you have been using to make web applications or very high-level language applications based on VB etc. then you are going to get frustrated very quickly and think “It's impossible!”

The most important thing when coding games is to keep your programming clean, fast, and simple. Do NOT be clever, clever is slow, complicated and hard to debug. Also, when you code a game, it will tend to be a very complex program to follow, so make it easy to modify and debug. For example, don't use really clever syntax. Here's a C example from a programmer that is way too clever:

```
* (++x) --;
```

...which means, pre-increment pointer “x”, then dereference “x” and subtract 1 from it. This is valid C, but it's really hard to track, really hard to debug, and three things are happening all at once. The problem is that in a simple embedded system like the HYDRA we can almost code like this which is really bad, since if we are trying to find where a bug is happening on this line of code, there is only 1 line of code, we can't figure out what's happening in between.

So a better way to code is:

```
x++;  
*x -- ;
```

Now, we have broken it into two lines, we can put “prints” before and after the lines, and it’s easier to understand. Remember, to the compiler both methods are usually the exact same, so why write cryptic, hard-to-debug-and-understand code? The trick to game programming is to code in a very straightforward manner. If you think that putting more statements or operations on the same line or mashing them together makes the compiler create faster code, it does not; the compiler will create the same code usually no matter what. So make your code really easy to understand. When you are debugging a game, this will help immensely since games are so complex and hard to track, since they run in real-time, and since and they are very hard to step through, thus, the easier the code is to deal with the better. You can always go and make the code more clever later.

#### 17.4.2 Naming Conventions and Style

This is a favorite area for many people to get “artistic” when programming. Games should use intelligent naming, but not overboard, come up with a convention and stick to it. Also, use variable names that are short enough, so that you don’t have to work in a 5 point font to see more than a few lines of code and columns of code. For example, here’s a bad way to name variables:

```
Players_X_Velocity_variable
```

First off, never mix upper and lower case in variables, just make them all lower case, or make the first letter always upper case, or the first letter of each sub word upper case, something sane. Secondly, the name is simply too long, what this tends to do is make you view your code in a really small font to get enough code on a single page. This increases the chances of not seeing bugs, etc. Try to use short names that are not cryptic, but not overboard:

```
player_x_vel
```

This still gets the point across, is short, and easy to type. Another good rule of thumb is try to code in a certain width, for example, set some boundaries like 80, 120, or 160 (max) columns to do your coding. This makes it easier to “see” more at once on the same page. Game code is very complex, and due to the constant desire to optimize you make VERY long functions, thus you want to be able to see as much of a function on the editor screen at once as possible. Also, using too much white space in your code, too much indenting, and large variable names is a sure-fire way to make debugging very hard and frustrating. One of my

latest 3D rendering engines is about 1,000,000 lines of highly optimized code; if I were to put too much white space, it would bloat to 1.5 million or maybe 2 million lines of editor code, which would take too long to search and scroll in. Game programming is a very interactive process: you tweak, recompile, look at it, play it, then stop, re-tweak, etc. so you want as much code on the screen as possible and to keep typing to a minimum without losing the simplicity I spoke of earlier.

This stuff might seem obvious, but I have seen countless souls become frustrated trying to code games since they exponentially get complex in no time and are too hard to debug, then the programmers give up. But, if you follow some sane rules and conventions you can get over the exponential complexity “hump” in your game code and finish your games.

Last, but not least, choose clever algorithms, not clever syntax. A optimal algorithm is worth more than clever, ugly, contrived code. If you have a bad algorithm, all the syntactic cleverness is not going to make it faster. For example, I can code a **Bubble Sort** in a couple lines of code, but no matter how much I mash the code into 1-2 lines, it will never beat a 100-line **Quick Sort**.

#### 17.4.3 Finite State Machines

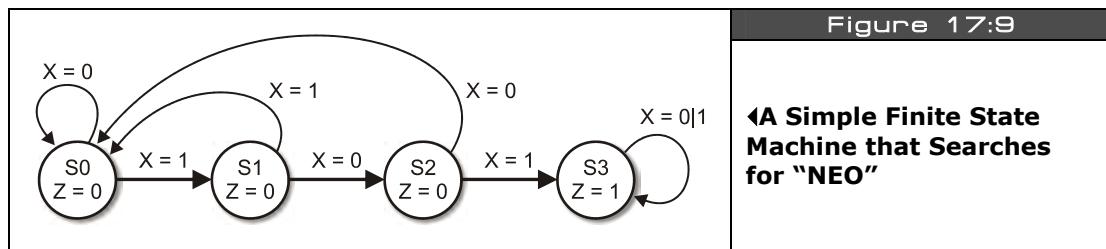


Figure 17:9

◀A Simple Finite State Machine that Searches for “NEO”

One of the most commonly used software structures in games is the **finite state machine** or **FSM**. If you already know what an FSM is just skim this section. An FSM is an abstract machine implemented physically, electronically, or virtually, that is a machine that has a finite number of possible states. These states are controlled by the FSM's current state along with its inputs. Figure 17:9 shows a generic finite state machine. As you can see each state is labeled by a circle with the state value / name inside the circle. Also inside the circle shows the output variables of the state, in this case this state machine has input x and output z. There are no limits or constraints on the number of inputs or outputs, it's up to you. Finally, each state has one or more transition edges leaving or entering each state. This particular FSM hunts for the sequence “101” in the input stream via x (“101” was the apartment number in the movie “The Matrix,” so we are searching for “NEO” with this state machine).

Table 17:1 shows the state transition table (another tool used in FSM design).

| Table 17:1         |              | State Transition Table for the "101" Search State Machine▼ |            |  |
|--------------------|--------------|--|------------|--|
| Present State (Si) | Input (x)    | Next State (Si*1)  | Output (z) |  |
| S0                 | 0 / 1        | S0 / S1  | 0          |  |
| S1                 | 0 / 1        | S2 / S0  | 0          |  |
| <b>S2</b>          | <b>0 / 1</b> | <b>S0 / S3</b>   | <b>0</b>   |  |
| S3                 | 0 / 1        | S3 / S3  | 1          |  |

Referring to the state table, there is no "correct" way to draw one; there are a number of styles, but Table 17:1 is what you will see in most college EE texts in one form or another. Sometimes, the present states are written as column heads with inputs down the left edge and so forth, thus it's a matter of taste and what is appropriate to get the point across. In this particular table, we have 4 states: S0, S1, ... S3. S0 is the starting state; when the system is reset it starts in this state, then the state machine reads in x and searches for the pattern "101." Each time another symbol in the sequence "101" is reached the state machine advances to the next state; if a bit in the sequence is incorrect then the machine goes back to state 0. Also, once the machine reaches state 3, it stays there outputting 1. Also, notice that the state outputs are irrelevant of the inputs, they are coupled to each state S0, S1, ..., S3. Now, to read the table you simply note what your current state is, say S2 (I have bolded this row), then you take a look at what your input (x) is. If its 0 in this case then the next state would be S0, if x is 1 then the next state is S3. The use of the "a / b" notation simply saves space and is a way to say for these input states "a / b" map them to these next states "c / d." You could put numerous inputs with more slashes if need be.

Now, there should be one little detail burning in your mind and that's "What happens when the state transitions and inputs are scanned/reviewed?" This is a good question. In an electrical system, the states would be represented by clocked flip flops, and the inputs would be re-evaluated each clock. So the system would follow a clock, but in a computer program this is a little harder to nail down. But, the idea is that you will have a main "game loop" and all your FSMs will re-evaluate as the main loop evaluates, so if your main loop evaluates 60 times a second (video rates) then so will your main loop FSMs.

So, how can FSM help us in games? Well, they are everywhere in games, for example:

- ▶ Game loop control
- ▶ Artificial intelligence algorithms
- ▶ I/O reading
- ▶ Telecommunications

In fact, we are going to write all our games as a hierarchy of state machines in almost a fractal manner.

#### 17.4.3.1 States of a Game

Now we are ready to talk about game program architecture. Games are written as state machines within state machines. Games have to react to input, render the display, play music, perform calculations, do artificial intelligence, model physics, send packets of data over networks, and a lot more. The only way to begin to control all this madness is with state machines and a hierarchical design approach. So let's think for a moment about the tasks that a game must perform at the highest level: think about Pacman, Asteroids, Centipede, Breakout, Pong, or some other basic arcade game. They all have a number of things in common from a software point of view. Each game consists of two main components; the program and data:

1. The game program itself.
2. Assets such as graphics, sound, tables, and data.

Also, all the games aside from the gameplay and what they look like all do the same thing more or less. They sit and wait for you to start them, then the game starts, you play, you die, it ends, the game resets and waits for the next player (or quarter). So we are starting to see some organization here. Let's continue drilling down with our programming hats on.

All these games are applications that have a number of states they must go through before the "game" starts. Typically these global game states can be broken down into a list similar to the one below, and organized as shown in Figure 17:10 on the next page.

- ▶ Initialization
- ▶ Menu Mode
- ▶ Game Start
- ▶ Game Run
- ▶ Game Over
- ▶ Game Restart
- ▶ Game End

This list is by no means ultimate truth, but simply a guideline, you might do things slightly different by splitting up states, merging them, or adding others, but at the end of the day, these states in the abstract will all exist in one way or another. Now, let's review what each might entail.

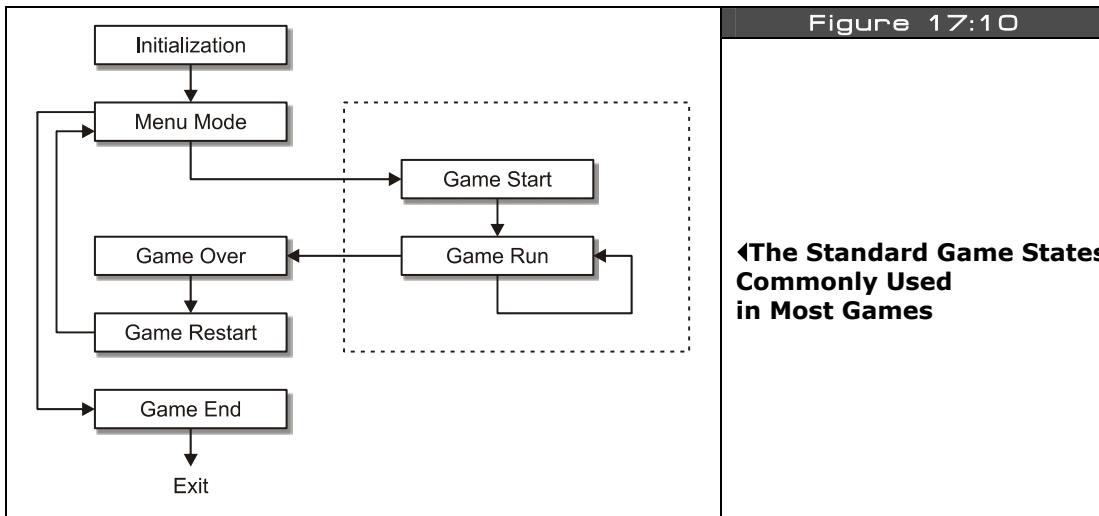


Figure 17:10

◀The Standard Game States Commonly Used in Most Games

**Initialization** — In this state the game program just started up. It needs to load assets, initialize devices, load drivers, and do all the housekeeping chores that are associated with not only the game, but with the program as an application. Memory is allocated here and other resources as well.

**Menu Mode** — After the game initializes, typically the game will jump into a “menu” mode, or in more advanced games a “demo” or “attract” mode (which we will discuss later). In this mode, typically the game logic will not be running (for simpler games) and the user will simply be presented with a menu and allowed to navigate the menu with various input devices to select number of players, skill level, preference settings etc. This Menu Mode may itself be a number of state machines, but globally the “menu state” is unique.

**Game Start** — At some point the player is going to start the game via the Menu mode and the game needs to start. The Game Start mode is designed to get the game ready to run and clear out variables, and get everything ready for the game to enter into the “run” mode. This is the last state before the game runs so anything that needs to be reset for a new game play round needs to get reset here. When the state is complete, it typically automatically transitions into the Game Run state and the game begins immediately on the next frame or main loop cycle. Note: notice below there is a “Game Restart” state, many times there is a slight difference when a game runs the first time, and when a game runs the 2nd time onward. The Game Restart state is a state to catch this and do any processing. Of course, it's easy to catch this in Game Start by tracking a variable that indicates the current “run” of the game, but some programmers like a separate state, so no harm to add it for fun.

**Game Run** — This is the main state of the game. If the main loop is here then the game is running and running at 30-60 frames per second doing everything internally to render, calculate game logic, do animation, get input and so on. The state loops back to itself each cycle unless the player dies, or exits, for example, hits ESC and then forces the system back to the menu state. This state is the “real-time” state of the game more or less.

**Game Over** — At this state the player has usually died or requested an exit some other way. Before going back to the main menu the Game Over state might want to do some clean up, or specifically some kind of sequence or state sequence pertaining to dying or the end of the game. This state again could be merged into a “sub-state” of the Game Run, but then again we can merge everything into everything if we really want to, so let’s keep it separate for now. When the Game Over state is complete it will usually transition right back to the Game Menu state.

**Game Restart** — As noted, this is a secondary state that in some game loops is called after a Game Over state to reset a few more things, or update some other variables that pertain to the nth run of the game rather than run 1 of the game.

**Game End** — This state can only be reached via the Menu Mode state and more or less releases all the resources that the game used. So here is where you release drivers, de-allocate memory (if you are in an operating system environment), turn all the sound channels off, and make as if it all never happened.

That’s some of the main global states a game has. The trick is to write a state machine in your code as a series of case/switch statements or even “if” statements that implement these states (or a subset of them). Now, let’s take a look more closely at some of the specific needs for basic games.

#### 17.4.3.2 Basic Game Loops

Alright, now that we have discussed the structure of main game loop for a game, let’s discuss some details and then talk about some more simplified models of the loop to start with. First off, the main idea is that it’s a good architecture to use a state machine as the main loop. The state machine cleanly separates each of the game’s main states and makes it easy to program, otherwise, you will find yourself “coupling” states and things will quickly turn to a mess. Now, the states previously outlined are only suggestions, you can merge, add states, whatever, the point is to keep it simple.

Additionally, since we are writing games, there is a very tight relationship with the game loop and the animation of the game. Typically, we want to run a game at 30-60 FPS, so that animation is fluid and not jerky. This rate of animation can be difficult to maintain in Spin, since with a lot of logic updating the screen 30-60 times a second might not be possible. But, when this starts happening then we simply have to switch to ASM, but I am going to try and offload as much work as possible into the graphics and NTSC drivers, so the main Spin game

logic does very little. So the question is, "How do you maintain a constant frame rate in a game?" Well, the answer to this is complicated. First, let's say that there are 100 objects on the screen and with the 100 objects the game runs at 5 FPS; there is no way to make this faster, so we can either remove objects or let the game run slow. It's not really acceptable to remove game objects, so typically a programmer will write a game such that the game can maintain 30-60 FPS a most cases. But, what if a game only has 1 object on the screen? Then the main loop will update much faster than 30-60 FPS and the game will go too fast! This is a very common problem with games that have wildly varying amounts of core logic. So what you want to do is simple: at the top of your game run state you take a measure of the current time or clock, you run your logic, and then at the end of the game loop you "wait" until  $1/30^{\text{th}}$  or  $1/160^{\text{th}}$  of second has elapsed then continue. So if the game loop took more than  $1/30^{\text{th}}$  or  $1/60^{\text{th}}$  of second (depending on how fast you want the game to run) then the wait code would fall through, but if the game logic only took  $1/1000^{\text{th}}$  of a second, then the wait code would wait and the game would run at a consistent speed. For example, if we were running the HYDRA at its normal 80 MHz then each clock is 12.5 ns, therefore,  $1/60^{\text{th}}$  of a second would be 1,333,333.33 clocks, so all we need to do is wait this many clocks to guarantee that the main loop runs no faster than 60 FPS and the game has consistent timing for the animation. Here's some Spin code that would do this:

```
' main loop entry
timer_count := CNT + 1_333_333

' game logic goes here...

' now wait until 1/60th of second from entry elapses...
waitcnt(timer_count)
```

Of course, if the "game logic" takes more than  $1/60^{\text{th}}$  of second then the loop would just fall through. Next, let's talk about the main animation cycle or run state of the game.

In the game run state, the game logic follows these general steps shown below and diagramed in Figure 17:11:

**Step 1:** Erase the image on the screen or off-screen buffer.

**Step 2:** Get player input and process it.

**Step 3:** Perform game logic, AI, collision detection, etc.

**Step 4:** Draw image on screen or offscreen buffer.

**Step 5:** Copy offscreen buffer to visible screen (only if using a double-buffered scheme).

**Step 6:** Synchronize to frame rate (optional).

**Step 7:** GOTO 1

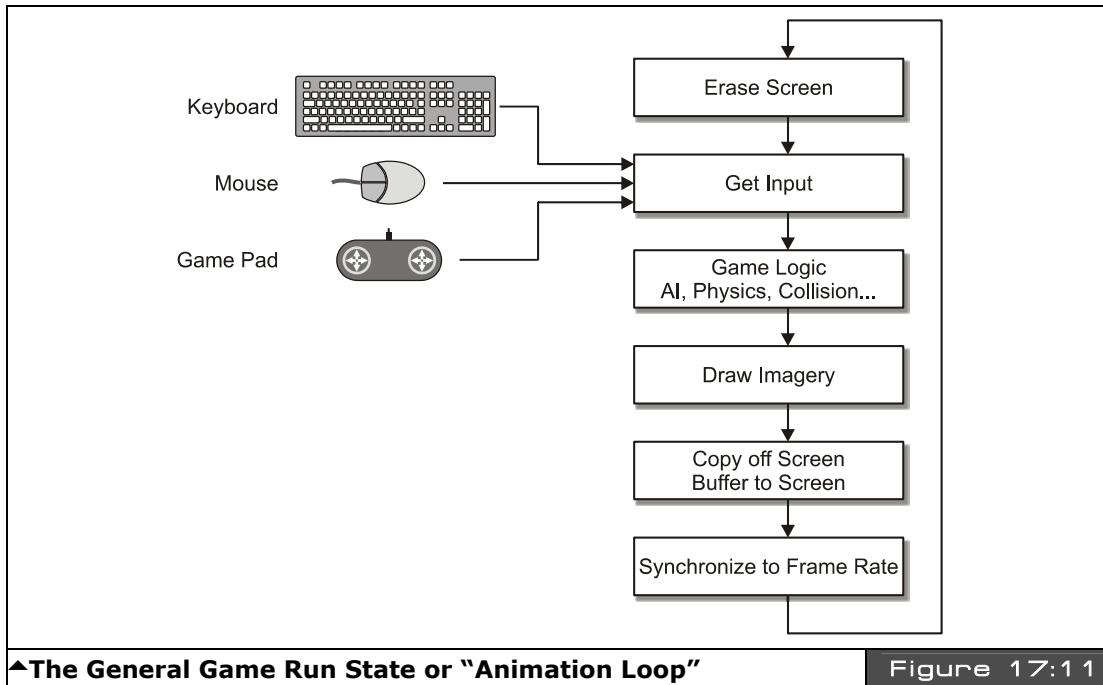
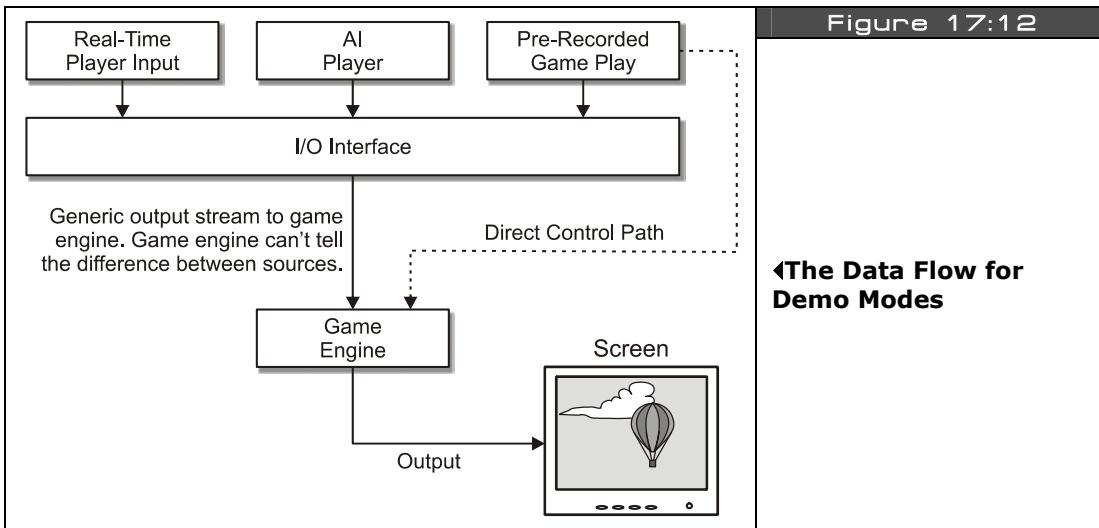


Figure 17:11

Once again, these steps are a guideline and in reality might be further separated or merged, but the idea is "**erase-move-draw**" – this is the basis of all games – "**erase-move-draw.**" For every game demo that we develop, you will see this structure in the main loop in one form or another.

#### 17.4.3.3 "Attract" / Demo Modes

The next subject I want to talk about is demo and "attract" modes. The term "attract" mode was coined by Atari since they wanted their early games to "attract" attention, so the term "attract mode" is similar in meaning to demo mode. Anyway, the idea of a demo mode is that the game "demos" the game play either using artificial intelligence or pre-recorded user game play that is feed back through the input system as if the player were playing, this is shown in Figure 17:12 on the next page. This is yet another game state and usually related to the menu state of a game. If you leave a game long enough, it automatically transitions from the menu state after some time (maybe 10-30 seconds) and goes into demo mode to show the game playing, then if a player hits a key it jumps back to the menu state.



To implement this kind of feature, aside from the actual demo mode logic and/or data, the way to approach it is the concept of “sub-states” in the game run state. That is, when the main loop enters into the game run state, normally there might only be one state, “normal,” but to support a demo mode state, there could be a sub-state that indicates further sub-processing within the parent state. This can save code since it’s usually easier to code a sub-state in a main state rather than copy an entire state. For example, both the run and demo states both erase, move, draw everything, but the demo mode doesn’t read player input, it reads from a file or an artificial intelligence controls game play. Thus, the only real difference between a normal run state and the demo mode is one section of code, thus it’s wasteful to copy all the other code. A better approach is to use a conditional and a sub-state variable to branch to various blocks to get the player control either from input devices or a data file or AI. Below shows a snippet of pseudo code to illustrate the idea:

```

CON
  ' a couple primary states
GAME_STATE_INIT = 0
GAME_STATE_RUN  = 1

  ' a couple sub-states relating to the "run" state
GAME_STATE_RUN_NORMAL = 0
GAME_STATE_RUN_DEMO   = 1

VAR

```

```

long game_state, game_sub_state

Pub Start

' state off in run/normal
game_state      := GAME_STATE_RUN
game_sub_state := GAME_STATE_RUN_NORMAL

'...lots of stuff

' main loop
case game_state

    GAME_STATE_INIT: ' do all the init here...

    GAME_STATE_RUN:   ' here's the run state
                      ' erase...

                      ' test for sub-state here
if (game_sub_state = GAME_RUN_NORMAL)
    ' do normal user input...
else ' must be GAME_RUN_DEMO
    ' read from demo file or use AI to play game

    ' move / logic...

    ' draw...

    ' end run state

```

Of course, there might be many sub-states, and even sub-states within the sub-states, the point is to balance code re-use with code complexity. If the code complexity goes up too much then you might have to break a state back out from a sub-state to a primary state. Also, you might want to always use "case" statements rather than "if's" based on memory usage, the only way to find out which is better is to compile and check memory usage. Remember, Spin programs use up a lot of memory compared to ASM, so code needs to be as optimal as possible.

#### 17.4.4 Advanced architectures wth engines

The last topic I want to discuss is more advanced game architectures that you might find in "level" based games or more modern games like DOOM, HALO, etc. If you write a brute force "shooter" game, where objects appear on the screen and you simply shoot them and then re-generate, the game "engine" is the "game," there isn't a nice delination between "program" and "data," but unless you want to "code" every little thing in a game, a more

modern technique is to write a “game engine” that runs the game, and then the behavior of the game is more data-driven by a “level file” of sorts. The level file might have game field data only, or it might have other data in it, even little “scripts” written in some custom language.



For example, say you want to make a “**Dig Dug**” clone as shown in Figure 17:13. Dig Dug is more or less a “chase” game like Pacman, but you are under ground, can dig away rock, drop rocks, and fire a water hose at the enemies. The point is that each “level” has different graphics, different positions of the enemies to start, different positions of the rocks, and so forth. To “program” each level would be a pain since you would have to use code, recompile, etc. But, if you make an engine that can read “files” or level data in some format, then an artist or level designer can design levels and know nothing about game programming! This is exactly how all modern games are made; level designers are given tools to design levels and don’t even know how to program, but they can play characters, apply textures, place traps and so forth. Let’s see how we might do this with the Dig Dug example. Let’s assign the following ASCII characters the values shown below:

|     |                      |     |                   |
|-----|----------------------|-----|-------------------|
| ' ' | = Empty dug out rock | 's' | = Sky             |
| 'y' | = Dirt yellow        | 'R' | = A Rock          |
| 'o' | = Dirt orange        | 'F' | = A Fygar dragon  |
| 'r' | = Dirt red           | 'P' | = A Pooka         |
| 'b' | = Dirt brown         | 'H' | = Dig Dug himself |

Alright, now based on these character encodings, if we want to generate level data like something shown in Figure 17:13, (assuming a  $16 \times 18$  tile universe) then the data would look like:

```
"ssssssssssssssss"
"ssssssssssssssss"
"ssssssssssssssss"
"yyyyyyyy yyyyyyyy"
"yyyyyyyy yyy P y"
"yy yRyy yyyyyyyy"
"yyPyyyy yyyyyyyy"
"00 0000 00000000"
"00 0000 00000000"
"00000 H 000000"
"0000000000000000"
"bbbbbbbbbbbbbbbbbb"
"bbbbbbbbbbbbbb Rbb"
"bbb F bbbb bbb"
"bbbRbbbbbbPbbb"
"rrrrrrrrrrrr rrr"
"rrrrrrrrrrrr rrr"
"rrrrrrrrrrrrrrrr"
```

Take a moment and stare at the data and you will see that if you map the key to the ASCII data it is indeed similar to the image shown in Figure 17:13! Thus, once you write an “engine” that reads a string array or ASCII array in Spin of this format, then there are countless game levels you can design! Better yet, a non-programmer can design the game levels and simply give them to you for inclusion in the game source. This is the power of game engines and “data driven” design.

## 17.5 Data Structures Used in Games

Spin has no data structure support other than singletons and arrays, thus, if you are used to complex structures like linked lists, trees, or even named records you are out of luck. However, this isn’t really an issue since game developers like to keep things simple anyway. In the paragraphs below, we are going to discuss some ideas and tactics when it comes to data structures used in games.

### 17.5.1 Globals, Arrays, Linked lists

Writing a video game is like rendering a painting, you do it one layer at a time: first the background, then some of the foreground objects, then lighting, then touch-up, etc. Therefore, as you code, you don’t need to be perfect and follow every rule in the book. For example, games must be fast. This is the number one concern second to size, thus the use of globals is very liberal, in fact, most games have a “global pool” at the top of the program that is used in many algorithms throughout the game. Moreover, the concept of functional

encapsulation and side effects are loose. That is, it's okay to have functions that have no locals and that simply refer to globals, this way, there is nothing created on the stack and destroyed on exit to a function. So, in general globals are good in games and help get things going. If you are a messy programmer and have a hard time remembering what's what then globals will bury you, but the point is that when you start coding a game, many of your functions may have no parameters and no locals, everything will be global.

Next, application programmers love to over-design data structures, many times a simple array will suffice for 90% of all programs. Sure, for sorting, searching and advanced algorithms we have to use linked lists, trees, and other more advanced data structures. But, in most cases static arrays are the best way to represent a set of objects even if the number of objects changes. Although, this isn't as much a concern in Spin since there is no heap, no OS, and no memory allocation/de-allocation functionality; the idea is that if you know the maximum size something is going to be, simply make an array that big and use a variable to track how many elements are active, or the last element.

### 17.5.2 Simulating Records

One area that neither Spin nor assembly language support is records. That is a way to create a named data structure, or an array of them, and access them with an index and field operator. For example, say you wanted to define a player like so with C code:

```
typedef PLAYER_TYP
{
    word state // state of player
    word x,y   // position of player
    word xv, yv // velocity of player
    word color // color of player
} PLAYER;
```

Then you could create an array of PLAYERS with the following syntax:

```
PLAYER players[10];
```

...and you could access the ith player's state field like this:

```
players[i].state
```

Spin has no support for named structures and accessing data like this, however, we can synthesize it with some clever programming. The idea is that we want to use a single array to hold n records, each record composed of a number of fields. Let's synthesis one possible solution using Spin to emulate the above C language structure support:

```

CON
    ' index values into the record
    PLAYER_STATE_INDEX = 0      ' index of "state" in record
    PLAYER_X_INDEX      = 1      ' index of "x" in record
    PLAYER_Y_INDEX      = 2      ' index of "y" in record
    PLAYER_XV_INDEX     = 3      ' index of "xv" in record
    PLAYER_YV_INDEX     = 4      ' index of "yv" in record
    PLAYER_COLOR_INDEX  = 5      ' index of "color" in record

    PLAYER_SIZE = 6             ' 6 words per player record

    NUM_PLAYERS = 10

```

**VAR**

```

wordplayers[NUM_PLAYERS*PLAYER_SIZE]           ' set aside a total of 60 words to hold
                                                ' all the data

```

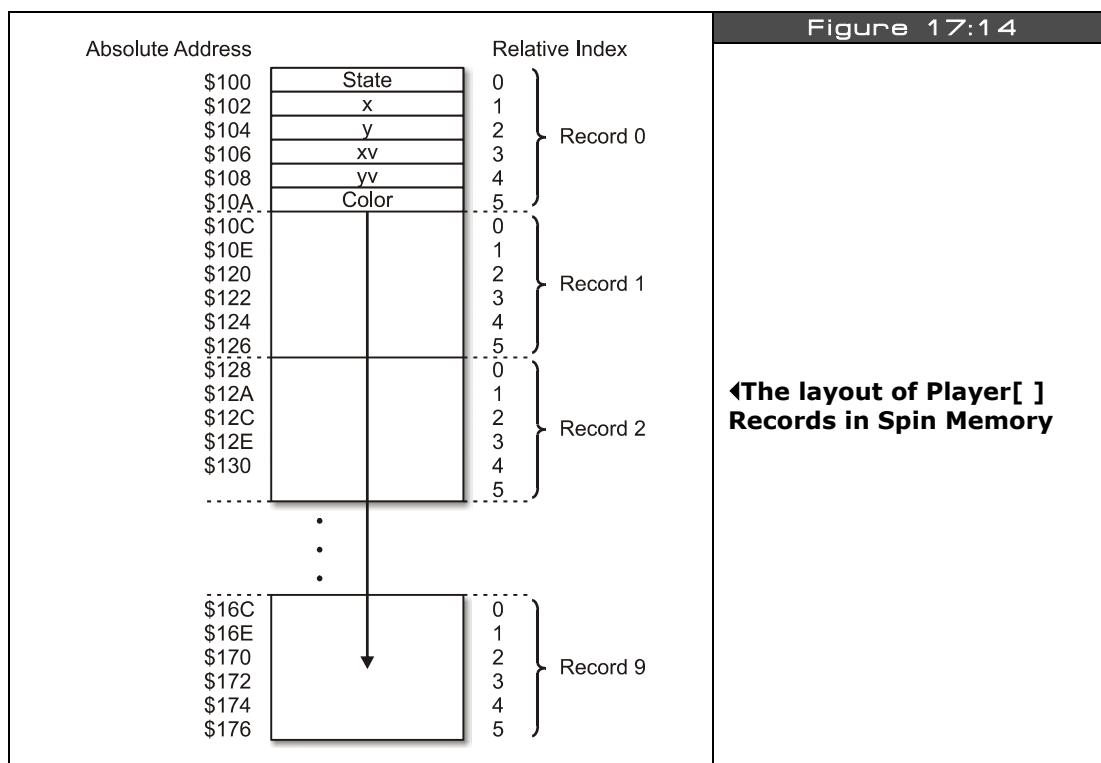


Figure 17:14 shows how memory is laid out for our ***player[ ]*** array assuming the starting address of the array is \$100. Basically, we simply use a consistent convention to access each record as an offset from a base and then index into the field to get the appropriate field. So syntax to access any field of any record n is simply:

```
players[PLAYERS_SIZE * n + field_index]
```

...where field\_index is one of the constants PLAYER\_STATE\_INDEX, PLAYER\_X\_INDEX, etc. For example, if we wanted the 3rd player's color we would type:

```
players[PLAYERS_SIZE * 3 + PLAYER_COLOR_INDEX]
```

...and that's it. Now, there is some really bad news here with Spin: there is very little optimization going on inside those brackets, so the index calculation will be done each time and waste code and time. You can surround the internal index of the brackets with a CONSTANT() call, but this only works for constants, that are not a function of a variable. So, be careful if you start using complex mathematical expressions to generate array indices as the time to calculate the array index will kill your performance, so try to keep things to a ***multiply*** and an ***add*** if possible.

Also, a simple optimization you can do is this: say that you are indexing with n as the index and need to access each element in a record and do something with it, simply pre-compute the multiplication to find the base, then use this as part of your final index. Thus instead of this code:

```
players[PLAYERS_SIZE * n + PLAYER_STATE_INDEX]
players[PLAYERS_SIZE * n + PLAYER_X_INDEX]
players[PLAYERS_SIZE * n + PLAYER_Y_INDEX]
players[PLAYERS_SIZE * n + PLAYER_XV_INDEX]
players[PLAYERS_SIZE * n + PLAYER_YV_INDEX]
players[PLAYERS_SIZE * n + PLAYER_COLOR_INDEX]
```

...pre-compute the multiplication factor like this:

```
player_base_address := PLAYERS_SIZE * n

players[player_base_address + PLAYER_STATE_INDEX]
players[player_base_address + PLAYER_X_INDEX]
players[player_base_address + PLAYER_Y_INDEX]
players[player_base_address + PLAYER_XV_INDEX]
players[player_base_address + PLAYER_YV_INDEX]
players[player_base_address + PLAYER_COLOR_INDEX]
```

...so now, each index expression has been simplified to a single addition rather than a multiplication and addition. Of course, in a modern compiler, this would be done automatically, but with Spin you have to give it a little help which is kinda fun, since you can use a lot of old DOS programming optimizations in Spin that have long been optimized by modern compilers and don't work anymore.

### 17.5.3 Pre-computation, Lookup Tables, and Caching Strategies

The above pre-computation trick leads us to caching and lookup tables. With Spin, the best way to do math and computation is not to do it at all, so the more you can cache, pre-compute, or otherwise calculate before run-time the better. For example, there are few places to do this; in Spin "what you see is what you get" so if you perform a multiplication and then 5 lines down the *same* multiplication, the compiler will simply do it again. An optimizing compiler will track this and store the computation and cache it for later use in the current block. So after you do your coding, if you find a term that is in common, try pre-computing it at the top of the loop, and caching it in a single variable and use the variable for the expression or factor to speed things up.

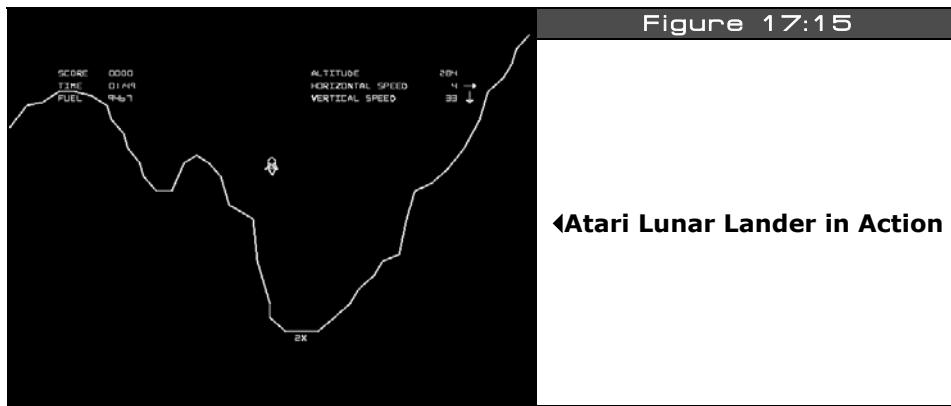
The second place to use these techniques is where you can generate complex mathematical or functional tables rather than use logic to compute them in real-time. A simple and obvious example is trigonometric tables, which the Propeller chip actually has in look-up tables along with log tables. But, don't think look-up tables are only for math, you can use look-up tables for anything that you need to be fast. If it's worth the speed versus memory trade off then do it, or at least try.

Lastly, formal "caching" is a technique where you are forced to perform some kind of calculation or resource access during real-time that you simply can't pre-compute or generate, there is too much of it; however, you might find that if you perform one computation at time t, then you continue to perform that computation temporally near time t, thus you can cache the result, and before you do the computation test if the cache holds the results. Thus the cache might only be few hundred bytes of storage, but can save you a lot of computation time. Graphics algorithms make heavy use of caches for bitmap data, texturing, lighting, and so forth, so give crude caching a try as well.

## 17.6 Mars Lander

Well, this wouldn't be a game book if we didn't write some games, so it seems only traditional to start off with something simple to use our techniques thus far. I was going to make a Pong game, but I am so sick of Pong for the "hello world" of games, I thought why not a lunar lander game? That's a little more interesting I think. So, let's design "Mars Lander" together then I will go off and code it. I am going to give myself no more than 1 hour to code it, and this is a good way for you to get good at games as well, that is, set a time limit, an hour, week, month or year to make your game, and when the time is up, the

time is up, otherwise, you will never finish. An hour is a good amount of time to make a lunar lander along the lines I am thinking. So, let's do the design. First, if you have never seen **Lunar Lander**, it's yet another Atari classic game (however there were earlier PC-based versions), based on the excitement of the moon landing in 1969. Lunar Lander is a simulation game, and the idea is simple: land the lunar module on the moon's surface without smashing it into the ground at too high a velocity. The game looks something like that shown in Figure 17:15.



The original Atari version game was done with vector graphics and an o-scope display controlled by a 6502 @ 1.5 MHz. We will try to make our game similar by using green vector-like line graphics. The gameplay consists of a randomly generated terrain and then the lander drops into view, you can control the horizontal and vertical velocity with thrusters. The idea was to land as soft as possible and use the least amount of fuel as possible. Thus, our design consists of the following elements:

1. We need to generate a random terrain with at least one flat spot for landing.
2. We need to draw the ship and terrain each frame, get user input, and simulate gravity and velocity effects.
3. We need to perform a collision detection algorithm to test when the lunar lander touches the terrain and if it has landed on the landing zone with a low enough velocity. Then the player gets some points and the game restarts.

Some things that need to be developed are ways to draw random terrain, how to implement gravity, and finally, some kind of floating-point or fixed-point support for the velocity and acceleration. We will get more into these details later, but for now, I am going to use fixed-point math (if you haven't used fixed-point, don't worry we will discuss it later). For gravity, I am going to use these simple equations for linear motion from any physics book:

$$\begin{aligned} \text{velocity} &= \text{acceleration} \times \text{time} \\ \text{position} &= \text{velocity} \times \text{time} + \frac{1}{2} \times \text{acceleration} \times \text{time}^2 \\ \text{acceleration} &= \text{gravity (on moon)} \end{aligned}$$

Now, in a game, "time" is virtual and can be "real-time" or simulated time, such as the frame rate, so at the end of the data, the final form of the equation we are going to use is simply this, given the y position of our lander is `lander_y`:

$$\begin{aligned} \text{lander_ya} &= \text{thrust} + \text{gravity_moon} \\ \text{lander_yv} &= \text{lander_yv} + \text{lander_ya} \\ \text{lander_y} &= \text{lander_y} + \text{lander_yv} \end{aligned}$$

...where, "lander\_yv" is the y component of velocity of the lander, "lander\_ya" is the y component of acceleration of the lander (generated by thrust or gravity), and finally "lander\_y" is the y position on the screen of the lander. Of course, there are lots of scaling and sign issues, but don't worry about them for now, the idea here is to just get a general design down and how we are going to do it. The code of course will look quite different since there are going to be tricks, shortcuts and fixed point math, but its all based on the above equations.



The results of all our hard work is shown in Figure 17:16. The code for the game can be found on the CD here:

**CD\_ROOT:\HYDRA\SOURCES\mars\_lander\_011.spin**

Simply load this file and compile and download it into the HYDRA. The game only uses the NES compatible controller for input, the controls are as follows:

| Table 17:2       |              | Mars Lander Controller▼ |
|------------------|--------------|-------------------------|
| Controller Input | Action       |                         |
| Dpad Right       | Rotate Right |                         |
| Dpad Left        | Rotate Left  |                         |
| B                | Thrust       |                         |
| Start            | Start Game   |                         |

Try to keep the lander downward velocity under a couple pixels/sec and land it on the "flat spot" on the terrain highlighted in green. You will notice that the game has all the main game states when you review the code such as **initialization**, **menu**, **start**, **run**, and **end**.

See if you can add some features to the game, maybe sound or some "zooming" technology, so as you get closer to the landing zone the game "zooms" into it. Also, notice the game logic is very simple, and by no means robust, the collision for example is very crude. The player's ship is a polygon composed of lines, the polygon can rotate all around, therefore to test for all collision possibilities you would have to test each line of the polygon against the terrain and test if it intersects. This is very slow and there are tricks around this (not implemented at this time), alas, this demo's collision detection for the mars terrain simply "reads" pixels from the screen and if the center of the ship pierces "red" then we know we are hitting the terrain and the player dies. This technique is called "**color space**" collision detection and is based on reading the pixel data out of the screen image and knowing that one or more colors mean different things like hot, cold, water, barrier, or die! On the other hand the landing zone collision detection works by testing the current x,y position of the lander against the landing zone with is more or less a line from (x1, y) to (x2, y), if the lander is close to y and between x1 and x2 and the downward velocity of the lander is less than our threshold then a safe landing has occurred. As you can see, the devil is in the details.

Collision detection is one of the biggest problems in game programming, that is, how to test collision between objects (many of them bitmaps) in a fast and efficient manner. There are all kinds of algorithms designed for this since the problem turns out to be  $n^2$  or  $C(n,2)$  in many cases which even for small n explodes. Anyway, this game is meant to be a black box for you to play with, so how it works isn't important yet.



## MATH

" $c(n,2)$ " in the paragraph above means "n choose 2", it comes from a field of math called "*Combinatorics*" and relates to the number of ways to choose subsets from a set where order is unimportant. The formula in general for  $c(n,r)$  is  $[ n!/(n-r)! ]$  where  $n!$  is means "n-factorial" and is equal to  
[  $n \cdot (n-1) \cdot (n-2) \cdots \cdot 2 \cdot 1$  ],  
...where  $1! = 1$  as well as  $0! = 1$ .

## 17.7 Summary

In this chapter we discussed a number of artistic and technical issues and concepts related to game development. Hopefully, you have a better idea of the work flow and what's involved now, so you can see how things "connect" together. You are probably a bit overwhelmed right now seeing all the tools that are involved, most people really have no idea what goes into a game and when they learn a little about it they are shocked to see how complex it all is! The important thing about a game to understand is that is more than just a program, it's a huge array of assets, art, sound, music, level data and more and all this is used to make the game work. In the following chapters, we are going to tackle the technical aspects of game development including graphics, input, sound, 3D, optimization, and so forth – it should be a lot of fun, so let's get cracking!



## Chapter 18: Basic Graphics and 2D Animation

In this chapter, we are going to start formalizing graphics and animation techniques on the HYDRA. For the most part, we will probably stick with the Parallax reference drivers for graphics and NTSC generation since in this chapter we are more interested in discussing concepts that relate to simple point, line, and geometrical graphics rather than high performance concepts. Also, we need to cover a bit of math to find robust ways to describe motion and so forth. Lastly, this is not a “graphics theory” book, and thus, we are not going to derive and implement line drawing algorithms, flood fills, texture mappers, etc. as that is beyond the scope of this book, but I will point you in the right direction if you’re interested when the subjects come up. Rather, we are going to use API functions that either myself or Parallax has written, so we can simply concentrate on getting things on the screen, moving them around, and building our arsenal of game programming techniques. With that in mind, here’s what’s in store this chapter:

- ▶ Coordinate systems
- ▶ Plotting pixels
- ▶ Drawing lines
- ▶ Polygons
- ▶ Erase-Move-Draw
- ▶ Double buffering
- ▶ Page flipping
- ▶ Translation and coordinate frames
- ▶ Simple motion techniques
- ▶ Color animation

### 18.1 2D Coordinate systems

In computer graphics and rendering there are countless “coordinate systems” used to transform graphics problems into a more relevant format. There are systems that you have heard about such as **Cartesian**, **Polar**, and **Cylindrical** and those more exotic used in games such as **Hexagonal**, **Isometric**, and others. However, for our purposes we are sticking to basic 2D graphics, so we can get away with Cartesian and Polar coordinates for now. Let’s briefly review these systems since both the Parallax graphics drivers as well as the ones provided in this book use these systems more or less.

### 18.1.1 Cartesian Coordinates

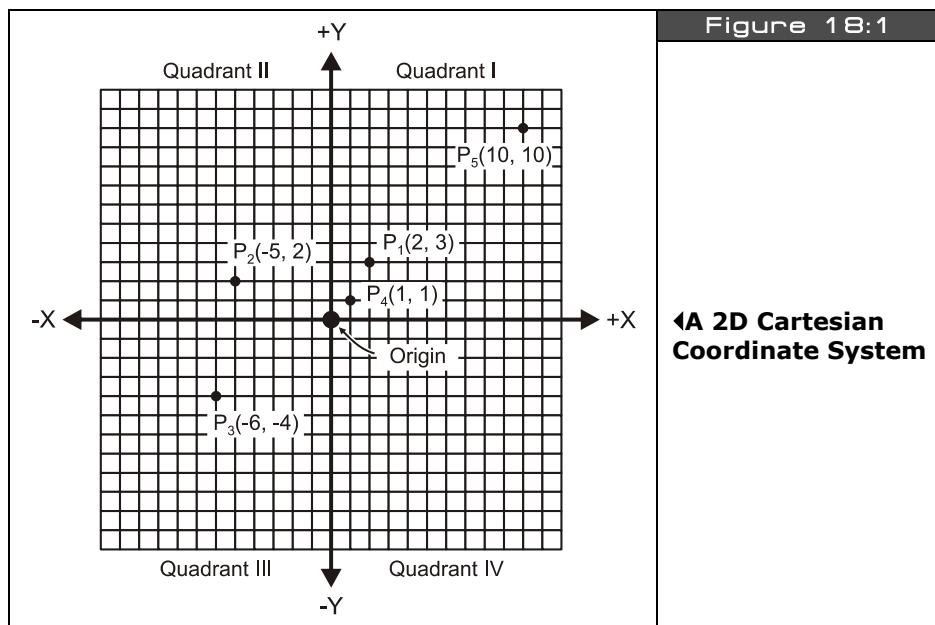


Figure 18:1

◀ A 2D Cartesian Coordinate System

Referring to Figure 18:1, this is the standard Cartesian coordinate system you have seen a million times in school and have probably drawn many graphs on. The 2D version has two axes – the X-axis (also known as the **abscissa**) which is horizontal as well as the Y-axis (also known as the **ordinate**) which is vertical. There are four quadrants labeled counter-clockwise. The top right is Quadrant I, top left is Quadrant II, bottom left is Quadrant III, and finally the bottom right is Quadrant IV. If you are graphing all positive values then you would typically use only Quadrant I.

To locate a point on the coordinate system, an ordered pair  $(x,y)$  is used. For example, refer to Figure 18:1. There are a number of points labeled. The coordinate  $(0,0)$  has special meaning and is referred to as the "**origin**." Other points are all generic, for example in the figure I have labeled  $P_1$  as  $(2,3)$ ,  $P_2$  as  $(-5, 2)$ , and so on. The naming of coordinates allows us to refer to them by symbol rather than the actual coordinates. For example, once again referring to the figure, if I were to refer to  $P_4$ , you know that means coordinates  $(1,1)$ . Additionally, when writing coordinates it's customary to write them with their label and then the coordinates in parenthesis; for example  $P_5(10,10)$ .

That's about all there is to Cartesian coordinates. But, there are some very important differences when using them for computer graphics. First, computer screens are **integer matrices**, meaning there is a finite number of pixels horizontally and vertically. This is commonly referred to as **resolution**. For example, on an NTSC screen some common games systems use  $256 \times 192$ ,  $224 \times 192$ ,  $160 \times 192$ ; however, on a computer monitor the resolutions are much higher such as  $800 \times 600$ ,  $1024 \times 768$  and even up to  $2400 \times 2400$  on high-end graphics workstations.

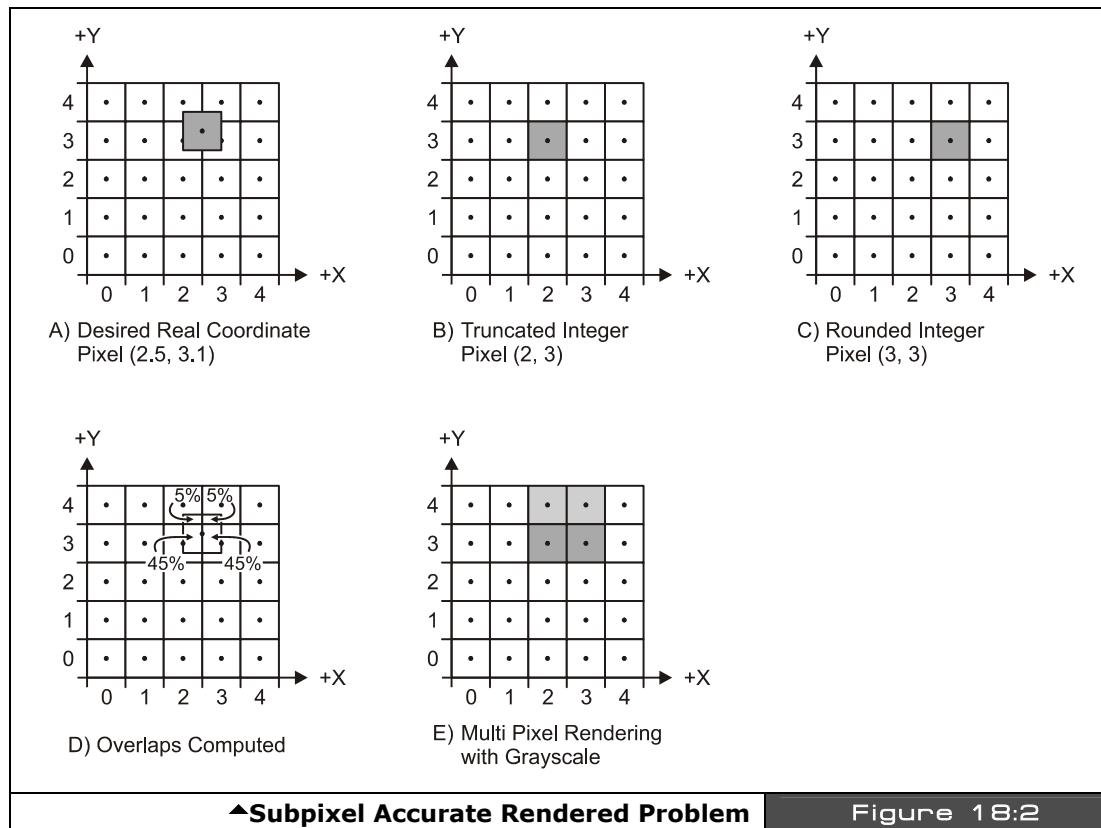


Figure 18:2

Coming back to the comment about integer matrices – what this means is that you can only plot pixels at integer valued (x,y) coordinates, there are no decimal coordinates like there are in a real Cartesian coordinate system. The computer can't plot a pixel between two pixels on the NTSC/VGA screen, that's just a fact of the physical limitations of the screen. Thus when rendering, there are many techniques that have been developed to "synthesize" the effects

of fractional coordinates. For example, if your graphics engine outputs (2.5, 3.1) there is no coordinate here on the screen, so you have to make a decision what pixel(s) to plot. Referring to Figure 18:2(A), we see the mathematically desired pixel location, and the reality of the integer computer screen we must plot on. Notice that the integer coordinates are now the “centers” of each rectangular grid element (dots indicate dead centers). An easy way out is to simply truncate all coordinates when they get to the rendering engine; using this technique we have:

$$\text{trunc}(2.5, 3.1) = (2, 3)$$

...and we can simply plot this which is shown in Figure 18:2(B). This is a bad idea since you completely throw away the fractional information. The question is “Is there any way to take advantage of the fractional information, even a little bit?” Yes, we can “round” the coordinates like so:

$$\text{round}(2.5, 3.1) = (3, 3)$$

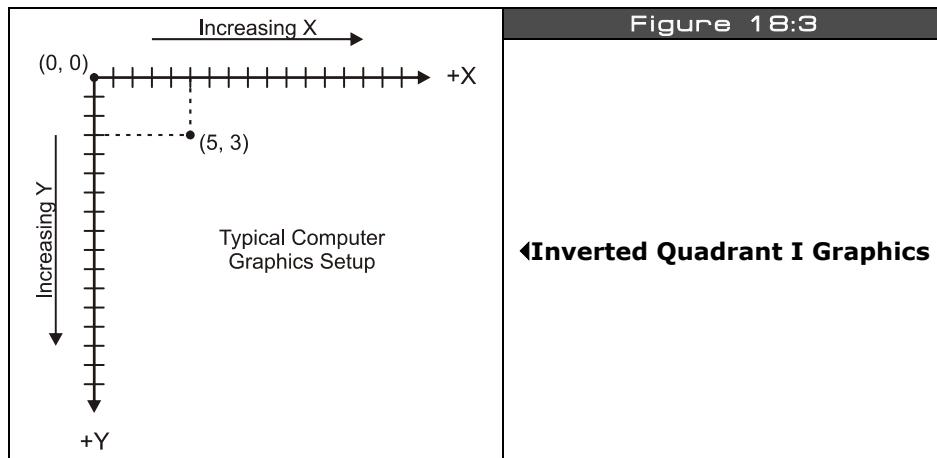
The results of the rounding and plotting are shown in Figure 18:2(C), this is a much better approach and the best you can do when you only want to plot single pixels. However, if you want to work a little harder you can anti-alias the image and plot multiple pixels around the center of the desired pixel which will cost more work, but give a more realistic result. For example, looking at Figure 18:2(A), and doing a little geometry, we see that the mathematically correct pixel overlaps 4 pixels with the following coordinates and percentages, shown in Figure 18:2(D):

|                                |
|--------------------------------|
| Overlap Region 1 – (2,4) = 5%  |
| Overlap Region 2 – (3,4) = 5%  |
| Overlap Region 3 – (3,3) = 45% |
| Overlap Region 4 – (2,3) = 45% |

So taking this into consideration, we can distribute the fractionally located pixel onto multiple integer coordinate locations by plotting 4 pixels each with an intensity equal to the percentage of overlap into the neighboring integer coordinates. This technique costs a lot more computation obviously, and tends to average or blur an image, but gives better results depending on what you are doing. The final results are rendered in Figure 18:2(E) to show you the effect in gray scale. Typically, games are more concerned with speed rather than correctness, so if you can get away with truncation or rounding then do so.

The next detail we need to discuss are the inversion of the Y-axis on 99% of all graphics workstations and APIs. The Cartesian coordinate system has positive X moving to the right, and positive Y moving upward. However, on most graphics systems and APIs, game programmers usually use an inverted Quadrant I of the Cartesian coordinate system and map it to the screen, this is shown in Figure 18:3. In this system the origin is at the **top-left** hand corner of the screen with positive X moving right, and positive Y moving down. The reasons

for this inversion compared to Cartesian coordinates comes from the fact that early computers graphics drivers had very little computation time to work with, thus instead of rendering a nice Cartesian system, they inverted the Y axis to save time since memory was scanned out top to bottom to facilitate feeding the rasterizer. So positive Y ended up going downward. Alas, most graphics systems work with (0,0) as the top-left with positive X to the right and positive Y going down.

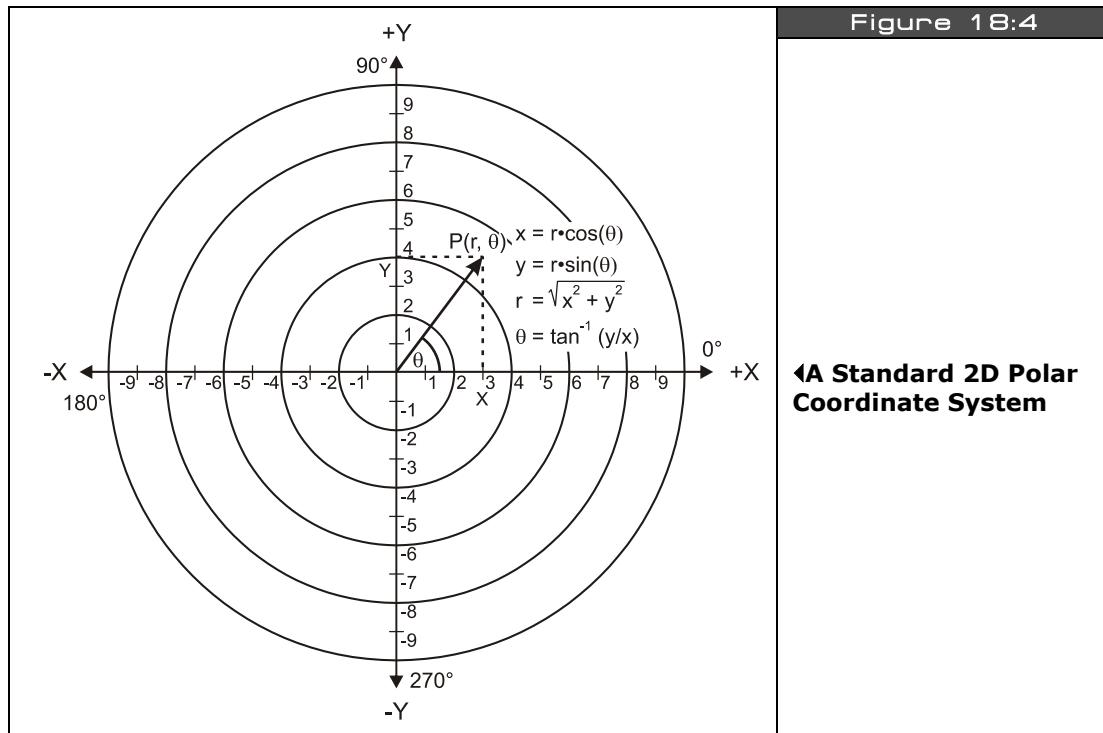


However, on modern computers and APIs, you have enough time to invert coordinates, so you can map the screen anyway you like; nonetheless, 2D game programmers still like the old way with (0,0) at the top. Please note that the Parallax graphics driver we are going to use in this chapter uses a standard Cartesian Quadrant I approach, but later when we see my drivers and the other demos know they all use normal (0,0) top left format.

Alright, so Cartesian coordinates are what most people are used to, you simply give an (x,y) coordinate and locate it on the screen or graph paper, but many times certain operations lend themselves to different types of representations. Once such representation is called Polar coordinates; let's take a look at that since the Parallax driver makes heavy use of Polar coordinates for polygon definition and other functions.

### 18.1.2 Polar Coordinates

Polar coordinates are useful to represent geometries with circular or radial symmetry as well as motions that are circular. Figure 18:4 shows the standard 2D Polar system overlaid on a 2D Cartesian system. Points in Polar coordinates are represented by a distance or length term referred to  $r$  (measured from the origin) and an angle  $\theta$  (theta), (measured from the positive X-axis) in the format  $P(r, \theta)$ .



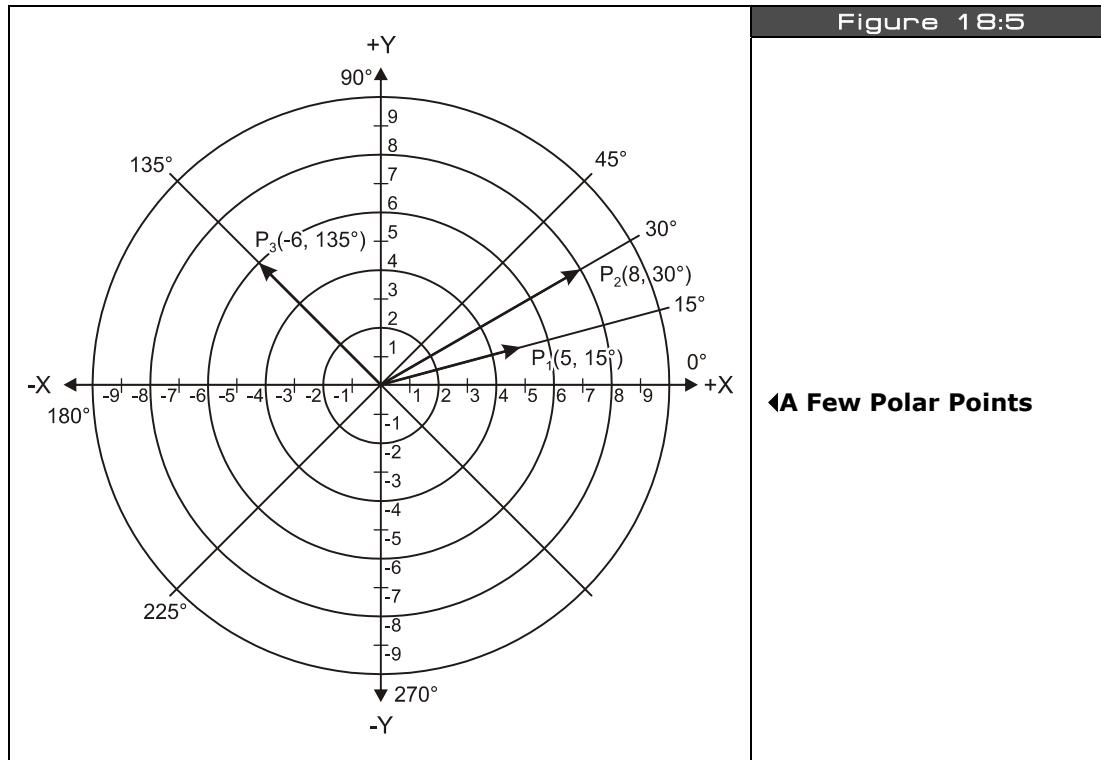
In Figure 18:5 we see a number of Polar points plotted with various distance  $r$ 's and  $\theta$  angles. The reason this type of coordinate system is useful for example is rotation. If I asked you to write me the equations for rotation in a 2D plane you might have a little trouble remembering them; but here's a hint:

$$\begin{aligned}x' &= x * \cos(\theta) - y * \sin(\theta) \\y' &= x * \sin(\theta) + y * \cos(\theta)\end{aligned}$$

For example, if we wanted to rotate the point (1,0) in Cartesian coordinates 90 degrees counter-clockwise, applying the formulas, we better get (0,1) – let's see:

$$\begin{aligned}x' &= 1 * \cos(90) - 0 * \sin(90) = 0 \\y' &= 1 * \sin(90) + 0 * \cos(90) = 1\end{aligned}$$

...which is correct. But, surely not at all obvious, the derivation is about a page long.

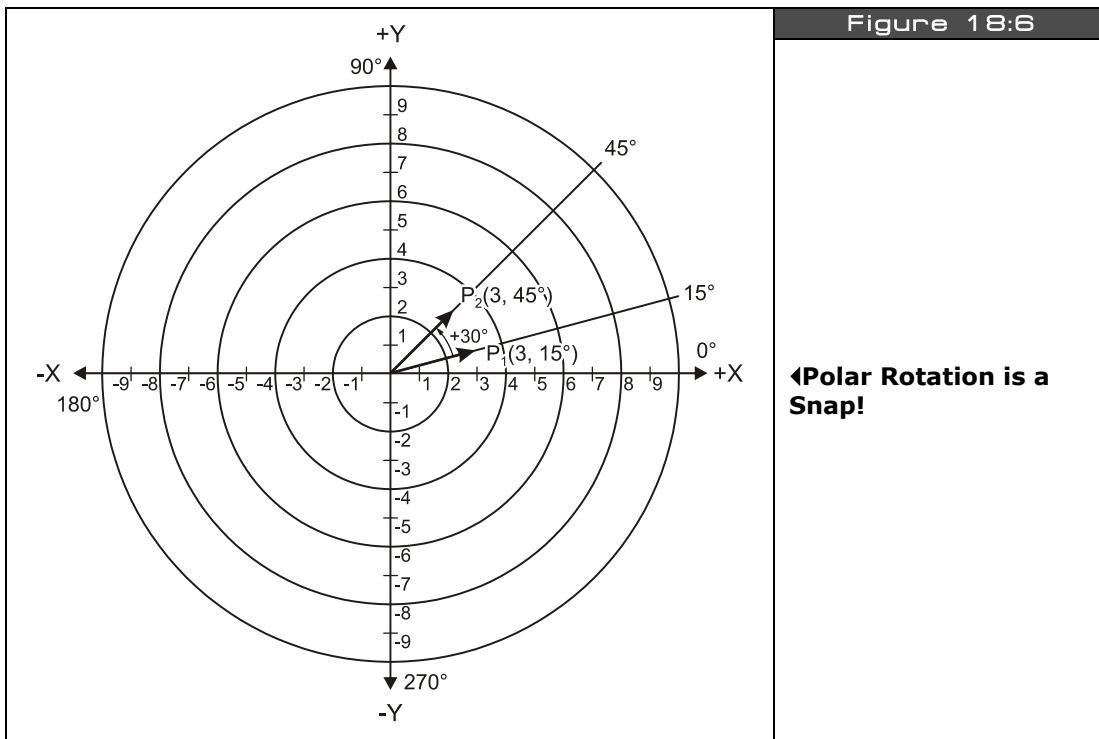


But, in Polar coordinates, look how easy it is to rotate a point. Referring to Figure 18:6 on the next page, if we want to rotate point  $P_1$  by 30 degrees counter-clockwise, well we just add 30 degrees to the Polar coordinate and we are done, thus:

$$P_1(3, 15) \rightarrow \text{rotated 30 degrees} \rightarrow P_1'(3, 15+30) = P_1'(3, 45)$$

That's what's cool about Polar coordinates. Now, the only problem is that rotation is great, but it's not for free, you must transform your Cartesian coordinates to Polar, perform the

rotation and then transform **back**. Also, computer screens do not operate on Polar coordinates, so they are purely mathematical in nature and a tool used to simplify certain operations such as rotation as shown. In any case, now let's look at the transformation equations that convert Polar to Cartesian and vice versa. Referring back to page 466, Figure 18:4 has some extra labeling on it showing the Cos and Sin terms in relation to the angle as well as the computation of r. The formulas are given below.



### Polar to Cartesian

Given a point in Polar coordinates  $P(r, \theta)$  the Cartesian coordinates:

$$x = r \cos(\theta)$$

$$y = r \sin(\theta)$$

As you can see the Cartesian to Polar conversion is pretty complex as far as computer cycles go, so this is one you want to do offline or pre-compute.

### Cartesian to Polar

$$r = \sqrt{x^2 + y^2}$$

$$\theta = \tan^{-1}(y/x)$$

## 18.2 Drawing Primitives

At this point, we are going to experiment with some of the drawing "**primitives**" that are commonly used in computer graphics: point, lines, and polygons. We could draw them manually by manipulating video memory, but instead we will rely on the reference graphics driver from Parallax. Additionally, I have created a couple templates that you can use to get a demo up and running quickly. The first template is called **graphics\_template\_010.spin**; it sets up a  $256 \times 192$ , 4-color graphics mode with only a single graphics buffer which is directly mapped to the screen, that is, if you plot a point or draw a line, you will immediately see it. The code for the template is shown below (slightly abridged for space):

```

CON
    _clkmode = xtal2 + pll4x          : enable external clock and pll times 4
    _xinfreq = 10_000_000 + 3000      : set frequency to 10 MHZ plus some error
    _stack = ($3000 + $3000 + 64) >> 2 : accomodate display memory and stack

    ' graphics driver and screen constants
PARAMCOUNT      = 14
OFFSCREEN_BUFFER = $2000           : offscreen buffer, unused in this template
ONSCREEN_BUFFER = $5000            : onscreen buffer

    ' size of graphics tile map
X_TILES          = 16
Y_TILES          = 12

SCREEN_WIDTH     = 256
SCREEN_HEIGHT    = 192

    ' color constant's to make setting colors for parallax graphics setup easier
COL_Black        = %0000_0010
COL_DarkGrey     = %0000_0011
COL_Grey         = %0000_0100
COL_LightGrey    = %0000_0101
COL_BrightGrey   = %0000_0110
COL_White         = %0000_0111

COL_PowerBlue   = %0000_1_100
COL_Blue         = %0001_1_100
COL_SkyBlue      = %0010_1_100
COL_AquaMarine   = %0011_1_100
COL_LightGreen   = %0100_1_100
COL_Green         = %0101_1_100
COL_GreenYellow  = %0110_1_100
COL_Yellow        = %0111_1_100
COL_Gold          = %1000_1_100
COL_Orange        = %1001_1_100

```

```

COL_Red      = %1010_1_100
COL_VioletRed = %1011_1_100
COL_Pink     = %1100_1_100
COL_Magenta  = %1101_1_100
COL_Violet   = %1110_1_100
COL_Purple   = %1111_1_100

' each palette entry is a LONG arranged like so: color3|color2|color1|color 0
COLOR_0 = (COL_Black << 0)
COLOR_1 = (COL_Red    << 8)
COLOR_2 = (COL_Green  << 16)
COLOR_3 = (COL_Blue   << 24)

' VARIABLES SECTION /////////////////////////////////
VAR
  long tv_status      '0/1/2 = off/visible/invisible           read-only
  long tv_enable       '0/? = off/on                                write-only
  long tv_pins         '%ppmmm = pins                           write-only
  long tv_mode         '%ccinp = chroma,interlace,ntsc/pal,swap write-only
  long tv_screen        pointer to screen (words)                  write-only
  long tv_colors        pointer to colors (longs)                 write-only
  long tv_hc            'horizontal cells                      write-only
  long tv_vc            'vertical cells                       write-only
  long tv_hx            'horizontal cell expansion             write-only
  long tv_vx            'vertical cell expansion              write-only
  long tv_ho            'horizontal offset                   write-only
  long tv_vo            'vertical offset                     write-only
  long tv_broadcast     'broadcast frequency (Hz)                write-only
  long tv_auralcog     'aural fm cog                         write-only

  word  screen[X_TILES * Y_TILES]  ' storage for screen tile map
  long colors[64]          ' color look up table

' OBJECT DECLARATION SECTION ///////////////////////////////
OBJ
  tv   : "tv_drv_010.spin"      ' instantiate a tv object
  gr   : "graphics_drv_010.spin" ' instantiate a graphics object

' PUBLIC FUNCTIONS /////////////////////////////////
PUB start | i, dx, dy, x, y

  'start tv
  longmove(@tv_status, @tvparams, paramcount)
  tv_screen := @screen
  tv_colors := @colors
  tv.start(@tv_status)

  'init colors, each tile has same 4 colors

```

```

repeat i from 0 to 64
  colors[i] := COLOR_3 | COLOR_2 | COLOR_1 | COLOR_0

'init tile screen
repeat dx from 0 to tv_hc - 1
  repeat dy from 0 to tv_vc - 1
    screen[dy * tv_hc + dx] := onscreen_buffer >> 6+dy+dx*tv_vc+((dy&$3F)<<10)

{ start and setup graphics 256x192, with origin (0,0) at bottom left of screen,
simulating quadrant I of a cartesian coordinate system. notice that the setup call
uses the PRIMARY onscreen video buffer, so all graphics will show immediately on
the screen, this is convenient for simple demos where we don't need animation }

gr.start
gr.setup(X_TILES, Y_TILES, 0, 0, onscreen_buffer)

' BEGIN GAME LOOP //////////////////////////////// //////////////////////////////// ////////////////////////////////

' infinite loop
repeat while TRUE

  ' RENDERING SECTION (render to offscreen buffer always////////////////////)

  ' set pen attributes, first parm color, second parm size
  gr.colorwidth(3,0)

  ' render graphics directly to screen here, replace Plot with all your calls...
  gr.plot(0,0)

  ' END RENDERING SECTION //////////////////////////////// //////////////////////////////// ////////////////////////////////

  ' END MAIN GAME LOOP REPEAT BLOCK //////////////////////////////// //////////////////////////////// ////////////////////////////////

' DATA SECTION //////////////////////////////// //////////////////////////////// //////////////////////////////// ////////////////////////////////
DAT
' TV PARAMETERS FOR DRIVER //////////////////////////////// //////////////////////////////// ////////////////////////////////
tvparams      long   0           'status
              long   1           'enable
              long %011_0000     'pins
              long %0000          'mode
              long   0           'screen
              long   0           'colors
              long   x_tiles      'hc
              long   y_tiles      'vc
              long   10          'hx timing stretch
              long   1           'vx
              long   0           'ho
              long   0           'vo

```

```
long    55_250_000      'broadcast on channel 2 VHF
long    0                'auralcog
```

In the main loop, you will see a single call to “plot” and you would simply replace this with your code. But, there is no erasing of the previous image and or off-screen buffering, so whatever is written to the on-screen buffer will immediately show up there. We will use this template as a starting point for anything we want to simply graph or draw that doesn’t need animation. If we do need animation, that is, objects to move around and not leave a trail, we need some of the techniques detailed in the next section to “double-buffer” or “page flip” the off-screen buffer and on-screen buffer. There is another template just for this purpose, its name is **graphics\_template\_020.spin**. Its nearly the same as the single-buffered version except the main even loop looks like this:

```
' infinite loop
repeat while TRUE

' clear the offscreen buffer
gr.clear

' RENDERING SECTION (render to offscreen buffer always///////////
' set pen attributes, first parm color, second parm size
gr.colorwidth(3,0)

' render graphics to offscreen buffer for "presentation" by copy() function
gr.plot(0,0)

' copy bitmap to display offscreen -> onscreen
gr.copy(onscreen_buffer)
```

As you can see, the loop begins by clearing the **off-screen buffer**, then rendering, then copying it to the viewable **on-screen buffer**. This is one of the basic techniques of animation called double-buffering which we will discuss in more detail in the next section; for now we just need these templates to experiment. As usual, the complete source for them can be found in this directory:

**CD\_ROOT:\HYDRA\SOURCES\**

### 18.2.1 Plotting pixels

Plotting pixels isn’t the most interesting thing you can do, but it’s the start of everything. Pixels are great for bullets, particles, debris and so forth, so don’t discount them! You have seen pixel plotting a couple of times, but for fun let’s use pixel plotting to graph some functions. The idea is that we will have two nested loops that iterate over the entire screen. Then we will take each x,y Cartesian pair and plug them into a function  $z = f(x,y)$  that we

want to plot. The results can be very interesting. For example, you can plot transcendents or fractals or whatever you like. Then for x,y you use some rules to derive the color from z. Figure 18:7 shows a screen shot of a demo program that plots the function:

$$z = f(x * (x \text{ XOR } y) * y)$$

Of course, you have to scale the results properly, so the color is an integer from 0..3 (since there are only 4 colors possible). But, it's a lot of fun. The demo program is called **function\_plot\_demo\_010.spin** and is located in the **CD\_ROOT:\HYDRA\SOURCE** directory as usual. The main loop code that does the rendering is shown below:

```
' render graphics directly to screen, replace this with your code
repeat y from 0 to 191
    repeat x from 0 to 255
        ' make this any functions of x and y you like
        ' simply uncomment the function you want to plot and comment the rest

        ' gets interesting. be patient....
        color := 1*x*3*x ^ 5*y*7*y

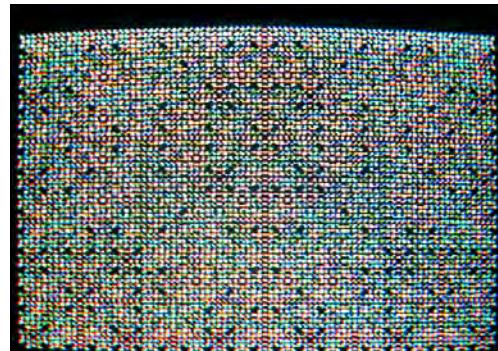
        ' see the flowers?
        color := x*(x^y)*y

        ' reminds me of brain tissue
        color := (x*x) ^ (y*y)

        ' Use this rule when the color is negative -> make positive
        if (color < 0)
            color := -color

        ' use this rule to set the color -> color mod 3
        gr.colorwidth(color // 3,0)

        ' finally plot pixel
        gr.plot(x,y)
```



▲Function  
Plotting Demo

Figure 18:7

Notice there are a couple other functions in there commented out? Give them a try and see what you get!

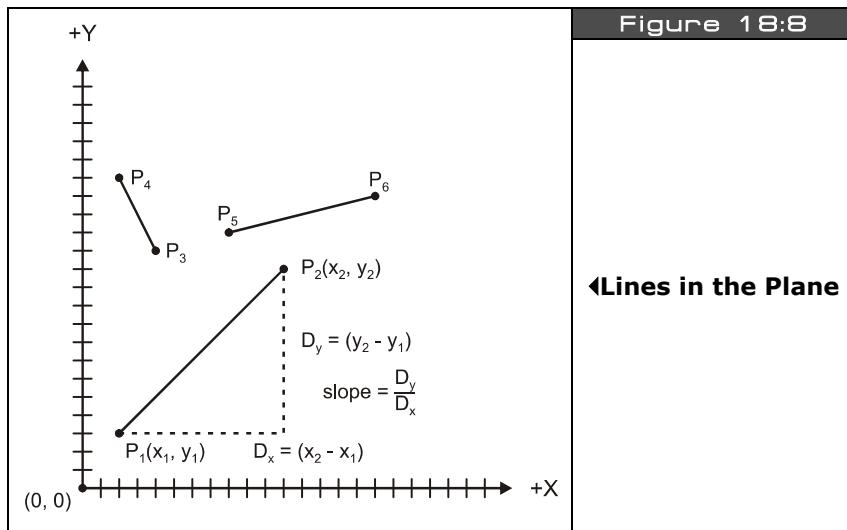
Also, before moving onto lines, note that in Spin the rendering is very slow, you can actually see the pixels being drawn. If we were to code this in ASM, we could probably get it to run at 60 FPS which means that it's possible to algorithmically or **procedurally** create imagery on the fly and use it for backgrounds in games or whatever. The point is that with a single line of code (a function), we have defined every single pixel on the screen! So imagine what some very clever functions could be used for in a game where memory is at a premium – you could simply use functions to generate bitmap data in game. Of course, the imagery will usually be "**mathematical**" looking, but it's better than a black playfield.

**NOTE**

See if you can use the graphing program plus the proper rules and scaling to do some Fractal rendering. Remember, fractals are "self similar" functions; simply put, they are generated by seeding a function then using the output of the function as the input back to the function.

### 18.2.2 Drawing lines

The next important primitive is the **line**. Lines are the basis of wireframe geometry and with them we can create a number of types of graphics displays and games. Now, technically the "lines" in Figure 18:8 are line segments, a line usually extends in both directions for infinity, but in graphics people tend to refer to line segments as lines, so we will adhere to this convention. Anyway, referring to the figure, any particular line is defined by two endpoints  $P_1(x_1, y_1)$  and  $P_2(x_2, y_2)$ .



One of the earliest problems in computer graphics was how to draw lines. This was more or less solved by **Jack Bresenham** in 1965 roughly, while working at IBM. He basically created a line drawing algorithm based on integer calculations and decision variables. I am not going to go into details since we are going to use library API calls to draw lines for us (which actually use Bresenham's algorithm as well). But, I do want to talk about a couple line representations, since this will become important later when we do other types of rendering and collision detection.

First, the "**Y-Intercept**" form for a line is:

$$y = m \cdot x + b$$

...where  $m$  is the "**slope**," (rise over run, or  $dy/dx$ ) and  $b$  is the "**y-intercept**" which is where the line intercepts the Y-axis at  $x=0$ . To plot a line with this form, you need  $(m, b)$ , then you simply plug in values for  $x$  (or  $y$ ) and solve for  $y$ . This form is great in math books and algebra tests, but doesn't help us much in computer graphics. A more practical form of the line is called the "**Point-Slope**" form, shown below:

$$y - y_1 = m \cdot (x - x_1)$$

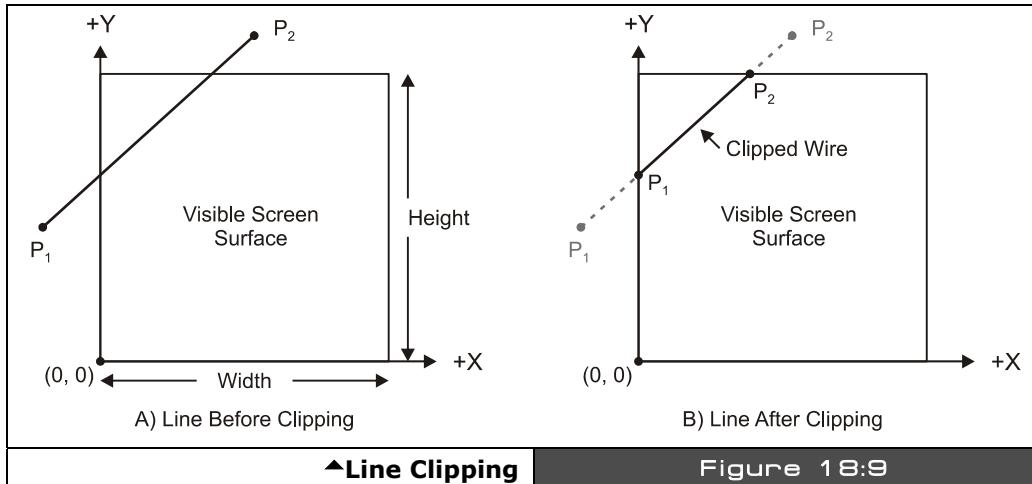
...where,  $m$  is the slope and  $(x_1, y_1)$  is any point on the line (even either end point). This form is much better, since for computer graphics we tend to think of lines as two points, thus we can compute the slope of any line  $P_1(x_1, y_1)$  to  $P_2(x_2, y_2)$  as:

$$m = dy/dx = (y_2 - y_1) / (x_2 - x_1)$$

Plugging back into our point slope form we get:

$$y - y_1 = [ (y_2 - y_1) / (x_2 - x_1) ] * (x - x_1)$$

...and you can re-arrange and solve for either  $x$  or  $y$ . Now, we already have a line drawing API call, so why learn this? Well, understanding lines comes in handy for two main reasons other than drawing them; **clipping** and **collision**. For example, the line drawing function inside of the Parallax graphics driver has **no** clipping. That means if you pass a line that is outside of the visible screen area, it will actually compute all the points on the line, pass them to the plotter which finally clips, thus a lot of work is done for nothing. A better approach would be to clip the lines before passing them to the line drawing API.



▲Line Clipping

Figure 18:9

Figure 18:9 shows a line before and after clipping. As you can see, by clipping the line we can save ourselves a lot of work, if we only draw the clipped line (or pass the clipped line to the line function). Thus, given a line  $P_1(x_1, y_1)$  to  $P_2(x_2, y_2)$ , the idea is to write a function that clips the line to the screen rectangle which in the case of our discussions so far is (0,0) to (255, 191) and outputs a new line  $P_1'(x_1', y_1')$  to  $P_2'(x_2', y_2')$ .

Clipping is a very complex problem, give it a try and you will see why. Thus, there are dozens of well-known algorithms to do it, but at the end of the day they all have to find intersections between lines and that's where the point-slope form of the line comes into play. For example, referring to Figure 18:9(A) before the clipping, we can visually ascertain that the line pierces the left edge of the screen, but the question is "Where?" Well, this is **easy** to compute since we have both endpoints of the line:  $P_1$  and  $P_2$ , thus we can compute the slope which is just:

$$m = dy/dx = (y_2 - y_1) / (x_2 - x_1)$$

Also, since we are clipping against the left edge of the screen, this is really just a line with  $x = 0$ , thus we can plug  $x = 0$  into either line formula and compute the resulting  $y$ .

Using the point slope form and re-arranging a bit get:

$$y = y_1 + m * (0 - x_1)$$

$$y = y_1 - m * x_1$$

Therefore, the clipped endpoint on the left side is  $(0, y_1 - m * x_1)$ . This technique can be used on all 4 sides of the screen ( $x=0, x=255, y=0, y=191$ ), to clip any line against any boundary, and the resulting end points of the line can then be sent out to the rendering function and

you can rest assured that only the visible line will be drawn. Again, lines simply drawn aren't that interesting and we have done this already, so to keep the policy of all demos are game development related, let's use lines to create a screen saver-like display.

What we need to do is start with two endpoints, call them  $P_1$  and  $P_2$ , then each of these points has a translation applied to it each frame (we will formalize this in the last section of this chapter), then we simply move the end points, draw the line and see what happens. Of course, we have to have some rules for when an endpoint hits the screen edge; we will simply bounce the endpoint off and change its direction. Also, we will select color by some simple function. Lastly, as the lines are drawn they are going to quickly fill the screen up, thus we are going to ***follow*** the screen saver with a screen eraser that lags behind some number of lines; maybe 10-20, so you can see this constantly changing pattern.

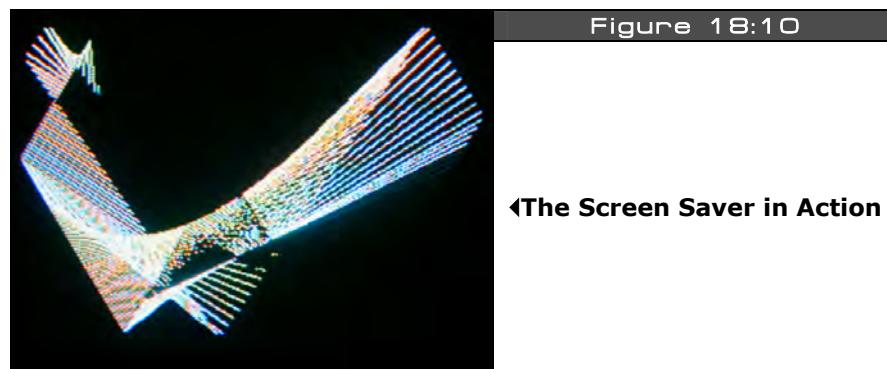


Figure 18:10 shows the screen saver in action. The code for it is in the file **screen\_saver\_010.spin** located on the CD in the usual **CD\_ROOT:\HYDRA\SOURCES\** directory. The code is based on the graphics template **graphics\_template\_010.spin** (the one with only an on-screen video buffer). The main code that performs the screen saver rendering is shown below:

```
' infinite loop
repeat while TRUE

' RENDERING SECTION (render to offscreen buffer always//////////)
' based on function of line state select a color
gr.colorwidth(1+(eraser_count / 20) // 3,0)

' draw the current line
gr.plot(plines[0], plines[1])
gr.line(plines[2], plines[3])
```

```
' move the endpoints
plines[0] += vlines[0]
plines[1] += vlines[1]

plines[2] += vlines[2]
plines[3] += vlines[3]

' test for out of bounds
if (plines[0] > 255)
    vlines[0] := -vlines[0]
    plines[0] += vlines[0]

if (plines[2] > 255)
    vlines[2] := -vlines[2]
    plines[2] += vlines[2]

if (plines[1] > 191)
    vlines[1] := -vlines[1]
    plines[1] += vlines[1]

if (plines[3] > 191)
    vlines[3] := -vlines[3]
    plines[3] += vlines[3]

' should we start erasing?
if (++eraser_count > 100)
    ' begin erase code
    gr.colorwidth(0, 0)
    gr.plot(plines[4], plines[5])
    gr.line(plines[6], plines[7])

    ' move the endpoints
    plines[4] += vlines[4]
    plines[5] += vlines[5]

    plines[6] += vlines[6]
    plines[7] += vlines[7]

    ' test for out of bounds
    if (plines[4] > 255)
        vlines[4] := -vlines[4]
        plines[4] += vlines[4]

    if (plines[6] > 255)
        vlines[6] := -vlines[6]
        plines[6] += vlines[6]
```

```

if (plines[5] > 191)
    vlines[5] := -vlines[5]
    plines[5] += vlines[5]

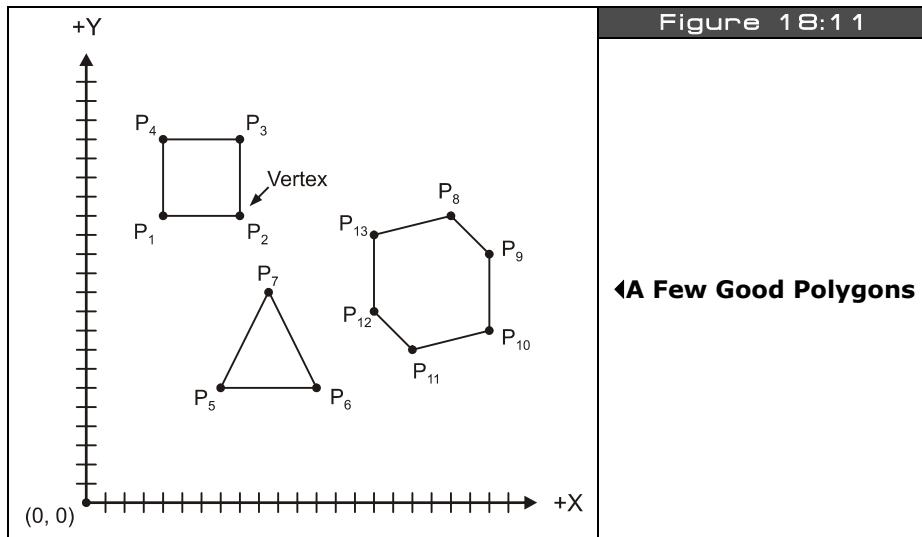
if (plines[7] > 191)
    vlines[7] := -vlines[7]
    plines[7] += vlines[7]
' end erase code

' add a time delay with a little flair
repeat i from 0 to 100 + 3*(eraser_count // 10)

```

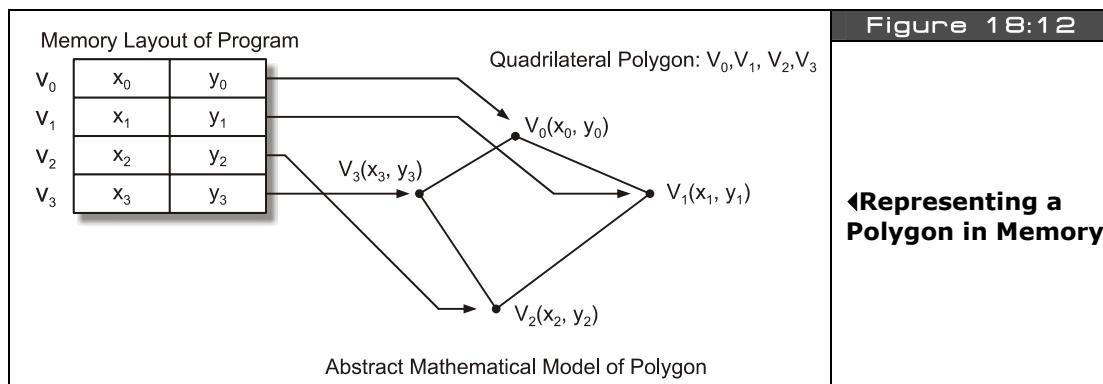
Referring to the code, the line is drawn, the positions updated, collision detection is run, then the code loops. Additionally, refer to the variable eraser\_count in the main loop; when it reaches 100, then it starts and erases the line that follows the screen saver with the exact same starting conditions, thus it erases the lines that were drawn in the past. Try optimizing the code by using loops and a lookup table for the boundary conditions rather than hard coding them (as 191 and 255).

### 18.2.3 Polygons



A **polygon** more or less is a closed shape composed of 3 or more connected line segments in a plane. For example, Figure 18:11 shows a triangle and square, as well as an arbitrary polygon. In computer graphics polygons are the basis for everything you see in a modern 3D

computer game, except that the polygons in games are typically always triangles: they are textured, lit, and there are millions of them. You might ask "Why represent everything as triangles in 3D games?" Well, triangles have a lot of nice properties; like they are always coplanar, also they are easy to render, and easy for hardware to fill, texture, and light. Polygons like quadrilaterals etc. are much harder to work with. Thus, even when 3D modelers draw game objects with tools like 3D Studio MAX, at some point all the complex geometry is turned in triangles. Similarly, pretty much every 3D engine on the planet at some point turns all the objects in the game into a stream of triangles and passes them to the rendering pipeline. So if you can get triangle rendering down then you can make anything, since you can decompose any polygon into a set of triangles.



The first thing we need to do is come up with a way to represent polygons, so we can manipulate them. This is really a data structure decision, but in most cases, a polygon is a collection of 2D points which are referred to as **vertices**, so a simple array will suffice. Thus, we could define a polygon as a list of  $(x,y)$  pairs where each  $(x,y)$  entry defines a single vertex as shown in Figure 18:12. The interesting thing is that we do not define a polygon as a set of lines, but rather as a set of vertices, then to draw the polygon, we draw lines between the vertices starting at vertex 0 and then ending at vertex n, then we "**close**" the polygon by drawing a line from vertex n to vertex 0.

Now, earlier in the chapters on Spin programming and the graphics demos, there were some demos that used the Parallax reference graphics driver's **Vec( )** sub-function to draw a polygon. Basically, the **Vec( )** sub-function of the graphics driver takes a data structure that consists of a set of vectors in polar format; here's the function prototype for reference:

```

PUB vec(x, y, vecscale, vecangle, vecdef_ptr)
  `` Draw a vector sprite
  ``

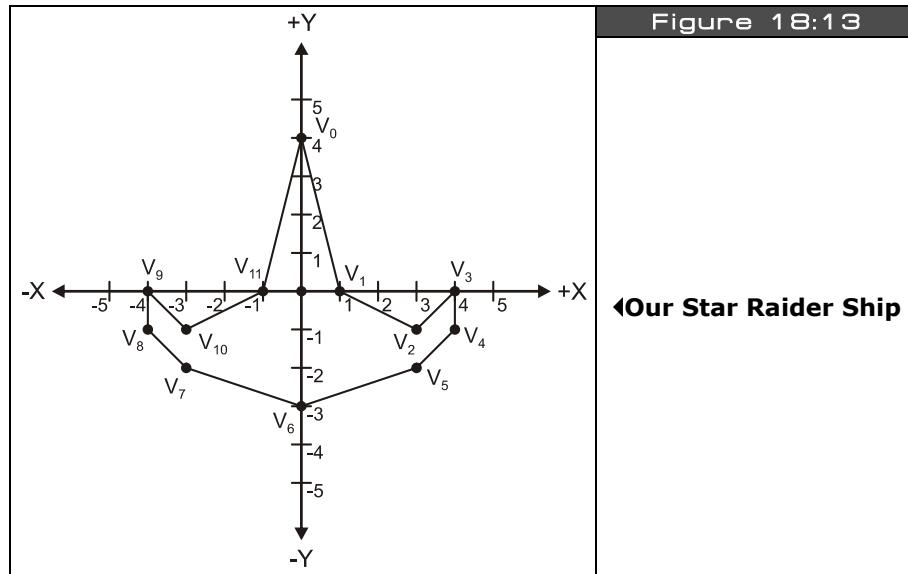
  ``    x,y           - center of vector sprite
  ``    vecscale       - scale of vector sprite ($100 = 1x)
  ``    vecangle       - rotation angle of vector sprite in bits[12..0]
  ``    vecdef_ptr     - address of vector sprite definition
  ``

  `` Vector sprite definition:
  ``

  ``    word $8000|$4000+angle 'vector mode+13-bit angle (mode: $4000=plot,$8000=line)
  ``                                'where angle is a 13 bit value bits[12..0]
  ``                                'mapping (0..$1FFF = 0°..359.956°)
  ``    word    length      'vector length
  ``    ...
  ``    ...
  ``    word    0           'end of definition

```

We have already played with this, so I am not going to review it, but the problem is that it uses polar coordinates to define the vertices of the “sprite” or polygon. This is hugely inconvenient since drawing objects in polar coordinates is very hard since you have to compute the angle and length of every vertex. Alas, we are going to tuck Vec( ) away for a rainy day and for now keep things more abstract, and come up with our own polygon drawing function that uses Cartesian coordinates.



With that in mind, our first attempt might simply be a function that leverages the graphics library's line function and takes an array of vertices along with a color to draw the polygon. Here's a function that does the job:

```
PUB Draw_Polygon(vertex_list_ptr, num_vertices, color) | v_index
' draws the sent polygon, totally unoptimized, no error detection
' vertex_list_ptr = pointer to WORD array of x,y vertex pairs
' num_vertices    = number of vertices in polygon
' color           = color to render in 0..3

' step 1: set color
gr.colorwidth(color, 0)

' notice the pointer casting to byte and the sign extension ~ operator
' step 2: plot starting point
gr.plot(~byte[vertex_list_ptr][0], ~byte[vertex_list_ptr][1])

' step 3: draw remaining polygon edges
repeat v_index from 1 to num_vertices-1
    gr.line(~byte[vertex_list_ptr][2*v_index+0], ~byte[vertex_list_ptr][2*v_index+1])

' step 4: close polygon by drawing back to starting vertex
gr.line(~byte[vertex_list_ptr][0], ~byte[vertex_list_ptr][1])
```

The function takes a pointer to the vertex list, the number of vertices, and the color you want the polygon rendered in. If we wanted to use the function, we simply need a polygon model such as shown in Figure 18:13; there are 12 vertices in the model, and we design it on graph paper with (0,0) at the center of the model. The actual data for the model in Spin looks something like:

```
' Polygon definition for space ship, array of (x,y) pairs,
' each representing a vertex
' 2 bytes per vertex, allows vertices to be -128 to +127
' notice they are scaled by PSCALE
fighter_poly      byte   0*PSCALE,4*PSCALE          ' vertex 0
                   byte   1*PSCALE,0*PSCALE          ' vertex 1
                   byte   3*PSCALE,-1*PSCALE         ' vertex 2
                   byte   4*PSCALE,0*PSCALE          ' vertex 3
                   byte   4*PSCALE,-1*PSCALE         ' vertex 4
                   byte   3*PSCALE,-2*PSCALE         ' vertex 5
                   byte   0*PSCALE,-3*PSCALE         ' vertex 6
                   byte   -3*PSCALE,-2*PSCALE        ' vertex 7
                   byte   -4*PSCALE,-1*PSCALE        ' vertex 8
                   byte   -4*PSCALE,0*PSCALE         ' vertex 9
                   byte   -3*PSCALE,-1*PSCALE        ' vertex 10
                   byte   -1*PSCALE,0*PSCALE         ' vertex 11
```

Note that it's inconvenient to work in large numbers on graph paper, so I designed the model very small and then scale it in the data set via the factor PSCALE (which is set to 10 in the upcoming demo). Now, let's put all this to use: we will start with the template graphics\_template\_010.spin, and add the function and the data. The resulting program is named **draw\_polygon\_010.spin** and can be found in the standard directory **CD\_ROOT:\HYDRA\SOURCES\**. Load and run the program on the HYDRA and see what you get!

If you see part of a line and a dot then the program worked right, but what happened? Well, we defined the polygon model at the origin (0,0), and we rendered it there as well, that is, we drew it at (0,0) on the screen which is the bottom left hand corner (when using the Parallax reference driver as we have set it up). So what we need to do is translate the model more toward the center of the screen. This brings us the concept of "**local**" and "**world**" coordinates which we are going to delve into in detail in the next section, but for now, suffice it to say it's a good idea to define your models with a local origin at (0,0), but when you actually draw them you want to be able to add an offset to each (x,y) vertex so you can translate the model anywhere on the screen during rendering. So what we need to do is add some more parameters to the function to support this translation, we will call them (x0, y0). Updating the polygon drawing function we get something like this:

```
PUB Draw_Polygon2(vertex_list_ptr, num_vertices, color, x0, y0) | v_index
' draws the sent polygon, totally unoptimized, no error detection
' vertex_list_ptr = pointer to WORD array of x,y vertex pairs
' num_vertices    = number of vertices in polygon
' color           = color to render in 0..3
' x0, y0          = x,y translation factors

' step 1: set color
gr.colorwidth(color, 0)

' notice the pointer casting to byte and the sign extension ~ operator
' step 2: plot starting point
gr.plot(~byte[vertex_list_ptr][0]+x0, ~byte[vertex_list_ptr][1]+y0)

' step 3: draw remaining polygon edges
repeat v_index from 1 to num_vertices-1
  gr.line(~byte[vertex_list_ptr][2*v_index+0]+x0, ~byte[vertex_list_ptr][2*v_index+1]+y0)

' step 4: close polygon by drawing back to starting vertex
gr.line(~byte[vertex_list_ptr][0]+x0, ~byte[vertex_list_ptr][1]+y0)
```

The only difference is that we pass translation factors x0,y0 to the function and simply offset the polygon rendering by these factors – simple. A demo named **draw\_polygon\_011.spin** shows the new function and adds the ability to move around with the game pad for fun. The demo is located on the CD in **CD\_ROOT:\HYDRA\SOURCES\**.



Both Draw\_Polygon( ) and Draw\_Polygon2( ) are totally unoptimized. See if you can optimize them 10-20x by using pre-computation, shifts, etc. Try making the call to the rendering function 1000-10,000 times and use a stop watch to review your optimizations, that is, run the program with the call 1000 -10,000 times, get a baseline, then make an optimization, and time it again, and so forth.

## 18.3 Screen Update Techniques

We have discussed the concept of screen updating and animation a number of times informally and have in fact been using various techniques thus far ad-hoc. However, now I want to clearly define the various methods of screen updating so you can see what they do and how they are used.

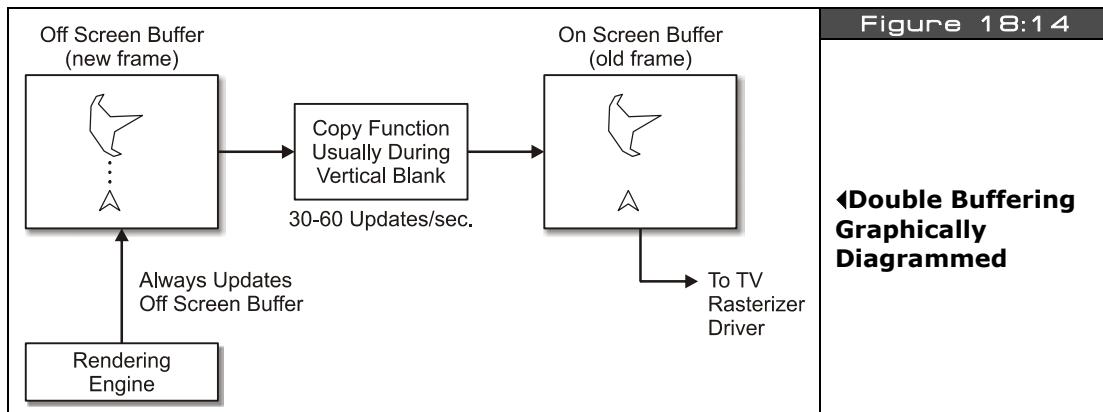
### 18.3.1 Erase-Move-Draw

The first form of animation that was historically used in computer games is simply to erase the old image, move it, draw it, and then loop. Additionally, programmers would put a little time delay in after the drawing portion so the image would seem to be stable. The problem with this method is that as you erase the image, if you take more than a 60<sup>th</sup> of second or so to draw it again, the human brain will pick this up and you will see "flicker" which I am sure everyone has seen once in their life playing a game. To show this, try program **draw\_polygon\_012.spin** located on the **CD in CD\_ROOT:\HYDRA\SOURCES\**. Basically, I took the last demo and removed the off-screen buffer and drew everything in the on-screen primary buffer, notice that you see flicker now – it's horrible! But, there is a way to minimize it a bit by leaving the image on the screen for more time than it's off screen, so let's add a small delay to the end of the main loop, something as simple as:

```
repeat 5000 ' time delay
```

A demo of this version can be found in **draw\_polygon\_013.spin** located on the CD at **CD\_ROOT:\HYDRA\SOURCES\**. Try running the demo and you will see that it looks a lot better, the flicker is still there, but it doesn't look like the ship is phasing in and out of space-time like an episode of **Star Trek**. Of course, a side effect of this is that we have slowed down the main loop and wasted thousands of compute cycles simply to make sure the image persists on our retinas a little better. Nonetheless, this simple technique is useful for quick-and-dirty graphics and/or when you have a very slow graphics system and erasing the entire screen or having off-screen buffers is out of the question. In conclusion, if you want to use the simple erase-move-draw technique in your game to perform animation, you simply erase all the objects in the game at the top of the loop, then move them, then draw them and optionally put a delay in there to keep them on the screen longer.

### 18.3.2 Double Buffering



The Parallax reference driver (as well as many graphics APIs used commonly for games) uses the technique of **double buffering** to perform flicker free animation. Double buffering is a surprisingly simple technique where you have two video buffers; one is being accessed by the video driver and rendered on the screen while the other is simply memory that has the same shape and size. So the trick is to draw all your objects on the off-screen buffer, so the user can't see the manipulation, then in a single instant **copy** the off-screen buffer to the on-screen buffer, this is shown graphically in Figure 18:14. Therefore, you could take an hour drawing the image in the off-screen buffer, but the user would see it instantly appear on the screen when it was finally rendered. Of course, there is a concern about the copy function and how fast it is. For example, if the copy function is really slow then the user will see the old image replaced by the new one. But, the idea is to copy the off-screen buffer to the on-screen buffer at a time when the raster is retracing, such as the vertical blank, that way the user never sees any glitches and the image is rock solid.

Using the Parallax reference graphics driver, double buffering is a snap, you simply start the graphics driver up with a pointer to a chunk of memory you want to refer to as the off-screen buffer and then all calls to the graphics functions will render into that buffer. The size of the buffer can be calculated as follows:

#### 1-bit color depth (2 colors)

screen RAM needed for buffer = SCREEN\_WIDTH \* SCREEN\_HEIGHT / 8

#### 2-bit color depth (4 colors)

screen RAM needed for buffer = SCREEN\_WIDTH \* SCREEN\_HEIGHT / 4



The term “*color depth*” simply means how many bits per pixel. The terms “*on-screen buffer*” and “*off-screen buffer*” are also known as “*primary buffer*” and “*back buffer*” or “*secondary buffer*.” I may use these more contemporary terms from time to time.

As you can see, the formula is very straightforward and makes sense. For example, in the last few demos we have been using a  $256 \times 192$  screen resolution at 4 colors, and plugging this into the memory formula we get:

$$256 * 192 / 4 = 12288 \text{ or } \$3000 \text{ hex}$$

This is why you see the lines of code at the top of each program:

```
_stack = ($3000 + $3000 + 64) >> 2      ' accomodate display memory and stack

' graphics driver and screen constants
OFFSCREEN_BUFFER = $2000                  ' offscreen buffer
ONSCREEN_BUFFER = $5000                    ' onscreen buffer
```

They manually set the location of the buffers and let the stack directive know where we have placed them, so the compiler can indicate an overflow if the code encroaches on them. The entire double-buffering rendering loop we have been using looks like:

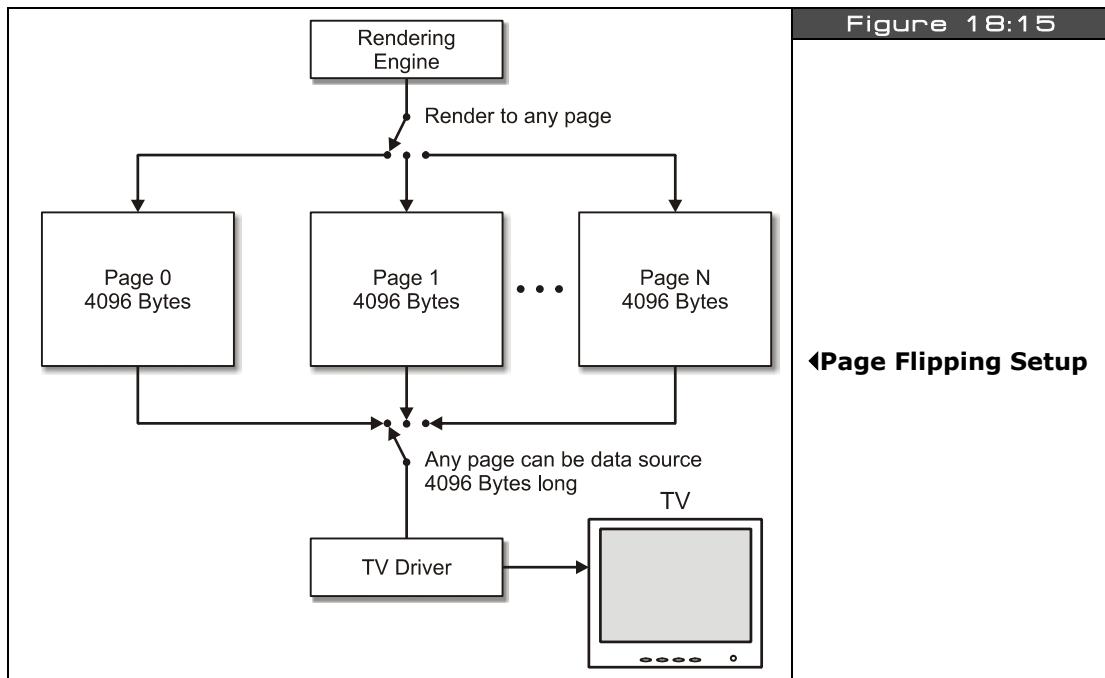
```
' initialize graphics driver with offscreen buffer
gr.start
gr.setup(X_TILES, Y_TILES, 0, 0, offscreen_buffer)

repeat
    ' clear the offscreen buffer
    gr.clear

    ' render graphics here...
    'copy bitmap to display offscreen -> onscreen
    gr.copy(onscreen_buffer)
```

...and that's it! First, the offscreen buffer is cleared off, so we can render on a clean slate, then we draw all the graphics we want on it, and finally copy the off-screen buffer to the on-screen buffer. Of course, at the end of the loop you might want to add a counter that locks the frame rate to 30-60 FPS and no higher, so the animation stays consistent as the game changes.

### 18.3.3 Page Flipping



**Page flipping** is similar to double buffering, but not exactly the same. With page flipping there is no **copy** operation from the off-screen buffer to the on-screen buffer, rather the TV rasterization engine/driver is redirected to read from another region of memory, i.e. another **page** – hence the term page flipping. To implement page flipping you have to design it into the rasterizing driver to support reading any region of memory as the video buffer. For example, if your TV driver could only use the memory from \$2000 - \$3000 as video RAM and video RAM was always \$1000 (4096 bytes) in size then you can't page flip. Thus, as shown in Figure 18:15, you need the ability to re-vector or re-point the video RAM pointer from the video driver's point of view.

The Parallax reference TV driver doesn't support page flipping by design, but it does if you want to cheat a bit. If you look at all our graphics demos thus far, during setup you will see a snippet of code that looks like this:

```
'init tile screen
repeat dx from 0 to tv_hc - 1
    repeat dy from 0 to tv_vc - 1
        screen[dy*tv_hc+dx] := onscreen_buffer >> 6+dy+dx*tv_vc+((dy & $3F) << 10)
```

This little magical snippet sets up the screen tile pointer array if you recall. This array is more or less a tile map where each tile has a pointer to a bitmap region, if the bitmaps are assigned in a way such that they are linear and organized then the graphics driver can render into them as if they were a contiguous large bitmap. The point is that, see that variable "**onscreen\_buffer**"? All we need to do is change this to the starting address on any memory region that is large enough for the tile map, such as another page of memory, and once the loops run we will have performed a page flip. In a roundabout way albeit since we are going to do it a tile at a time, but still it's a page flip. If we time this during the vertical blank, then chances are we wouldn't see anything as well, and it would be perfect.

So to test this out, let's write a program that draws an image on one page and a different image on another page, then with the game pad, pressing a button(s) will change the current page simply by calling this looping code with the other page. First, we need an image for each page, so how about on one page we draw a kaleidoscope image by plotting random pixels and colors on the screen and then mirroring it vertically. On the second page, I will render a set of 3D spheres, this way there is no mistake that each page is different.

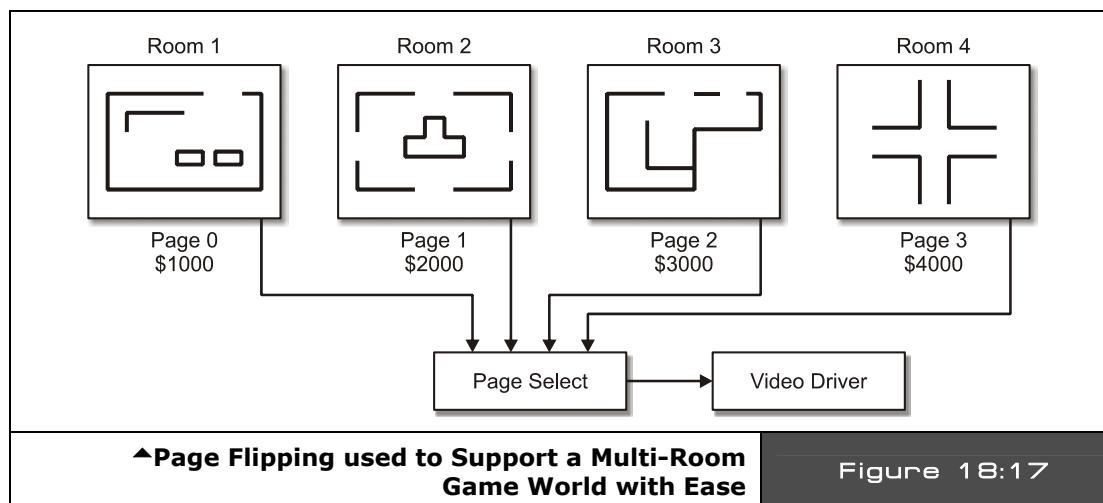


The page flipping demo is called **page\_flip\_demo\_010.spin** and is located on the CD in **CD\_ROOT:\HYDRA\SOURCES\**. Simply load and run the demo with the game pad plugged into the left port, and wait for it to finish drawing, you should see something like that shown in Figure 18:16. When it's done, press the right or left game pad arrow and instantly the page will flip between the two video images. As you can see this is a very cool technique because the **copy** step needed in a double-buffered scheme is no longer needed (which makes graphics faster). All that's needed to support page flipping in a rendering engine that allows you to pass a pointer to the region of memory you want rendered. The Parallax reference driver doesn't support this directly, but we hacked it to make it work by altering the screen pointers on the fly. Later in the book when we start using more advanced tile engines with sprites they **will** support.

Page flipping is a more efficient method of performing screen updates since you save the copy operation; moreover, if you have a tile-based system, you can even save the rendering time and simply prepare each screen of the game as a page and then as the user moves around the game world from room to room, you simply switch pages without any copying or other work, this is shown in Figure 18:17 abstractly. The function that performs the actual page flip from the demo looks like this:

```
PUB Set_Video_Page(page_address) | dx, dy
  ' init tile screen with sent page address
  repeat dx from 0 to tv_hc - 1
    repeat dy from 0 to tv_vc - 1
      screen[dy*tv_hc+dx] := page_address >> 6+dy+dx*tv_vc+((dy & $3F) << 10)
```

More or less it's just the screen setup loop embedded in a function with a variable parameter for the starting address of the page.



## 18.4 Coordinate Frames and Basic Animation

In this last section, we are going to formally talk about some more mathematical concepts relating to coordinate systems along with some animation tricks. So, first let's review the ideas behind local, world, and screen coordinates and see why they are needed and desired in game programming.

### 18.4.1 Local, World, and Screen Coordinates

The first step in designing a polygon model 2D or 3D is to create the model itself. As in our previous example I did this on simple graph paper, but a tool could have been used as well. The technique is simply to start with a 2D (or 3D) Cartesian coordinate system and draw the model out, then locate the vertices and make a vertex list. All the vertices in the vertex list are **relative** to the origin of the object/model at (0,0). These coordinates are called **local coordinates** because they refer to the model's own "local" coordinate system at (0,0), the coordinates are abstract and not useful until we further process them. Figure 18:18 shows a fighter defined in local coordinates.

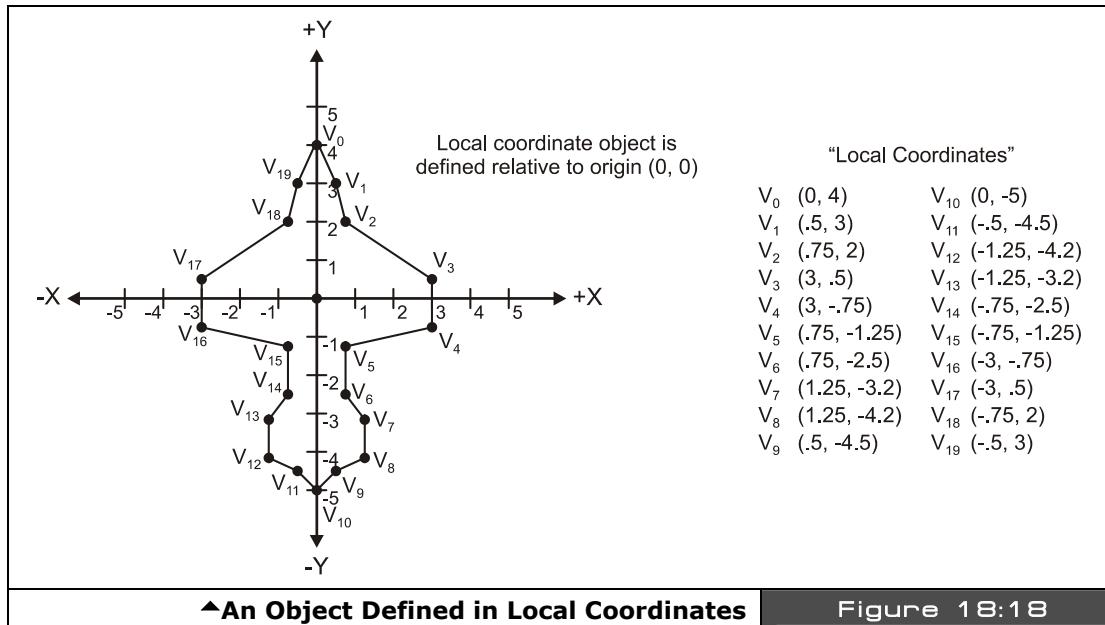
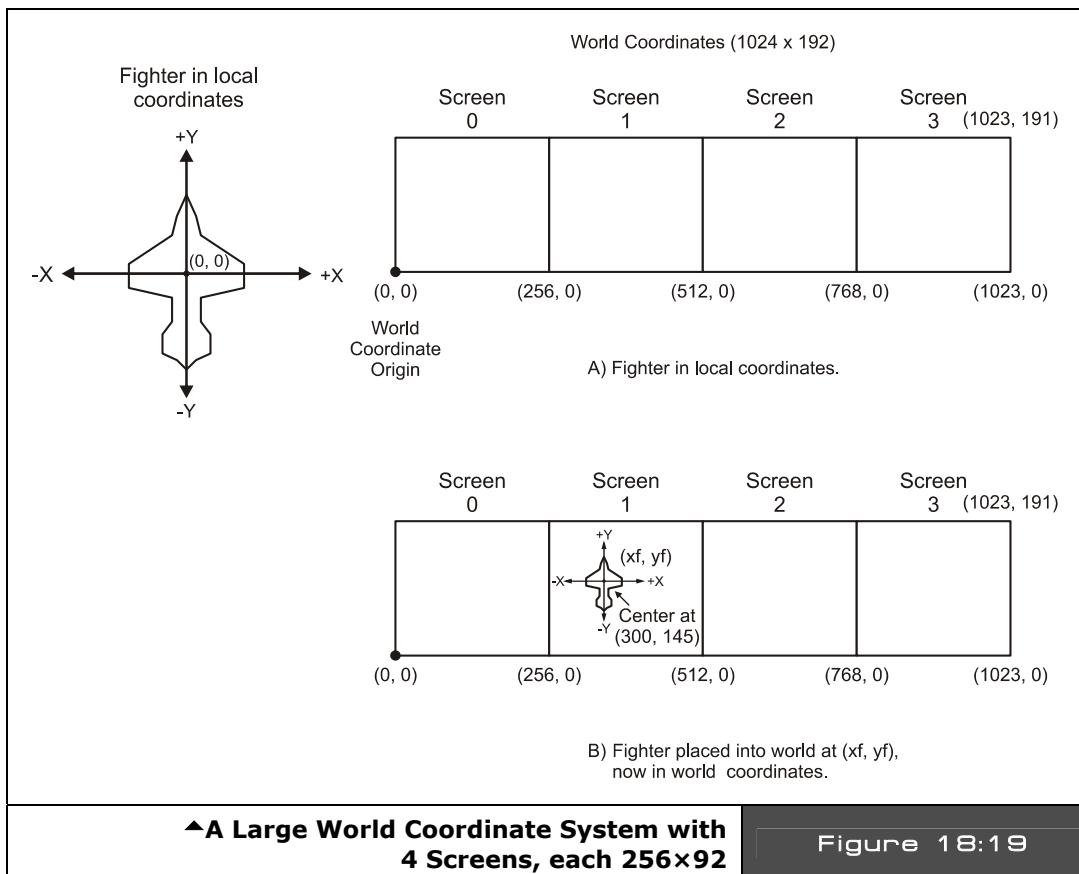


Figure 18:18

For example, let's say we wanted to have a giant scrolling game world  $4 \times 1$  screen, where each screen was  $256 \times 192$  pixels for a total of  $1024 \times 192$  resolution. Figure 18:19(A) shows something like this. This is the entire "world" that the game lives in, the universe if you will, thus it's referred to as **world coordinates**. So, world coordinates locate an object in the game world or the entire universe of geometry, if you will. Now, the idea of world coordinates is they help you define the entire game world, you simply move your objects around in world coordinates then finally map them to the screen which we will get to in a moment. A crude and naive approach at graphics is to try and "hack" this functionality, but if you want a big world, its better just to have one.

Now, the cool thing about local and world coordinates is that it is very easy to build up a scene for a game. You take your local coordinate models at  $(0,0)$ , then you translate them to their current world coordinate positions. Then, add each local coordinate vertex value to the object's final world coordinate location and all the points are perfectly translated or transformed to world coordinates. For example, referring to Figure 18:19(B), I have assumed that the fighter's world position center is at  $(xf, yf) = (300, 145)$ .



Thus, if we wanted to move the entire model into world space, then we simply need to add these offsets to each vertex; the pseudo-code for this transform in general is:

```
' Assume local coordinates of each vertex stored in local_x[], local_y[]
' move local model to position (x0, y0) in world space

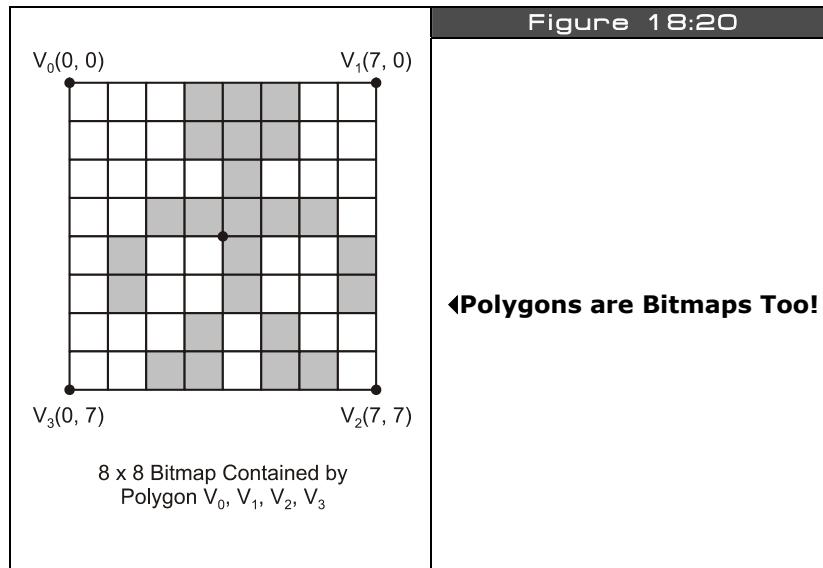
repeat j from 0 to num_vertices - 1
    world_x[ j ] := local_x[ j ] + x0
    world_y[ j ] := local_y[ j ] + y0
```

Now, the last question is “Great, we have our objects running around in world coordinates, but how do we get them back on the screen?” This is a good question with many answers, but the simplest is that we need a screen transform, or to be consistent we need to convert to **screen coordinates**. In our case, screen coordinates have been a  $256 \times 192$  pixel matrix that mimics Quadrant I from the Cartesian coordinate system. Now, here is where you can get creative: you can compress, scale, shrink, shear, invert, flip, do whatever you want to the world coordinates when you transform them to screen coordinates. For example, the simplest transform is 1:1, that is:

```
screen x = world x
screen y = world y
```

In this case, you don’t do anything – you assume that your “window” to the world/universe is only  $256 \times 192$ , and as long as objects fall within it, you will see them. For example, Figure 18:19 shows this setup. See how we still have a large world universe, but the viewing window or screen is always from  $(0 - 255, 0 - 191)$ , so you only see objects in that region? This is great as long as your objects move through the window or screen, but if you want to scroll around then you have to **move** the window which just means more transformations, but we will get to scrolling later. For now, we will just use a 1:1 world-to-screen transform and always refer to any polygon models in local coordinates with world coordinate locations that we want them to end up at.

One last question you might have is “How do bitmaps work in local and world coordinates?” Well, bitmaps are usually  $8 \times 8$ , or  $16 \times 16$ , etc. matrices of pixels. In most cases they are referenced from a single origin, usually the top left corner, so this is the origin and we simply draw a bounding rectangle around them mentally. This is the polygon that defines them, thus when we want to move a bitmap model from local to world, we simply need to keep track of a single **point** – the origin of the bitmap which might be a corner or sometimes the center. Figure 18:20 shows this.



#### 18.4.2 Translation and Scaling

Alright, we already have used the concept of ***translation*** many times, translation is nothing more than moving a point in 2D space along a straight line by adding constants to the current position. For example, if we have a point at  $(x,y)$  and we want to translate it  $(dx, dy)$  then we apply the math:

$$\begin{aligned} x &:= x + dx \\ y &:= y + dy \end{aligned}$$

That's it. This code and underlying algorithm simply moves the object by  $(dx, dy)$  each frame or time unit. As an aside, this can be transformed into a parametric representation very easily, which is just a fancy way of using a single value to control how far the original point is moved. So we can parameterize the formula by making it a function of  $t$  (which is standard practice) like this:

$$\begin{aligned} x &:= x + t*dx \\ y &:= y + t*dy \end{aligned}$$

Now, as you plug in ..., -2, -1, 0, 1, 2, ... you can force the math to move the object any amount of positive or negative units along the path defined by  $(dx, dy)$ . This kind of formula is called ***parametric*** since its based on a single parameter, more on this in the next section.

Anyway, the  $(dx, dy)$  is really the slope of the line that we are translating the point along which is:

$$m = \text{slope} = dy/dx$$

And of course, we can normalize the translation direction (vector) by dividing the  $x, y$  components by their combined length:

$$\text{length} = \sqrt{dx^2 + dy^2}$$

$$\begin{aligned} dx' &= dx / \text{length} \\ dy' &= dy / \text{length} \end{aligned}$$

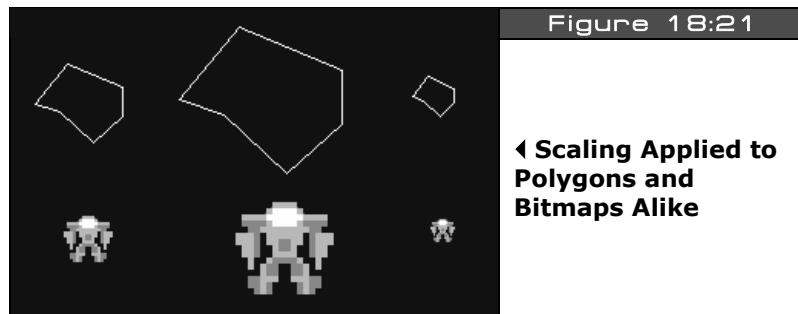
Then if you use these normalized versions of  $dx'$ ,  $dy'$  and plug it into the parametric equation you get this:

$$\begin{aligned} x &:= x + t*dx' \\ y &:= y + t*dy' \end{aligned}$$

The cool thing about the normalized  $dx'$ , and  $dy'$ , is that when  $t = 1.0$  the the translation is equal to the original equation:

$$\begin{aligned} x &:= x + dx \\ y &:= y + dy \end{aligned}$$

So it's like a "programmable" equation ☺.



Alright, so that's the formally informal deal with translation, now let's cover **scaling**. Scaling is simply the process of making an object larger or smaller, usually a polygon, but you can scale a bitmap just as easily. Figure 18:21 shows both a polygon and a bitmap scaled to 1.0, 2.0 and 0.5 (left to right) and how they look. Bitmap scaling is a bit complex and has to do

with sampling theory, so I might discuss it later, but for now let's stick to polygon scaling and see how to do it.

Remember our local coordinates used to define a polygon? Well, they are perfect to support scaling. All we need to do is multiply each vertex in the polygon model by a scale factor, call is scale, and that's it:

```
xs = scale * x
ys = scale * y
```



**For this to work properly the model, vertices or object must be in *local coordinates*, if not, the scaling operation will end up translating the object as well.**

Let's add this functionality to our Draw\_Polygon2( ) function by adding a scale parameter, and here's the results:

```
PUB Draw_Polygon3(vertex_list_ptr, num_vertices, color, x0, y0, s) | v_index

    ' step 1: set color
    gr.colorwidth(color, 0)

    ' notice the pointer casting to byte and the sign extension ~ operator
    ' step 2: plot starting point
    gr.plot(~byte[vertex_list_ptr][0]*s+x0, ~byte[vertex_list_ptr][1]*s+y0)

    ' step 3: draw remaining polygon edges
    repeat v_index from 1 to num_vertices-1
        gr.line(~byte[vertex_list_ptr][2*v_index+0]*s+x0, ~byte[vertex_list_ptr][2*v_index+1]*s+y0)

    ' step 4: close polygon by drawing back to starting vertex
    gr.line(~byte[vertex_list_ptr][0]*s+x0, ~byte[vertex_list_ptr][1]*s+y0)
```

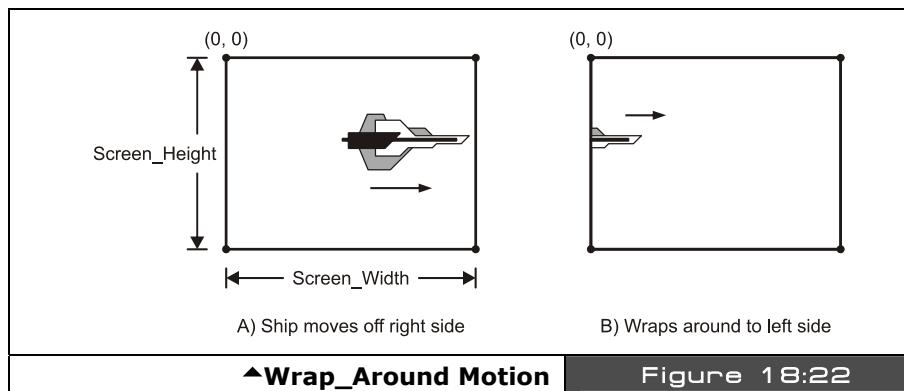
Some of the comments have been removed for brevity, but more or less the function is the same as Draw\_Polygon2( ) except that the parameter (s) has been added and used to scale each vertex value. As an example of scaling in action, take a look at program **scale\_demo\_010.spin** located on the CD in **CD\_ROOT:\HYDRA\SOURCES\**. It's basically the previous translation demo with the added scaling, but it's neat since you can make the ship any size you want, simply use the game pad to move the ship around (translate) and use the NES A and B button to change the size of the ship. Notice, that the Parallax reference driver clips the lines for us, so you can make the ship any size you want and it will draw properly and clip to the screen edges. Note that the scale factor can only be an integer, if you want to scale by fractional values then fixed-point or floating-point math must be programmed in software. Lastly, for fun, I called the drawing function multiple times

to draw a small “fleet” of ships, see if you can add logic so that as they scale their separation distances also scale.

### 18.4.3 Simple Motion Techniques

One of the themes of this chapter is “animation,” but you might be thinking that you haven’t seen a whole lot of animation as of yet! Well, this is not true, in computer graphics anything that **moves** or **changes** is animated, so all these demos are animation demos of a kind. But, if you are thinking about walking, jumping, running, etc. these are animations of course, but really nothing more than playing data sets through a renderer. For example, with our simple polygon function, if we were to digitize the vertices of some character walking and then load and play each as a polygon, it would look like animation. This is called **keyframe animation** and is a type of character animation, but first things first, we need to get the hang of moving single points around in different ways then we can connect points to lines, lines to polygons, polygons to models, and so on. Now, lets take a look at some different motion methods that lend themselves to old school game programs.

#### 18.4.3.1 Wrap Around Motion



▲Wrap\_Around Motion

Figure 18:22

This effect has been used in a number of demos thus far, more or less the idea is to test your object or point of interest to see if it has passed some threshold, usually the screen edges; if so, simply send it to the other side of the screen as shown in Figure 18:22. The pseudo-Spin code for a point at (x,y) moving with velocity (dx, dy):

```
' translate point first
x := x + dx
y := y + dy

' test x-bounds
if (x >= SCREEN_WIDTH)
```

```

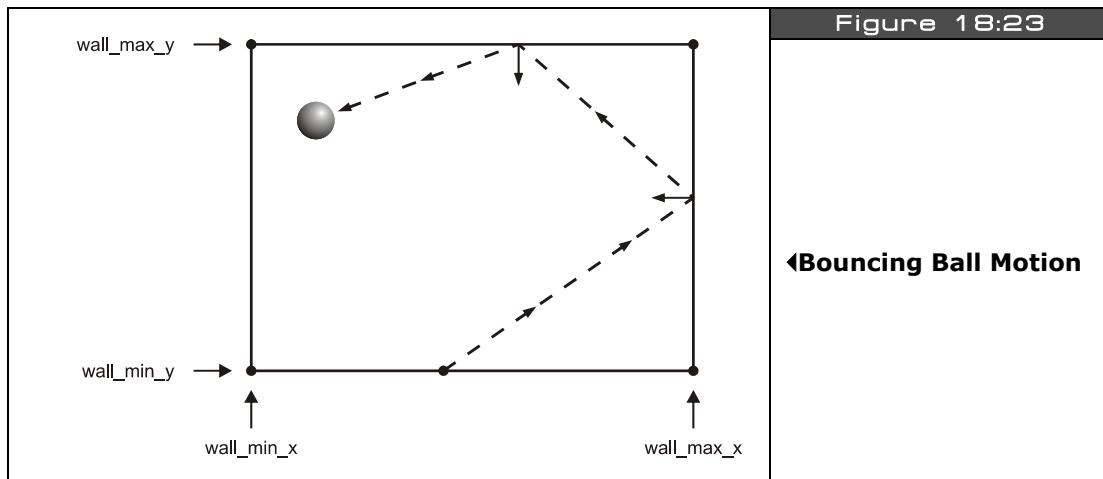
x := x - SCREEN_WIDTH
else
if (x < 0)
  x := x + SCREEN_WIDTH

' test y-bounds
if (y >= SCREEN_HEIGHT)
  y := y - SCREEN_HEIGHT
else
if (y < 0)
  y := y + SCREEN_HEIGHT

```

The only part of the code that is tricky is the reset of the x or y location, you would think that if the object moves off the right edge then you simply reset x to 0. This will work, but it's not as accurate as slightly adjusting x to take into consideration the amount that x exceeded the SCREEN\_WIDTH during the conditional, so if x went off the screen by 5 pixels then it winds up on the other side 5 pixels in, which just looks better.

#### 18.4.3.2 Bouncing Ball Motion



This is the basis of many games, such as a bouncing ball as shown in Figure 18:23. If you ask a physicist how to do it, he would reply "Well you need to consider the elastic and non-elastic collision response, compute the angle of reflection, taking into consideration deformation, energy absorbtion, friction, slippage, and other aspects..." You ask a game programmer how to bounce a ball, he replies "Easy!" and shows you the following pseudo-code:

```

' move ball
x := x + dx
y := y + dy

' reflect on x
if (x >= wall_max_x or x <= wall_min_y)
  dx = -dx
  x := x + dx

' reflect on y
if (y >= wall_max_y or y <= wall_min_y)
  dy = -dy
  y := y + dy

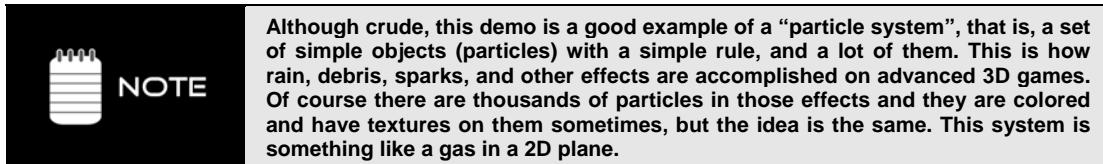
```

So what is this code doing exactly? If it's not obvious to you, don't worry, the simplest things are so simple they are hard to see sometimes – this fragment assumes there is an object with a **"virtual"** center at (x,y) moving at a rate (dx, dy). And by virtual, I mean that maybe it's a ball, an object, a car, but for purposes of bouncing and collision we are only going to consider its center point (incorrect technically, but good enough for games). The algorithm moves the ball, then tests the ball against four boundaries which are planes parallel to the X and Y axes, typically they are the screen boundaries but they might be smaller like a little square in the middle of the screen. If the ball's position exceeds any of the boundaries then the algorithm "bounces it back" by inverting the velocity on that axis and then repositioning the ball by re-evaluating the motion equation in that dimension/axis.

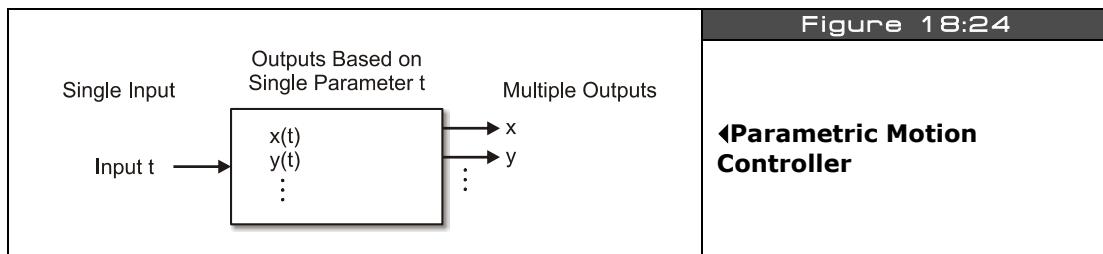
Since this is a little more tricky than the wrap around algorithm, a demo is in order. So for kicks, let's bounce a square ball in a square region in the middle of the 256×192 screen so you can see the algorithm in action. Also for fun, let's give you control over the size of the region, so you can make it wider or taller with the game pad right/left and up/down arrow keys for fun. The program that does this is called **bounceball\_region\_010.spin** and is located on the CD here: **CD\_ROOT:\HYDRA\SOURCES\**. Give it a try and see how it reacts. Also, notice that the region has a minimum width and height requirement, otherwise, the "ball" might get out and travel into oblivion – can you get a ball to escape?

The code of the demo is nearly identical to the algorithm above, so no need to list it, but you might want to take a look at the whole program since it's a hop, skip and a jump away from a start of a Pong or Breakout game. But, before moving on, I want to discuss a couple important concepts in relation to **collision detection**. Collision detection is a very complex field in computer graphics, simulation, and physics modeling; determining exactly when two bodies collide and how they collide is computationally complex and expensive. Obviously, games do not do all these calculations (at least old ones don't), so there must be tricks to it. And there are – tricks like using a bounding box around a complex object, or assuming an object is a single point and only testing its center like we did. Tricks like these are usually tolerated in simple games and thus uses, but as games get more complex, especially 3D

games, when your foot is on the ladder you need to know if your foot is on the ladder. But you would be surprised at the collision detection even in games like HALO and DOOM, in many cases, the complex characters you see are surrounded with invisible cylinders or simplified bounding boxes to perform collision detection for both weapon/player collision and player/world collision. This is why we have all said, more than once, "That didn't hit me!" while dying in a game. The collision detection used a crude bounding volume or trick to speed up collision testing and that time it just was wrong! So no, you're not crazy, games **do** make mistakes.



#### 18.4.3.3 Parametric Motion



**Parametric motion** simply means that a single variable, a "**parameter**," is used as an input to "drive" a set of equations that control the position of an object, usually (x,y) in 2D or (x,y,z) in 3D. However, parametric control can be used to control anything like color, shape, size, and so forth. Nonetheless, for this brief discussion we are going to focus on parametric motion just to keep it simple. Referring to Figure 18:24, the idea is that we control a single variable and the "parametric controller" outputs any number of variables; x,y in our case. Typical examples of parametric motion are found in physics texts where time (t) is used to drive a system of linked Newtonian motion formulas. For example, if we start with the formula for position then we get the following parametric formulas for position (x,y) , velocity (vx, vy), and acceleration (ax, ay):

##### Position (x,y) at time t

$$x(t) = x_0 + v_x \cdot t + \frac{1}{2} \cdot a_x \cdot t^2$$

$$y(t) = x_0 + v_y \cdot t + \frac{1}{2} \cdot a_y \cdot t^2$$

Where  $(x_0, y_0)$  are the initial position at  $t=0$ .

### Velocity ( $xv$ , $yv$ ) at time $t$

$$xv(t) = x_{v0} + a_x \cdot t$$

$$yv(t) = y_{v0} + a_y \cdot t$$

Where  $(x_{v0}, y_{v0})$  are the initial velocity at  $t=0$ .

The formulas assume constant acceleration, that is,  $(a_x, a_y)$  are constant for all  $t$ . So, the idea is that if you have the initial position  $(x_0, y_0)$  and the initial velocity  $(x_{v0}, y_{v0})$  then you can compute the position of your point at any time  $t$  from negative infinity to positive infinity. These basic motion equations are commonly used to model basic physics and we will get to that when we discuss the subject later in the book. But for now, they are just an example of parametric motion.

As another example, say you wanted to make a shoot-em-up game and wanted the aliens to follow a circular or elliptical path, but how? Simple, just use the parametric versions of a circle to control a point  $(x, y)$  as a function of angle:

$$x(t) = r_1 \cdot \cos(t)$$

$$y(t) = r_2 \cdot \sin(t)$$

Where  $0 \leq t \leq 360$ .

The above formula will create a circular path with x-axis intercepts at  $(-r_1, +r_1)$  and y-axis intercepts at  $(-r_2, +r_2)$ . If  $r_1=r_2$  then you will get a circle. What about a spiral? Well, for a spiral to work, we need to slowly change the radius as a function of  $t$  as well and make it bigger or smaller, no problem:

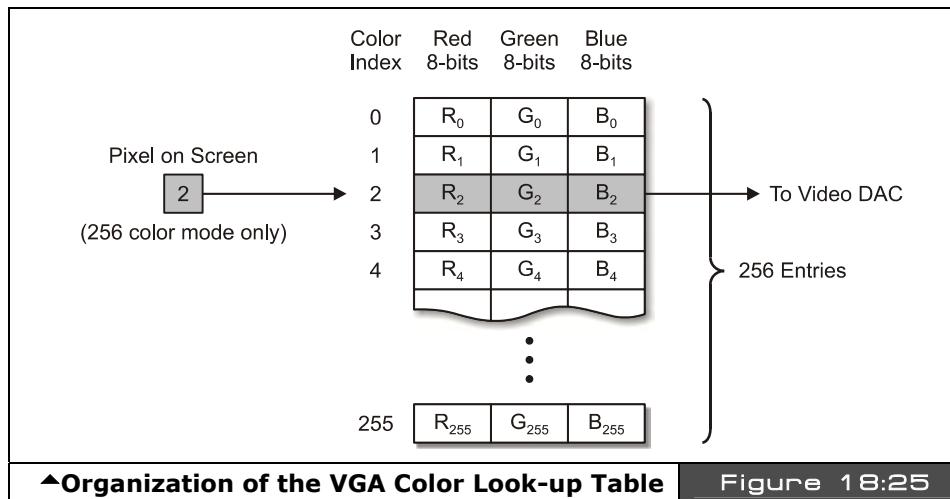
$$x(t) = (r_1 + t/rate_1) \cdot \cos(t)$$

$$y(t) = (r_2 + t/rate_2) \cdot \sin(t)$$

So if  $t$  ranged from 0 to 360 depending on how you selected  $r_1$ ,  $r_2$ ,  $rate_1$ , and  $rate_2$ , you could get almost any spiral you wanted, of course, the above formulas work best with floating-point math and the Propeller doesn't support floating-point math natively nor does Spin. So you have to fudge things to get them to work, for example by using large numbers and division/multiplicaton to simulate fixed-point math. As an example of this in action take a look at **spiral\_demo\_010.spin** on the CD located in **CD\_ROOT:\HYDRA\SOURCES\**. Try altering the constants at the top of the program to get different spiral motion patterns in real-time. Also, notice the program renders with triangles and draws a grid each frame.

#### 18.4.4 Color Animation

Well, at this point, I think you can see it's a lot of fun to move objects around the screen, you can make them do anything and look like anything. Game and graphics programming is very artistic for this reason, it's "art in motion," and it's programmed, so it's the fusion of art and science which is very cool. In any event, in the previous section, the concept of keyframe animation was brought up which was animation by means of displaying various frames or models of a character as it's performing some action: running, jumping, dying, whatever. But, geometrical animations are not the only ones you can do; remember animation as far as we are concerned as game programmers is anything that moves or changes, thus we can even animate the **colors** of the screen!



Color animation is simple. For it to work, you must have color indirection, that is, a register or memory location needs to hold a color value, then this value is referenced indirectly during rendering. For example, on the PC VGA architecture there is what's called **a color look-up table (CLUT)**, this table has 256 entries, each entry is usually a full RGB color in 18 to 24 bit, but that would give up to 16.7 million colors which obviously the VGA didn't display at once. But you could select 256 of these 16.7 million colors at one time, thus you would set the color palette up with 256 colors you wanted and then use an index 0..255 as the pixel value which would be used by hardware to "look up" the full 24-bit RGB value in the CLUT, and then that color would show up on the VGA screen; this is shown in Figure 18:25. Now, the cool thing about this is that drawing pixels is expensive, if you wanted to redraw 50% of the VGA screen that's  $640 \times 480 \times 50\% = 153,600$  BYTES, ouch! But, if you only wanted to change the color of all these pixels then a single write to the CLUT would do it.

With this technique, you could simulate movement, like marquee signs do, or turn an object off and make it invisible by selecting a color that had RGB (0,0,0). All these tricks are called color animation. Now on the HYDRA, we basically need to write the graphics engine ourselves to support this properly, but the Propeller has the hardware indirection to make it easy. If you recall from the discussion on the VSU, the VSU streams out bytes of color indexed by the pixels we send to it, the bytes are "colors" stored in the "colors" LONG, thus we have our look-up! However, to expose this the high-level engine needs to do it somehow and the Parallax reference driver we have been using isn't very cooperative here, but again, we can force it to at least show the effect and later with the more advanced engines I will show you, this type of functionality will be built-in more directly.

To animate colors on the screen, we have to go back to the setup of the colors array during the initialization of the Parallax reference driver, here's the code for reference:

```
{ init colors, each tile has same 4 colors, (note color_1 and color_2 are flipped  
due to bit flipping in graphics driver) }  
  
repeat i from 0 to 64  
    colors[i] := COLOR_3 | COLOR_2 | COLOR_1 | COLOR_0
```

...where colors[i] is simply a LONG array where each entry is a 4-BYTE color look up table which is perfect, and in fact is even more flexible since we can do color animation on a tile by tile basis. So, to perform color animation, we simply modify the 64 entries (or fewer) and do whatever we want to them. Let's start with a couple common effects and you can go from there.

#### 18.4.4.1 Glowing Effect

The first color animation trick will be to make a color "glow," to do this you need to change the color or brightness or both at some rate. So what we are going to draw is a random Mars cavern scene in the primary buffer only and animate a single color. We have four colors for each tile to play with: color 0, 1, 2, 3. We are going to map the colors in the following way:

**Color 0:** Background color - black.

**Color 1:** Top cavern color - reddish.

**Color 2:** Bottom cavern color – reddish.

**Color 3:** Animated color will cycle through the greens.

To implement this animation, we first need to draw the trench, that's easy, we will use one of the primary buffer templates to do that and use a random variable to create the top and bottom terrain, then for the last pixel or two of the top layer of radioactive "crust" in our cavern we will draw it in Color 3 (the animation color), then fall into our main loop and animate the color.



The program that makes this all happen is **caverns\_glow\_010.spin** which is located in **CD\_ROOT:\HYDRA\SOURCES\**. The demo is shown running in Figure 18:26 which of course doesn't do it justice, so make sure to run it. The program is too big to list, but the color animation fragment is listed below for reference:

```
' rotate colors
repeat while TRUE

    ' animate the color (glow it)
    glow_intensity += glow_delta

    ' keep glow_intensity between 2 and 6
    if ( (glow_intensity) < 2 or (glow_intensity) > 6)
        glow_delta := -glow_delta
        glow_intensity += glow_delta

    ' now mask in glow_intensity as the luminance component of the green that is
    ' representing the crust
    palette[3] := (COL_Green & $F8) | glow_intensity

    ' write the new colors into all the tiles
    repeat i from 0 to 63
        colors[i]:= (palette[3]<<24) | (palette[2]<<16) | (palette[1]<< 8) | (palette[0]<<0)

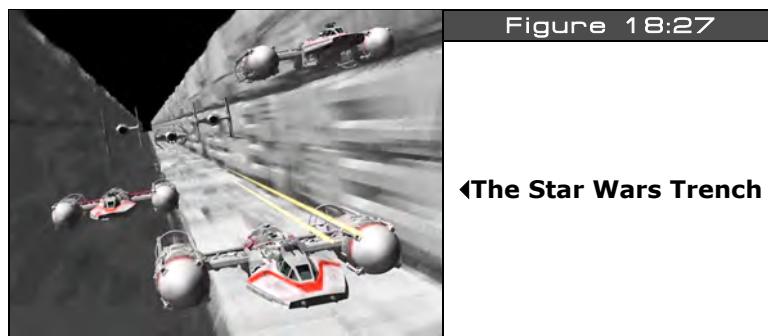
    ' delay a moment
    waitcnt(cnt + 5_000_000)
```

As you can see, the code is a very simple loop that animates color 3 of every single tile. The animation slowly increments through the brightness of a pure green and then once they reach maximum brightness start decreasing, so you get a nice glowing effect. Try using a different base color other than red, maybe blue, and see what they look like. The rendering

of the caverns themselves are nothing more than a random variable that is queried to determine whether to shift right or left as the cavern is rendered, more or less, the cavern is simply two "**random walks**" that are filled to the right and left respectively.

#### 18.4.4.2 Color Rotation and the Star Wars Trench

Every respectable game programmer at one time or another has tried to replicate the effect of the trench from the movie Star Wars; Figure 18:27 shows a screen shot from the Playstation version of it. There are direct ways of doing it, such as 3D graphics and solid or wire frame graphics, or more indirect ways such as cheating like was done in the 80's on simple game systems to get the "effect." Thus, we aren't going for what you see in the figure since that's real 3D, we are just trying to make something look like we are flying through a 3D trench.



So the idea here to achieve the animation is similar to the marquee idea, that is, to mimic movement by sequencing lights, but instead of sequencing lights we are going to sequence colors with a technique called "**color rotation.**" Color rotation is just that, we "rotate" a set of colors just like rotating a set of bits, for example, when you use a ROL or ROR instruction in assembly, they mean to "Rotate Left" or "Rotate Right," same idea here, but with larger chunks of data representing the colors in a tile. Referring to Figure 18:28, you can see the idea schematically. Colors 1,2,3 are rotated in increasing order, so here's what happens in pseudo code (notice we need to use a temp var):

```
temp := color 3    ' hold color 3, so we don't loose it
color 3 := color 2    'rotate color right
color 2 := color 1    'rotate color right
color 1 := temp      'finally copy color 3 back into color 1
```

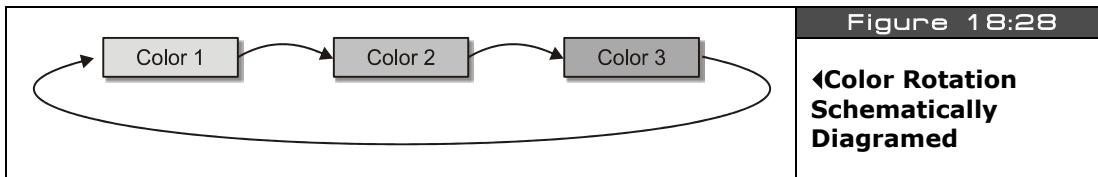
...and to rotate in the opposite direction would be:

```
temp := color 1    'hold color 1, so we don't loose it
```

```

color 1 := color 2      'rotate color left
color 2 := color 3      'rotate color left
color 3 := temp          'finally copy color 1 back into color 3

```



Of course, the concept of left and right is really arbitrary and nothing more than *right* means *increasing* and *left* means *decreasing* integer order. Anyway, to rotate in the opposite direction is the same idea, just invert the indices. So, as a first shot at color rotation, let's try this: draw a pseudo 3D perspective horizon covering the bottom half of the screen as horizontal strips of color in the sequence color 1,2,3,1,2,3,... and then rotate to create the illusion of forward motion in 3D. The code for this rendering is shown below for reference:

```

' render perspective colorized horizon for rotation
repeat y from 0 to SCREEN_HEIGHT/2
    gr.colorwidth(1 + (y/(30-y/5)) // 3, 0)
    gr.plot(0,y)
    gr.line(SCREEN_WIDTH-1, y)

```

Notice all the fudging with the math – this is typical when doing this kind of rendering, rather than use real 3D math, you simply “experiment” until you get the visual results you like. In this case, 4 lines of code create the perspective illusion! The program that shows everything is **color\_rotation\_010.spin** which is located on the CD here:

#### CD\_ROOT:\HYDRA\SOURCES\

Try the program out, you can increase and decrease the speed of color rotation with the up and down directionals on the game pad (plugged into the left port of course). The program uses a standard primary-only setup to save memory; the actual color rotation is shown below:

```

' the 4 colors are located in palette, we are going to rotate 3->2->1->3
temp_color := palette[1] ' save this for a moment
palette[1] := palette[2]
palette[2] := palette[3]
palette[3] := temp_color

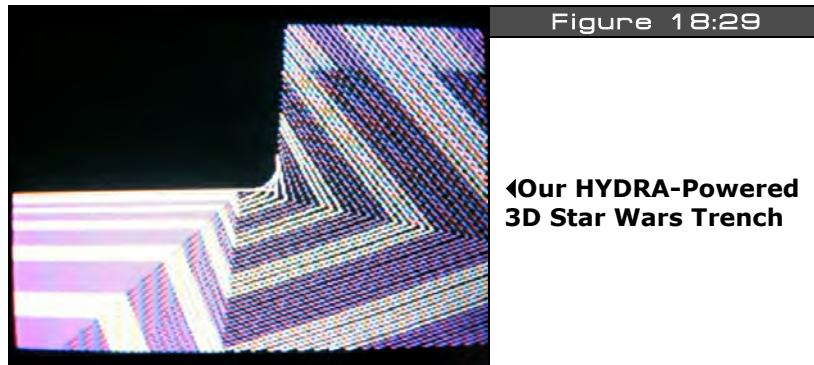
' now write color palette back into screen colors array, so tiles use them
repeat i from 0 to 63
  colors[i]:=(palette[3]<<24) | (palette[2]<<16) | (palette[1]<<8) | (palette[0] << 0)

```

Notice the color rotation works in two parts: part one performs rotation on a set of "**shadow**" colors, then in part two they are copied into the 64-element color array that represents the color look-ups for each tile. See if you can alter the code so that you can change directions of the rotation from up/down.

Now, that we have that under our belts, I think you get the idea of how motion can be simulated without actually moving anything! The previous demo literally moved the entire screen RAM, so it seemed, but really all that moved was the colors of the rendering, not the data rendered, this is the key to color animation. The indirection of color look-up tables gives you the ability to seemingly move a lot of data when in fact you are only changing what it looks like. In any event, to get the Star Wars trench animation to look semi-real, what we need is to first draw a perspective correct 3D trench of some gray metal colors that gets bigger as it gets closer, then to rotate the colors toward us. So the plan will be to use the following color scheme:

- Color 0:** Background black
- Color 1:** Dark violet
- Color 2:** Dark violet
- Color 3:** White



Notice that colors 1 and 2 are the same? The reason is that this will help “sell” the 3D effect better. Alright, taking that all in to consideration, Figure 18:29 shows our meager attempt at the trench effect with a little tile on the aspect to make it look better. To try the program out load **color\_trench\_010.spin** located in **CD\_ROOT:\HYDRA\SOURCES\**. The program does absolutely nothing different than the previous color rotation demo other than draw something **different** to animate. This is the cool part about this type of animation, whatever is on the screen will animate, so you can do all kinds of cool tricks with it. The Spin code that performs the rendering of the trench is semi-interesting and shown below for reference.

```
repeat y from 0 to SCREEN_HEIGHT/2
    gr.colorwidth(1 + (y/(25 - y/5)) // 3, 0)

    ' draw pseudo-3D trench
    y_inv := SCREEN_HEIGHT/2 - y
    gr.plot(0,y)
    gr.line(SCREEN_WIDTH/2 - y_inv/1 - 10, y)
    gr.line(SCREEN_WIDTH/2 - y_inv/3 - 10, y - 2*y_inv)
    gr.line(SCCREEN_WIDTH/2 + 5*y_inv/1 - 10, y - y_inv/5)
    gr.line( (SCREEN_WIDTH/2 + y_inv/3 + 10) , y + 5*y_inv)
```

Note, this kind of “artistic” graphics programming is mostly trial and error to get the visual effect with as few lines of code as possible.

## 18.5 Summary

This chapter has covered a lot of material and a lot of new concepts such as double buffering, page flipping, coordinate systems, color rotation, and much more. Hopefully you are starting to see how fun game development and graphics programming is! There is no limit to what you can do with a few simple ideas. The idea is to keep building upon them until you have a HALO III, so let’s keep working!



## Chapter 19:

### Tile Engines and Sprites

In this chapter, we are going to discuss tile and sprite engines from a technical and design point of view then take a look at a simple “starter” tile/sprite engine that I have developed for you. This engine supports tile graphics, 4 colors per tile from a unique palette per tile, multiple sprites, page flipping, scrolling, and more. Additionally, the tile engine works on a single cog and generates video as well! With it, you should be able to make anything you see on an Atari 800 or C64 more or less. We aren’t going to go into the programming of the tile engine, that’s a bit too much to cover for right now. Later in the book we’ll discuss the design, but for now, think of it as an object like anything else, with a really simple interface. Considering that, here’s what’s in store for this chapter:

- ▶ Tile and sprite engine basics
- ▶ Overview of the sample tile/sprite engine
- ▶ Displaying multiple tile maps
- ▶ Moving tile based objects around tile maps
- ▶ Using the sprite engine

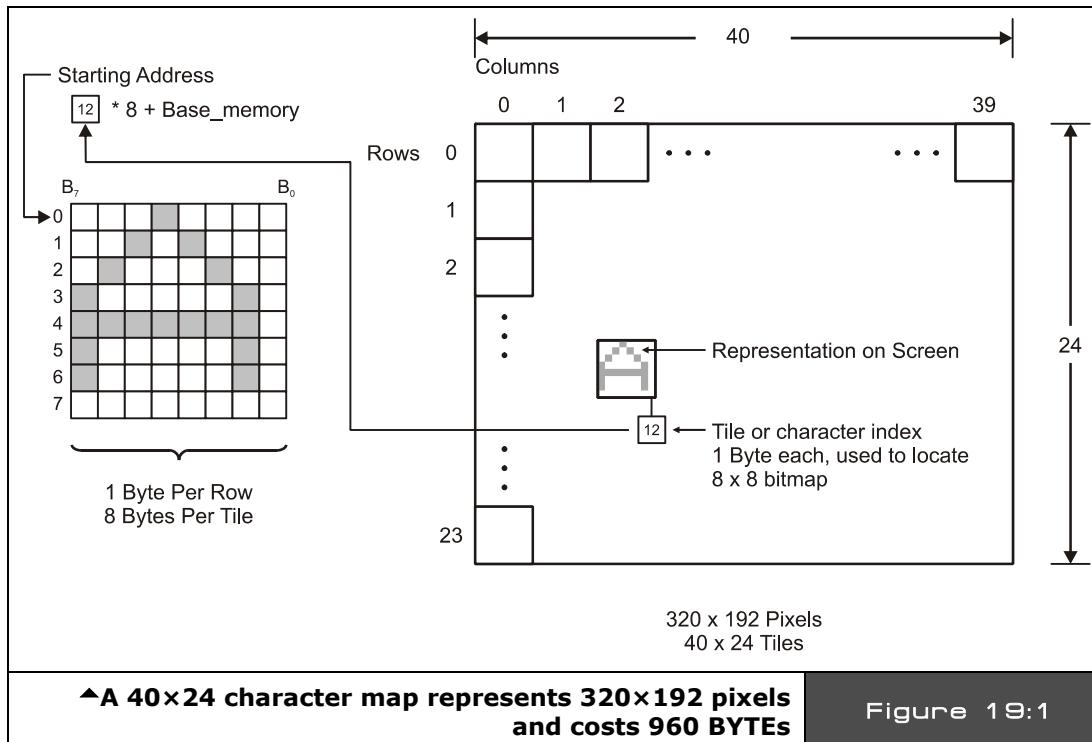
### 19.1 Tile Engine Technology Overview

Simply put, bitmapped graphics take up too much memory and are too slow for most small game systems to handle. For example, if you do some simple math you will see that supporting bitmapped graphics is challenging on constrained hardware. Let’s say you wanted to implement a 256 color (1 BYTE per pixel) bitmapped display with two pages of video and a resolution of  $224 \times 192$ . Assuming that 256 colors can be encoded with 1 BYTE per pixel using the pixel data directly or a look-up that maps the 8-bit pixel data we have:

$$\mathbf{1 \text{ byte} * 224 * 192 * 2 = 86016 \text{ BYTES or } 84 \text{ Kbytes!}}$$

This is nearly three times as much static RAM than the Propeller chip has, so this isn’t going to work. Moreover, that amount of data is a lot of refresh, clear, and move at 60 FPS, so simply trying to update the screen is difficult even if you had the memory. Even if we backed off quite a bit down to 2 bits per pixel, and lowered the resolution to  $160 \times 192$ , we still end up with:

$$\mathbf{160 * 192 * 2 / 4 = 15360 \text{ BYTES or } 15 \text{ Kbytes.}}$$



This is a little more reasonable, and in fact is exactly how the Parallax bitmap video drivers works, that is, you can select 1 or 2 bits per pixel and with a double-buffered graphics system you can fit it in memory, but it only leaves you 17K roughly for your program code! Not very good tradeoffs. These are the exact same problems game programmers were faced with 20-30 years ago when they first started developing commercial games.

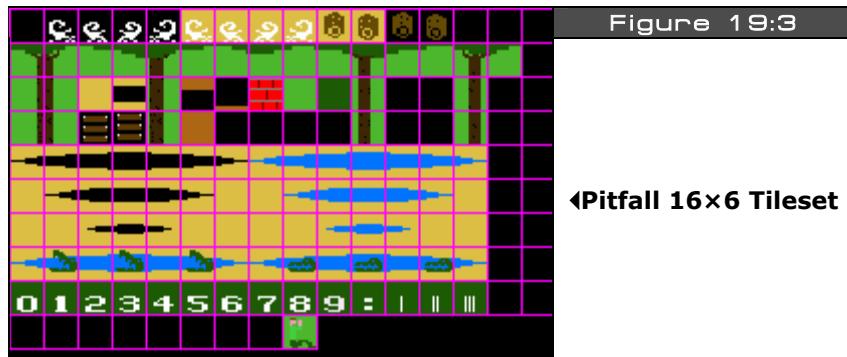
One of the solutions to the problem was to redefine the character set of the computer, so that the bitmaps that normally represent the characters "A" "B" "C" etc. were overwritten with game characters and then printed out like text. This was good since character modes take much less memory than bitmap modes. For example, a 40×24 display of characters that are 8×8 bitmaps only takes  $40 \times 24 = 960$  BYTES, assuming 1 BYTE per character (which is usually the case) and each character is represented by an 8×8 character definition index within the 960 BYTES. With this we can represent a screen with a resolution of (320×192) as shown in Figure 19:1. Of course, the character definition bitmaps take up memory themselves, but we only need to define the characters we are going to use, we don't need to define 256 of them. So for example, we might only need 30-40 characters to "build" up all our game art in character format.

Additionally, we can use 1, 2, 4, or 8 bits per pixel or whatever we want to save more memory for the actual characters themselves. For example, most game programmers will use 2, 4, or 8 bits per pixel, so the amount of memory to define each character is minimal; more on this in a moment.

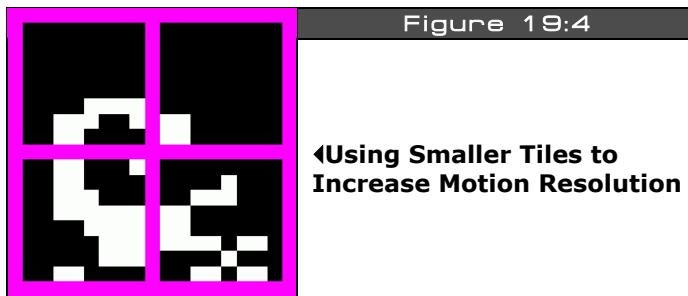
Alright, so game programmers started redefining the character sets in game systems and PCs to represent game characters and this worked out great, an entire screen would take 1-2K to represent, but could look like anything. Of course, the only problem was that depending on the hardware you were on you might be stuck with a certain number of characters per screen, a certain bit depth, and worst of all a ROM character set that you couldn't redefine. In these cases, some programmers were able to synthesize "character" graphics with the bitmap graphics, and render the characters "on the fly" straight to the raster without using bitmap memory etc. However, the point is that this technique is very powerful however you do it and later became known as "**tile graphics.**" More or less, any game can be made with tile graphics.



Now, the bad news...tile graphics are great, but the problem is objects can only be drawn on tile boundaries. For example, say you have tiles that are all  $16 \times 16$  pixels, then you can lay them down to make your background or what is known as the "**playfield**" in old-school parlance. You can only place a tile on a tile boundary, just like characters on a text screen, you can't put a tile half way between two tiles; Figure 19:2 shows this. Referring to the figure, you see there is an imaginary tile "matrix" (fine white lines) that shows the boundary of where tiles can go, so you can only place them on these integral locations. For a tile setup of  $16 \times 16$  pixels, this means that each tile has to be located at pixel location  $(i*16, j*16)$ , where  $(i, j)$  run from  $0..m$ , and  $0..n$ , the tile map width and height.



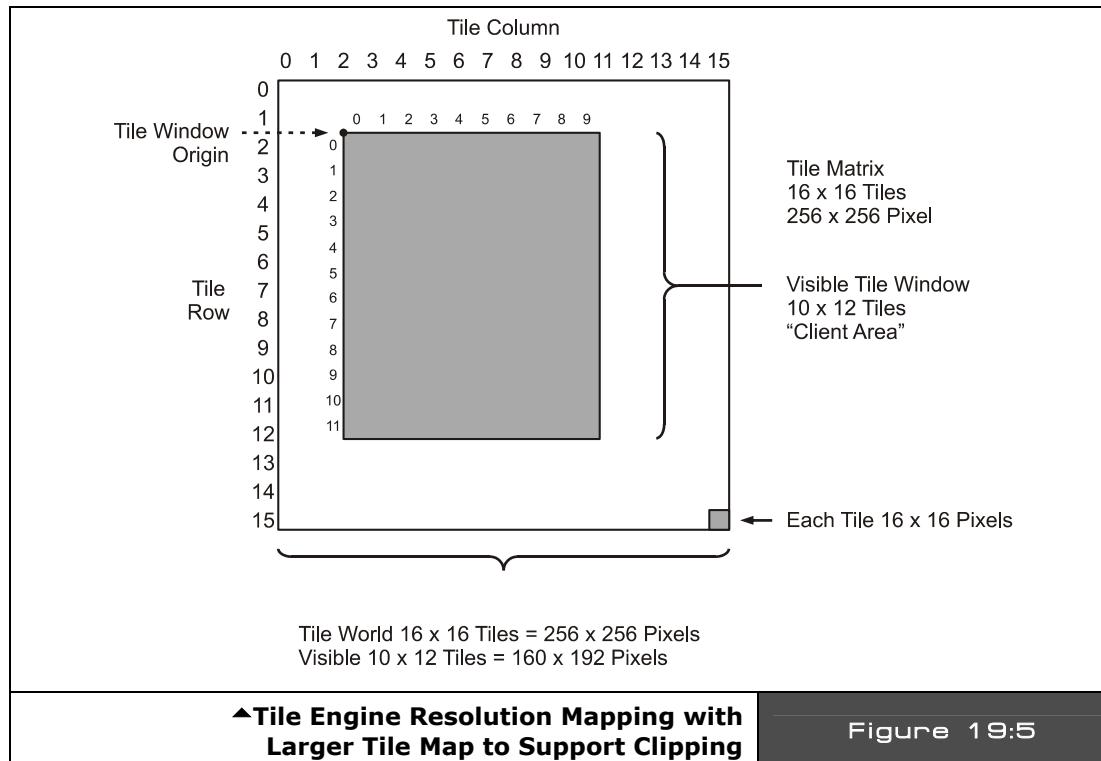
This isn't too bad of a problem, but if you want to move a game character around then you have to move it by an entire tile size which may look pretty rough. For example, Figure 19:3 shows some tiles I created based on the Pitfall game, they are all  $16 \times 16$  and you can see how "tiling" them next to each other would result in complete backgrounds. But, the problem is the game characters that need to move like the "scorpion" up top and "Pitfall Harry" bottom center. If we were to move these objects by whole tiles they would look pretty rough during game play. If your game can live with this then fine, otherwise, you have to come up with some concessions to make it look better.



One such concession is to make the tiles smaller. For example, you could make the tiles  $8 \times 8$ , then each  $16 \times 16$  tile would be broken into (4)  $8 \times 8$  tiles, that when tiled next to each other make the original  $16 \times 16$ . Figure 19:4 shows this for my little rendition of the scorpion. Now, if we want to draw or move the scorpion, we must move/draw 4 tiles, this isn't bad, it's 4 BYTES to update in tile memory. But, a side effect is that tile memory is now 4 times bigger which can start to become an issue. Nonetheless, this is a good approach since now we can move a tile character 8 pixels at a time that is 16 pixels large, or 50% of its width or height, this is still "a lot" and surely not what you would call "fine" motion, but usually tolerable. And

you will find many 8-bit games that do just this and you never noticed while playing! Now that you have an idea of what a tile engine is, let's talk about modern tile engines and what they tend to support.

### 19.1.1 Modern Tile Engines



Modern tile engines are usually based on hardware, or a hardware/software combination. Most modern graphics cards do not have any kind of tile graphics support, tile graphics are simply supported via bitmapped graphics and a layer of software. Thus, there are no constraints on them unless dictated by hardware. Tile engines usually have a few parameters that define their capabilities such as:

- ▶ Tile sizes
- ▶ Screen size
- ▶ Scrolling support
- ▶ Page flipping support
- ▶ Special effects and layering

**Tile Sizes** — You will usually find tile engines that support numerous tile sizes such as  $8\times 8$ ,  $16\times 16$ ,  $32\times 32$ , and sometimes other sizes that are not powers of two, and not equal in the X and Y dimensions, but game programmers and artists like tiles that are  $8\times 8$ ,  $16\times 16$ , and  $32\times 32$ , so most people stick with these. Additionally, these sizes make math and computations very easy since they are powers of two.

**Screen Size** — This is the actual size of the screen in pixels, for NTSC, you will find the following resolutions common for tile engine implementations:  $160\times 192$ ,  $224\times 192$ ,  $224\times 224$ ,  $256\times 192$ ,  $256\times 224$ ,  $256\times 256$ . Where considering the bandwidth of NTSC, the highest “visible” on-screen resolution is  $160\times 192$ , the other modes extend off the screen edges or they are compressed on screen, but single pixels can’t respond to color changes on a pixel by pixel basis and need 2 or more pixels in a row to actually see the color. The larger tile resolutions are good to support clipping. That is, you make the tile map  $256\times 256$  logically, but physically you can only see  $160\times 192$  of it, thus the other portion of the screen client area is off the edges of the screen logically, so when you move or draw tiles they tend to “clip” off the screen as shown in Figure 19:5. Also, using  $256\times 256$  for a screen resolution is nice since position is encoded in a single BYTE and wraps around nicely.

**Scrolling Support** — Scrolling simply means moving a view window over the data set. In tile graphics, this might mean that the tile map is  $100\times 100$  tiles, but only  $40\times 24$  of these tiles are on screen at once. Thus, scrolling might be implemented in a number of ways such as how the tile memory is addressed or with specific registers or memory locations that control scrolling of the tile map. Also, scrolling can be **“fine”** or **“coarse.”** Fine scrolling usually means you can scroll by a single pixel or line, coarse scrolling means you must scroll by an entire character/tile size. If you are doing a space shooter game or a high-speed racing game then coarse scrolling will suffice, but if you want a character to slowly walk around the environment then fine scrolling is a must.

**Page Flipping Support** — We have already discussed what page flipping is in the previous chapter, but to reiterate: page flipping simply is the ability to “point” the screen memory base address to another region of memory and instantly the new data is used to draw the screen. This is page flipping and is much faster than copying the screen of data from a back buffer to the primary buffer. Of course, with tile graphics, we are talking about screens that cost only 1-2 K, so even without page flipping we can always copy data from an off-screen tile buffer to an on-screen tile buffer in a few thousand machine cycles. Nevertheless, page flipping is a nice feature to have especially for a nice **“Adventure”** type game where you might have 10-20 levels each represented by a single page of tiles and you want to change a single pointer to move the player from room to room.

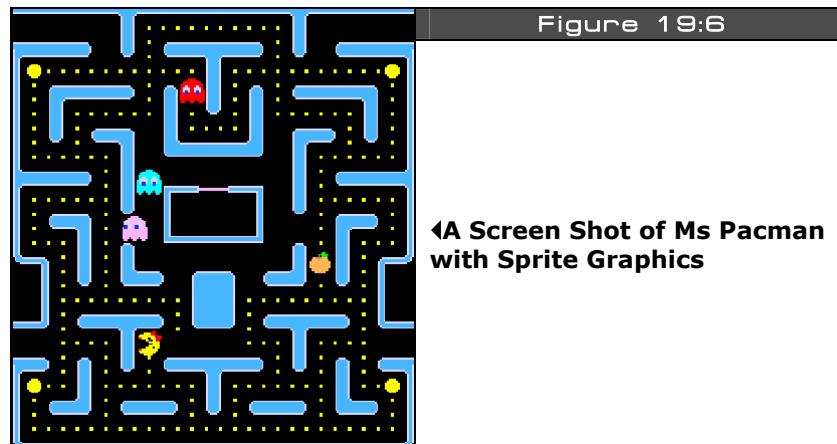
**Special Effects and Layering** — This covers a lot of ground and could be anything from color effects to distortions and so forth. For example, a tile engine might use a single BYTE to represent each tile, and each tile is encoded as a  $16\times 16$  bitmap where each pixel is 2 bits, and these 2 bits represent 1 of 4 colors from a palette of 16. Thus, each tile might have a

palette assigned to it as well. So lots of color special effects can be achieved with this, for example, on the bottom tiles of the screen you use color 1 to represent water, but on top you use color 1 to represent grass, so when a character that uses color 1 as part of its bitmap walks on grass or water, you see the green or blue change which is cool and nearly a free effect. Another feature for tile engines is "***layering***" – here what we are talking about is at the driver or rendering level, multiple tile maps are layered on each other either with some kind of stencil, or logical combination rule (AND, OR, XOR) etc. This can be a very powerful effect to create layered scrolling and 3D parallax effects.

## 19.2 Augmenting Tile Engines with Sprites

Your first question might be "What is a sprite?" Well, we aren't talking about the "sprites" in fairy tales, we are talking about sprites in video games. A "***sprite***" is usually a 2D bitmap object that can move freely over the background bitmap or tile graphics. Sprites usually have collision detection and can even be scaled. Usually, they are implemented in software these days, but in the 70's and 80's systems usually had hardware sprites as part of the design. For example, the Atari 800 had 4 sprites (plus another 4 missiles that could be combined into one more sprite), and the C64 had 8 sprites with more colors than the Atari though, and the Apple II had no sprites!

Figure 19:6 shows a screen shot of ***Ms Pacman*** in play. The ghosts and player are all sprites, while the background maze, power pills, dots, and power-up fruits were all tile graphics. In fact, if you boot a real Ms Pacman machine or a MAME emulated version, you can actually see the tile graphics start up.



**NOTE**

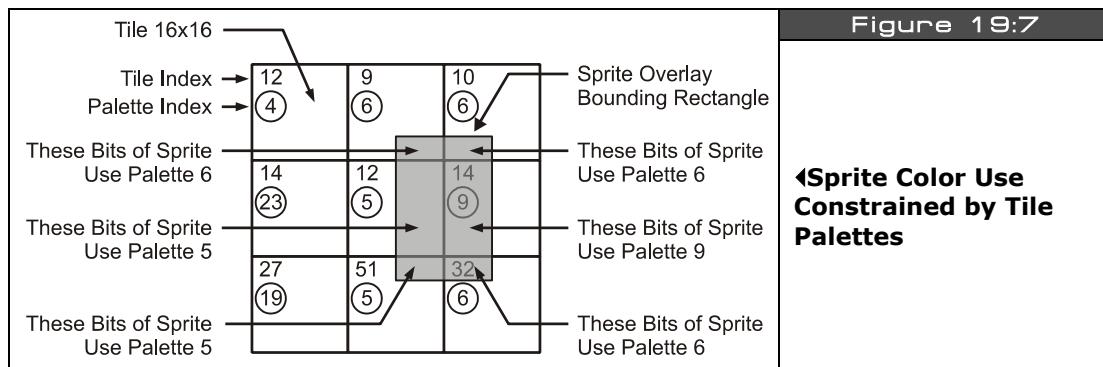
The term “**Sprite**” was originally coined in the 1970’s by Texas Instruments documentation about their video generation chip. Atari also coined the terms “*Player Missile*” graphics to refer to sprites as well.

Sprites are the last feature you need to complete a graphics engine for games. As noted, tile graphics are fine to create the background or playfield for your games, but the objects moving around in the foreground usually need to move over the background without disturbing it, but more importantly need to move smoothly on a pixel-by-pixel basis rather than in “**tile space**.**”** This is exactly what sprites give us the ability to do. Typically, sprites are implemented as bitmaps just like the tiles, and may even share the same format as the tile’s bitmaps; however, we can place sprites anywhere we want instantly, and moving them is usually done with single operations to registers or memory locations from an API stand point (the actual implementation might be hardware or software though at the driver level, thus there could be a lot of magic happening underneath).

Sprites usually have a number of features just like the tile engines such as:

- ▶ Sizes
- ▶ Colors and transparency
- ▶ Scaling
- ▶ Z-Ordering

**Sizes** — Sprites usually are the same size as the tile engine or a multiple thereof. So, common sizes are  $8 \times 8$ ,  $16 \times 16$ ,  $32 \times 32$ . However, since sprites mostly represent foreground game objects and not a regular matrix of background tiles, the constraint of width equaling height is loosened. For example, if you needed a “tree” sprite, it would be inefficient to have a  $192 \times 192$  size sprite when you only needed it to be  $32 \times 192$ . Thus, many times sprites will actually have a programmable height or width, and/or give you more size choices like  $16 \times 32$ ,  $32 \times 16$ , etc.



| 8 x 8 Sprite Definition |                 |                 |                |    |    |    |                | Figure 19:8    |                     |
|-------------------------|-----------------|-----------------|----------------|----|----|----|----------------|----------------|---------------------|
| Row                     | B <sub>15</sub> | B <sub>14</sub> | 2 bits / pixel |    |    |    | B <sub>1</sub> | B <sub>0</sub> | 16-Bit Word Per Row |
| 0                       | 00              | 00              | 00             | 00 | 01 | 00 | 00             | 00             |                     |
| 1                       | 00              | 00              | 00             | 01 | 01 | 01 | 00             | 00             |                     |
| 2                       | 00              | 00              | 00             | 00 | 01 | 00 | 00             | 00             |                     |
| 3                       | 00              | 00              | 00             | 00 | 01 | 00 | 00             | 00             |                     |
| 4                       | 00              | 00              | 00             | 00 | 01 | 00 | 00             | 00             |                     |
| 5                       | 00              | 11              | 00             | 11 | 01 | 11 | 00             | 11             |                     |
| 6                       | 00              | 11              | 11             | 11 | 11 | 11 | 00             | 11             |                     |
| 7                       | 00              | 11              | 00             | 11 | 11 | 11 | 00             | 11             |                     |

00 = Transparent  
Background Shows Thru

11 = Color 3

Colors

Color Code Description

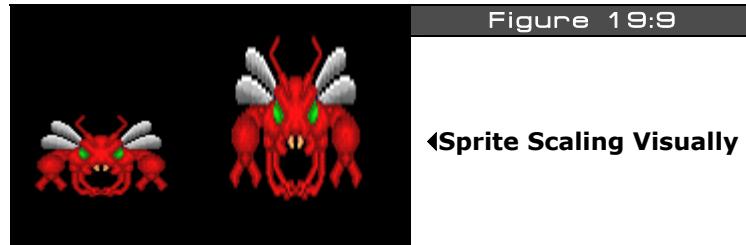
00 Transparent  
01 Color 1  
10 Color 2  
11 Color 3

Sprite Transparency Encoding

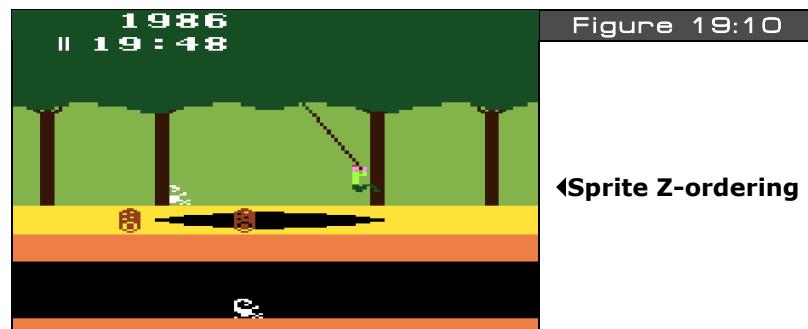
**Colors and Transparency** — Depending on how the graphics hardware/software/drivers work the sprites may have to use the same colors as the tile or bitmap graphics do. For example, any portion of a sprite bitmap that overlaps a tile must use its palette, this is shown in Figure 19:7. This might be a physical limitation of the hardware itself, or simply a way to save memory. On the other hand, each sprite might have its own set of colors and might even have more color space than the tiles (or less). For example, maybe the tiles have 4 colors each, and the sprites have 256. Lastly, sprites represent objects that need to move over the playfield graphics, thus they need to have “transparency” in them, so the background can show through. This is usually represented by a single color code, usually Color 0. Therefore, in a sprite bitmap anywhere there is a Color 0, this will show through the background. This is shown in Figure 19:8 for an 8×8 sprite with 2-bit color. Thus, in a sprite with 4 colors encoded in 2 bits, the encoding might be like that shown in Table 19:1.

| Table 19:1 |                                    | Color Encoding for 2-bit Sprites |
|------------|------------------------------------|----------------------------------|
| Color Code | Description                        |                                  |
| 00         | Transparent color, show background |                                  |
| 01         | Color 1                            |                                  |
| 10         | Color 2                            |                                  |
| 11         | Color 3                            |                                  |

So, the problem with transparency (other than the nightmare to implement it in the driver) is that one color encoding, namely Color 0, is used to represent transparent, thus we loose a whole color in our 2-bit encoding. Alas, one strategy is to have a flag in the sprite definition that indicates if you want the sprite to be “transparent,” otherwise, the color code 00 will just render over the background as opaque (whatever actual color it is).



**Scaling** — Having the ability to scale a sprite is very powerful. For example, by simply scaling a sprite by some factor, you can make it look larger or smaller (closer or farther), and get 3D effects. Implementing sprite scaling is usually quite easy once you have written the sprite rendering software (or designed the hardware) since it's mostly a matter of oversampling, undersampling or playing games with memory addresses; there is no real “scaling” going on. However, most sprite scaling systems only allows multiple-of-two scaling. Figure 19:9 shows a character from Ari Feldman's **"SpriteLib"** at 1:1 and then scaled 2× on the Y axis (making it taller). As you can see, the sprite still looks good, and could be used as another sprite or game character simply by scaling it. Thus, sprite scaling can also be used to create other characters from the sprites you have or character variations programmatically. One of the most famous examples of this is **"Wing Commander"** which was a 3D game on the PC implemented 100% via sprite scaling and transformations!



**Z-Ordering** — The last important feature of sprites is called “Z-ordering” which is more or less that sprites are drawn in some order, thus if you place one sprite on another, they will look like they are layered in 3D from back to front. Thus, this effect can be used to make sprites walk behind trees, etc. You can use one sprite as a tree or a rock for example, and one sprite for your walking character. As long as the walking character is rendered first, and the tree second, the tree will look like it's in front of the sprite. As an example, take a look at the Pitfall mock up in Figure 19:10, here we see a scorpion sprite behind a tree (top left), and player sprite in front of the trees (swinging on the vine). Thus, the order in which everything is rendered creates the illusion of 3D.

Alright, now that you have a good grasp on tile engines and sprites let's take a look at the first tile engine we are going to use to write the forthcoming demos with.

### 19.3 Our First Tile Engine – HEL GFX 4.0

The first tile engine we are going to experiment is named **HEL\_GFX\_ENGINE\_040.SPIN** and is 100% assembly language. The engine is located in **CD\_ROOT:\HYDRA\SOURCE** directory as usual along with all the other demos from this chapter. The engine was written over about 4 days with a number of rewrites to keep the code as simple to understand as possible and it's heavily commented. The idea of this book and source is for you to be able to use it yourself for education and experimenting, and if you can't understand it then it's worthless! So as an author I always defer to easy rather than clever, but sometimes features have to be removed to make that happen. Alas, I had a number of goals when creating this first engine:

1. The ASM code has to be straightforward, not too clever, but some cool techniques should be used.
2. The entire engine and NTSC driver has to fit in a single cog.
3. The programming interface has to be really easy as well as the data structures, be and similar to 8-bit game programming.
4. The tile engine should be a reasonable resolution and support multiple sprites.
5. Scrolling and page flipping should be supported.
6. Each tile should have its own color palette.

Taking all that into consideration, I came up with an engine with the following features for the HEL (**HYDRA Extreme Graphics Library**) GFX 4.0 engine:

### Tile Engine Specs

- ▶ Tiles are  $16 \times 16$ , 2 bits per pixel (4 colors per tile), each with its own palette.
- ▶ Each tile takes 16 LONGs of memory.
- ▶ Tile map is  $10 \times 12$  tiles physically ( $16 \times 12$  logically) at  $16 \times 16$  pixel tiles that equals a screen resolution of  $160 \times 192$ .
- ▶ The tile map can be 1, 2, 4, 8, 16, etc. screens wide, so large horizontal scrolling regions are possible.
- ▶ Index color palettes, with 256 palettes possible, each with 4 colors per tile.
- ▶ The tile map can be any vertical height in memory as long as there are at least 12 rows of data.
- ▶ The sprites can be disabled and not rendered.
- ▶ Horizontal, vertical, and other “state” information is passed back to the caller in real-time through a shared variable.

### Sprite Engine Specs

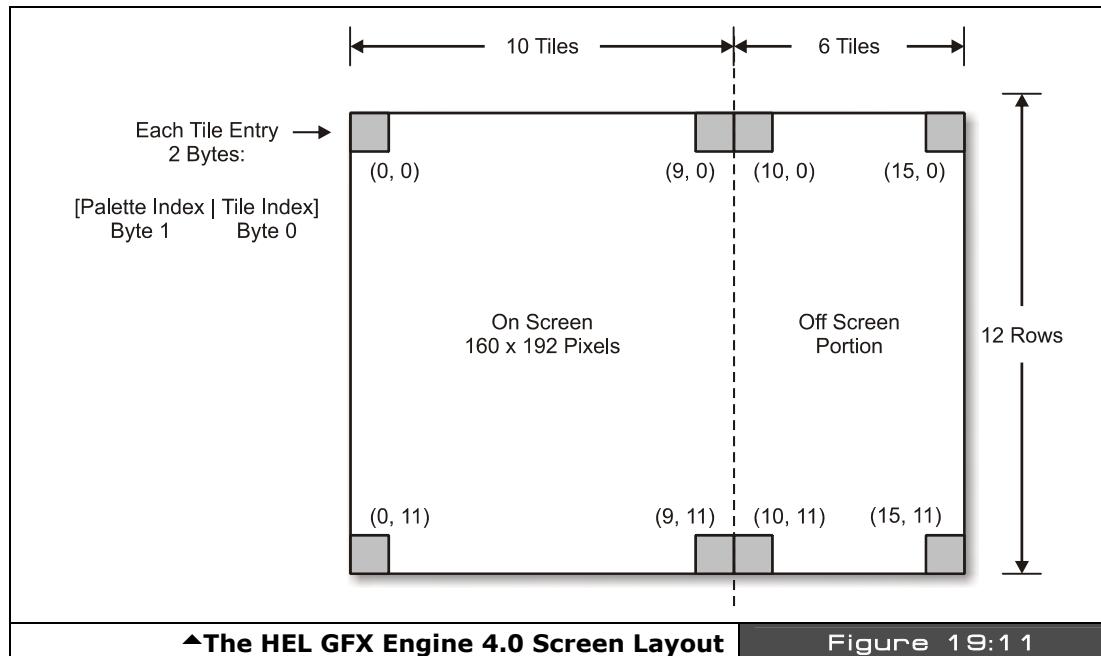
- ▶ Sprites are  $16 \times 16$ , no scaling currently, but only simple code changes are needed to support it later.
- ▶ Up to 8 sprites on the screen at once (with support for 12 before engine degrades).
- ▶ Up to 5 sprites on a single scan line at once.
- ▶ Sprites support transparency with 3 foreground colors mapped from tiles they overlay.
- ▶ Z-ordering of sprites, always rendered in order of sprite 0...n, so 3D effects possible.
- ▶ Sprites are clipped on edges of screen, so smooth on-screen / off-screen transitions are possible.
- ▶ Sprite motion de-coupled from tile engine scrolling, so they don't interfere with one another.
- ▶ Each sprite is composed of 16 LONGs for the sprite, plus 16 LONGs for the sprite mask.

As you can see, the engine isn't a bad start. Also, this isn't “version” 4.0 per se, but more like engine model 4.0. There are other engines with different features that I made, but this seemed the most appropriate for now.

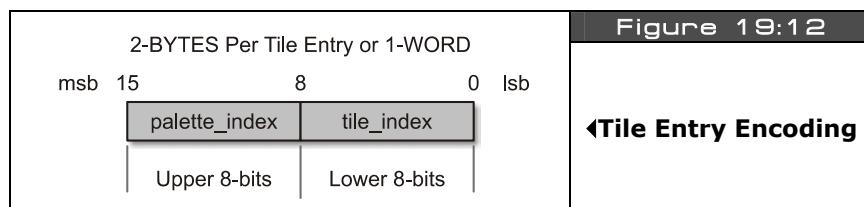
The engine has way too many features to review in this chapter, plus I am getting anxious to get to more game coding, so we are going to look at a subset of the features, look at the setup and data structures, see some demos (many of them actually) and then move on to the next chapter. The idea is to get you up to speed ASAP, you can always read the source yourself if you want to peek ahead!

Anyway, as outlined in the specs there is both the tile engine and the sprite engine that composes the graphics engine itself. You can turn sprites off as well and just use the tile engine alone if you like. Another little quirk of the engine is that each tile screen is  $16 \times 12$ , but only  $10 \times 12$  tiles are shown. This is so the math is easy, and you can scroll a few tiles without much work.

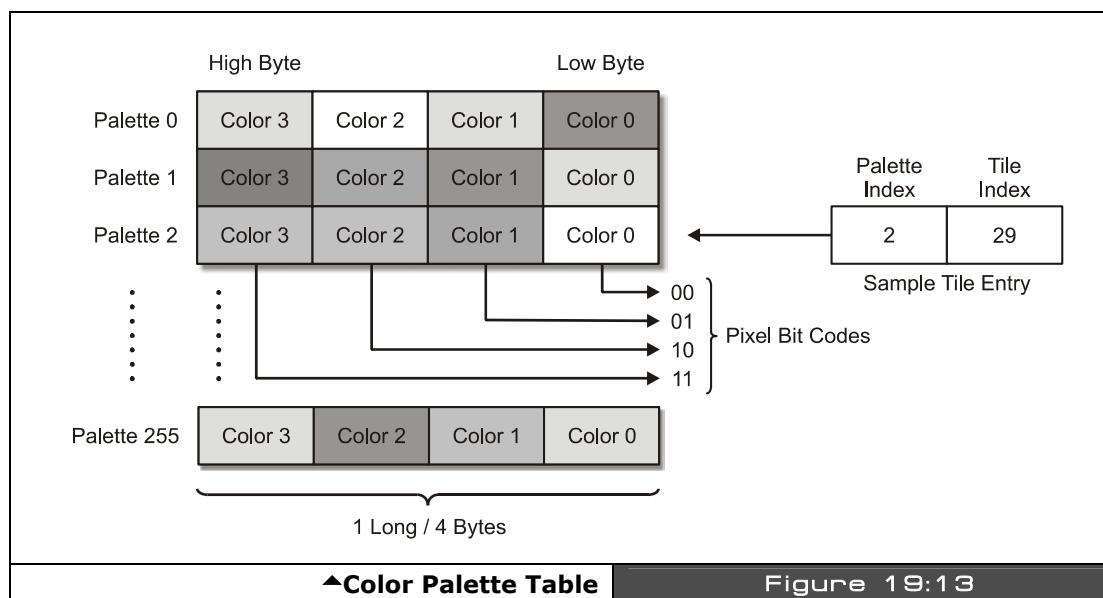
### 19.3.1 HEL GFX Engine 4.0 theory of operation



Now that you know the specifications of the engine, let's discuss the basic theory of operation (concentrating on the tile aspect only for now), that is, how you use it, set it up, the data structures and so forth. Then we will move onto the sprite engine component and some real demos and see it in action. Let's start by looking at Figure 19:11, this is the general layout of the graphics engine's tiles and sprites. As you can see, the origin of the tile engine is at the upper left hand corner of the screen, this is tile (0,0) while the lower right hand corner is tile (9, 11) on the visible screen. The tile map extends past the visible screen logically to column 15, but these tiles won't be visible unless you scroll the tile map.



Moving on, we see that each tile is composed of a single 2-BYTE WORD that contains the index to the tile (0..255) and the index to the palette you wish the tile to use (0..255) as shown in Figure 19:12. The high BYTE holds the palette index, the low BYTE holds the tile index. Although the engine comments say you can only have 64 palettes and 64 tiles, you can in fact have up to 256, but this would eat memory up, so *theoretically* 256 palettes and 256 tiles are the limits.



Each tile represents a bitmap that you would like displayed at that location, and the palette you wish it to use, as shown in Figure 19.11. The palette table can be up to 256 entries, where each entry represents a 4-color palette where the low BYTE is Color 0, and the high BYTE is Color 3. This is shown in Figure 19.13. The encoding of each color is standard VDU

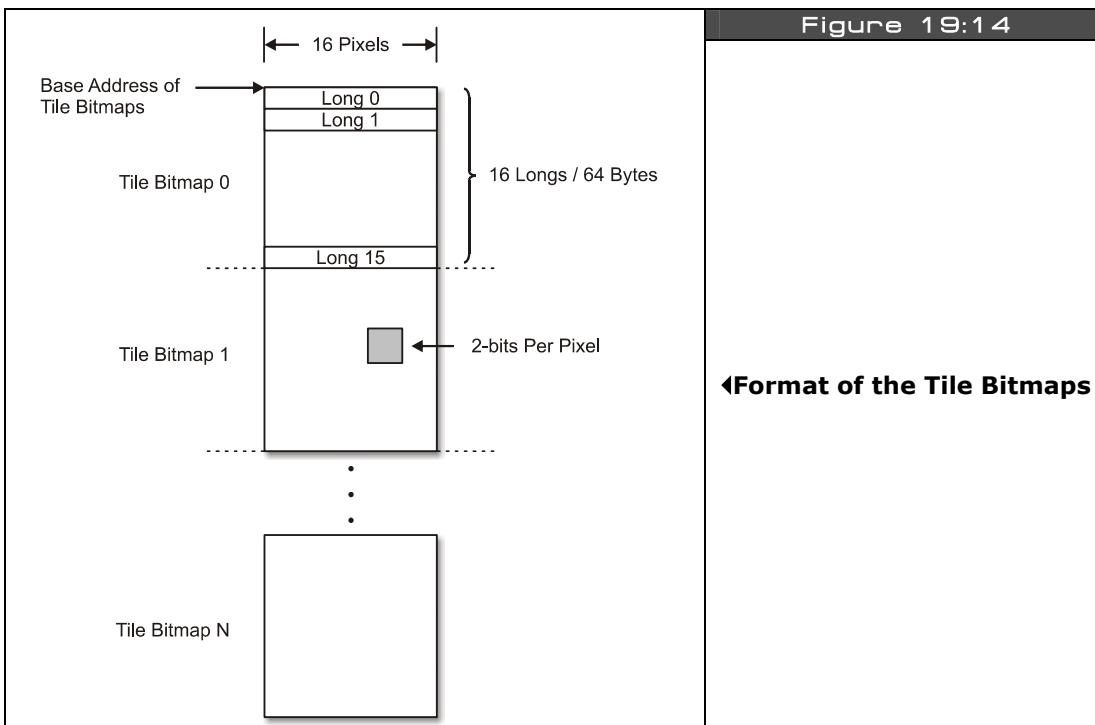
format where you need to put in the chroma, luma, etc. However, for reference I have created a named table of colors shown below in Table 19:2.

| Table 19:2   |  | Color Table Names and Values used by HEL GFX Engine 4.0▼ |              |            |              |
|--------------|--|--|--------------|------------|--------------|
| SHADES       |  | COLORS   |              |            |              |
| Color Name   | Binary Value   | Color Name   | Binary Value | Color Name | Binary Value |
| Black        | %0000_0010   | PowderBlue   | %1111_1_100  | Gold       | %0111_1_100  |
| Dark Grey    | %0000_0011   | Blue   | %1110_1_100  | Orange     | %0110_1_100  |
| Grey         | %0000_0100   | SkyBlue  | %1101_1_100  | Red        | %0101_1_100  |
| Light Grey   | %0000_0101   | AquaMarine   | %1100_1_100  | Violet Red | %0100_1_100  |
| Bright Grey  | %0000_0110   | Light Green  | %1011_1_100  | Pink       | %0011_1_100  |
| White        | %0000_0111   | Green  | %1010_1_100  | Magenta    | %0010_1_100  |
|              |  | GreenYellow  | %1001_1_100  | Violet     | %0001_1_100  |
|              |  | Yellow   | %1000_1_100  | Purple     | %0000_1_100  |
| <b>Note:</b> | (Last 3 bits controls LUMA, colors are all at LUMA value 4 in table) |  |              |            |              |


**NOTE**

Colors are in reverse order from Parallax drivers, or in order 0-360 phase lag from 0 = Blue, on NTSC color wheel so code \$0 = 0 degrees, \$F = 360 degrees, more intuitive mapping, and is 1:1 with actual hardware.

You can create a color palette with a single entry if you wish and then point all your tile palette indices to this single palette with the index equal to 0. After the tile palette index entry in the tile structure is the tile bitmap index itself, this index references one of 256 potential tiles you want displayed on the screen. Each tile is a 2-bit-per-color 16×16 bitmap, thus each tile takes 16 LONGs or 64 BYTES which isn't bad! Figure 19:14 on the next page shows the layout of the tile bitmaps. Each bitmap is 16 LONGs where each LONG represents one row of the tile bitmap. The tiles must be contiguous in memory, since the graphics engine locates the tile bitmaps based on the base address of the tile bitmaps plus the tile index \* 64, since there are 64 BYTES per tile.



To create the tiles, you can use a tool, or whatever, but for now we will hand enter them. For example, here's the tile bitmap for a Pacman ghost which we will use in upcoming demos:

```
' a ghost with eyes to left
tile_ghost_lt long %%0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0 ' tile 4
long %%0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0
long %%0_0_0_0_2_2_2_2_2_2_0_0_0_0_0
long %%0_0_0_2_2_2_2_2_2_2_2_2_2_2_0_0_0_0_0
long %%0_0_0_2_2_2_2_2_2_2_2_2_2_2_2_0_0_0_0
long %%0_0_0_2_2_2_2_2_2_2_2_2_2_2_2_2_0_0_0_0
long %%0_0_2_3_3_3_3_2_2_3_3_3_3_3_2_0_0
long %%0_0_2_3_3_3_3_2_2_3_3_3_3_3_2_0_0
long %%0_0_2_3_3_3_1_1_2_2_3_3_1_1_2_0_0
long %%0_0_2_3_3_1_1_2_2_3_3_1_1_2_0_0
long %%0_0_2_2_2_2_2_2_2_2_2_2_2_2_2_2_0_0
long %%0_2_2_2_2_2_2_2_2_2_2_2_2_2_2_2_2_0_0
long %%0_2_2_2_2_2_2_2_2_2_2_2_2_2_2_2_2_0_0
long %%0_2_2_0_0_2_2_0_0_2_2_0_0_2_2_0_0_2_2_0
long %%0_2_2_0_0_2_2_0_0_2_2_0_0_2_2_0_0_2_2_0
long %%0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0
```

The best way to see it is to blur your eyes and the image will form. Also, notice I am using the feature of the IDE where you can encode 2 binary bits with a single digit 0..3 if you use the %% directive, so it makes this kind of encoding very easy.

Looking at the bitmap, all the 2's are the general base color of the ghost, the 3's are the whites of his eyes, and the 1's are the color of his eyes. The 0's are background color (not transparent, tiles use all 4 colors) and in this case will actually be made black in the demo, but could be gray, blue, whatever as well. Remember, all these numbers 0,1,2,3 are really color references in the palette for the tile. And the palette for the tile is the high BYTE of the tile entry!

Of course, if you want more tile bitmaps you just put them one after another in your program until you run out of memory, and remember they are indexed 0..n as they are defined linearly in memory.



**To save the graphics engine a step, all tile bitmaps are read low bit to high bit, What this means is that the bitmaps are actually flipped on the horizontal axis, thus left is right, right is left like an image in the mirror. Thus, when you draw you bitamaps, draw them backwards or make your tool do it.**

That's about all there is to it. Here's a list of steps you need to set up for the tile engine so far:

**Step 1:** You need a  $16 \times 12$  array of tile entries where each entry is a WORD; the upper BYTE is the palette index and the lower BYTE is the bitmap index.

**Step 2:** You need at least one palette entry to reference for the tile set. Each palette entry is 1 LONG and each BYTE in the LONG represents the colors 0,1,2,3 as referenced by the 2-bit pairs in the tile bitmap. The color palette is in standard VSU format and the colors represented are those listed in Table 19:2. You can have up to 256 palettes if you want, but in most cases you will have only a few palettes or maybe one palette for each tile if you are really trying to be colorful.

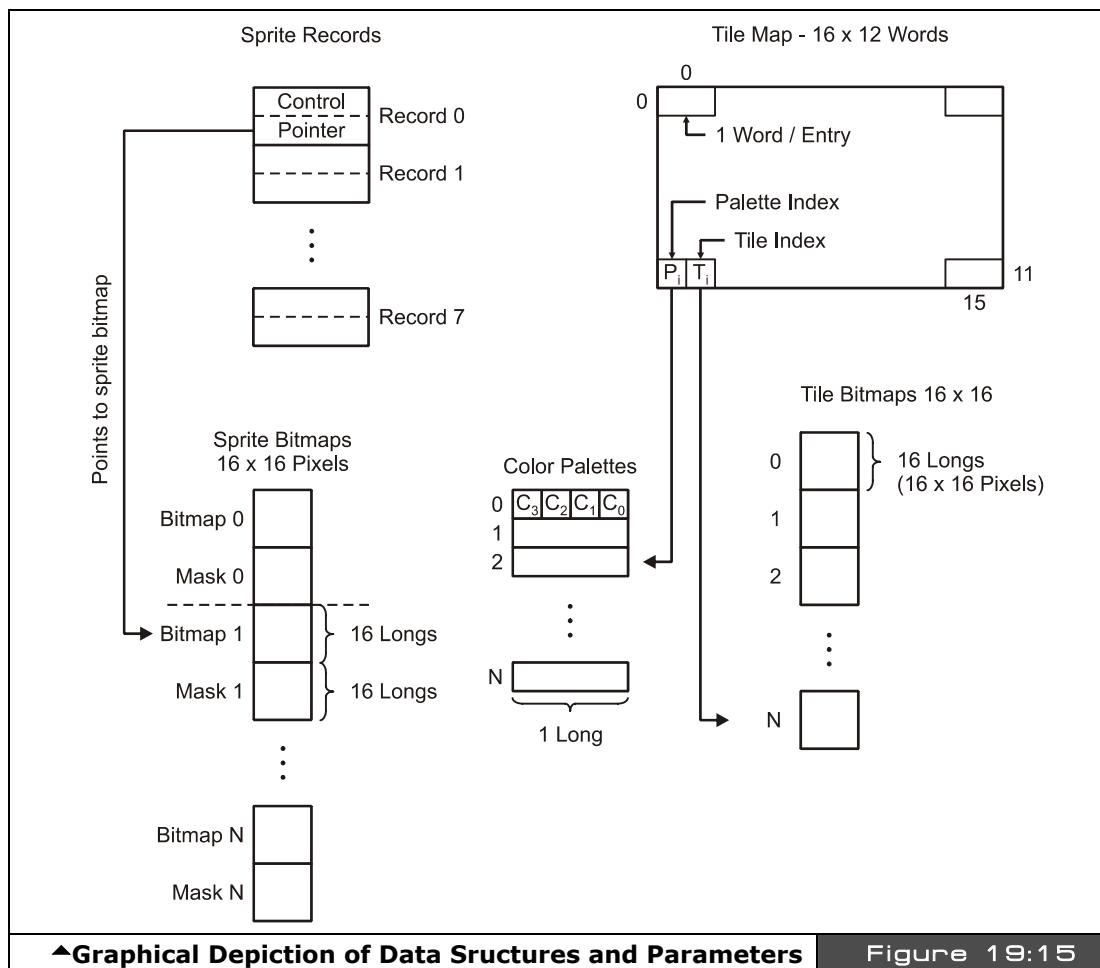
**Step 3:** The tile engine supports up to 256 tiles. Each tile is  $16 \times 16$  pixels, where each pixel is 2 bits, thus you need 1 LONG per row, or 16 LONGs per bitmap. Bitmaps are defined linearly in memory from top to bottom, index 0 to index n. And they are mirrored on the X-axis to save the graphics engine a step.

### 19.3.2 HEL GFX Engine API and Data Structures

In the previous section, we outlined the graphical data elements needed for the tile engine (we will get to the sprite engine shortly). We need a tile map, palettes, and some tile bitmaps. Once we have them, we should be able to tell the graphics engine where they are and we should see something on the screen, that's as simple as it gets! Alright, so again there are decisions to make about how to interface to the engine, but again instead of making it complicated and writing a zillion support functions to access variables, etc. I went with a memory-mapped approach like the old game systems do, so you just set some pointers and parameters and pass it to the engine and presto the engine starts working. So first off let's take a look at the parameters for the engine and what they control. There are a total of 6 parameters that control the interface to the graphics engine, that's it. We tell the graphics engine about them when we call the "Start" method and simply pass the base address of the first parameter in Spin memory. The parameters are shown below from the code demo itself:

```
long tile_map_base_ptr_parm      ' base address of the tile map
long tile_bitmaps_base_ptr_parm ' base address of the tile bitmaps
long tile_palettes_base_ptr_parm ' base address of the palettes
long tile_map_sprite_cntrl_parm  ' points to value that holds various "control"
                                ' values for the tile map	sprite engine
                                ' currently, encodes map width & no. of sprites
long tile_sprite_tbl_base_ptr_parm ' base address of sprite table
long tile_status_bits_parm       ' real-time engine status vars vsync, hsync, etc
```

This is a lot easier with a picture to see what goes where, so refer to Figure 19:15 for the explanation as well as the code listing above. As you can see, there are only 6 parameters and they are assumed to be in binary order as shown in the listing since the base address of the 1st parameter will be passed to the engine and it will index from there 0..5 to access each parameter. They control the following things: the base address of the tile map itself, the base address of the tile bitmaps, the base address of the palettes, general control and setup for the tile and sprite engine, the sprite table itself (more on this later), and finally a status WORD that can be read from the caller to see where the tile engine is. In Spin this isn't that useful, since Spin is about 200 times slower than ASM. But if you use the engine from another ASM module then special effects can be implemented on the fly by looking at the location of the raster, etc. which is returned in the status bits. Below is a detailed explanation of each parameter:



▲Graphical Depiction of Data Structures and Parameters

Figure 19:15

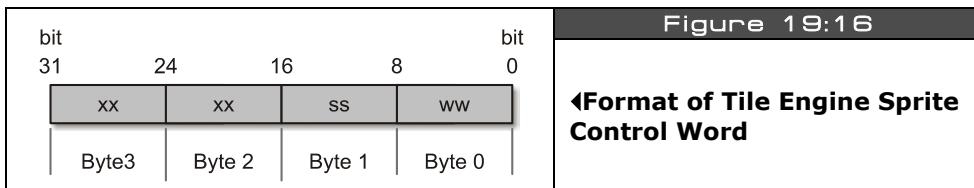
### Parameters to Graphics Engine

**long tile\_map\_base\_ptr\_parm** - This is the base address of your tile map(s). The tile map(s) must be on a WORD boundary and each tile map must be  $16 \times 12$  WORDS (or larger if scrolling is desired, but width must always be a 16, 32, 64, 128, or 256).

**long tile\_bitmaps\_base\_ptr\_parm** — This is the base address of the tile bitmaps, assumes that each tile bitmap is 16 LONGs and encoded as 2 bits per pixel. You must have at least a single tile bitmap for the engine to operate.

**long tile\_palettes\_base\_ptr\_parm** — This is the base address of the palette table which is used to color each tile. Each entry in the table is exactly 1 LONG and represents one single palette which can be indexed by each tile map entry. A minimum of one palette is needed for the tile engine to operate.

**long tile\_map\_sprite\_cntrl\_parm** — This, passed by value parameters, is the control interface to the tile/sprite engine. Currently, it only controls two features of the engine: the width of the tile map and the number of active sprites (0..8). The control word is a single LONG formatted as shown in Figure 19:16.



Where,

xx = don't care/unused.

ss = number of sprites to process 0..8.

ww = the number of "screens" or multiples of 16 that the tile map is. eg.

0 would be 16 wide (standard)

1 would be 32 tiles

2 would be 64 tiles, etc.

This allows multiscreen-width playfields and thus large horizontal/vertical scrolling games. Note that the final size is always a power of 2, multiple of 16, such as 16, 32, 64, 128 or 256.

**long tile\_sprite\_tbl\_base\_ptr\_parm** — This is the base address of the "sprite table" data structure. Each sprite is composed of 2 LONGs that define its position, bitmap, and other control aspects. More on this later. There can be up to 8 sprites, thus the data structure pointed to by this parameter is up to  $8 \times 8 = 64$  BYTES.

**long tile\_status\_bits\_parm** — Last, but not least, is the tile engine's status flags. This is passed as an address to the tile engine, so it can output real time "state" information back to the caller. It's mostly here for future expansion, and this particular engine only tracks Vsync and Hsync. The bit definitions are shown in Figure 19:17.

| Format of tile_status_bits_parm |                  |                           |               |                             |               |              |              |
|---------------------------------|------------------|---------------------------|---------------|-----------------------------|---------------|--------------|--------------|
| Byte 3<br>(unused)              | Byte 2<br>(line) | Byte 1<br>(tile position) |               | Byte 0<br>(sync and region) |               |              |              |
| x x x x x x                     | Line 8-bits      | Row 4 bits                | Column 4-bits | x x x x                     | Region 2-bits | H SYNC 1-bit | V SYNC 1-bit |
| b31...b24                       | b23...b16        | b15...b12                 | b11...b8      | b7...b4                     | b3...b2       | b1           | b0           |

Region 0 = Top Overscan, 1 = Active Video, 2 = Bottom Overscan, 3 = VSYNC  
Note: In this version of the tile engine only HSYNC, VSYNC and REGION are valid.

**▲ Bit Encoding for Tile Engine Status Bits**

Figure 19:17

So, all you have to do is create these data structures, instantiate a parameter list as outlined, and then point everything correctly and start the engine up. Let's do just that with an example.

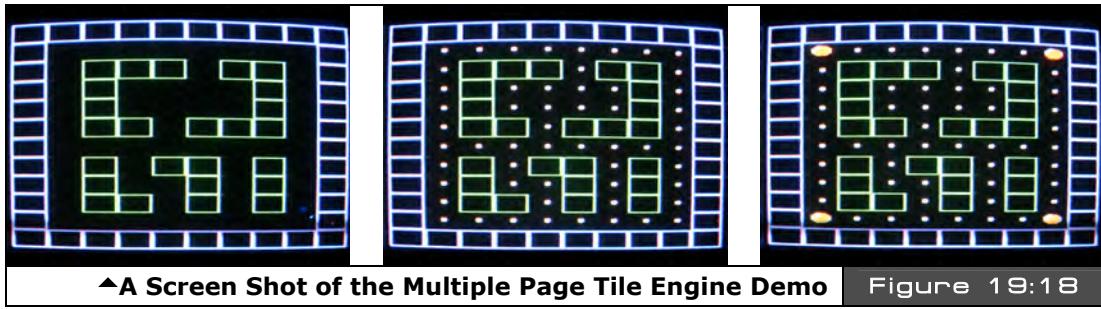
## 19.4 Using the HEL GFX 4.0 Tile Engine

I have created a number of demos to show you how to use the tile/sprite engine. Of course, since I had to draw the art by hand with numbers, don't expect HALO or anything! For the first set of demos, I decided on something that looked like Pacman since it's easy to draw and we all have an idea of what it should look like. Moreover, Pacman-type games are good examples of tile backgrounds with sprite foreground objects. And of course, in Pacman there are 4 ghosts, and the player, so sprite-wise it works out great if you want to complete the demo into a full-blown game.

Since the source code for all the demos is rather large and we are trying to save space here, what I am going to do is show you a lot of detail on the first demo's setup via code listings and then as the demos progress only show code listings of the important changes. Of course, you can always look on the CD for the full listings. So without further ado, let's take a look at all the demos.

### 19.4.1 Multiple Page Tile Engine Demo

For the first demo we are going to set up three tile pages, each  $16 \times 12$  tiles, then using the gamepad you can cycle through them. Figure 19:18 on the next page shows the three tile pages during runtime. Left to right, it shows the first tile page, the second tile page with the dots added, and the final tile page with the dots and power ups added. The cycling of the pages is simply an address change and happens within one frame update. Thus, this demo shows you how to set up the tile engine for a standard tile display, switch tile pages, and that's about it.



▲A Screen Shot of the Multiple Page Tile Engine Demo

Figure 19:18

You may wish to open the programs to view the complete source at a comfortable font size as we cover aspects of it; this file's name is **PACMAN\_TILE\_DEMO\_001.SPIN** and is in the source directory on the CD as usual. When the demo runs, simply press the **<SELECT>** button on the gamepad (plugged into the left port) to cycle through tile sets. Remember, we are NOT drawing anything new, only switching a single pointer!

```

DAT
tile_maps : you place all your 16x12 tile maps here, you can have as many as you like, in real-time simply re-point the
tile_map_base_ptr_parm to any time map and within 1 frame the tile map will update
the engine only renders 10x12 of the tiles on the physical screen, the other 6 columns allow you some "scroll room"
: 16x12 WORDS each, (0..191 WORDS, 384 bytes per tile map) 2-BYTE tiles (msb)[palette_index | tile_index](lsb)
: 16x12 tile map, each tile is 2 bytes, there are a total of 64 tiles possible, and thus 64 palettes
: <----- visible on screen ----->|<----- to right of screen ----->|
: column 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

' just the maze
tile_map0 word $00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01 : row 0
word $00_01,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00 : row 1
word $00_01,$00_00,$01_01,$01_01,$00_00,$01_01,$01_01,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00 : row 2
word $00_01,$00_00,$01_01,$00_00,$00_00,$01_01,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00 : row 3
word $00_01,$00_00,$01_01,$00_00,$00_00,$01_01,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00 : row 4
word $00_01,$00_00,$01_01,$00_00,$00_00,$01_01,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00 : row 5
word $00_01,$00_00,$01_01,$00_00,$00_00,$01_01,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00 : row 6
word $00_01,$00_00,$01_01,$00_00,$00_00,$01_01,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00 : row 7
word $00_01,$00_00,$01_01,$00_00,$00_00,$01_01,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00 : row 8
word $00_01,$00_00,$01_01,$00_00,$00_00,$01_01,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00 : row 9
word $00_01,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00 : row 10
word $00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01 : row 11

' maze plus dots
tile_map1 word $00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01 : row 0
word $00_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 1
word $00_01,$00_02,$01_01,$01_01,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 2
word $00_01,$00_02,$01_01,$00_02,$00_02,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 3
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 4
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 5
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 6
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 7
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 8
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 9
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 10
word $00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01 : row 11

' maze plus powerpills
tile_map2 word $00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01 : row 0
word $00_01,$00_03,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_03,$00_01,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00 : row 1
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 2
word $00_01,$00_02,$01_01,$00_02,$00_02,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 3
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 4
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 5
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 6
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 7
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 8
word $00_01,$00_02,$01_01,$01_01,$00_02,$00_02,$01_01,$01_01,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02,$00_02 : row 9
word $00_01,$00_03,$00_02,$00_02,$00_02,$00_02,$00_03,$00_01,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00,$00_00 : row 10
word $00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01,$00_01 : row 11

```

As you can see there are three tile maps, each  $16 \times 12$  WORDs, where each WORD is a single tile entry. Each tile map is complete and represents an entire screen of data that can be displayed by the engine, and we can flip or cycle through them at will by changing a single pointer. Now, take a look closely at the tile map data for the last tile map "tile\_map2" and note that the left most BYTE of each WORD is of course the palette index for the tile (most of them are \$00), while the rightmost BYTE is the actual tile index, in this it case ranges from \$00 - \$03, where these codes represent the following tiles as shown in Table 19:3 along with the label names of the actual bitmap data.

| Table 19:3 Tile Code Representations and Data Structures |  |                  |
|--|--|------------------|
| Tile Code  | Represents                               | Bitmap Data Name |
| \$00   | Blank tile used for background           | tile_blank       |
| \$01   | Box tile used to draw the maze geometry  | tile_box         |
| \$02   | Dot tile used to draw the maxe dots      | tile_dot         |
| \$03   | Powerup tile used to draw the 4 powerups | tile_powerup     |

So referring to Table 19:3, we see that tile index \$01 for example means use the bitmap from "tile\_box." This bitmap and all the others must be 16 LONGs that define the bitmaps for the actual tiles. Here's the actual declaration for the first two tile bitmaps "tile\_blank" and "tile\_box":

If you blur your eyes, you will easily be able to see the single wide pixel border in the box tile. Alright, so that's the data structures for the tiles; of course the dot and powerup are defined in the demo as well. Next, we need those palettes. When you run the program, you will see that there is a bit of color, so more than one palette is needed. As explained in the design discussions above, we know that each palette (up to 256 of them) represents the 4 colors that any tile can use via bit code 00, 01, 10,11. The palettes are a single LONG each, with one BYTE representing each color in VSU format, low BYTE is color 0, high BYTE is color 3. Here are the actual palettes for this demo:

```
' some pacman palettes...
palette_map    long $07_5C_0C_02 : palette 0 - background and wall tiles, 0-black,
                           1-blue, 2-red, 3-white
                  long $07_5C_BC_02 : palette 1 - background and wall tiles, 0-black,
                           1-green, 2-red, 3-white
```

That completes the outline of the data structures, now let's see how they are used by the engine setup. First, assuming that the VAR section has the set of the 6 parameters we need defined, then of course the tile engine object needs to be instantiated like so (along with the gamepad driver in this case):

```
OBJ
game_pad :      "gamepad_drv_001.spin"
gfx:          "HEL_GFX_ENGINE_040.SPIN"
```

...and we are ready to go. So we need to make the following connections before starting the tile engine:

1. Point the tile map pointer to the tile map we want displayed.
  2. Point the tile bitmap(s) pointer to the base of the tile bitmap definitions.
  3. Point the tile palette(s) pointer to the base of the tile palettes.
  4. Set the tile/sprite engine control parameters.

5. Point the sprite bitmap pointer to the base of the sprite bitmap data (0 for now).
6. Point the sprite data structure pointer to the base of the sprites records themselves (0 for now).

The last two steps we still have to do even though we aren't using sprites yet. The following code excerpt shows how this is all done in the demo:

```
' set up tile and sprite engine data before starting it, so no ugly startup
' points ptrs to actual memory storage for tile engine
tile_map_base_ptr_parm      := @tile_map0
tile_bitmaps_base_ptr_parm   := @tile_bitmaps
tile_palettes_base_ptr_parm := @palette_map

' these control the sprite engine, all 0 for now, no sprites
tile_map_sprite_cntrl_parm   := $00_00 ; 0 sprites, tile map set to 0,
                                ; where 0=16 tiles wide
                                ; 1=32 tiles, 2=64 tiles, etc.
tile_sprite_tbl_base_ptr_parm := 0
tile_status_bits_parm        := 0
```

Then last but not least we call the "start" method of the tile engine object with the address of the first parameter in the parameter passing area, and it will start running.

```
' launch a COG with ASM video driver
gfx.start(@tile_map_base_ptr_parm)
```

At this point, we should see the first tile map as shown in Figure 19:18(left) on the TV screen. Now, the next step is to control the current page shown, this is nothing more than a matter of reading the controller input and cycling through the pages of tiles. Here's the entire main event loop that does that:

```
' enter main event loop...
repeat while 1
    ' main even loop code here...

    if (game_pad.button(NES0_SELECT))
        select next tile map...
        if (++tile_map_index > 2)
            tile_map_index := 0

    ' set proper tile map (can you think of another way to do this?
    ' lookup, or fixed math offsets?)
    case tile_map_index
    0:
        tile_map_base_ptr_parm := @tile_map0
    1:
        tile_map_base_ptr_parm := @tile_map1
```

```

2:
tile_map_base_ptr_parm := @tile_map2

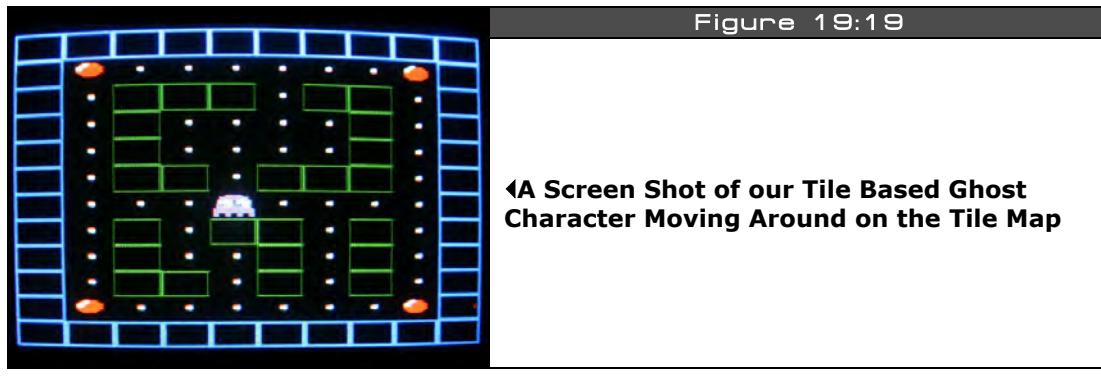
' wait a moment...
repeat 100_000

' return back to repeat main event loop...

```

Pretty cool huh? In 10 lines of code or so, we are flipping through multiple pages of tiles which in this case are not that exciting, but they could be levels in an adventure game, or rooms, or whatever. The code that actually makes the change is in the **case** statement, any change made to **tile\_map\_base\_ptr** will be shown on the next frame, since the tile engine is “watching” this pointer. Thus, this simple memory-mapped interface works quite well to control the engine without a bunch of function calls! Anyway, make sure to take a close look at the whole program in its entirety **PACMAN\_TILE\_DEMO\_002.SPIN**. Now, let’s move on to something a little more exciting...

#### 19.4.2 Moving a Tile Based Character Around the Screen



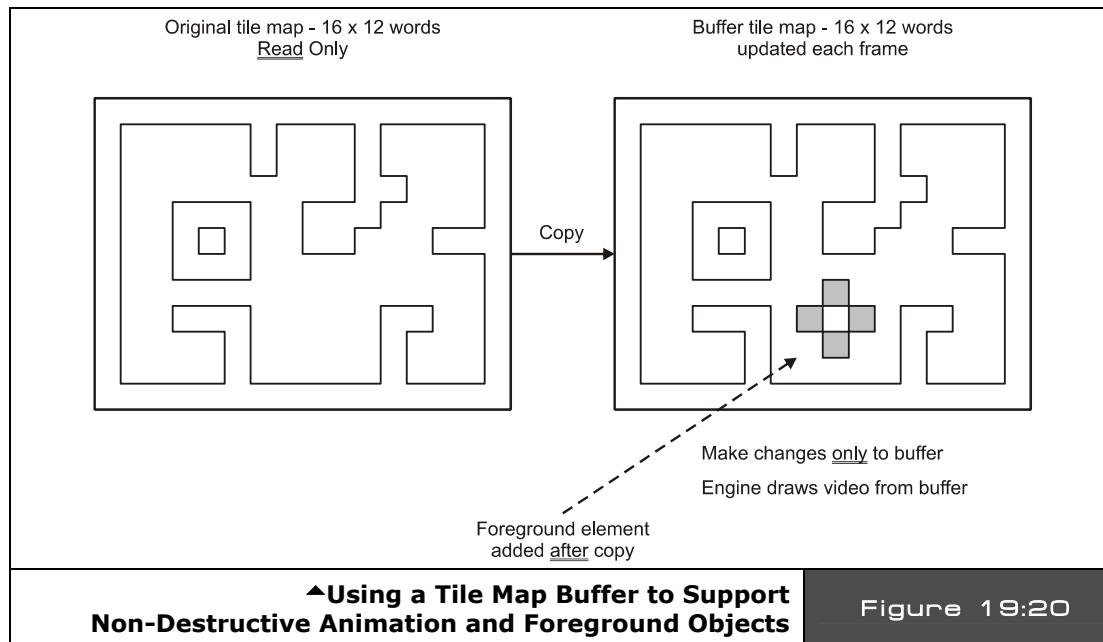
For the next demo, we are going to move an object around the tile map. Figure 19:19 shows a screen shot of the next demo for this section running. The demo’s name is **PACMAN\_TILE\_DEMO\_002.SPIN** and it’s almost identical to the last demo except for the fact that I have added a ghost that you can move around. I know, I know, in Pacman you control the little yellow pacman, but I like being the bad guy, so we are the ghost! In any event, there are a couple important concepts to understand that are brought to light by this demo. The first is that, as noted before when working with tile graphics, we can only move a tile-based object a tile at a time, we can’t move it on sub-tile boundaries. Go ahead and play with the demo to see this for yourself, **run PACMAN\_TILE\_DEMO\_002.SPIN** and control the ghost with the gamepad’s dpad. See how it only moves a whole tile in each direction?

This is “ok” but it would be much nicer if it were smooth depending on your goals for gameplay and taste. Nonetheless, without sprites, we have quite a powerful engine here even with moving objects on tile boundaries. Also notice that as the ghost moves it “destroys” the tiles under it. This is because I purposely didn’t “save” them, I simply overwrote the actual tile map data itself with the ghost tile and when I move the ghost tile, I put a blank in its last position. This is a destructive form of animation, and if it’s what you want then great, otherwise, you have to use another approach if you don’t want the tiles disturbed. Basically, the destructive motion algorithm is:

### Destructive Tile Map Motion

If player moves ghost then...

1. Draw a blank where ghost is right into tile map data.
2. Move ghost’s coordinates based on controller’s input.
3. Draw ghost at new position right into tile map data overwriting data there.



But, if you don’t want to disturb the tiles then you have to do something different. For example, save the tile under the ghost, or maybe **copy** the entire tile map to a buffer each frame, then draw on top of the buffer destructively with the ghost or whatever, then point the tile map engine to the buffer instead of the source data. This way you never lose your

source tile map or destroy or damage it in any way. The only cost of the method is the memory for the tile map buffer (small) and the copy operation (small). All in all, this is the easiest way to perform complex layered animation with tile engines. Simply create a tile buffer, copy your source tile map into each frame, copy your foreground tiles onto it, then point your tile map engine base point to it, and presto, perfect, flicker-free animation (we will get to this later on with a demo as well). Figure 19:20 shows this architecture graphically.

Now that you know what we are doing, let's see the important code changes. First, we are simply going to use the 3<sup>rd</sup> tile map set, but the data is the same, so the tile map data is just like it was in the last demo. The only addition really is the new ghost character; we need a tile bitmap for it, which is down in the DAT section of the demo source. But, I have added a little feature to make this demo a little more interesting and that is to have 4 different bitmaps for the ghost, each with the ghost's eyes pointing in one of four directions: right, left, up and down (more or less), thus we need 4 bitmaps to make this happen, here they are:

Again, try blurring your eyes and staring at the page a moment and you will see the ghosts and even their eyes! To make the ghost move around, we need some variable to track its tile position along with a state variable to track which way the ghost is looking (or was moved last). Then we simply take that state variable and add it to the base of tile index of the ghost tiles (4 in this case), and write it right into the tile map data, and presto you will see the ghost moving around the tile map maze. Lastly, to add a little more color, I added another palette to the demo, so the ghost also destroys not only the tile index it is drawn on, but purposely overwrites the tile's palette index as well. Here are the new palettes:

```
' some pacman palettes...
palette_map    long $07_5C_0C_02 : palette 0 - background and wall tiles, 0-black,
                1-blue, 2-red, 3-white
                long $07_5C_BC_02 : palette 1 - background and wall tiles, 0-black,
                1-green, 2-red, 3-white
                long $07_2C_0C_02 : palette 2 - background and wall tiles, 0-black,
                1-green, 2-violet, 3-white
```

The ghost's palette index is "\$02", so you will see this updates in the ghost data write as well. Taking all this into consideration, here's the main even loop that does everything:

```
' enter main event loop...
repeat while 1

    ' main even loop code here...

    ' draw the ghost tile by overwriting the screen tile word destructively, both
    ' the palette index and the tile index
    ' note the add of "ghost_dir", this modifies the tiles, so we can see the ghost
    ' turn right, left, up, down as he moves.

    ' test if player is trying to move ghost, if so write a blank tile at current
    ' location overwriting tile index and palette, then move ghost
if (game_pad.button(NES0_RIGHT))
    ' clear tile
    tile_map2[ghost_tx + ghost_ty << 4] := $02_00
    ' move ghost
    ghost_tx++
    ' set eye direction, which affects tile selected during rendering.
    ghost_dir := GHOST_TILE_RIGHT

if (game_pad.button(NES0_LEFT))
    ' clear tile
    tile_map2[ghost_tx + ghost_ty << 4] := $02_00
    ' move ghost
    ghost_tx--
    ' set eye direction, which affects tile selected during rendering.
    ghost_dir := GHOST_TILE_LEFT

if (game_pad.button(NES0_UP))
    ' clear tile
    tile_map2[ghost_tx + ghost_ty << 4] := $02_00
    ' move ghost
    ghost_ty--
    ' set eye direction, which affects tile selected during rendering.
    ghost_dir := GHOST_TILE_UP

if (game_pad.button(NES0_DOWN))
    ' clear tile
    tile_map2[ghost_tx + ghost_ty << 4] := $02_00
    ' move ghost
    ghost_ty++
    ' set eye direction, which affects tile selected during rendering.
    ghost_dir := GHOST_TILE_DOWN

    ' bounds check ghost, keep it on screen, use SPIN operators for bounds testing
ghost_tx <#= 9 ' if (ghost_tx > 9) then ghost_tx = 9
ghost_tx #>= 0 ' if (ghost_tx < 0) then ghost_tx = 0
```

```

ghost_ty <#= 11 ' if (ghost_ty > 11) then ghost_tx = 11
ghost_ty #>= 0 ' if (ghost_ty < 0) then ghost_ty = 0

' draw ghost down
tile_map2[ghost_tx + ghost_ty << 4] := $02_04 + ghost_dir

' delay a moment, otherwise everything will blur!
repeat 20_000

```

The main loop is nothing more than a gamepad query, where each direction has a small code body that updates the direction of the ghost, the tile map, and actual position of the ghost. The last section of code does some bounds-checking and if the ghost is off the tile screen wraps him around, lastly one last render pass is done and the ghost is drawn on the screen. Also, there is a little time delay to slow the process down since moving a single tile around is **really** fast! Try commenting out the delay code and see how fast Spin moves the ghost. Imagine all the tile based games you can make with Spin and this little tile engine!

Moving forward, the demo is pretty brutal to the poor maze. The next step is to add some kind of collision detection with the ghost and the maze, and if the ghost is banging into a wall of the maze we don't want the ghost to go through it. On the other hand, if the ghost is eating up dots or powerups, that is perfectly legitimate. Thus, we need to add some code to make this happen that tests where the ghost is trying to go, and if there is a wall there, the ghost is backed up. This is implemented by simply saving the current tile position of the ghost, then computing where the player is trying to move the ghost, and testing that tile; if the tile is a wall, the move is disregarded, else the move is allowed.

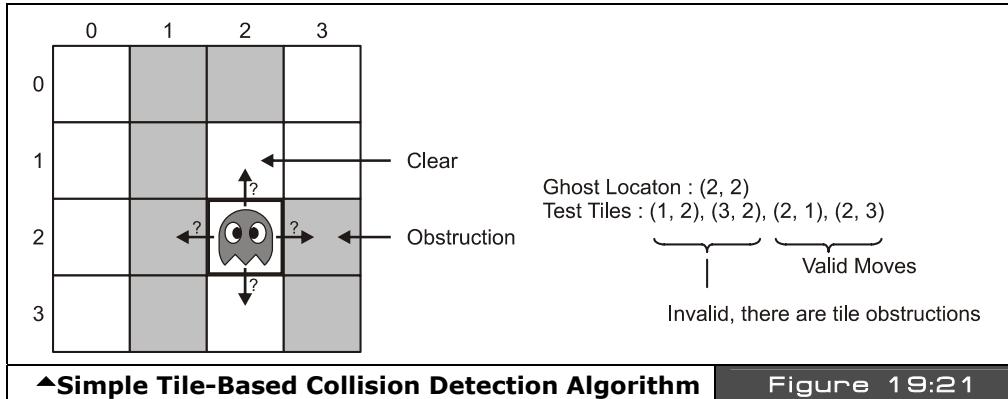


Figure 19:21

Figure 19:21 shows this graphically. To see this algorithm in action take a look at the next demo **PACMAN\_TILE\_DEMO\_003.SPIN**. Go ahead and load it into the HYDRA and try

moving the ghost around the game maze. As you can see, it can't go through walls anymore, but it eats the dots and powerups as it should. Of course, the ghost doesn't "know" it's eating dots and powerups, but this is easy to code as well, you simply test the tile the ghost is moving into and if it's a dot, you give the player some points, and if it's a powerup, you do whatever the "powerup" does! The code that implements all this motion and collision control from the demo is listed below for you reference:

```
' enter main event loop...
repeat while 1

    ' main even loop code here...

    ' draw the ghost tile by overwriting the screen tile word destructively, both
    ' the palette index and the tile index
    ' note the add of "ghost_dir", this modifies the tiles, so we can see the ghost
    ' turn right, left, up, down as he moves.

    ' test if player is trying to move ghost, if so write a blank tile at current
    ' location overwriting tile index and palette, then move ghost

    ' store old ghost position in case we need to back up
old_ghost_tx := ghost_tx
old_ghost_ty := ghost_ty

    ' now move ghost, ok to obliterate tile he is on always
if (game_pad.button(NES0_RIGHT))
    ' move ghost
    ghost_tx++
    ' set eye direction, which affects tile selected during rendering.
    ghost_dir := GHOST_TILE_RIGHT

if (game_pad.button(NES0_LEFT))
    ' move ghost
    ghost_tx--
    ' set eye direction, which affects tile selected during rendering.
    ghost_dir := GHOST_TILE_LEFT

if (game_pad.button(NES0_UP))
    ' move ghost
    ghost_ty--
    ' set eye direction, which affects tile selected during rendering.
    ghost_dir := GHOST_TILE_UP

if (game_pad.button(NES0_DOWN))
    ' move ghost
    ghost_ty++
    ' set eye direction, which affects tile selected during rendering.
```

```

ghost_dir := GHOST_TILE_DOWN

{ we can add "PLAYFIELD" collision detection here, the idea is simple in tile
graphics test where the player is going and if he is going to intersect a solid
object then back him up to his previous position, a number of ways to code it, up
to you }

' test tile player is about to be rendered on, if background tile(s) is there
' back him up!
' retrieve tile only
test_tile := (tile_map2[ghost_tx + ghost_ty << 4] & $00_FF)

if (test_tile == $01) ' tile index of background tile
    ' reset position, player is trying to drive through a wall!
    ghost_tx := old_ghost_tx
    ghost_ty := old_ghost_ty
else
    ' clear the old tile position
    tile_map2[old_ghost_tx + old_ghost_ty << 4] := $02_00

' bounds check ghost, keep it on screen, use SPIN operators for bounds testing
ghost_tx <#= 9 ' if (ghost_tx > 9) then ghost_tx = 9
ghost_tx #>= 0 ' if (ghost_tx < 0) then ghost_tx = 0

ghost_ty <#= 11 ' if (ghost_ty > 11) then ghost_ty = 11
ghost_ty #>= 0 ' if (ghost_ty < 0) then ghost_ty = 0

' draw ghost down at new position
tile_map2[ghost_tx + ghost_ty << 4] := $02_04 + ghost_dir

' delay a moment, otherwise everything will blur!
repeat 20_000

```

Well, that's about it for basic tile graphics, later we will see scrolling and other special effects as we need them through the book, but you have more than enough now to create a multitude of tile based games. With that in mind, let's move onto adding sprites into the display.

#### 19.4.3 Adding Sprites to the Tile Engine

Adding sprites to the tile engine is easy since they are already in there more or less, we simply haven't turned them on. The important data structure pointers are once again these variables:

```

tile_map_sprite_cntrl_parm
tile_sprite_tbl_base_ptr_parm

```

...where the first controls the tile / sprite itself, and the second is the pointer to the base of the sprite bitmaps, so all we need to do is indicate there are 1 or more sprites via the ***tile\_map\_sprite\_ctrl\_parm*** variable, and point ***tile\_sprite\_tbl\_base\_ptr\_parm*** to the sprite records themselves (which are each two LONGs) and that's about it. Of course, we need one or more sprite bitmaps (and mask), but that's it. So let's do this step by step with another demo as the platform. Take a look at demo **PACMAN\_TILE\_DEMO\_004.SPIN**, go ahead and run it and you will see the ghost sprite on the screen, try moving it around now...see how smoothly it moves, and it clips to the edges of the screen. This is a sprite, and they are pretty cool. Also, note that the "eyes" of the ghost use the same color as the foreground objects, so as the ghost moves over tiles, you will see his eyes change colors. This is unavoidable since each sprite only gets 3 colors, but I call it a "**feature**" ☺.

The sprite demo itself implements the changes discussed in the paragraph above, so let's take a look at the code elements one by one. First off we need the ghost bitmap **and** we need the ghost mask. Here they are from the demo:

```
' sprite bitmap table
' each bitmap is 16x16 pixels, 1 long x 16 longs
' bitmaps are reflected left to right, so keep that in mind
' they are numbered for reference only and any bitmap can be assigned to any sprite through the use of
' the sprite pointer in the sprite header, this allows easy animation without data movement
' additionally, each sprite needs a "mask" to help the rendering engine, computation of the mask is
' too time sensitive, thus the mask must follow immediately after the sprite

sprite_bitmaps      long

' bitmap for sprite use, uses the palette of the tile its rendered into
sprite_bitmap_0      long    %x0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0
long    %x0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0
long    %x0_0_0_0_2_2_2_2_2_2_0_0_0_0_0_0_0
long    %x0_0_2_2_2_2_2_2_2_2_2_2_2_0_0_0_0_0
long    %x0_0_2_2_2_2_2_2_2_2_2_2_2_2_0_0_0_0
long    %x0_0_2_3_3_3_3_2_2_3_3_3_3_2_0_0
long    %x0_0_2_3_3_3_3_2_2_3_3_3_3_2_0_0
long    %x0_0_2_1_1_3_3_2_2_1_1_3_3_2_0_0
long    %x0_0_2_1_1_3_3_2_2_1_1_3_3_2_0_0
long    %x0_0_2_2_2_2_2_2_2_2_2_2_2_2_0_0
long    %x0_0_2_2_2_2_2_2_2_2_2_2_2_2_0_0
long    %x0_0_2_2_2_2_2_2_2_2_2_2_2_2_0_0
long    %x0_0_2_2_2_2_2_2_2_2_2_2_2_2_0_0
long    %x0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0
long    %x0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0

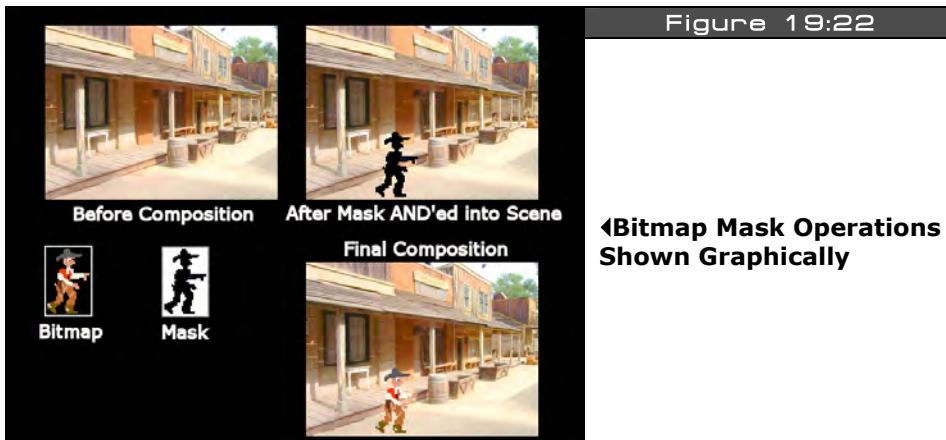
' the mask needs to be a NEGATIVE of the bitmap, basically a stencil where we are going to write the
' sprite into, all the values are 0 (mask) or 3 (write thru) however, the algorithm needs a POSITIVE to
' make some of the shifting easier, so we only need to apply the rule to each pixel of the bitmap:
' if (p_source == 0) p_dest = 0, else p_dest = 3
```

Take a close look at the sprite bitmap at the top of the listing, this is the actual sprite data where color 0 means transparent, and colors 1,2,3 mean use colors 1,2,3 from the palette index entry for that tile. Thus a sprite can change colors as it moves based on the tiles it's on. Anyway, the sprite bitmap is straightforward, but the bitmap *mask* takes a bit of explanation.

#### **19.4.3.1 Bitmap Masks**

When you write bitmapped graphics engines you very quickly come to the realization, that computers aren't magical, and they have no idea what you want, thus you have to do ***everything*** yourself, you are responsible literally for every pixel on the screen. This means that such a seemingly simple operation as drawing a sprite on top of the tiles is very hard. The reason why is that there is a lot of data there; we have the tile bitmap data, and the sprite bitmap data, to combine them we just can't overwrite the data. We first must make a ***"hole"*** where we want the sprite to go in the tile data. To make matters worse, this is all happening line by line, tile by tile, plus throw in caching and speed requirements and you end up with the Mensa entrance exam more or less!

Given that, one of the operations needed is to write one bitmap on another without disturbing the bitmap underneath; in the areas that are supposedly transparent in the top bitmap, you have to mask off the bitmap under the operation, then logically OR the new bitmap data into the zero'ed out hole. Of course, you can do this with pure code and derive the mask on the fly, but this takes a little more time than we have with this sprite engine, plus I wanted you to see this since its very common on gaming consoles and graphics hardware to have to supply your own masks. Even Microsoft Windows needs masks for cursors and whatnot!



Anyway, it's best to start with a drawing so you can see what we need to do graphically, take a look at Figure 19:22. Referring to the figure, you see a background that we want to draw a sprite into, then you see a mask that looks like a shadow of the sprite. The mask is used to cut the hole out via a logical AND operation, then once the hole is cut out, we logically OR the sprite data into the background and everything looks correct. This is what the mask bitmap is for, to cut a hole (if you are a Photoshop person then you do this all the time). The format of the mask for this engine is simple: you copy your original bitmap, then anywhere you have a non-zero value you make it 3, this more or less create a 2-bit positive mask everyone there is color, and since 0 represents transparent this works fine. The engine takes the bitmap and the mask for the sprite and does the rest.

So the tradeoff is that for every 64-BYTE sprite we need a 64-BYTE mask. However, if I was smarter in my data structures, then we could have a separate pointer for the bitmap and the mask, thus we could reuse masks that were the same. That is, if the shape of a bitmap was the same, but only the colors changed inside it, then the same mask would work, saving 64 BYTES each time this was the case. Alas, not this time around, the sprite engine assumes that each sprite is 64 BYTES, followed by a 64-BYTE mask, thus a total of 128 BYTES make up each sprite data set. However, the good news you can at least point multiple sprite records to the **same** sprite data and mask and reuse that at least.

Alright, now that we have the sprite data and mask under control, we need to define a sprite record or structure. As outlined earlier in the chapter, each sprite record is composed of two LONGs in the following format: the first is a control/state LONG (broken into 4 bytes), followed by a LONG ptr to the bitmap data, the format of the control/state LONG is shown in Figure 19:23. Note that only the enabled flag is supported currently, the other flags are for future expansion and place holders. The 2<sup>nd</sup> LONG is simply a pointer to the bitmap data followed by the mask.

| Sprite Header Format          |                               |                               |                               | Figure 19:23               |
|-------------------------------|-------------------------------|-------------------------------|-------------------------------|----------------------------|
| Long 0 - state/control bits   |                               |                               |                               |                            |
| Byte 3                        | Byte 2                        | Byte 1                        | Byte 0                        |                            |
| $y_7 y \ y \ y \ y \ y \ y_0$ | $x_7 x \ x \ x \ x \ x \ x_0$ | $z_7 z \ z \ z \ z \ z \ z_0$ | $s_7 s \ s \ s \ s \ s \ s_0$ |                            |
| y - pos                       | x - pos                       | z - pos                       | state/control bits            |                            |
| State/Control bits flags      |                               |                               |                               | ◀ The Sprite Record Format |
| Enabled                       | %00_000_0_0_1 (supported)     |                               |                               |                            |
| Mirrorx                       | %00_000_0_1_0                 |                               |                               |                            |
| Mirry                         | %00_000_1_0_0                 |                               |                               |                            |
| Scale1x                       | %00_000_0_0_0                 |                               |                               |                            |
| Scale2x                       | %00_001_0_0_0                 |                               |                               |                            |
| Scale4x                       | %00_010_0_0_0                 |                               |                               |                            |
| Scale8x                       | %00_100_0_0_0                 |                               |                               |                            |
| Raster_OP                     | %xx_000_0_0_0                 |                               |                               |                            |



Sprites have NO palette, they "use" the palette of the tile(s) that they are rendered onto, thus your sprites will change colors as they move over tiles.

Considering the information in Figure 19:23, all we need to do is set the x,y bytes and enable the sprite and we are good to go. Of course, we have to point the 2nd LONG of the sprite record to the bitmap data itself so the engine can get to it, plus we have to tell the tile engine there are some sprites to render with the general control variable. Here's how you would define the sprite records themselves in your DAT section:

```
' sprite table, 8 sprites, 2 LONGs per sprite, 8 LONGs total length
    sprite 0 header
sprite_tbl    long $00_00_00_00      : state/control word: y,x,z,state,
                long $00_00_00_00      : bitmap ptr

    ' sprite 1 header
    long $00_00_00_00      : state/control word: y,x,z,state
    long $00_00_00_00      : bitmap ptr

    ' sprite 2 header
    long $00_00_00_00      : state/control word: y,x,z,state
    long $00_00_00_00      : bitmap ptr

    ' sprite 3 header
    long $00_00_00_00      : state/control word: y,x,z,state
```

```

        long $00_00_00_00    ' bitmap ptr

        ' sprite 4 header
        long $00_00_00_00    ' state/control word: y,x,z,state
        long $00_00_00_00    ' bitmap ptr

        ' sprite 5 header
        long $00_00_00_00    ' state/control word: y,x,z,state
        long $00_00_00_00    ' bitmap ptr

        ' sprite 6 header
        long $00_00_00_00    ' state/control word: y,x,z,state
        long $00_00_00_00    ' bitmap ptr

        ' sprite 7 header
        long $00_00_00_00    ' state/control word: y,x,z,state
        long $00_00_00_00    ' bitmap ptr

' end sprite table

```

Then in your mainline you would actually write into these records the values you are interested in, for example, in this demo we only need one sprite, so we only need to set up sprite record 0, thus in the code you will see something like this:

```

' enable/initialize a sprite
sprite_tbl[0] := $70_50_00_01      ' sprite 0 state: y=xx, x=$xx, z=$xx,
                                    ' enabled/disabled
sprite_tbl[1] := @sprite_bitmap_0 ' sprite 0 bitmap ptr

```

...which enables the sprite (the \$01 in the low BYTE), and sets the sprite's position to x=\$50, y=\$70 (about the middle of the screen). Then lastly, the only thing left is when we set up the tile engine initially, we need to tell it there is 1 sprite rather than 0 as we have been doing. Here's the changes to the setup variables:

```

' points ptrs to actual memory storage for tile engine
tile_map_base_ptr_parm := @tile_map2
tile_bitmaps_base_ptr_parm := @tile_bitmaps
tile_palettes_base_ptr_parm := @palette_map
tile_map_sprite_cntrl_parm := $00_00_01_00 ' set for 1 sprites and width 16
                                                ' tiles (1 screens wide), 0 = 16
                                                ' tiles, 1 = 32 tiles, 2 = 64 tiles,
                                                ' 3 = 128 tiles, etc.
tile_sprite_tbl_base_ptr_parm := @sprite_tbl[0]
tile_status_bits_parm := 0

```

Notice how we set ***tile\_sprite\_tbl\_base\_ptr\_parm*** to point to the base address of the sprite table ***@sprite\_tbl[0]***. This is very important, don't forget. But, also realize you can

on-the-fly change to another sprite table at will: the interface is totally programmable, it will update within one frame of a change, so you can play all kinds of games with sprites, tiles, etc. Now, that you have seen all the pieces, let's review the steps to get sprites working with the tile engine.

### Steps to Setting up the Sprite Engine

**Step 1:** You need to define some actual sprite bitmap data along with a mask that follows it.

**Step 2:** You need to allocate a sprite record table with room for 8 sprites (even if you don't use them, this is a good idea).

**Step 3:** You need to set up your sprite table entries for each sprite you want to use. Each entry is two LONGs: one for the state/control of the sprite, the other is a pointer to the bitmap data for the sprite.

**Step 4:** You need to tell the tile engine there is 1 or more sprites and it will start rendering.

That's it!

The demo does all this setup and then falls into the main loop which consists of even less code than the tile engine demos to move an object:

```
' enter main event loop...
repeat while 1
    ' main event loop code here...

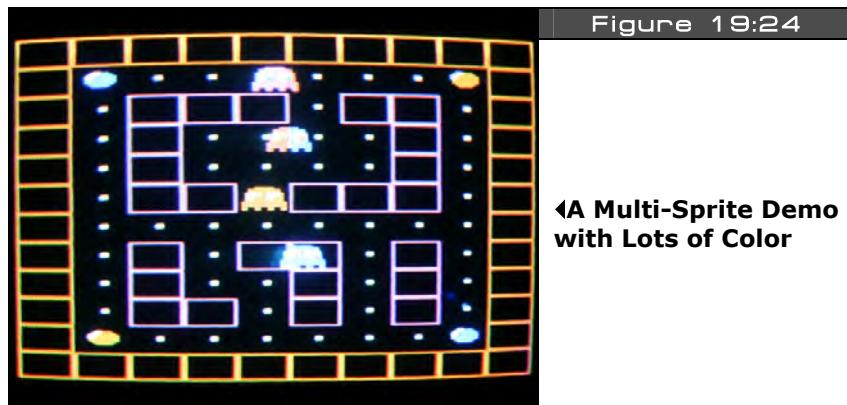
    ' move the sprite
    if (game_pad.button(NES0_RIGHT))
        ghost_x+=2
    if (game_pad.button(NES0_LEFT))
        ghost_x-=2
    if (game_pad.button(NES0_DOWN))
        ghost_y+=2
    if (game_pad.button(NES0_UP))
        ghost_y-=2

    ' update sprite record 0 to reflect new position, sprite updates on next frame
    sprite_tbl[0] := (ghost_y << 24) + (ghost_x << 16) + (0 << 8) + ($01)

    ' delay a little bit, so you can see the sprite, they are VERY fast!!!
    repeat 5000
```

The only action occurs at the bottom where we update the sprite 0 record's first LONG which is the control/state variable for the sprite, here is where we update the position of the sprite with our globals tracking the position of the ghost. Notice the shift and logical operations to move the values into their proper BYTE positions in the record – that's it. Basically, a handful

of lines to move a sprite anywhere on the screen, plus the sprite comes with built in clipping and screen wrap around since its position is encoded with a single BYTE. Try playing around with the demo and see what you can change to make it better, then in the next section we will add some more sprites.



To show off, let's put some more sprites in the demo; take a look at **PACMAN\_TILE\_DEMO\_005.SPIN** on the CD and run it. Figure 19:24 shows a screen shot of it. More or less this is the previous demo with the addition of 3 more sprites on autopilot that simply move across the screen and wrap around. Also, notice the weird color effects that happen as the other sprites as well as when you move your sprite around. This is accomplished through multiple palettes. In this demo there are 16 palettes; I keep the maze colors the same, but change the colors used by the sprites in each tile, so as the sprites move around they take on this palette's colors. You can get all kinds of cool effects like this such as a sprite walking into water (turns blue) or darkness (turns dark), and so on.

The source for this demo is nearly the same as the previous, the only big changes are the addition of all the palettes themselves shown below:

```
' some pacman palettes...
palette_map long $07_0C_6C_02
             long $07_FC_3C_02
             long $07_EC_0C_02
             long $07_DC_2C_02
             long $07_CC_3C_02
             long $07_BC_4C_02
             long $07_AC_5C_02
             long $07_9C_6C_02
             long $07_8C_7C_02
             long $07_7C_8C_02
```

```
long $07_6C_9C_02  
long $07_5C_AC_02  
long $07_4C_BC_02  
long $07_3C_CC_02  
long $07_2C_DC_02  
long $07_1C_EC_02  
long $07_0C_FC_02
```

The new tile map uses these palettes all over the place to create all the color effects, take a look below at the first BYTE of each tile entry you will see the color palette index incrementing all over the place:

The other big addition to the core demo is simply enabling the first 4 sprites like so:

```
' enable/initialize a sprite
sprite_tbl[0] := $00_50_00_01      : sprite 0 state: y=xx, x=$xx, z=$xx, enabled/disabled
sprite_tbl[1] := @sprite_bitmap_0   : sprite 0 bitmap ptr

sprite_tbl[2] := $20_50_00_01      : sprite 0 state: y=xx, x=$xx, z=$xx, enabled/disabled
sprite_tbl[3] := @sprite_bitmap_0   : sprite 0 bitmap ptr

sprite_tbl[4] := $40_50_00_01      : sprite 0 state: y=xx, x=$xx, z=$xx, enabled/disabled
sprite_tbl[5] := @sprite_bitmap_0   : sprite 0 bitmap ptr

sprite_tbl[6] := $80_50_00_01      : sprite 0 state: y=xx, x=$xx, z=$xx, enabled/disabled
sprite_tbl[7] := @sprite_bitmap_0   : sprite 0 bitmap ptr
```

And the main event loop motion control for the automated sprites is nothing more than a simple loop:

```

' now move all the other sprites on the x-axis, that is increment the 3rd byte in sprite record
repeat index from 1 to 3
    ' move sprite i, extract current x, increment, write back to record
    bx := ((sprite_tbl[index*2] & $00_FF_00_00) >> 16) + index
    sprite_tbl[index*2] := (sprite_tbl[index*2] & $FF_00_FF_FF) | (bx << 16)

```

Sorry if the loop is a little cryptic, but more or less it moves each sprite horizontally at a different rate, then updates the sprite record for each, then on the frame update by the engine the sprite is moved. Well, that's it for basic sprite graphics, let's end the chapter with one more demo that shows some animation tricks.

#### 19.4.4 Sprite Animation Primer

Creating games is about art just as much as it is about programming. The idea is to create a world or environment that's "alive" or interesting, and animation is one means to this end. As noted, all art is being drawn manually with data statements, so we can't go to crazy artistically yet until we have more tools to import art, but we can do other things such as simple animation and some other tricks. To show off some of these ideas, I created a little Centipede-like demo which you can see in Figure 19:25. It is nothing more than the mushrooms and the bug blaster (and a missile shortly), but it's a good start and gives us a platform to try some things out. Go ahead and load and try the demo, it's called **CENTIPEDE\_SPRITE\_DEMO\_001.SPIN**. As usual, it uses the gamepad, just move the "bug blaster" around, it can't fire yet though. Notice the eyes blink on the little bug blaster – cool huh?



The first technique I wanted to show you was that with careful planning you can get color effects for free. In this demo, we use tiles for the mushrooms, but only one bitmap per tile; however, each tile gets its own randomly generated palette from a set of 16, so this gives us a lot of color to play with. A little too much actually, so what I decided to do was create a random palette for regions of the mushroom patch and break it into 3 vertical regions covering the screen – this looks pretty good.



The next effect I wanted to show you was some sprite animation. Remember, each sprite record has a pointer to the sprite bitmap (and mask) for that sprite. You can change this pointer any time you wish, thus if you have an animated set of bitmaps like a monster walking or an explosion or whatever then you can animate the sprite. So what I decided to do was make the bug blaster (the character at the bottom of the screen) blink its eyes, so I need two frames of animation, one for normal, one for the eyes blinked. Figure 19:26 shows this graphically for my “ideal” sprite, then I had to convert it to less colors! Then all we need to do is write some code and a state machine that blinks the eyes randomly and updates the sprite record pointers. These are the main ideas in the demo. This demo is interesting enough that I want you to see the main source of the initialization and the main event loop which is below:

```
PUB Start
' This is the first entry point the system will see when the Propeller Chip starts,
' execution ALWAYS starts on the first PUB in the source code for
' the top level file

' start the game pad driver
game_pad.start

' initialize all vars

' bug blaster
blaster_x           := 160/2          ' set sprite location of blaster to center of screen, bottom
blaster_y           := 190
blaster_frame       := 0              ' set to eyes open animation frame
blaster_blink_state := 0

' seed random number generator
random_seed := cnt + 172372371

' generate random palettes
repeat index from 1 to 15
  random_seed := ?random_seed
  ' get random color nibbles
  color_1 := ((random_seed & $00_00_00_F0) >> 0) | $0C ' add brightness to it
  color_2 := ((random_seed & $00_00_F0_00) >> 8) | $0B ' add brightness to it
  color_3 := ((random_seed & $00_F0_00_00) >> 16) | $0D ' add brightness to it
  palette_map[index] := (color_3 << 24) | (color_2 << 16) | (color_1 << 8) | $02
  ' color 0 is always background

' generate a random mushroom field, everywhere a mushroom is placed it will have its own palette
' thus if player moves bug blaster over mushroom, he will change colors :)
' for now, there are 3 "zones" top to bottom, so the screen is broken 3 color regions top to bottom
repeat NUM_MUSHROOMS
  random_seed := ?random_seed

  ' extract some data from random variable
  x := (random_seed & $00_FF) / 26          ' limit to range 0..9
  y := ((random_seed & $FF_00) >> 8) / 22   ' limit to range 0..11

  ' write to tile map
  tile_map0[x + y << 4] := ( ((y / 4) + 1) << 8) | $01
  ' points ptrs to actual memory storage for tile engine
```

```

tile_map_base_ptr_parm      := @tile_map0
tile_bitmaps_base_ptr_parm := @tile_bitmaps
tile_palettes_base_ptr_parm := @palette_map
tile_map_sprite_cntrl_parm  := $00_00_01_00 : set for 1 sprites and width 16 tiles (1 screens wide),
                                         0 = 16 tiles, 1 = 32 tiles, 2 = 64 tiles, 3 = 128
tiles, etc.
tile_sprite_tbl_base_ptr_parm := @sprite_tbl[0]
tile_status_bits_parm       := 0

' enable/initialize sprites
' bug blaster sprite
sprite_tbl[0] := $70_50_00_01      : sprite 0 state: y=xx, x=$xx, z=$xx, enabled/disabled
sprite_tbl[1] := @sprite_bitmap_1   : sprite 0 bitmap ptr

' launch a COG with ASM video driver
gfx.start(@tile_map_base_ptr_parm)

' enter main event loop...no need for game states, simple demo, one state - RUN
repeat while 1
    ' main even loop code here...

    ' update random number
    random_seed := ?random_seed

    ' save current count to lock frame rate
    curr_count := cnt

    ' get gamepad input and move the sprite
    if (game_pad.button(NES0_RIGHT))
        blaster_x+=1
    if (game_pad.button(NES0_LEFT))
        blaster_x-=1
    if (game_pad.button(NES0_DOWN))
        blaster_y+=1
    if (game_pad.button(NES0_UP))
        blaster_y-=1

    ' test if we want to fire blink animation
    if (blaster_blink_state == 0)
        if ((random_seed & $7F) == 1)
            start blink animation, basically change frames and count
            blaster_blink_state := 1
            blaster_frame       := 1
    else
        if (++blaster_blink_state == 30) ' done with blink/wink?
            blaster_blink_state := 0
            blaster_frame       := 0

    ' now update the bug blaster sprite record to reflect new position, sprite will update on next frame
    sprite_tbl[0] := (blaster_y << 24) + (blaster_x << 16) + (0 << 8) + ($01)
    sprite_tbl[1] := @sprite_bitmap_1 + (SPRITE_BITMAPMASK_SIZE)*blaster_frame

    ' lock frame rate
    waitcnt(curr_count + 666_666)

    ' return back to repeat main event loop...

```

The listing starts off with the initialization section that sets up the tile engine and some other working variables, then it falls into the random palette generation and the random mushroom patch generation algorithms, both interesting code fragments, so check them out. Next we enter into the main event loop and check for gamepad input and move the bug blaster if there is motion. After the gamepad tests we fall into the animation section which is more or less a simple state machine that works by testing if the bug blaster is blinking his eyes, if he is then it continues counting up to 30 clocks then resets to normal. The state of the blink (0 or 1) is used as an index to point the sprite's bitmap base pointer to either frame of animation. Since we know they are 128 BYTES from each other in the DAT section, it's a matter of a simple multiplication and addition to compute the base address of the normal and blinking bitmap. Lastly, the frame rate is locked down, so the demo game runs smoothly.

Now, in a real game you would of course have all the game states in the main event loop, and you would code the animation functionality into separate functions, but to save space and keep you from jumping all over the place, I am doing things in place. Play around with the demo a bit, notice that the bug blaster (initially green) takes on the tile palette colors of the mushrooms as it moves over them, this is unavoidable as usual. Next, let's add firing a missile!

#### 19.4.4.1 Adding Weapons to the Helpless Bug Blaster

Adding a missile is as simple as creating the missile sprite bitmap, setting up the sprite record, then enabling/disabling the sprite as it's fired, and of course controlling its trajectory. There are a myriad of ways to code this, so for a moment let's forget about the sprite aspect of it and focus on the missile itself. To control a single missile we need to know its position and state, and potentially its velocity and other parameters. Since this is a simple model we are only going to need to track the position of the missile and its state. By "**state**" I mean is the missile "**dead**," "**alive**," "**dying**," etc. These terms are context-sensitive, and simply terms used by game developers to assign meaning to different states of existence of game objects. Here are the variables we need to control a single missile:

```
' data structure for single missile
long missile_x, missile_y, missile_state, missile_counter
```

Typically, "state" will be encoded as an integer with the meanings outlined above, and the "counter" variable helps track how long a state might be running, etc. In our case, the states are encoded with constants to make the missile easier to code:

```
' states for missile
MISSILE_STATE_DEAD    = 0
MISSILE_STATE_ALIVE   = 1
MISSILE_STATE_DYING   = 2
```

And we are going to move the missile at a constant velocity of 2 pixels/frame, so here's a constant for that:

```
' missile constants
MISSILE_VEL      = 2      ' velocity of missile in pixels/frame
```

Now that we have a data structure to hold relevant information about the missile, let's discuss the plan to implement it. At startup we will initialize the missile's position to (0,0) and its state to MISSILE\_STATE\_DEAD, then we will have a **case** or **if** block that tests if the player is trying to fire the missile each frame. If the player is trying to fire the missile and the missile state is dead, then we can start the missile up, else, we do nothing.

To start the missile up, we are going to copy the position of the player's bug blaster into the missile's (x,y) position plus a little fudging to the position to make it look like the missile is coming from the front of the bug blaster. Additionally, we are going to set the state of the missile to MISSILE\_STATE\_ALIVE and reset the missile's counter variable to 0. Now, each time through the event loop, if the the missile's state is MISSILE\_STATE\_ALIVE then we are going to translate the missile vertically on the screen (upward) as it should be, and test if the missile hits the top of the screen, if so we terminate the missile by setting its state to MISSILE\_STATE\_DEAD. Now, if we wanted the missile to only operate for a few frames then we could use the counter variable (and still might in the future) to count down or up and when it reached a certain value the state would transition to dead. This way we can de-couple the state termination to the top of the screen, but this is not needed in this demo.

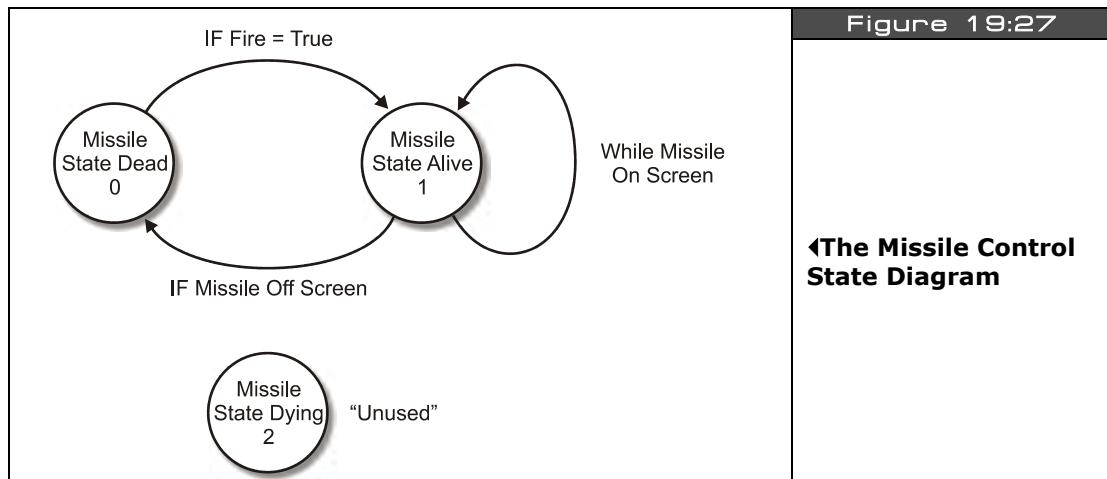


Figure 19:27 shows the complete state diagram for the missile control algorithm and. And of course, if you wanted to add more missiles, then you would simply array the data structure and loop through everything one by one. So that's the missile. But, this is old news, I wanted to show you something new here in this demo, not just another sprite, something to do with animation. To this end, "**procedural animation**" came to mind. Procedural animation is animation where instead of using frames or pre-drawn animation art, we generate the animation or effect procedurally or algorithmically. In this case, making the missile look like it was made of plasma energy was the desired effect. Accomplishing this is easy if we look at what we have to work with. First, here are the bitmap and mask for the missile sprite bitmap:

The sprite bitmap itself is made of 3's, thus a 2-pixel-wide line of color 3 would be the sprite; however, if we were actually go into the bitmap on-the-fly during run-time and alter this data we could make it look like anything. For example, if we were to generate 16 random 32-bit numbers and then logically AND them with the values in the original sprite bitmap this would have the effect of turning on pixels in patterns 00b, 01b, 10b, and 11b wherever the missile mask is, and presto we have our plasma effect. The code for this is shown below:

```

    ' animate missile by rendering random pixels into sprite buffer to make it look like "plasma"
    ' star trek "beam out" effect!
    repeat index from 2 to 13
        sprite_bitmap_3[index] := %%0_0_0_0_0_0_0_3_3_0_0_0_0_0_0 & (?random_seed)

```

So, we only want to overwrite rows 2 to 13 with the random pixels, but the final effect is pretty cool. If you wanted to make any shape make this energized effect, simply make the mask look like the shape, then write into the bitmap each mask row logically AND'ed with the random number like this:

```

    ' variant of algorithm uses the mask itself to energize any shape (a little slower)
repeat index from 0 to 15
    sprite_bitmap_3[index] := sprite_bitmap_3[index+16] & (?random_seed)

```

The ***sprite\_bitmap\_3[index+16]*** accesses the mask data since we know it's 16 LONGs ahead of the bitmap data. That's about all there is to the animation; the last thing to look at is the missile control code itself which is below:

```

    ' run motion / animation state machine for missile, normally this would be in a separate function
    ' but for brevity we are keeping everything in the main loop
    case missile_state

        MISSILE_STATE_DEAD:   ' do nothing...

        MISSILE_STATE_ALIVE: ' move and animate the missile, test for off screen
            if ( (missile_y -= MISSILE_VEL) < 0 )           ' move missile upward...test for offscreen
                missile_state := MISSILE_STATE_DEAD          ' terminate missile

            ' animate missile by rendering random pixels into sprite buffer to make it look like "plasma"
            ' star trek "beam out" effect!
            repeat index from 2 to 13
                sprite_bitmap_3[index] := %%0_0_0_0_0_0_0_3_3_0_0_0_0_0_0 & (?random_seed)

        MISSILE_STATE_DYING: ' not implemented, but maybe when the missile hits it has a death animation
    end case

```

That's about all the changes to create the new demo. The complete source code can be found in **CENTIPEDE\_SPRITE\_DEMO\_002.SPIN**, go ahead and give it a try right now, use the dpad on the gamepad to move and **<B>** to fire. Check out the plasma/energize effect on the missile; if it moves too fast for you to see, try slowing it down by changing the **MISSILE\_VEL** to 1.

I leave it to you to add collision detection to the mushrooms, but as a hint simply compute the tile coordinates of the missile by dividing by 16 (and offsetting by the coordinate system of the sprites since 0,0 in sprite space is off the top corner of the screen), then test the tile to see if a mushroom is there. If so, then erase it, or better yet, draw a new version of a mushroom into the screen that has some part of it blown away! Make sure to terminate the missile when it hits something as well.

## 19.5 Summary

This chapter hopefully has been a quantum leap for you and you can see how the pieces are starting to fit together to make games. Bottom line, once you have a powerful tile/sprite engine, then it's just a matter of creating game art, and coding the logic for the game, and that's a video game! Of course, subjects like artificial intelligence and others are important, but we are getting there. At this point, you can more or less make just about any 8-bit tile based game you have ever seen (graphically at least). Before moving on to the next chapter, try taking some of the demos and playing with them, and changing them around and see if you can make any complete rudimentary games with them.



## Chapter 20: Getting Input from the “User” World

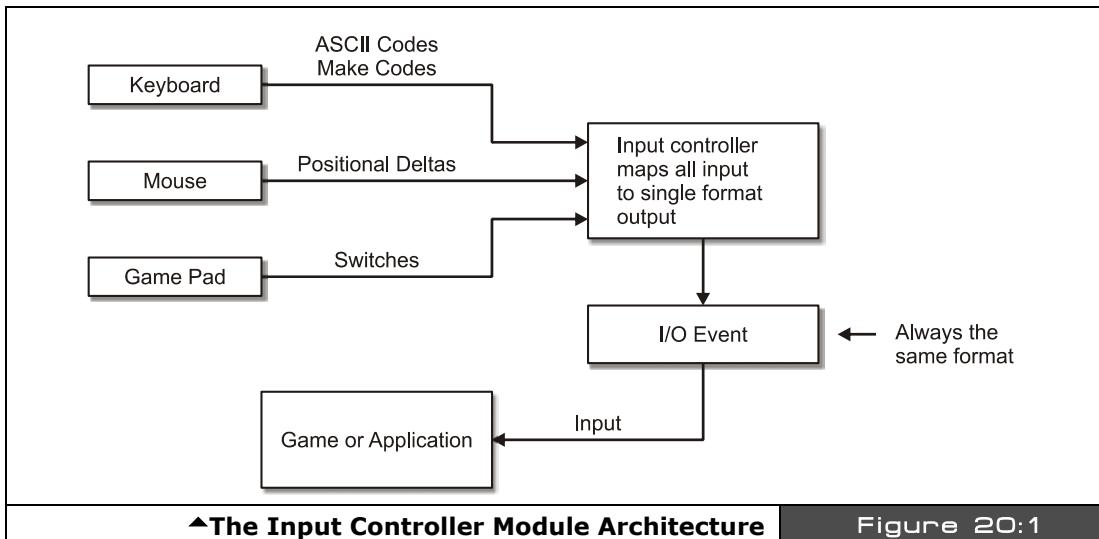
I don't think I have made a single reference to the movie "**TRON**" thus far, so this chapter's title changes all that! In this chapter, we are going to discuss some issues related to reading input devices in the context of a game. We aren't going to cover how the input devices work in detail since we have already done that, but rather how they are used in games to control characters, and also some of the techniques used to make a keyboard seem like a mouse, a mouse like a gamepad, and other similar problems. Here's what's in store:

- ▶ What is an input device “controller?”
- ▶ Input device review
- ▶ Selected examples of controller filtering and mapping
- ▶ Game controller data input sequencing techniques
- ▶ Universal input module architectural concerns for games
- ▶ Final demo – **ZoneBall**

### 20.1 What is an Input Device Controller?

You already know how to read the keyboard, mouse, and gamepad, so you might wonder “What else is there?” Well, reading the input device is only the tip of the iceberg, what you *do* with that input is what counts. Thus far, for the demos we have reviewed, we have simply read the input device in question (mouse, keyboard, gamepad) and then taken the raw data without any processing and used it directly in conditionals to control the game/demo itself. This is fine and works in cases where the control of the game characters is simple. However, as games get more complex, you will need to **process**, **interpret**, and **transform** game control inputs into multiple formats that better suit the needs of the game play.

The module that does this in a game is usually referred to as the “input device controller” or “input module.” It's is more or less a piece of software that takes one or more input devices that are potentially connected to the game system (mouse, keyboard, gamepad, etc.) and collects all of the heterogenous input data from the different controllers and APIs, and then transforms the data into a nice stream of homogenous data packets that the game engine can use and not care what controller(s) it came from. This is shown in Figure 20:1 on the next page.

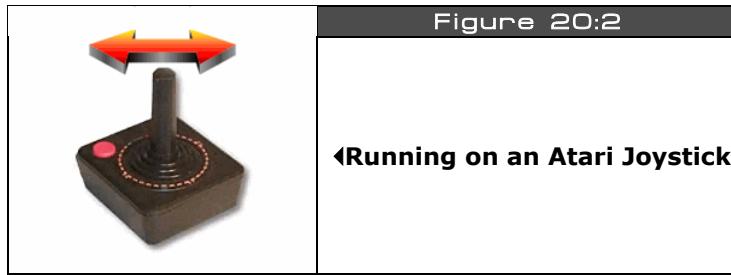


▲The Input Controller Module Architecture

Figure 20:1

When you think about this it makes good sense, since there is a lot of difference between a mouse, keyboard, and gamepad. Sure, they have some things in common, but a mouse for example can move instantaneously to a different position, a keyboard can't. A gamepad on the other hand has a collection of buttons, not as many as a keyboard, but typically on a gamepad you can press 2, 3, 4 or more buttons at once, whereas on a keyboard, only 1-2 keys can be pressed at the same time (usually a control key and one normal key), so there isn't a direct mapping.

Another problem with input device data is that sometimes it's not in the format we want, that is, maybe we need to "filter" it a bit and output what the player "meant" to do. For example, say you have a running game; there is no way to "run" on a game controller, keyboard or mouse, thus game developers come up with various physical actions to "represent" running. For example, in Activision's "**Summer**" and "**Winter Games**" from the early 80's, you would move the joystick rapidly back and forth from left to right as shown in Figure 20:2. The faster you moved right and left, the faster the game character would run, but this has no direct mapping to translation or speed, so a **filter** of sorts had to be employed. In this case, the filter might be general speed of the running character, and a counter counts how many complete "right-left" joystick cycles there are per second, this number is then scaled and used to increase or decrease the virtual speed of the running. However, once in a while the player might "miss" a left or right thrust, so the input "filter" might be reasonable and allow a "miss" every 10 hits, that is, the controller realizes that the player and controller aren't perfect and once in a while the player might miss a cycle even though he made the motion, so the "input controller" helps the player out.



This is the idea of input controller software; depending on the game, the input controller software might at very least allow the player to play with all input devices, and/or there might be a lot of filtering and even crude “intelligence” in the input controller to help the player out with what he “meant” to do based on what he has been doing. With that in mind, in this chapter, we are going to look at a few examples that illustrate these concepts to get you started, so you don’t end up kludging code to support multiple input devices, but rather code cleanly with an **“input controller”** module. Before we get started, let’s briefly review the gamepad, joystick, and mouse interfacing APIs, to refresh your memory.

## 20.2 Input Device Programming Review

The HYDRA supports three input devices currently: the mouse, keyboard, and gamepad. The mouse is the most alien of the three since it only has a couple buttons and returns position in packets as deltas or absolute position of the virtual mouse position. The keyboard and gamepad on the other hand are very similar in functionality except that the keyboard of course has over 100 keys while the controller only has a few, but the gamepad controller supports multiple key presses simultaneously, where the keyboard does not (usually). Now, let’s quickly take a look at the objects and a little code to read each device, so you can have it fresh in your mind as we move through the material ahead that uses the functions.

### 20.2.1 Reading the Mouse

The standard reference driver for the mouse is called **MOUSE\_IS0\_010.SPIN**. You simply import it into your Spin program like so:

```
OBJ
mouse : "mouse_iso_010.spin"      ' instantiate a mouse object
```

...then start it up with a single parameter (which is the port for the I/O’s which on the HYDRA is 2):

```
'start mouse
mouse.start(2)
```

The driver for the mouse can return both the delta from the last read mouse position or the absolute mouse position with the functions:

```
' read delta from last position
dx := mouse.delta_x
dy := mouse.delta_y

' read absolute mouse position (9-bit accurate)
abs_x := mouse.abs_x
abs_y := mouse.abs_y
```

Next, to read the buttons, you call the button function as shown below:

```
' bit4 = right-side button
' bit3 = left-side button
' bit2 = center/scrollwheel button
' bit1 = right button
' bit0 = left button
button_state := mouse.buttons
```

...where the buttons are encoded as a bit vector as shown in the comments above. That's all there is to reading the mouse. The last function that is interesting to our discussion is a way to determine if the mouse is present:

```
' 3 = five-button scrollwheel mouse
' 2 = three-button scrollwheel mouse
' 1 = two-button or three-button mouse
' 0 = no mouse connected
mouse_present := mouse.present
```

The function not only returns if the mouse is present or not, but the type of mouse installed (if any). However, this takes approximately 1-2 seconds before it's valid, thus you might not want to wait for it in your application.

### 20.2.2 Reading the Keyboard

The reference keyboard driver is named **KEYBOARD\_ISO\_010.SPIN** and is much more complex than the mouse as far as functionality goes. However, we only need to communicate with the keyboard in a couple different ways. First, the keyboard driver knows when a key is pressed, so this can be queried by a call, if the call is true then you can retrieve the key that was pressed. The second way to read the keyboard is like a giant array of switches (which is more common in game development). You simply access an array that indicates the "state" of all the keys simultaneously.

The code to import the keyboard object and start it up is shown below (the 3 parameter on start means pingroup 3 which is the HYDRA’s keyboard port):

```
OBJ
key : "keyboard_iso_010.spin"  ' instantiate a keyboard object
' start keyboard on pingroup
key.start(3)
```

Once the keyboard is started up, we can read single key events or the state of the keyboard. To read the state of any key, we use the **keystate** function below along with a key constant:

```
key.keystate(KB_RIGHT_ARROW)
```

This returns a Boolean value if the key is pressed or not.



### NOTE

Remember, in Spin, 0 is FALSE, and anything else is TRUE, especially -1!

The constant “KB\_RIGHT\_ARROW” in this example is simply one of the constants defined in the driver’s code itself, refer to **KEYBOARD\_ISO\_010.SPIN** at the end of the listing to see the actual values of all the “key codes” which are more or less the “**make**” codes for standard PC keyboards. Table 20:1 shows a short list of useful codes:

| Table 20:1     | Keycodes Commonly Used in Games▼ |
|----------------|----------------------------------|
| Symbolic Name  | Driver Key Code                  |
| KB_LEFT_ARROW  | \$C0                             |
| KB_RIGHT_ARROW | \$C1                             |
| KB_UP_ARROW    | \$C2                             |
| KB_DOWN_ARROW  | \$C3                             |
| KB_ESC         | \$CB                             |
| KB_SPACE       | \$20                             |
| KB_ENTER       | \$0D                             |
| KB_LEFT_CTRL   | \$F2                             |
| KB_RIGHT_CTRL  | \$F3                             |

Next, if you are writing something more like a text input system or editor, you are more interested in ***when*** a key is pressed, rather than ***if*** a key is pressed. Then you need the ***gotkey*** function which tests if a key is pressed, if so then you simply make another call to read the key with ***getkey***:

```
if (key.gotkey == TRUE)
    key := mouse.getkey
```

...and that wraps it up for the keyboard interface. Also, the keyboard driver also has a present function which returns a Boolean if the keyboard is present or not as shown below:

```
is_present := key.present
```

However, this takes approximately 1-2 seconds before it's valid, thus, you might not want to wait for it in your application.

### 20.2.3 Reading the Gamepad Controller

The Nintendo-compatible gamepad controller is more or less a set of digital switches, they are read in as a single bit vector and then you simply logically AND mask bits to test if a button is pressed. The reference driver for the gamepad is **GAMEPAD\_DRV\_001.SPIN**, here's how you load and start it up:

```
OBJ
game_pad :      "gamepad_drv_001.spin"

' start the game pad driver
game_pad.start
```

The gamepad driver is even simpler than the keyboard and mouse. You read the "state" of all the button bits at once with ***read***:

```
' read all the button bits as WORD that represents both controllers
' (low byte is left controller, high byte right controller)
game_pad.read
```

...where the buttons are encoded in the following way:

```
' NES bit encodings for NES gamepad 0
NES0_RIGHT   = %00000000_00000001
NES0_LEFT    = %00000000_00000010
NES0_DOWN    = %00000000_00000100
NES0_UP      = %00000000_00001000
NES0_START   = %00000000_00010000
NES0_SELECT  = %00000000_00100000
NES0_B       = %00000000_01000000
NES0_A       = %00000000_10000000
```

```
' NES bit encodings for NES gamepad 1
NES1_RIGHT = %00000001_00000000
NES1_LEFT = %00000010_00000000
NES1_DOWN = %00000100_00000000
NES1_UP = %00001000_00000000
NES1_START = %00010000_00000000
NES1_SELECT = %00100000_00000000
NES1_B = %01000000_00000000
NES1_A = %10000000_00000000
```

Also, if you like, you can let the driver do a little work for you and “test” the buttons if a specific button is down with a single call **button** like this:

```
if (game_pad.button(NES0_START)
    ' game code...
```

...which tests if the left most controller’s <START> button is down.

There is no “present” function in this version of the driver, but simply read the button state and compare it to \$FF for the controller, this means the controller is not plugged in, for example to determine if the left controller is **not** plugged in you would use the following code:

```
if ( (game_pad.read & $00FF) == $FF)
    '.. not plugged in...
```

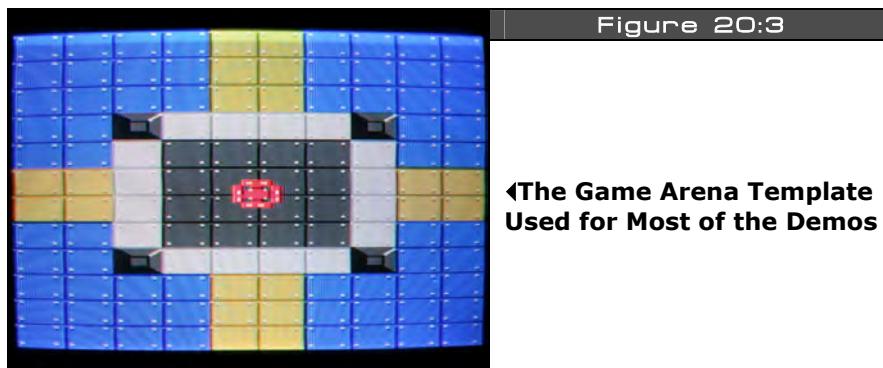


### NOTE

An \$FF is returned since there is a pullup resistor on the controller’s serial data stream, so without the controller plugged in the HYDRA reads all 1’s.

## 20.3 Input Device Filtering Demos

In this section, we are going to take a look at a few common examples of input device filtering and controller architecture, and finish off with a universal input system and command code tracker which will explained shortly. Now, like any demo in the book an effort is made to put the demo in the context of game development with something that relates to graphics, thus, I decided that we really need a single screen and some object to move around to “see” our input algorithms at work. So I put together a little “arena” game field demo that we will use to experiment with input devices. It’s shown in Figure 20:3 on the next page; more or less the tile engine is being used here and a single sprite to create the character which is supposed to be some kind of 4-directional tank or hover craft (hey you try drawing with 1’s and 0’s).



Anyway, aside from the demos and algorithms we are about to see, there are some interesting techniques going on with the arena demo, for example, the color mapping for the tile engine is shown in Table 20:2 below:

| Table 20:2  |  | Arena Game Demo Tile Engine Color Usage▼ |  |
|-------------|--|--|--|
| Color Index | Usage  |  |  |
| 0           | Used as bright background object color and transparent for sprites |  |  |
| 1           | Used as dark background object                                     |  |  |
| 2           | Used solely for sprite primary color                               |  |  |
| 3           | Always white   |  |  |

As you can see, the sprites can use colors 1, 2, 3; color 2 is the sprite color, 3 is always white, but color 1 is a “dark” version of the background tile color, so more or less the sprite can use this for a “gray” color shade and you won’t notice the color of it for a pixel or two. But, the interesting thing to note is as the sprite moves over the arena, I changed the two background colors along with the sprite color, so the sprite actually changes colors over some tiles. This is a cool effect to keep in mind if you need it. So with that in mind, let’s get to the demos.

### 20.3.1 Unifying the Input Devices

One of the main problems with input devices is that they all tend to output different kinds of data: button presses, mouse positions, ASCII keys, whatever, but in a game you don’t want to ask if the “CTRL” key is pressed, you just want to know if the FIRE command has been sent from the input devices. To accomplish this we need to unify the input device’s output data into a common command language for processing downstream by the game logic. As a

first attempt at this, let's work from the game designer's point of view rather than the guy that has to write the driver (us in this case).

Let's assume we are going to make a game(s) that needs the following inputs:

- ▶ START
- ▶ ESC
- ▶ FIRE
- ▶ RIGHT
- ▶ LEFT
- ▶ UP
- ▶ DOWN

Let's further assume that they are all digital in nature and will be represented by Boolean values 1 and 0. The first step is to look at each of the input devices and decide on a universal **“mapping”** – that is, what control element (sometimes referred to as a widget or gadget) on the input devices maps to these concepts (if at all) and assign control elements. Table 20:3 shows the mapping we are going to use (commas separate multiple control element mapping):

| Table 20:3           |                          | Universal Input Controller Mapping▼ |                 |  |
|----------------------|--------------------------|-------------------------------------|-----------------|--|
| Universal Command ID | Keyboard                 | Mouse                               | Gamepad         |  |
| START                | <SPACE>, <CTRL>, <ENTER> | Left Button                         | <Start> Button  |  |
| ESC                  | <ESC>                    | Right Button                        | <Select> Button |  |
| FIRE                 | <SPACE>, <CTRL>          | <Left Button>                       | <A>, <B>        |  |
| RIGHT                | <Right ARROW>            | Motion Right                        | <Dpad Right>    |  |
| LEFT                 | <Left ARROW>             | Motion Left                         | <Dpad Left>     |  |
| UP                   | <Up ARROW>               | Motion Up                           | <Dpad Up>       |  |
| DOWN                 | <Down ARROW>             | Motion Down                         | <Dpad Down>     |  |

That was simple enough. Ok, so counting up commands, there are 7, so we can encode them all into a single BYTE. However, Spin does a lot of work with LONGs especially for parameters and returns from function calls, so it doesn't save any memory to use a BYTE when using function calls to send or receive parms, thus we will use a LONG for command IDs, but ignore the upper 24 bits (for now). This is a good idea since we can “grow” into the other bits in the future, and this command code set can be compatible with a superset system later!

At this point, we need three functions to filter the input devices. For kicks, when we start up each device we are going to set a global flag that indicates if the controller is present, then in the read functions we are going query it, and if the particular input device is not plugged in then the function will simply return. But, before we get to coding we have some **"arbitration"** issues to discuss.

When merging data from multiple input devices, it could be that on the keyboard you are pressing **left** while your cat is walking on the gamepad and pressing **right**. How you want to handle this depends on the game. In most cases you can simply logically OR everything together and be done with it; however, maybe you are actually playing with a friend and he is using the gamepad to control just the firing and you are steering. In this case, collaborative play is the idea, so what if someone hits ESC at the same time someone hits SELECT? Both are high-level commands, so should the game escape to the menu, or do whatever SELECT fires off? This depends on the game. Thus, you might have to write extra logic that tests for these cases and prioritizes them or possibly even queues them up? However, in most cases, and most games, programming just OR's it all together and that's it. Considering that, let's write some example code to handle the startup of all the input devices and then the query functions.

First off, let's define the "input command ID's" we are using in our example:

```
CON
    ' encode each as a bit
IID_START = $01
IID_ESC   = $02
IID_FIRE   = $04
IID_RIGHT  = $08
IID_LEFT   = $10
IID_UP     = $20
IID_DOWN   = $40
```

Then somewhere in the VAR section, let's define some globals to track if the input devices are even plugged in:

```
VAR
    Long keyboard_present
    long mouse_present
    long gamepad_present
```

...and finally, let's import all the objects:

```
OBJ
mouse      : "mouse_iso_010.spin"      ' instantiate a mouse object
key        : "keyboard_iso_010.spin"    : instantiate a keyboard object
game_pad   : "gamepad_drv_001.spin"    : instantiate game pad object
```

...and in the initialization section you would start them all up correctly and test for presence:

```
' start mouse
mouse.start(2)
repeat 250_000 ' give driver a moment to warm up
mouse_present := mouse.present

' start keyboard
key.start(3)
repeat 250_000 ' give driver a moment to warm up
keyboard_present := key.present

' start the gamepad
game_pad.start
repeat 1000 ' give driver a moment to warm up

if ( (game_pad.read & $00FF) <> $00FF)
    gamepad_present := 1
else
    gamepad_present := 0
```

### 20.3.1.1 Universal Input Controller Version 1.0

Now, we are ready to read each input device and collect all the data into a single global data packet, so let's write some universal controller interface (UCI) functions for each device that performs the mapping, filtering, and construction of the data packet as a return value; here they are:

```
PUB UCI_Read_Keyboard(device_present) : keyboard_state
' universal controller interface for keyboard

' make sure the device is present
if (device_present==FALSE)
    return 0

' reset state var
keyboard_state := 0

' first control id's
' set ESC id
if (key.keystate(KB_ESC))
    keyboard_state |= IID_ESC

' set start id
if (key.keystate(KB_SPACE) or key.keystate(KB_ENTER) or key.keystate(KB_LEFT_CTRL) or key.keystate(KB_RIGHT_CTRL) )
    keyboard_state |= IID_START

' set fire id
if (key.keystate(KB_SPACE) or key.keystate(KB_LEFT_CTRL) or key.keystate(KB_RIGHT_CTRL) )
    keyboard_state |= IID_FIRE
```

```

' now directionals
if (key.keystate(KB_LEFT_ARROW))
    keyboard_state |= IID_LEFT

if (key.keystate(KB_RIGHT_ARROW))
    keyboard_state |= IID_RIGHT

if (key.keystate(KB_UP_ARROW))
    keyboard_state |= IID_UP

if (key.keystate(KB_DOWN_ARROW))
    keyboard_state |= IID_DOWN

return keyboard_state

' end UCI_Read_Keyboard

' /////////////////////////////////
PUB UCI_Read_Mouse(device_present) : mouse_state | m_dx, m_dy
' universal controller interface for mouse

' make sure the device is present
if (device_present==FALSE)
    return 0

' reset state var
mouse_state := 0

' set ESC id
if (mouse.button(1))
    mouse_state |= IID_ESC

' set start id
if (mouse.button(0))
    mouse_state |= IID_START

' set fire id
if (mouse.button(0))
    mouse_state |= IID_FIRE

' get mouse deltas
m_dx := mouse.delta_x
m_dy := mouse.delta_y

' now, we need to convert the delta or absolute mouse position into digital output,
' thus thresholding and clamping them, notice the threshold of "2" used, this helps
' only move the mouse when the user is really moving and not an accidental nudge
if (m_dx > 2)
    mouse_state |= IID_RIGHT
else
if (m_dx < -2)
    mouse_state |= IID_LEFT

if (m_dy < -2)
    mouse_state |= IID_DOWN
else
if (m_dy > 2)
    mouse_state |= IID_UP

```

```

return mouse_state

' end UCI_Read_Mouse

' ////////////////////////////////



PUB UCI_Read_Gamepad(device_present) : gamepad_state
' universal controller interface for gamepad
' note the gamepad maps very naturally to the universal codes, we could use
' some really clever lookup or logic code to map the codes, but instead lets
' just keep it readable...

' make sure the device is present
if (device_present == 0)
    return 0

' reset state var
gamepad_state := 0

' set ESC id
if (gamepad.button(NES0_SELECT))
    gamepad_state |= IID_ESC

' set start id
if (gamepad.button(NES0_START))
    gamepad_state |= IID_START

' set fire id
if (gamepad.button(NES0_A) or gamepad.button(NES0_B) )
    gamepad_state |= IID_FIRE

' now directionals
if (gamepad.button(NES0_LEFT) )
    gamepad_state |= IID_LEFT

if (gamepad.button(NES0_RIGHT) )
    gamepad_state |= IID_RIGHT

if (gamepad.button(NES0_UP) )
    gamepad_state |= IID_UP

if (gamepad.button(NES0_DOWN) )
    gamepad_state |= IID_DOWN

return gamepad_state

' end UCI_Read_Gamepad

```

If any input device is not present then the function(s) simply returns a 0, assuming that the caller is going to perform a logical OR with all the input devices at some point. This way, we can minimize the conditional logic making calls to the filters and use a single statement to read all devices like so:

```

player_input := UCI_Read_Keyboard(keyboard_present) | UCI_Read_Mouse(mouse_present) |
    UCI_Read_Gamepad(gamepad_present)

```

Each function is fairly straightforward, the only one that's even remotely interesting is the mouse function since it has to threshold and clamp the mouse movement and turn it into a digital output. When you try the demo, you will see how this "feels" wrong, but for this version it is exactly what we want. To see the new universal input system in action, go ahead and run **ARENA\_INPUT\_DEMO\_001.SPIN** from the CD, it uses the controls as we have defined them. Try using each input device, plug them all in, pull them all out, etc.



**Our code only detects if an input device is present during startup, thus if you pull something after you start the demo up (or plug something in) the demo won't know about it and might not function properly. To test this, start the demo with everything in, then unplug the gamepad, notice how the demo locks up, what's happening? Hint: the phantom gamepad is returning \$FF which means all buttons down!**

### 20.3.1.2 Universal Input Controller Version 2.0

)At this point, we have a very simple system that works well. It supports keyboard, mouse, and gamepad, detects devices present, and outputs a single data packet that is 8 bits (used in a 32-bit word). The only problem is that during the "port" of all the input devices to a single virtual game input stream, we lost something in the translation...specifically, the mouse doesn't work very well anymore. When people use the mouse as an input, they expect the mouse to move the cursor, control, pointer or whatever as the mouse moves. When we "digitized" the mouse, we got rid of this feature to make it more compatible with the generic data stream we were creating for the system. This is a no-no in game development, you never want to penalize the game player for using an input device with special features, in fact, you want to take advantage of them if you can. For example, when you buy a new graphics card would you expect games to look better? Sometimes they do, but sometimes the programmers program for the lowest common denominator which is bad. In any event, let's see if we can augment our first data packet format with some new fields and so on to help support more advanced devices like the mouse feel better.

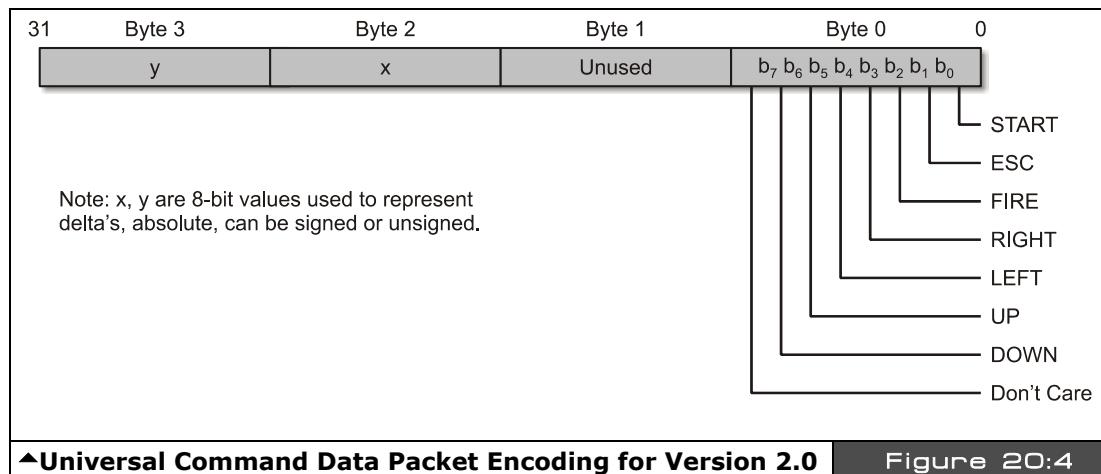
Reviewing our universal controller mapping events, we have the following digital outputs bits:

- ▶ START
- ▶ ESC
- ▶ FIRE
- ▶ RIGHT
- ▶ LEFT
- ▶ UP
- ▶ DOWN

All we need to support analog devices such as the mouse is a way to send back deltas for x, y motion. This can easily be accomplished by adding some extra variables to our data packet.

We could embed each the dx and dy into the LONG itself as a 8-bit 2's complement number which would give us the range of (-128 to +127) which is perfect. Luckily, we only used the first 7 lower bits so far to encode the above commands, so we are going to place x,y encoded in the upper WORD as shown in Figure 20:4.

Referring to Figure 20:4, the idea here is that “x” and “y” will go in BYTES 2 and 3 respectively, their format is not restricted, they could be 2's complement values for absolute position or deltas, so we aren't defining that in the specification, only that some kind of “x” and “y” data will go there. This gives us the latitude to change the type of data in there if we want. Also, notice we haven't touched BYTE 1? This is perfect for more state information or possibly command format codes, that is, we might later put a 4-bit field in there that defines if the x,y are deltas or absolutes, in 2's complement form and so forth. For example, a first step might be to use bit 0 of BYTE 1 as a “digital/analog” bit, if it's 0 then the format is digital as before, if it's 1 then the format is analog and we should take into consideration the x,y fields in BYTES 2 and 3, but for now we will just always assume that the packet output is analog.



As you can see this little data format is really starting to take shape. Now, all we have to do is code something that takes advantage of it and try and keep it as compatible as possible with our previous system, so we don't “break” too much of our software – what there is of it! The idea will be to use the functions we wrote before and augment them to modify the x,y fields. For example, the keyboard and game pad both are digital in nature, so they might set the x,y fields to ±1's; on the other hand, the mouse might actually stuff the dx, dy values for its motion in the BYTES, so if the player does have a mouse, he can take advantage of this

functionality. In either case, we will still set the digital state bits always for RIGHT, LEFT, UP, and DOWN to keep the data packet as "compatible" as we can.

Taking all this into consideration, the new universal input functions for version 2.0 are shown below. I have only shown the mouse and gamepad to save space, the keyboard is similar and you can always review it in the upcoming demo in a moment. The only work that had to be done was that in the gamepad and keyboard in addition to setting the RIGHT, LEFT, UP, DOWN flags in the data packet, they also put arbitrary values into the x,y fields, thus all data packets all have the same format. Lastly, before moving on and reviewing the functions below, be aware that Spin doesn't do sign extension automatically, you have to use special operators to make sure that 8 and 16 bit values sign-extend when you assign them to LONGs, so keep that in mind when reviewing the code and trying to implement a similar system. This is an issue since Spin only does 2's complement math with 32-bit LONGs, so we have to work with LONGs then down-convert to 8 bits, then up-convert to LONGs again, the last step is the gotcha. Specifically, examples of the operators to sign-extend an 8-bit and 16-bit value are:

```
8-bit Sign Extension

LONG x
BYTE y

x := ~y ` the 8th bit (sign bit) is sign extended into x

16-bit Sign Extension

LONG x
WORD y

x := ~y ` the 16th bit (sign bit) is sign extended into x

Without further ado, here are the version 2.0 universal input functions:

PUB UCI_Read_Mouse2(device_present) : mouse_state | m_dx, m_dy
' universal controller interface for mouse version 2.0
' now supports the x,y fields in bytes 2,3

' make sure the device is present
if (device_present==FALSE)
    return 0

' reset state var
mouse_state := 0

' set ESC id
if (mouse.button(1))
    mouse_state |= IID_ESC

' set start id
if (mouse.button(0))
    mouse_state |= IID_START

' set fire id
```

```

if (mouse.button(0))
    mouse_state |= IID_FIRE

' get mouse deltas
m_dx := mouse.delta_x
m_dy := -mouse.delta_y ' invert due to mouse coordinate mapping is inverted on y-axis

' now, we need to convert the delta or absolute mouse position into digital output,
if (m_dx > 0)
    mouse_state |= IID_RIGHT
else
if (m_dx < 0)
    mouse_state |= IID_LEFT

if (m_dy < 0)
    mouse_state |= IID_DOWN
else
if (m_dy > 0)
    mouse_state |= IID_UP

' merge x,y into packet
mouse_state := mouse_state | ((m_dy & $00FF) << 24) | ((m_dx & $00FF) << 16)

return mouse_state

' end UCI_Read_Mouse2

' ///////////////////////////////// ///////////////////////////////// /////////////////////////////////

PUB UCI_Read_Gamepad2(device_present) : gamepad_state | gpx, gpy
' universal controller interface for gamepad versions 2.0
' now supports the x,y fields in bytes 2,3
' note the gamepad maps very naturally to the universal codes, we could use
' some really clever lookup or logic code to map the codes, but instead lets
' just keep it readable...

' make sure the device is present
if (device_present == 0)
    return 0

' reset state var
gamepad_state := 0
gpx := 0
gpy := 0

' set ESC id
if (gamepad.button(NES0_SELECT))
    gamepad_state |= IID_ESC

' set start id
if (gamepad.button(NES0_START))
    gamepad_state |= IID_START

' set fire id
if (gamepad.button(NES0_A) or gamepad.button(NES0_B) )
    gamepad_state |= IID_FIRE

' now directionals
if (gamepad.button(NES0_LEFT) )
    gamepad_state |= IID_LEFT

```

```

gpx := -2

if (gamepad.button(NES0_RIGHT) )
    gamepad_state |= IID_RIGHT
    gpx := 2

if (gamepad.button(NES0_UP) )
    gamepad_state |= IID_UP
    gpy := -2

if (gamepad.button(NES0_DOWN) )
    gamepad_state |= IID_DOWN
    gpy := 2

' merge x,y into packet
gamepad_state := gamepad_state | ((gpy & $00FF) << 24) | ((gpx & $00FF) << 16)

return gamepad_state
' end UCI_Read_Gamepad2

```

Notice that in both cases we still set the state bits for RIGHT, LEFT, etc, this is to keep the versions as compatible as possible. To see the new functions in action check out **ARENA\_INPUT\_DEMO\_002.SPIN** on the CD, go ahead and run it. Notice it takes a second or two to boot up, this is to detect what devices are plugged in and takes a bit of time. When the demo runs, try all the input devices, especially the mouse, and you will see how now they all seem to do what they should do and "feel" good which is the point. The demo is nearly the same as the first version, but a little code was added to read the packet differently from the input funtions and extract the x,y fields; this code is shown below:

```

' retrieve all input from all devices
player_input := UCI_Read_Keyboard2(keyboard_present) | UCI_Read_Mouse2(mouse_present) | UCI_Read_Gamepad2(gamepad_present)

' extract out x,y fields, x is in byte 2, y is in byte 3 "~~" only works on variable not expression???
player_input_x := (player_input >> 16)
player_input_y := (player_input >> 24)

' now perform sign extensions
player_input_x := ~player_input_x
player_input_y := ~player_input_y

' move the sprite
if ( (player_input & IID_RIGHT) or (player_input & IID_LEFT) )
    player_x += player_input_x

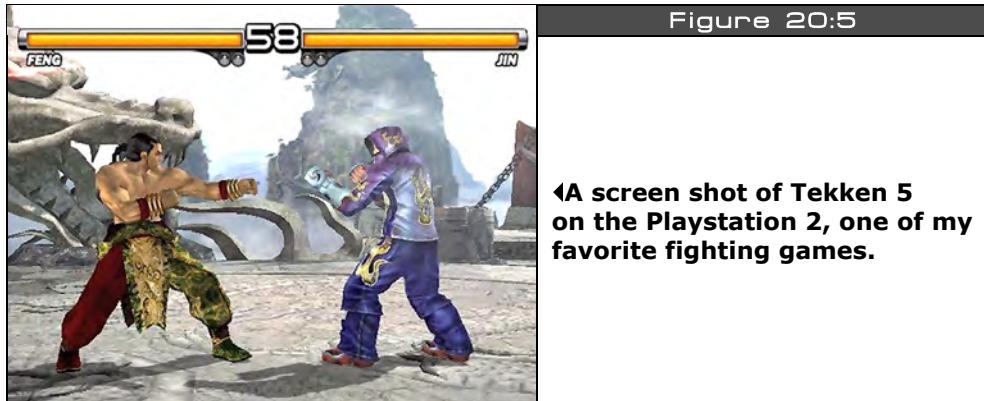
if ( (player_input & IID_DOWN) or (player_input & IID_UP) )
    player_y += player_input_y

```

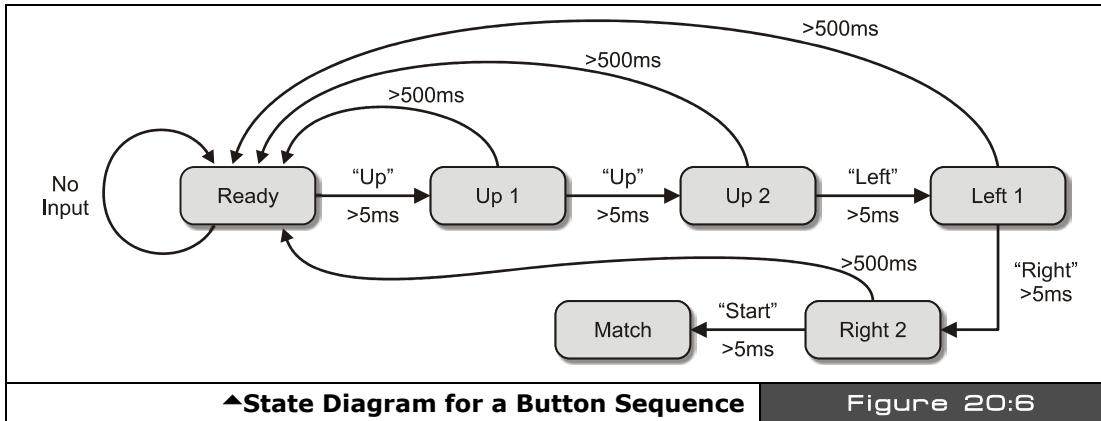
Notice that first the x,y fields are extracted, then the sign extensions must be done separately. Then we save a little code since in the conditionals we can test for right, left as one statement and then move in the x-axis with a similar test on the y-axis, thus saving all four directional tests that we needed with the totally digital packet format before.

## 20.4 Input Device Sequence Tracking

If you have ever played any of the popular fighting games such as *Virtua Fighter*, *Tekken* (shown in Figure 20:5), *Street Fighter*, and so forth then you are probably a master at multiple-button fight moves. The idea is that a standard controller only has so many buttons: usually a directional keypad, select, start, and a couple action buttons. As fighting games in particular got more and more complex, the number of fighting moves and defenses quickly outnumbered the number of control buttons on the game interfaces, so programmers had to come up with a way to add more controls to a controller or interface. The solution was rather than adding more controls, the idea was to use **sequences** of button presses to create new events. For example, "**round house kick**" might be "**down, down, punch,**" and "**flying arm bar**" might be "**up, punch, punch, kick**" and so forth. This had two positive effects: first it allowed the programmers to literally add hundreds of offensive and defensive moves, plus it added another skill aspect to the game: the more moves a player remembered and the faster he could key in the sequence the better his fighter fights! So, when you play these games it's like you are really fighting since you have to work so hard and hit the buttons so fast to call up a specific move! This is why if you are in the arcade and you see some really good gamers playing a fighting game, they are not just hitting random buttons' they are both feverishly trying to enter in offensive and defensive moves faster than their opponent.



Having the ability to turn a few control inputs into hundreds is very desirable for more than just fighting games, any game can take advantage of this, especially games that are played on controllers with only a few buttons. If you have a keyboard handy then maybe you can map many extra moves to the keys, but players tend to like to only have to keep their fingers on a few controls and enter in sequences rather than use all the 101 keys of a keyboard. Taking that into consideration, this technique is a very important in game development, so we are going to take a practical look at it with an example.



As usual, I like to take a problem and simplify it to its core, then you can always improve it or generalize it later. So what we are interested in doing is simply to “*listen*” to the data packets coming from the input controller for a specific sequence, if the sequence is found then we should fire off the event that the sequence indicates. Figure 20:6 shows a state diagram for the sequence “UP, UP, LEFT, RIGHT, START”. Now, this problem is deceptively complex. At first glance, it seems like nothing more than a simple parser problem that you might solve every day when comparing strings, for example it’s very easy to write an algorithm that looks for a sub-string in a string, therefore, you might make an analogy that the sub-string is the sequence you are looking for and the string is the packet data stream. The problem is that we are talking about temporal events here and real time, when the player is entering a sequence, there is more than the sequence we are concerned about. We are concerned with:

- ▶ How long is each button held down?
- ▶ How long until the next button in the sequence is entered?
- ▶ How close is the up and down time of all the buttons?

That is, the player can’t press UP for 1 sec then press the next button for 5 secs, then wait 10 secs and hit the next button, the player has to enter the sequence quickly and with timing that is consistent with a video game’s tempo and speed. However, we have to give the player some “window” of time, so he doesn’t have to be perfect every time. Thus, we might say that given any sequence, once the first button in the sequence is detected then each button must be held down for at least 5 ms and at most 500 ms, and when a button is released, no more than 500 ms can elapse before the next button in the sequence is pressed, otherwise, the player is too slow and the sequence is lost! Of course, if a wrong button is pressed then the sequence is wrong as well. Hence, the devil is in the details of this one and the temporal coupling is what makes the algorithm non-trivial. As an example, take a look at

**ARENA\_INPUT\_DEMO\_003.SPIN.** Go ahead and run the program, and using the gamepad try hitting the button sequence "UP, UP, LEFT, RIGHT, START." Make sure to hit the buttons and release them cleanly, and do it quickly and consistently. If you do it right then you will see the tile background change! Then enter the sequence again and the background will return to its normal artwork. Now, try and slow down your button sequence, at some point you might take 1 second per button and this will be too slow and the sequencer will not accept it, since what kind of fighting move takes 5 seconds to enter! On the other hand, there is a minimum time you must hold each button down, but I have it set so short than no human could probably press the buttons too fast, but see if you can!

The code for the sequencer is in a single function called **Sequence\_Matcher**, it is simply called each game frame by the main event loop and its job is to test for the sequence. It uses globals to retain state and only looks for one sequence. The sequence is encoded in the exact same format as our data packets and is stored in an array in the initialization section of the program. Here's the constants the demo uses relating to the sequencer:

```
' sequence / pattern detector constants, with these rates you can enter the sequence as fast
' as your little primate fingers can enter it, and as slow as .5ish seconds per button
SEQ_COUNT_MIN          = 1
SEQ_COUNT_MAX          = 30

' states for sequence detector
SEQ_STATE_WAIT          = 0
SEQ_STATE_READY          = 1
SEQ_STATE_MATCH_SEQUENCE = 2
```

Nothing more than some constants for the timing variables and integers to represent the state of the sequencer detector state machine. Next are the globals needed for the sequencer:

```
' sequencer globals
long seq_state      : state of sequencer
long seq_counter    : used to count time a button is down or up
long seq_index       : index into sequence pattern data array
long seq_min_flag   : flags if the minimum time for a button to be held has elapsed
long seq_fire_event : this the message that says "do it" whatever the "event" is that the sequence
                     fires off

long sequence[32]    : storage for sequence
long seq_length      : how many buttons in sequence
```

The comments explain what each global does. Moving on, the main initialization simply needs to set up a sequence and that's it; here's the setup code that looks for the sequence "UP, UP, LEFT, RIGHT, START":

```
' initialize input sequencer to detect the sequence "UP, UP, LEFT, RIGHT, START"
seq_state      := SEQ_STATE_WAIT
seq_counter    := 0
seq_index      := 0
seq_min_flag   := 0
seq_fire_event := 0
```

```

' each button in the sequence is followed by "no button", and at the end is only the last button
' look for "UP, UP, LEFT, RIGHT, START"
sequence[0] := IID_UP
sequence[1] := IID_NULL

sequence[2] := IID_UP
sequence[3] := IID_NULL

sequence[4] := IID_LEFT
sequence[5] := IID_NULL

sequence[6] := IID_RIGHT
sequence[7] := IID_NULL

sequence[8] := IID_START

' total number of elements in sequence
seq_length := 9

```

The code starts by resetting all the globals (since Spin has no static initialization in VAR sections), and then, array element by array element, assigning the sequence. Also, note that "no button down" is also part of the sequence, since we want the player to release all buttons in between the sequence buttons, this gives us more flexibility. Finally, a call is made in the main event loop each cycle to the sequence matching-function which is shown below:

```

PUB Sequence_Matcher           | player_input_bits
' this function matches sequences of events from the input controller, it
' uses globals to make things simple, the sequence it tries to match is stored
' in the global sequence[] array, and when/if found it sends a message by
' setting seq_fire_event = 1

' extract the digital bits word only from the player_input
player_input_bits := (player_input & $FF)

case seq_state

SEQ_STATE_WAIT:
    ' wait until no key is pressed, then transition to ready state to try and catch another sequence
    if (player_input_bits == IID_NULL)
        if (++seq_counter > SEQ_COUNT_MIN)
            ' safe to transition into ready state and hunt for sequence
            seq_state := SEQ_STATE_READY
            seq_counter := 0
            seq_index := 0
            seq_min_flag := 0

SEQ_STATE_READY:
    ' this is the entry point to test the sequence whatever it may be, we know that the last
    ' command packet was empty so anything that comes through can potentially start the state
    ' transition to match sequence
    ' step 1: test for starting command in sequence if found then transition to match sequence
    if (player_input_bits == sequence[seq_index])
        ' transition to match sequence and try and match this "potential"
        seq_state := SEQ_STATE_MATCH_SEQUENCE
        seq_counter := 0

```

```

    ' test for incorrect button press, if so reset to wait state
    elseif (player_input_bits <> IID_NULL)
        ' send back to wait state, a wrong key was pressed
        seq_state := SEQ_STATE_WAIT
        seq_counter := 0
        ' else input was null, so its ok to stay in this state...

SEQ_STATE_MATCH_SEQUENCE:
    ' this is the primary matching logic, if we are here, the first button in the sequence is
    ' currently pressed, so we have to make sure the press is long enough, but not too long

    ' first increment the sequence time counter which is used to time how long buttons are down
    ++seq_counter

    ' test for minimum time for button down satisfied
if ( (player_input_bits == sequence[seq_index]) and (seq_counter > SEQ_COUNT_MIN) and (seq_min_flag == 0))
    ' set minimum count satisfied flag
    seq_min_flag := 1

    ' test for early withdrawel from button press
elseif ((player_input_bits <> sequence[seq_index]) and (seq_counter < SEQ_COUNT_MIN))
    seq_state := SEQ_STATE_WAIT
    seq_counter := 0

    ' test for next button in sequence pressed, or is this last button in sequence
elseif ((seq_counter > SEQ_COUNT_MIN) and (player_input_bits == sequence[seq_index+1]))
    ' two case: this button is in the middle of the sequence or its the last
    if ((seq_index+1) == (seq_length-1))
        ' end of sequence, fire off event!
        seq_fire_event := 1
        ' move to wait for next sequence
        seq_state := SEQ_STATE_WAIT
        seq_counter := 0
    else
        ' middle of sequence, consume button event and move to next
        seq_counter := 0
        seq_index++
        seq_min_flag := 0

    ' test if maximum time has expired, no matter what we are done..
elseif (seq_counter > SEQ_COUNT_MAX)
    ' player held button down too long, reset to wait state
    seq_state := SEQ_STATE_WAIT
    seq_counter := 0

```

The function is mostly comments, but is a little tricky; the general idea is that it sits in the **"waiting"** state waiting for the player to completely release the buttons, then it moves to the **"ready"** state looking for the first button in the sequence. If it detects the first button then the state machine moves to the **"matching"** state and looks for the remainder of the buttons, but uses a timing element to make sure that they are entered in a temporal fashion compliant with the min and max time limits. When and if the sequence is found then the variable ***seq\_fire\_event*** is set TRUE which is monitored in the main event loop, if TRUE, the main event loop toggles the background tile map with the following code:

```

' if event was fired change tile map
if ( seq_fire_event == 1)
  ' reset event seq_fire_event
  seq_fire_event := 0
  ' toggle tile map
  if (tile_map_base_ptr_parm == @tile_map1)
    tile_map_base_ptr_parm := @tile_map0
  else
    tile_map_base_ptr_parm := @tile_map1

```

And that's about all there is to it! Of course, the next step is to make the function able to read multiple sequences simultaneously, and be able to do more complex things like call functions when a sequence was detected and so forth. Supporting multiple sequences is best done with a linked list or a "**tree**" like data structure since many sequences will have common "**roots.**" For example "**LLR-UU**" and "**LLR-DRRD**" both have "**LLR**" in common, thus the sequences would follow the root and then make a decision based on the 4th button press to which way to go in the tree on a linked list to continue testing.

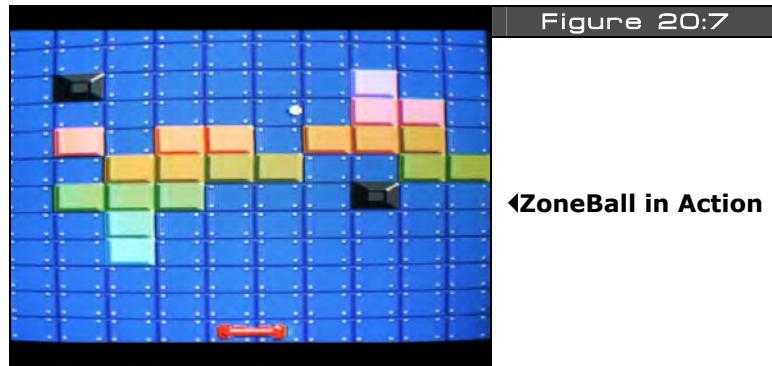
You can have a lot of fun with this input technology; it's great for sports and fighting games to make the player perform more "**physical**" sequences than single key presses.



You will notice that the keyboard doesn't seem to work when you enter the sequence. The reason why is that START and FIRE overlap, so when you press START on the keyboard it also sets the FIRE bit in the packet. Thus, to support this some extra logic is needed to mask bits etc. to take this special case into consideration. But, this is an input-mapping problem, not a problem with the sequencer.

## 20.5 ZoneBall

As an example of taking some of these input device techniques and putting them to good use, I put together a basic "Breakout" game skeleton called "**ZoneBall.**" This demo uses all 3 input devices based on the version 2.0 universal controller. The game play consists of a number of tile levels each with a set of tiles that represent background art and the foreground "blocks" that you need to hit with the ball via the paddle which is controlled by the player. A screen shot of the game is shown in Figure 20:7.



The rules of the game are simple; clear each level by hitting all the blocks with the ball and go to the next level. The game is just a demo, so there is lots for you to add. Right now, the game starts off by initializing everything then placing the paddle at the bottom of the screen with the ball in it. To launch the ball into play press the “**FIRE**” or “**START**” button on any input device and the ball will be fired. Control the ball by moving the paddle right and left with the standard “**RIGHT**” and “**LEFT**” controls on any input device. If the ball gets past you, it will load into the firing position again and you restart. This is where you would later add in score, and the number of balls, so the game doesn’t let the player miss balls forever! Anyway, when a level is cleared then the next level is started; there are a handful of levels then they cycle. The source can be found in: **ZONEBALL\_INPUT\_DEMO\_001.SPIN**.



#### NOTE

The virtual keys “**FIRE**”, “**START**”, “**RIGHT**” and “**LEFT**” are the generic values we assigned to the universal input controller’s data packet format. Depending on what input device you are using, they map to different sub-controls, refer to Table 20.3 to see the assignments.

The levels each consist of a tile set, the tile set is laid out to look cool with lots of color and blocks to show off the tile engine. Also, there are immovable blocks that look like little pyramids (dark gray) that the ball just bounces off to make things harder. Now, there are lots of details to a game like this, but I am only going to talk about three of them:

- ▶ Level Loading
- ▶ End of Level Determination
- ▶ Collision Detection

### 20.5.1 Level Loading

In a game that is based on levels, each level must be represented by a record or data structure of some kind. The level could be as simple as a few numbers or it could be as complex as geometry data, character data, sounds, etc. In the case of **ZoneBall**, each level is represented by a tile set which indirectly references tile data and palettes, thus, we need a single index number to represent which tile set to use for the level. Additionally, we need to know how many blocks the level has that the player needs to hit with the ball, of course we could count them on the level load, but for fun, we are going to add this to our level format. Thus, each level record only needs two pieces of data:

1. Level number 0..n
2. Number of blocks in level

The level number is used to index into a table that contains a list of addresses to the base memory of each tile, and the number of blocks is used by the game logic to determine when the level is completed, so the game engine can load the next level. Thus, we need an array of these records to control the entire level-loading process.

### 20.5.2 End of Level Determination

**ZoneBall** is based on the rules of “Breakout” thus the idea is to clear off the level of any blocks, this is done by striking the blocks with the ball. To determine the end of the level there are a couple ways to do this: one way would be each game cycle to count up how many blocks are left on the tile set, but this would be a waste of computation, a better approach would simply be to keep a running count of how many blocks are left from the start of the level. For example, say level 1 starts and there are 40 blocks on the screen, this is stored in a counter, then when the ball hits a block, it is removed from the screen and the counter is decremented. When the counter reaches 0 then the level has been cleared. This technique works since the number of blocks is deterministic. Even if we **added** blocks during game play we simply would increment the counter to represent this. As long as we don’t lose track of the number of blocks on the game level, a simple counter works. Basically, it’s like a “**reference counter**” in Windows COM-speak.

### 20.5.3 Collision Detection

When we cover physics modeling and collision detection later in the book we will discuss many ideas about collision detection in games which itself is a huge subject and one can easily write a 2000-3000 page book on! So our discussions are going to be very basic. However, as an introduction this game is a great place to start for a common collision problem found in any kind of breakout/pong game; that is, how to detect when the ball hits something and what to do when it does?

The first thing to remember is we are making games here not NASA simulations, our collision algorithms just have to work good enough for the game to be fun and playable, but they

don't have to be perfect. Computationally accurate collision detection is a complex field in physics and advanced game programming that deals with complex mathematics that we aren't going to need. The idea here in video games is to base your collision detection on real physics, but to simplify the algorithm considerably, so it's feasible to implement with simple math in a few lines of code. Also, how accurate you need the collision detection to be has a lot to do with the complexity of the algorithms.

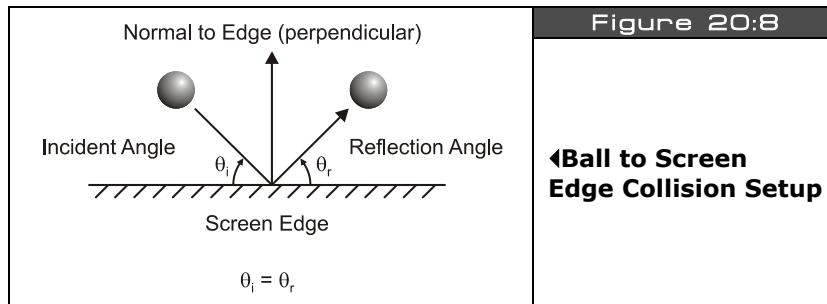
In the case of **ZoneBall**, we have a number of collision detection events we have to handle, they are:

- ▶ Ball-to-screen edge collisions
- ▶ Ball-to-paddle collisions
- ▶ Ball-to-block collisions

Each type of collision is handled slightly differently, so let's take a look at each in increasing order of difficulty.

#### 20.5.3.1 Ball-to-Screen Edge Collisions

This is the easiest collision to deal with since all 4 sides of the screen are straight lines, thus we can make a lot of assumptions about the math. We are going to simulate a "**perfectly elastic collision**" which means that the angle of incidence that the ball strikes the wall is the same as the angle of reflection and there is no energy lost, Figure 20:8 shows this graphically. Of course perfectly elastic collisions only occur in video games and high school physics tests, but we are ok here!



The math is simple to program this behavior, given that the ball's velocity **is ball\_xv, ball\_yv**, all we need to do is reflect this vector along the path of incidence. But, we can simplify this even more with some information; if we hit the top or bottom edges of the screen then we know that we need to reflect only the ball's y-velocity since the x stays the same. Similarly, if we hit the screen's right or left edge then we simply reflect the ball's x

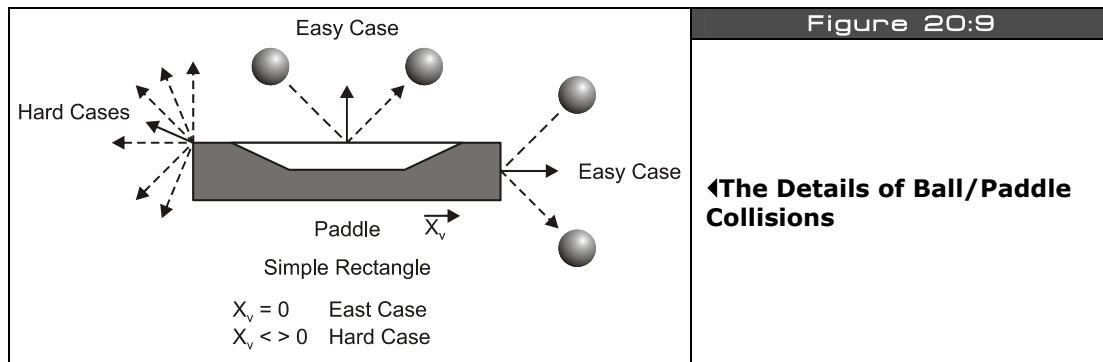
velocity. Also, we need to add in the rules of the game which state that if the ball hits the bottom edge of the screen (getting past the player's paddle) then the game restarts with a new ball. But, for now let's forget the rule, and concentrate on the physics. The code/math is shown below to create this behavior:

```
' test for ball collision with game playfield boundary
if ((ball_x > BALL_PLAYFIELD_MAX_X) or (ball_x < BALL_PLAYFIELD_MIN_X))
    ball_xv := -ball_xv
    ball_x += ball_xv
    ball_y += ball_yv

if ((ball_y > BALL_PLAYFIELD_MAX_Y) or (ball_y < BALL_PLAYFIELD_MIN_Y) )
    ball_yv := -ball_yv
    ball_x += ball_xv
    ball_y += ball_yv
```

...where the constants in the conditionals represent the various screen boundaries. Now, you might like to note that when a collision occurs, the ball is translated once again. This is a curious extra step, but it's needed since by the time you detect a collision you are ***already past*** the collision boundary, thus the object has pierced solid matter, so to make things "look" more realistic, a typical technique is to ***back the object up*** either by reversing it or to track the last known position, so when a collision does occur, we perform the changes in trajectory then use the ***old position*** to move the object back to the position right before the collision took place which is "more" correct than after it took place.

#### 20.5.3.2 Ball-to-Paddle Collisions

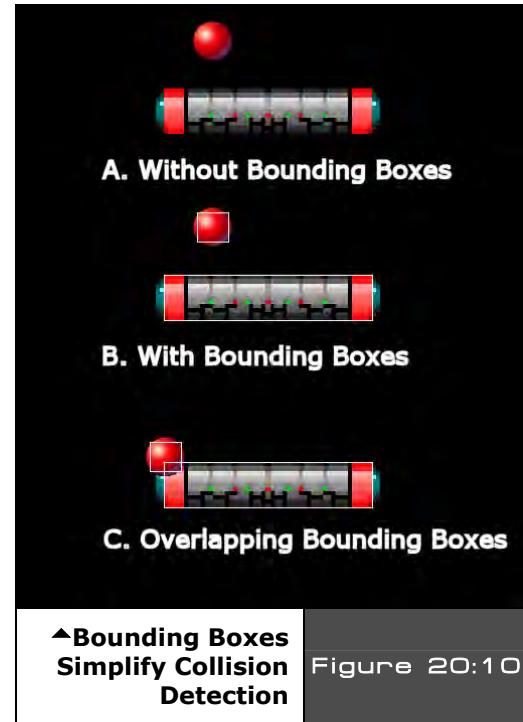


Now, here's where things get really tricky depending on how realistic you want your breakout game. In a real commercial breakout game, you might need hundreds of lines of code to perform the ball paddle collision correctly to give the player the right "feel." This is because a

real ball and a real paddle have a lot of parameters to model even if you are cheating. For example, in breakout games, many games give the ball a virtual "spin," this is used along with the velocity of the paddle to cause the ball to shoot off in another direction when you hit it. For example, if you play a modern breakout game, and right when you hit the ball, you apply some "**english**" to the paddle by moving it quickly, you can effect the reflection of the ball and target it better. Also, if you have a paddle that has a square surface, what if the ball hits the corner? For example, take a look at the "Hard Cases" in Figure 20:9 to see this, in these cases the ball should do something different since it's hitting a corner.

Alas, in our case, we aren't going to deal with all these factors, we just want the ball to reflect off the paddle and look reasonable. We are going to only have a couple "english" factors; if the paddle is moving when it hits the ball then we are going to factor this into the ball's response. Also, we are going to add a little bit of randomness to the response of the ball on the paddle as well. However, as long as the ball hits the paddle then the entire surface of the paddle is the same as far as we are concerned which brings us to another problem. How to detect if the ball has hit the paddle at all?

This is really a problem in geometry ultimately, the ball is a sprite with a certain size, the paddle is a sprite with a certain size (usually smaller than the sprite data which is always  $16 \times 16$ ), so step one is to simplify both problems by placing ***bounding boxes*** around the paddle and the sprite, since squares are easier to test collision against one another than arbitrary polygons or bitmaps, this is shown in Figure 20:10. Referring to Figure 20:10(B), see how the bounding boxes surround the ball and paddle, and are smaller than the actually sprite data (this makes for a more certain collision). Thus, the bounding boxes are mathematical in nature and you have to store them in a secondary data structure, either in a record or programmatically via your collision calculation's conditional logic test via test constraints. Either way you do it, at the end of the day, the problem is to determine a collision between two boxes as shown in Figure 20:10(B).



There are hundreds of algorithms to do this, but one of the simplest is to transform the problem from determining if two boxes intersect, to test a point and box intersection, this is shown in Figure 20:10(C). Testing if a point is in a box is very simple, then to test if the boxes intersect, we simply take the 4 points that make up box A and if none of them are inside box B then there can't possibly be a collision! As an example of the algorithm, let's say that box A is composed of 4 points: A1(x,y), A2(x,y), A3(x,y), and A4(x,y). Let's call any single test point (x,y), then let's test it against box B which consists of B1(x,y), B2(x,y), B3(x,y), and B4(x,y). The pseudo-code algorithm to test for containment is shown below:

```
if (x >= B1.x and x <= B2.x and y >= B1.y and y <= B2.y )
    ' ... the point is contained
else
    ' ... point not contained
```

Then you simply perform the test for all 4 points that make up Box A. However, if you really want to simplify the problem even more then forget that the ball has a bounding box at all and simply represent it as a **single point**. This is viable since a ball is round anyway, and we are interested in the center of the ball, since what the center does is mostly what the rest of the ball does, therefore, we can simplify the ball paddle collision to a single point (the ball's center) tested against a bounding rectangle (box) of the paddle and then perform the appropriate response for a perfectly elastic collision which is just to reflect the ball's direction about the paddle's surface along with adding a little "english" based on the motion of the paddle. The entire collision detection algorithm from the demo is shown below for reference:

```
' test for collision with ball and paddle, use center point of ball and test against bounding box of
paddle

if ( (ball_x > (paddle_x - PADDLE_WIDTH_2) ) and (ball_x < (paddle_x + PADDLE_WIDTH_2) ) )
    if ( (ball_y > (paddle_y - PADDLE_HEIGHT_2) ) and ( ball_y < (paddle_y + PADDLE_HEIGHT_2) ) )
        ' there's been a collision, now respond, the "response" depends on how accurate you want to be!
        ' first invert the y-velocity
        ball_yv := -ball_yv
        ball_yv += -3 + (?random_seed & $03)

        ' now add a little bit of english based on the movement of the paddle
        if (||player_input_x > 0)
            ball_xv -= player_input_x/2

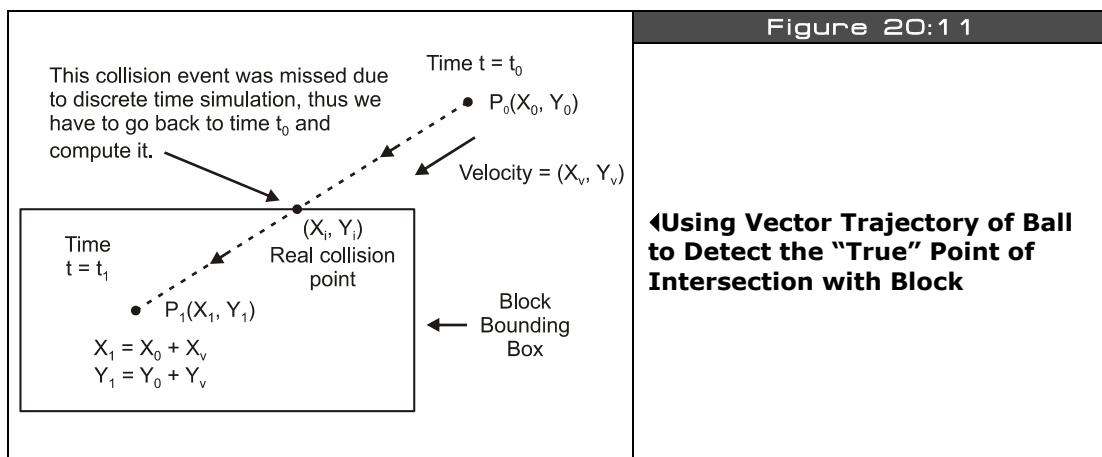
        ' clamp velocity of ball
        ball_xv #>= -4
        ball_xv <#= 4

        ball_yv #>= -4
        ball_yv <#= 4

        ball_x += ball_xv
        ball_y += ball_yv
```

### 20.5.3.3 Ball-to Block-Collision

These collision are nearly identical to the ball-to-paddle collisions, but are slightly simplified since the blocks aren't moving and there are no "english" calculations to make. On the other hand, to be accurate we have to consider that the ball can hit any block on all four sides, this makes the collision calculation a little longer since we have to determine which side; **top**, **bottom**, **left**, or **right** of the block that the ball hit and reflect the ball. Thus, the problem turns into the ball-to-paddle collision problem performed four times. Also, there is the additional problem in collision detection that, depending on how you perform the calculations, you might end up with more than one potential collision surface, thus you have to further process to resolve this issue. For example, if the ball is moving very quickly from one frame to another, it could be outside the block then all of a sudden inside the block! If the ball's trajectory was near the corner of the block we would have a hard time finding where the ball "**would have**" intersected the block if we could go back in time.



This is why in formal collision detection algorithms, you would use vectors, polygons, line equations, and so forth to determine where the trajectory vector of the ball strikes the collision surface as shown in Figure 20:11. In the figure at time  $t_0$ , there is no collision, then at time  $t_1$ , the ball is inside the block, thus a collision must have occurred. The problem is that we don't know where the collision occurred. To compute this, we must project a vector from the ball position at  $t_0$  to  $t_1$  and compute the intersection as shown in the figure.

This can be done surely, and isn't that hard, but for now, I want to keep things a little simpler, so in this case, we are just going to perform the four collision tests against all four sides of the block and try and figure out which side the ball hit, then reflect it, if we are wrong once in a while it doesn't matter since it's a game! The technique more or less is going

to compute the distance from the ball to each of the edges, and the closest edge will be assumed to be the edge the ball hit first. When we discuss physics and collision detection, we will formally look a little closer at these math problems. However, in all truth many game programmer that write simple 2D games rarely have to resort to formal algorithms, they usually can **"hack"** it and make it work and that gives the game a more **"arcade"** feel anyway.

Considering that, the math and techniques are the same as in the previous discussions, the only difference is that when the block is hit we need to decrement the global block counter, so the game engine knows that yet another block has been removed. This allows me to bring a point to light and that's how the physics engine can "***send messages***" to the game engine: the decrement, as simple as it is, is really a "message" and this is an example of message passing. However, good game programming keeps the rendering, physics, and gameplay engines decoupled. The only coupling is saved strictly for messages. That is, the renderer should render, the physics engine do physics, and the game engine do the game, they shouldn't be integrated and/or do each other's work. By de-coupling each portion it makes debugging, coding, and upgrading much easier. Please refer to the complete source of **`ZONEBALL_INPUT_DEMO_001.SPIN`** to see the source for this since it's very similar to the ball-to-paddle collision listed in the paragraphs above.

#### **20.5.4      Gameplay and Design Tricks**

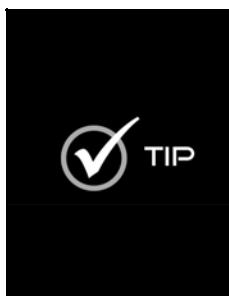
To play the game simply load up

**ZONEBALL\_INPUT\_DEMO\_001.SPIN**, grab an input device and press "START" or "FIRE" to launch the ball. Other than the basic game play there are some interesting things to note about the use of the tile engine here. For example, on some levels you will see that the paddle changes colors as it moves around right to left, this is by design, using different primary paddle colors in the palettes for the tiles. Also, the sprite that makes up the paddle is actually two sprites. One sprite wasn't large enough, so I took two sprites and placed them side by side, drew the proper art into their bitmaps and during each animation cycle made sure to draw them next to each other. Here are the bitmaps for each sprite half (minus the mask which you can look for in the source):

Notice the right half of the sprite is commented out, I drew the sprite in the comments then copied the right commented side out and made it `sprite_bitmap_1` (and then made small changes to it). This way I had two sprites `sprite_bitmap_0` and `sprite_bitmap_1` that represented the right and left halves of the paddle (mirrored of course). Then in the main even loop whenever the paddle is moved, both sprite halves are moved and re-positioned, so they stay in sync and look like one object. The following code performs this update:

```
' now update the sprite records to reflect the position of the paddle
sprite_tbl[0] := (paddle_y << 24) + (paddle_x << 16) + (0 << 8) + ($01)
sprite_tbl[2] := (paddle_y << 24) + ((paddle_x+16) << 16) + (0 << 8) + ($01)
```

Also, you will notice that the ball has a little shadow in it, this is simply drawn there and isn't real.



Also, if you look closely at some of the palette color entries you will see color values like:

**\$xF' where “x” is 0..F**

That is, the LUMA is \$F. This is not supposed to work, since the color modulation needs to have +1 to toggle the chroma signal. The rule was no LUMA value can be greater than 6, but in this case it's 7 (remember the 8<sup>th</sup> bit has to be on for color). This trick creates over-saturated colors!!! So you can get an extra 16 colors on the HYDRA by using the colors \$0F, \$1F, \$2F, ..., \$FF. The only downside is depending on your TV, they may look a bit different.

## **20.6 Advanced Concepts**

There are so many things you can do with input devices. For example, look at the Apple Macintosh or PC, with a single mouse and 1 or 2 buttons, you can control entire networks! This is due to the clever and creative use of the mouse. There is really no limit to how cool you can make your input controllers, for example we talked about input sequence testing to determine key presses, but what about the opposite? That is, pressing a button or sequence of buttons that output another sequence of buttons? For example, you press <START>+<SELECT> and instead of that firing off a single command, it "***plays***" a sequence of commands out the input controller as if they were coming from the player, this way you can do complex moves and sequences that would be impossible. Or as another example, giving the player the ability to record sequences he/she wishes and then play them back based on specific key sequences.

Another thing you're always hearing about is "**force feedback.**" This is easy to implement with the HYDRA, all you need is a really tiny motor like that found in the vibrator circuit of a cell phone or pager. Then you could crack open the NES controllers, add logic so that when the latch is disabled, the data line is used as an output to the controller and gated to the motor, then you can pulse the motor to make the controller vibrate during times in the game that were appropriate.

## 20.7 Summary

This chapter hopefully has opened your eyes to what most people take for granted – **input device programming.** There is a lot to it if you want to do it right and support all devices in the proper way. Also, filtering input devices through "software controllers" and sequencers can help games and applications respond much better than they would with raw data, so these concepts transfer to all kinds of programming in addition to game development. Alas, we have only scratched the surface here, but hopefully you have have a new found respect for input device programming!

## Chapter 21: Sound Design for Games

In this chapter, we are going to briefly discuss "**sound design**" techniques for games. Sound design is the art of using sound in games to add richness and depth to a game. This subject is huge on so many levels, thus it's nearly impossible to do it justice without 500+ pages. Alas, we are simply going to review some of the technical aspects of sound generation, take a look at a sound driver to get you started, and finally write an application that plays **RTTTL** (**R**ing **T**ones **T**ext **T**ransfer **L**anguage) phone ringtone files. By the end of the chapter you will have your hands on a very powerful sound engine that plays both FM and PCM sounds along with a cool little RTTTL player you can use in your games. Here's what's in store:

- ▶ Sound generation techniques review
- ▶ Working with sound and music for games, and problems to consider
- ▶ FM/PCM sound driver overview
- ▶ RTTTL (Ringtone) music player

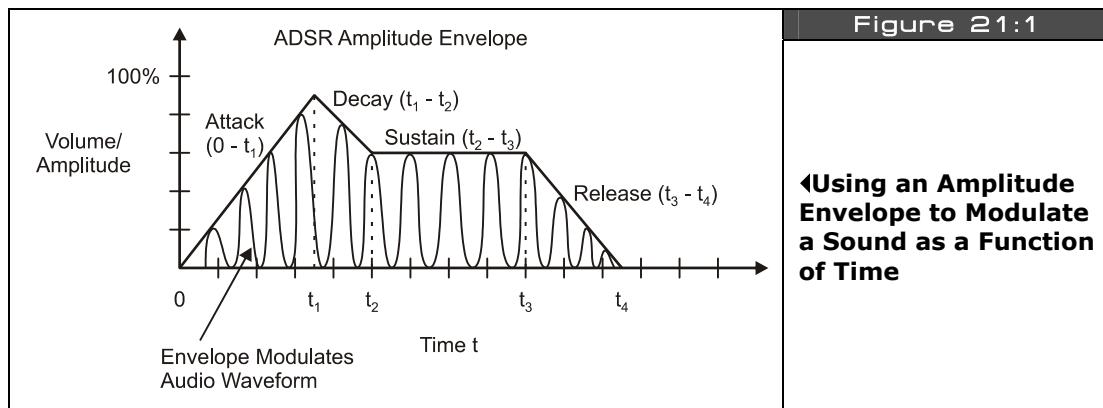
### 21.1 Sound Techniques Review

If you haven't read Chapter 9 then I highly suggest you do so now, as well as Chapter 16, sub-section 6. This material covers the sound hardware and sound generation techniques used on the HYDRA game system. To briefly review, the best way to create sounds on a limited memory system like the HYDRA is to use PWM (pulse width modulation) synthesis to generate analog time-varying waveforms in real-time to emulate the abilities you would find on a standard FM synthesizer such as a Sound Blaster. This technology will allow you to play musical notes and effects, and more or less create music and game sounds like lasers, explosions, and so forth. The only problem is that most games these days use pre-recorded **digitized** sound effects rather than trying to synthesize them by using PCM (pulse coded modulation) techniques, that is, sending out 8- or 16-bit samples to a D/A followed by the speaker. This is a stretch for the Propeller chip since it only has 32K of RAM on board, thus external memory like the HYDRA's larger 128K EEPROM have to be streamed in potentially or other memory added to get the megabytes needed to support large samples for games. Nonetheless, even with a few K, one can digitize a handful of very short samples and use them for key sound effects in a game: an explosion, a laser, a little bit of voice and so forth. Not to mention if you want to start compressing your PCM sounds then you can make 8 to 16K of sound memory go a pretty long way!

Supporting music is rather easy as long as you have a sound driver that can play any frequency in a selected waveform along with envelope control (desired, but not absolutely necessary). For example, a simple sound API like this is more than enough for a savvy game programmer to do a lot of damage:

#### **Play\_Sound(channel, frequency, envelope, duration, volume)**

Additionally, the more channels you have, the more instruments or tracks you play at once, adding to the richness of the musical piece. For example, most early game systems had four sound channels where three of them were used for tonal sounds and one for white noise or percussion. With the simple ability to play a tone along with the sound envelopes and some sequencing software to play notes on the channels at specific times, you can make any musical piece you wish.



**NOTE** The concept of “sound envelope” has been discussed in Chapter 9 and 16. Sound envelopes are really amplitude modulation envelopes that give you the ability to play a sound that doesn’t just abruptly turn on and off, but rather the amplitude can slowly increase, then sustain a particular level, then fall off based on the shape of the envelope. In sound programming, we use a simple ADSR envelope which stands for “Attack-Decay- Sustain-Release” as shown in Figure 21:1. By modulating a pure tone’s amplitude or volume with the envelope, you can get all kinds of effects that are similar to real instruments and how they sound when struck, blown, drummed or plucked.

The **MIDI** (Musical Instruments Digital Interface) is just such as “sequencing software” standard. MIDI is a serial protocol used by electronic instruments to play (and record) music. It consists of a number of commands that a MIDI device listens to and then plays the music based on the command(s). Of course, not all devices support all MIDI commands, thus any

MIDI device **tries** to do its best at reproducing the intended musical piece. Some of the commands include instrument selection, channel selection, play note, turn notes off, download instrument data, timing commands, and so forth. MIDI is very powerful, but a little overkill for our needs, so later we will look at a simplified musical format called RTTTL (ring tones text transfer language) which is used to play all those annoying cell phone ringtones you hear all the time. RTTTL is very much like MIDI, but it's only a single-channel format or what's called "**monophonic**" and has fewer commands to support. We will cover it in detail later.

## 21.2 Working with Sound and Music for Games

Simply put, sound and music makes a game more fun. For example, take your favorite game and play it with the sound turned off, I guarantee the experience will be 10% of what it is with the sound on no matter how good the graphics are. On the other hand, take a game with great sound and music and lower the resolution, decrease the color depth, and even slow it down and the game will still be fun. This simple psychological fact is well known among game developers. As another example, take a simple 2D game like asteroids, replace the simple "electronic" sounds with digitized explosions with deep bass, realistic plasma weapons sounds, and engines that roar, and that little game will put a smile on anyone's face! So the bottom line is that *games need sound* and the art of engineering the sounds for a game is called "**sound design.**" Once again this is a very deep and complex field that is both artistic and technical, but at very least the idea is to design a game and during the design be thinking of all the sounds that game needs at very least: when, what, where, and so forth. Also, what's the "theme" of the sounds? Will your game sound "old," "new," "alien," "rough," and so forth? These are all questions that you have to answer and get the hang of as you design the sounds and music for your games.

In our case, we are going to be talking about very simple sounds and how to do things in a practical manner. For example, let's say that we want to make a simple space shooter game. The first thing to do is make a list of what kinds of sounds the game will need:

1. Laser/plasma pulse when player fires (variations)
2. Explosions (various types)
3. New level sound effect
4. End of level sound effect
5. Player death sound
6. Boss level music track
7. Sounds of laser/plasma hitting various environmental objects: rocks, metal, glass etc.

As you can see, just off the top of my head we have quite a few sounds. Now, if we have digital sound abilities then these sounds aren't very hard to come by, you can make them, license them, or a mixture of the two. However, on the HYDRA with limited memory, you

would probably have to synthesize all of these sounds by playing waveforms through channels and then playing with frequency, volume, etc. There is an entire art form to this.

But first let's take an aside to some of the technical aspects of some common problems when playing sounds on a game system. First off, as you can see there are 7 classes of sounds in my little list, and there might be 1-10 instances of these sounds, that means something like 70 sound channels playing simultaneously! Well, even the XBOX doesn't do this, so how can a game as complex as Halo or Quake Arena with all the sound effects work? Well, first, there are a lot of sound channels, but not enough to play every sound at once that the game might throw at it.

Thus, when designing a sound engine, you have to think of the sound channels as **resources**. There might be 4-8 channels to choose from and each channel can play a simple tone with a given frequency (that can change programmatically) along with a volume and envelope. However, the problem is simple: let's say the player fires his plasma cannon, the sound algorithm for the plasma cannon starts running and allocates channel 0, then the pulse fires and hits an alien which causes an explosion and 6 other secondary explosions, all of a sudden there are 8 channels being used, the player tries to fire again and whoops a plasma pulse comes out, but no sound!

### **21.2.1 Designing a Sound Playback Resource Allocator**

The first thing you have to do when designing a sound engine is have a priority system that basically will pre-empt a playing sound for other higher priority sounds. In the example above, no matter what, when the player fires it **must** be heard. Also, when the player's plasma pulse hits something, that first explosion **must** be heard. Therefore, a typical strategy is to design a sound engine that has each channel available, then when you play a sound you assign a priority to the sound and a length to the sound. When the sound starts playing, a timer counts along with the sound as it plays keeping track of how long more the sound has to play, using this tracking system, you can tell if a sound is almost complete. Having this knowledge helps in the construction of a pre-emptive sound resource selection algorithm. A first pass at such an algorithm with the setup I have outlined would be something like the pseudo-code algorithm below which finds an available sound channel resource:

```

If      there are any free channels, use that channel, assign priority, length, and
            start timer. Done.
Else
            For all channels with priority less than desired sound, find the sound that is
            the most complete, pre-empt it, and use that channel, assign priority, and
            start timer. Done.

```

**Else**

For all channels with priority equal to desired sound, find the sound that is most complete, pre-empt it, use that channel, assign priority, and start timer. Done.

**Else**

Can't play sound right now, Queue sound up with "stale" count.

The algorithm tries to find a sound channel that it can use in the order of least disturbance to sounds playing. Ultimately, if the sound can't be played then its queued up in a timed queue in the last step, let's talk about this. The idea here is that if you can't play the sound now, then maybe you can in a few hundred milliseconds (or even a second or two). However, most sounds need to happen right now if they are game-action sounds, but a few milliseconds can be acceptable in most cases, thus a "**stale**" count is added to the queue entry of the sound that basically says, "if you can't play this sound in this many ticks, then forget it, throw it away."

The algorithm outlined above, as simple as it is, is very powerful and found in many games. Of course the devil is in the details, but you get the idea hopefully; that is to allocate your resources and pre-empt sound channels as need be, dictated by the game action.

### 21.2.2 Dealing with Real-Time in a Sound Engine

The next problem with designing a sound engine is the real-time nature of sound effects synthesis. For example, let's say that we have a sound API that has the simple sound call:

```
Sound(channel [0..3], frequency [0..255], volume [0..255])
```

...and all the sound function can do is play a square wave. Now, let's say that through experimentation, you find that you are trying to make a laser pulse and playing random frequencies with an increasing volume to make a cool laser sound like this:

```
repeat volume from 0 to 255
  Sound(0, random(255), volume)
  repeat 10_000 ' add a little delay
```

This little chunk of code is a "sound effect algorithm" and is perfectly legitimate, in fact, this is the exact way you engineer sound effects when you have an API you communicate through. But, what's the problem? The problem is that this is **not** real-time. If this algorithm were called as a result of a player pressing the fire button, the game would pause, play the sound then continue – that's not good! So here we have yet another dilemma – we need the sound engine to be real-time. This means that the sound engine has to be a function that is called every animation frame (or multiple times a frame) and each sound effect that is algorithmic must be updated, this means more complexity like state variables, timers, and so

forth. Thus, as you can see this gets complex very quickly. Taking this into consideration, we might have the following pseudo-code fragments:

```
Pub Sound_Engine(command, parm1, parm2, parm3)
{ called every frame by main event loop, inside this is every single sound effect
algorithm, the function iterates through all of them and any that are active are
updated... command tells engine what to do, and the generic parms are used based on
context of command }

' general command, simply to process all sound algorithms
if (command == PROCESS_SOUND_ALGORITHMS)
' begin process ALL sound algorithms here...
' laser blast algorithm
if (laser_sound_playing)
' update sound
Sound(0, random(255), laser_volume)
' update algorithm counter
if (++laser_volume > 255)
laser_volume := 0 ' reset volume for next user
laser_sound_player := 0 ' reset flag, so another call can use it
' turn sound channel off
Sound(0, 0, 0)

elseif (command == START_LASER_SOUND)
' request being made to start laser sound, high priority - start no matter what!
laser_sound_player := 1
laser_volume := 0 ' also used as counter

' end PROCESS_SOUND_ALGORITHMS /////////////////////////////////
```

This code allows the main event loop to start a laser blast with the following call:

```
Sound_Engine(START_LASER_SOUND, 0, 0, 0)
```

...and then in the main event loop each cycle, a call must be made to allow the engine to process the sounds like so:

```
Sound_Engine(PROCESS_SOUND_ALGORITHMS, 0, 0, 0)
```

...and this is the beginning of a complete sound engine! Of course, to do it right you would want to use clean data structures, have many more commands, and so forth, but this example illustrates the idea. The only problem with this real-time sound engine is that the update rate is coupled to the game's frame rate – this can be a problem.

The problem with coupling the sound engine to the game's frame rate is twofold: first, 30 to 60 frames per second is a typical game frame rate, this rate might not be nearly fast enough to update the sound engine. Secondly, if the frame rate changes as the game slows down due to complex calculations, then the rate at which the sound engine gets called, and consequentially at which the sound functions will slow, will be very perceivable to the player as the sounds slow down.

The solution to this problem is to use an interrupt to run the sound engine, so no matter what the foreground is doing, the background task is processed(the sound engine in this case is updated constantly), typically this might be 256 to 512 times a second if the sound engine is making lots of changes per second. However, the Propeller has no interrupts, but it does have multiple processors and the sound engine is a textbook example of what **should** be run as a separate process. Calls are made to the sound engine running on another cog, and no matter what happens to the game logic and graphics, the sounds play cleanly and consistently. That's about all there is to getting up and running a first-class sound engine that can handle all your needs. We don't have enough time to build an entire sound engine, but hopefully you have enough ideas to create one yourself, plus it's a lot of fun. Next, we are going to discuss the most important part of the sound engine, the sound driver, without that there is no sound!

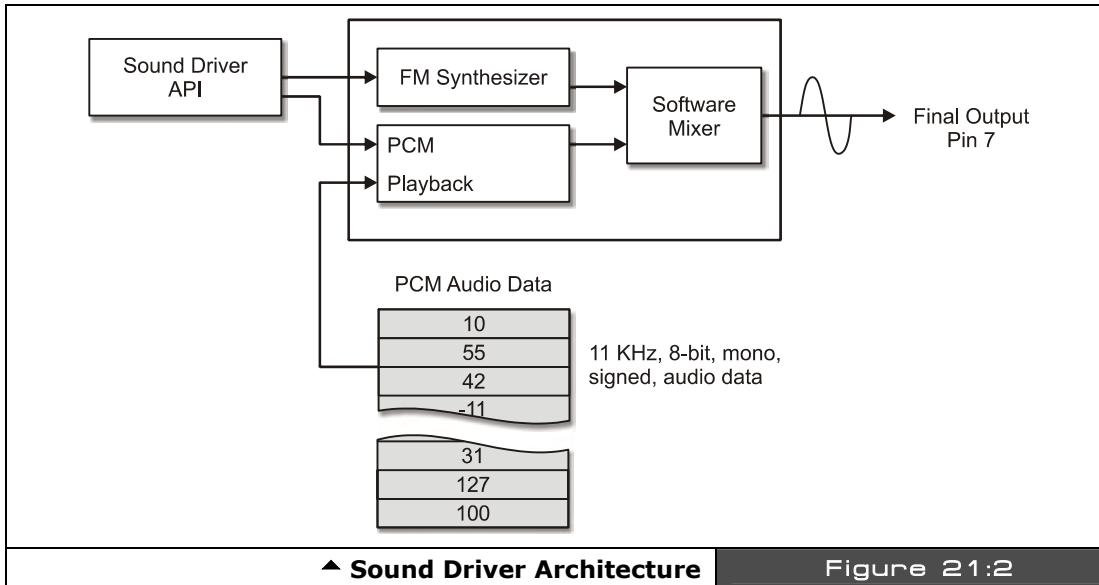
### 21.3 Sound Driver Object Overview

The sound drivers we are going to use for this discussion are:

**NS\_SOUND\_DRV\_051\_22KHZ\_16BIT.SPIN**  
**NS\_SOUND\_DRV\_051\_11KHZ\_16BIT.SPIN**

.....which are the 22KHz and 11 KHz versions respectively and as usual are located on the CD in **CD\_ROOT:\HYDRA\SOURCES\**. The driver was written by Jedi Master demo coder **Nick Sabalausky** over a period of a couple months and is for educational use. The driver is based directly on techniques from Chapter 9 and Chapter 16 section 6, so read those before you try to understand the source code. However, we aren't going to delve into the complexities of the driver, we are simply going to use it as a foundation to get sound into demos from here on our where needed. I highly suggest you review the code for the driver(s) if you're interested in how they work, be warned they are highly optimized ASM code, but very well commented, so a few hours of review should give you a handle on the internal workings of the drivers, so you can make your own and improve them. The drivers are identical except for the PWM synthesis rate, one driver runs its PWM engine at 11 KHz, the other at 22 KHz, meaning these are the highest frequencies that the driver can synthesize without distortion. The difference is more calculations have to be done to maintain the higher 22 KHz rate, thus that driver only supports 6 channels, while the 11 KHz supports 9 channels simultaneously. Taking that into consideration, we are going to use the 22 KHz

version just to make things sound better since we don't need 9 channels for anything we are going to do here, but you might want the added channels and trade off the quality hit, so the 11 KHz is available as well. In any case, let's take a look at the API interface to the driver which couldn't be simpler. Let's start with a diagram of the driver's architecture as shown in Figure 21:2.



▲ Sound Driver Architecture

Figure 21:2

The sound driver has two components:

- ▶ An FM sound module used to play standard waveforms (6-9 channels)
- ▶ A PCM digital audio module used to play digitized 11 KHz, 8-bit, mono, signed audio data

Between the two modules you can create almost any sound(s) you might need for your gaming needs. Of course, at a playback rate of 11 KHz, 8-bit mono, this means you use 11 Kbytes per second of recorded audio, so I suggest extreme conservation of samples – keep them short and sweet!

### 21.3.1 Starting the Sound Driver Up

To start the audio driver up, you simply need to include the audio driver object and call its start method with the Propeller pin you want the sound to stream from (Pin 7 on the HYDRA) as follows:

```
OBJ
  snd      : "NS_sound_drv_051_22khz_16bit.spin"      ' Sound driver
```

...and somewhere in your main initialization or event loop, you simply need to call the ***start()*** method:

```
' start sound driver on HYDRA's audio out pin which is 7
snd.start(7)
```

...then the driver is ready for calls to play sounds. When you're done with the driver if you need to release the cog it allocated, simply make a call to ***snd.stop***.

### 21.3.2 FM Audio Driver API

The FM driver is controlled through a handful of functions that allow you to start a sound on any particular channel 0..n, stop the sound, release the sound (more on this later), and finally modulate the frequency. The function names are respectively:

- PlaySoundFM(...)** Starts a continuous waveform on a specified channel with an envelope and general amplitude.
- StopSound(...)** Stops a playing sound channel.
- ReleaseSound(...)** Releases a sound's last "release" portion of ADSR envelope for infinite duration sounds.
- SetFreq(...)** Updates the frequency of a playing sound.
- SetVolume(...)** Updates the volume of a playing sound.

Below is each API function with its parameters formally defined as well as an example use of each:

#### Function Name:

```
PUBPlaySoundFM(arg_channel,arg_shape,arg_freq,arg_duration,arg_volume,arg_amp_env)
```

#### Description:

Starts playing a synthesized sound on the selected channel. If a sound is already playing, then the old sound stops and the new sound is played.

**Parameters:**

- arg\_channel:** The channel on which to play the sound (0-5) for the 22 KHz driver, (0-8) for the 11KHz driver.
- arg\_shape:** The desired shape of the sound. Use any of the following constants: SHAPE\_SINE, SHAPE\_SAWTOOTH, SHAPE\_SQUARE, SHAPE\_TRIANGLE, SHAPE\_NOISE. **Note:** Do *not* send a SHAPE\_PCM\_\* constant, use **PlaySoundPCM()** instead.
- arg\_freq:** The desired sound frequency. Can be a number or a NOTE\_\* constant (Listed in Table 21:1 on page 605). A value of 0 leaves the frequency unchanged.
- arg\_duration:** Either a 31-bit duration to play sound for a specific length of time, or (DURATION\_INFINITE | "31-bit duration of amplitude envelope") to play until **StopSound**, **ReleaseSound** or another call to **PlaySound** is called. See section 21.3.2.1 Explanation of Envelopes and Duration on page 605 below for important details.
- arg\_volume:** The desired volume (1-255) inclusive. A value of 0 leaves the volume unchanged.
- arg\_amp\_env:** The amplitude envelope, specified as eight 4-bit nibbles from \$0 (0% of arg\_volume, no sound) to \$F. (100% of arg\_volume, full volume), to be applied least significant nibble first and most significant nibble last, eg. \$8765\_4321 would modulate the amplitude in the order of \$1,2,3,4,5,6,7,8 as a function of note length/duration and time. See section 21.3.2.1 Explanation of Envelopes and Duration on page 605 below for important details.

**Example(s):**

```
' on channel 0 play middle C with a square wave that is 1 second long
' at a overall volume of 255 with envelope $2457_9DEF
snd.PlaySoundFM(0, snd#SHAPE_SQUARE, NOTE_C4, snd#SAMPLE_RATE, 255, $2457_9DEF)

' on channel 1 play middle D# with a sine wave that is 2 seconds long
' at a overall volume of 100 with envelope $2457_9DEF
snd.PlaySoundFM(1, snd#SHAPE_SINE, NOTE_Ds4, snd#SAMPLE_RATE*2, 100, $2457_9DEF)

' on channel 2 play middle F with a sawtooth wave that is infinitely long
' at a overall volume of 255 with envelope $2457_9DEF (note that the release portion, or last
' 4 nibbles "$2457" wont be played until the sound is "released" and of course will play in reverse
' order from low to high, that is, the release envelope will be 7,5,4,2...silence
snd.PlaySoundFM(2,snd#SHAPE_SAWTOOTH,NOTE_F4,snd#DURATION_INFINITE|(snd#SAMPLE_RATE/2),255,$28BE_F842)
```

**Function Name:**

PUB StopSound (arg\_channel)

**Description:**

Stops playing a sound.

**Parameters:**

**channel:** The channel number to stop.

**Example(s):**

```
'stop all channels
repeat channel from 0 to 5
  StopSound(channel)
```

**Function Name:**

PUB ReleaseSound(arg\_channel)

**Description:**

"Releases" an infinite duration sound, that is, starts the **release** portion of the sound's ADSR amplitude envelope which formally was parameterized as 8 nibbles in reverse order on the call to **PlaySoundFM**.

**Parameters:**

**channel:** The channel to "release".

**Example(s):**

```
' start an infinite sound on channel 2
snd.PlaySoundFM(2,snd#SHAPE_SAWTOOTH,NOTE_F4,snd#DURATION_INFINITE|(snd#SAMPLE_RATE/2),255,$28BE_F842)

' let sound play for a second or 2
repeat 1_000_000

' start the "release" portion of the amplitude envelope (the upper 4 nibbles)
ReleaseSound(2)
```

**Function Name:**

PUB SetFreq(arg\_channel, arg\_freq)

**Description:**

Changes the frequency of the playing sound. If called repeatedly, it can be used to create a frequency sweep or pitch-bending effect.

**Parameters:**

**channel:** The channel to set the frequency of.

**Example(s):**

```
' start a C note two octaves below middle C on sound channel 0 with infinite playback
snd.PlaySoundFM(0,snd#SHAPE_SQUARE,snd#NOTE_C2,snd#DURATION_INFINITE|(snd#SAMPLE_RATE),255,$28BE_F842)

' change frequency of playing sound a total of 4 octaves and back down again
repeat freq from snd#NOTE_C2 to snd#NOTE_C6
  snd.SetFreq(0, freq)
  repeat 5_000  lets hear it for a moment

repeat freq from snd#NOTE_C6 to snd#NOTE_C2
  snd.SetFreq(0, freq)
  repeat 5_000  lets hear it for a moment

' release sound
snd.ReleaseSound(0)
```

**Function Name:**

PUB SetVolume(arg\_channel, arg\_volume)

**Description:**

Changes the volume of the playing sound. If called repeatedly, it can be used to manually create an envelope.

**Parameters:**

- arg\_channel:** The channel to set the volume of.
- arg\_volume:** The desired volume (1-255). A value of 0 leaves the volume unchanged.

**Example(s):**

```
' ramp volume on channel 0 up and down on a triangular shaped envelope
repeat vol from 1 to 255
SetVolume(0, vol)
  repeat 1000

repeat vol from 255 to 1
SetVolume(0, vol)
  repeat 1000
```

| Table 21:1 |          | Sound Driver Note/Pitch Constants (from Driver CON Section)▼ |          |          |          |
|------------|----------|--|----------|----------|----------|
| NOTE_C4    | 262      | NOTE_C5  | 523      | NOTE_C6  | 1047     |
| NOTE_Cs4   | 277      | NOTE_Cs5   | 554      | NOTE_Cs6 | 1109     |
| NOTE_Db4   | NOTE_Cs4 | NOTE_Db5   | NOTE_Cs5 | NOTE_Db6 | NOTE_Cs6 |
| NOTE_D4    | 294      | NOTE_D5  | 587      | NOTE_D6  | 1175     |
| NOTE_Ds4   | 311      | NOTE_Ds5   | 622      | NOTE_Ds6 | 1245     |
| NOTE_Eb4   | NOTE_Ds4 | NOTE_Eb5   | NOTE_Ds5 | NOTE_Eb6 | NOTE_Ds6 |
| NOTE_E4    | 330      | NOTE_E5  | 659      | NOTE_E6  | 1319     |
| NOTE_F4    | 349      | NOTE_F5  | 698      | NOTE_F6  | 1397     |
| NOTE_Fs4   | 370      | NOTE_Fs5   | 740      | NOTE_Fs6 | 1480     |
| NOTE_Gb4   | NOTE_Fs4 | NOTE_Gb5   | NOTE_Fs5 | NOTE_Gb6 | NOTE_Fs6 |
| NOTE_G4    | 392      | NOTE_G5  | 784      | NOTE_G6  | 1568     |
| NOTE_Gs4   | 415      | NOTE_Gs5   | 831      | NOTE_Gs6 | 1661     |
| NOTE_Ab4   | NOTE_Gs4 | NOTE_Ab5   | NOTE_Gs5 | NOTE_Ab6 | NOTE_Gs6 |
| NOTE_A4    | 440      | NOTE_A5  | 880      | NOTE_A6  | 1760     |
| NOTE_As4   | 466      | NOTE_As5   | 932      | NOTE_As6 | 1865     |
| NOTE_Bb4   | NOTE_As4 | NOTE_Bb5   | NOTE_As5 | NOTE_Bb6 | NOTE_As6 |
| NOTE_B4    | 494      | NOTE_B5  | 988      | NOTE_B6  | 1976     |

### 21.3.2.1 Explanation of Envelopes and Duration

Sound theory is always tricky since it's not a science in the sense of chemistry or math. Music was created by artists and thus there has always been a lot of confusion with the terminology used to describe music theory and worst yet to describe technical applications like this sound driver! So, the next paragraphs hopefully will shed a little light on some of the terms used in the sound driver's descriptions, so you can make sense of them.

To begin with, the "**duration**" parameters are specified in 11 KHz or 22 KHz "ticks" (depending on which version of the sound driver you're using). So, use a duration of **SAMPLE\_RATE** (defined in the driver as a constant) to play for one second, **2\*SAMPLE\_RATE** for two seconds, **SAMPLE\_RATE/2** for a half-second, etc. To make a sound play for an infinite duration, you must "OR" the duration with **DURATION\_INFINITE** (which sets bit 31 to 1). You still need to specify an amount of time for the duration because the sound driver needs to know how long the amplitude envelope (explained below) should

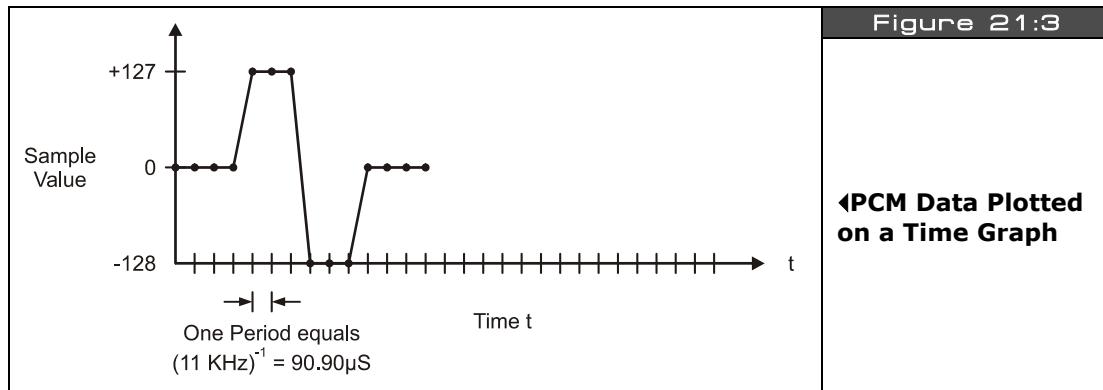
take. For example, use (***INFINITE\_DURATION / SAMPLE\_RATE***) to play a never-ending sound using an envelope length of one second.

The amplitude (ie. volume), envelope is a 32-bit value made up of eight 4-bit nibbles, with each nibble representing one of eight “segments” of the envelope. Each segment plays for  $1/8^{\text{th}}$  of the sound’s total duration. Each segment specifies a percentage of the sound’s desired volume, with \$0 representing 0%, and \$F representing 100%. For instance, if the sound is played at a volume of 200, then a segment of \$0 means “no volume,” \$8 means “volume 100,” and \$F means “volume 200.” The eight envelope segments are specified in reverse order. The first segment to be played (segment 0) is the least significant nibble and the final segment (segment 7) is the most significant nibble. For example, \$1346\_ACEF starts at full volume and ends at near-silence. An envelope of \$FFFF\_FFFF is effectively no envelope. Sounds with an infinite duration may also use envelopes. In this case, the “attack” and “decay” (ie. the first few segments) will play, and then the sound will remain indefinitely at the “sustain” segment (segment 3 by default, but can be changed by adjusting the ***AMP\_ENV\_SUSTAIN\_SEG*** constant anywhere from 1 to 6 (0 and 7 are untested)). When ***ReleaseSound*** is called, the “release” (ie. the last few segments) will play for the rest of the specified envelope duration and then stop. PCM sounds may also use an envelope, although for now you will have to modify ***PlaySoundPCM*** to do this. The next version of the driver will have this modification built in.

### 21.3.3 PCM Audio Overview

The PCM driver plays back raw pulse code modulated sounds at a rate of 11 KHz, 8-bit signed samples, 1-channel (mono). In another words, assuming that the output of the audio driver is 0-1 Vpp, the following stream of data would generate a square wave pulse (shown in Figure 21:3):

0,0,0,0,127,127,127,-128,-128,-128,0,0,0,0...



Assuming you have an audio file that you want to play through the driver the first problem is getting the audio data in a format that is readable by Spin. This is facilitated in two steps: the first is to export sound in the "RAW" data format which is more or less nothing other than PCM samples, there is no header, etc. So the data will literally look like the example above. The export must be in in .RAW file format at 11 KHz, 8-bit, mono, signed format, Then the second step is to enter these data elements into a Spin DAT statement, this is the hard part of course. It was bad enough drawing bitmaps with 1's and 0's by hand, but there is no way we are going to hand enter in thousands of numbers that represent a digital audio sample, so we need a tool that simply converts these numbers into Spin code. You can write the tool in C/C++, BASIC, PHP, PERL, or whatever. As an example, let's say you wanted to write some C/C++ code to output the data in Spin format, here's a function that would do the job:

```
int Raw2Spin(char *filename)
{
    int index;          // looping variable
    FILE *fp;           // file pointer
    int filesize;        // length of file
    unsigned char rawbuffer[32768]; // 32K raw data buffer

    // open file, if doesn't exist throw error and exit
    if (!(fp = fopen(filename, "rb")))
    {
        printf("\nRAW To Spin Error: File not found.\n");
        return(0);
    } // end if

    // read entire file at once, impossible to have file larger than 32K
    filesize = fread((void *)rawbuffer, sizeof(UCHAR), 32768, fp);

    // step 1: output header information compatible with sound driver's API interface
    printf("\n' Automated output from Raw2Spin.exe file conversion tool Version 1.0 Nurve
    Networks LLC\n");
    printf("\n' This getter function is used to retrieve the starting address of the sound
    sample.");
    printf("\nPUB ns_hydra_sound");
    printf("\nRETURN @_ns_hydra_sound");

    printf("\n\n' This getter function is used to retrieve the ending address of the sound
    sample.");
    printf("\nPUB ns_hydra_sound_end");
    printf("\nRETURN @_ns_hydra_sound_end");

    printf("\n\nDAT");
    printf("\n' Data Type: RAW signed audio data");
    printf("\n' Original filename - %s", filename);
    printf("\n' Size: %d Bytes", filesize);
    printf("\n' Range: 0 -> $%X\n", filesize-1);
    printf("\n_ns_hydra_sound\n");

    // step 2: output data statements 16 per line
    for (index=0; index < filesize; index++)
    {
        // test if this is first element
        if ((index % 16) == 0)
```

```

        { printf("\n          BYTE $%02X", rawbuffer[index]); }
    else
        { printf(" ,$%02X", rawbuffer[index]); }
    } // end for index

// step 3: output final closing header information
printf("\n\n_ns_hydra_sound_end\n");

// return the filesize
return(filesize);
} // end Raw2Spin

```

The C/C++ function takes as a single parameter the filename of the RAW format audio file and prints to STDOUT the data in Spin friendly code. I wrote an actual console program around this function called **RAW2SPIN.CPP** and compiled it into **RAW2SPIN.EXE**. Both the source and the executable are on the CD in the source directory with all the other demos, so you can run it right out of there using the following syntax:

**RAW2SPIN** inputsoundfile.raw > outputsoundfile.spin

...where "**inputsoundfile.raw**" and "**outputsoundfile.spin**" are whatever names you want. The final output looks something like:

```

' This getter function is used to retrieve the starting address of the sound sample.
PUB ns_hydra_sound
RETURN @_ns_hydra_sound

' This getter function is used to retrieve the ending address of the sound sample.
PUB ns_hydra_sound_end
RETURN @_ns_hydra_sound_end

DAT
' Data Type: RAW signed audio data
' Original filename = gameover_11_8.raw
' Size: 15316 Bytes
' Range: 0 -> $3BD3

_ns_hydra_sound

BYTE $F4,$F4,$F4,$F4,$F4,$F4,$F4,$F4,$F8,$F8,$F8,$F8,$F8,$F8
BYTE $F8,$F8,$F8,$F8,$FC,$FC,$FC,$FC,$FC,$FC,$FC,$FC,$00,$FC,$FC
BYTE $00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00
BYTE $00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00
BYTE $00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00,$00
.
.

_ns_hydra_sound_end

```

Then you simply include the file in your main Spin program like this in the OBJ section:

```

OBJ
sound_data: "outputsoundfile.spin"

```

...and then use the address resolution “getter” functions embedded in the file itself to get the starting and ending address:

```
' starting address
start := sound_data.ns_hydra_sound

' ending address
end := sound_data.ns_hydra_sound
```

Additionally, there is a more advanced tool supplied on the CD as well that is a general data conversion tool written by Colin Phillips called **XGSBMP.EXE**, it too is on the CD in the source directory along with its source in C/C++. This tool does much more and was designed with graphics conversions in mind (which we will get to later), but you can use it to perform RAW to Spin conversion as well with the following command line:

**XGSBMP** audiofile.raw audiofile.spin -op:copy -hydra



TIP

The trick here is that you can include pure data files with the OBJ directive then return the address of the data statements via the “getter” trick above. This is a good trick and a great way to emulate the ability to bring in data files and header like information into your programs.

#### 21.3.3.1 Creating Audio Samples

Creating audio samples is a whole other story and we don’t have time to go into it, but if you aren’t sound savvy then you can simply use royalty-free or public domain sound effects that you find on the web or purchase, to help you out, I have provided you with a number of royalty free sound samples in 11 KHz, 8-bit, mono format that I have created over the years for your own use. Copies are located in the directories:

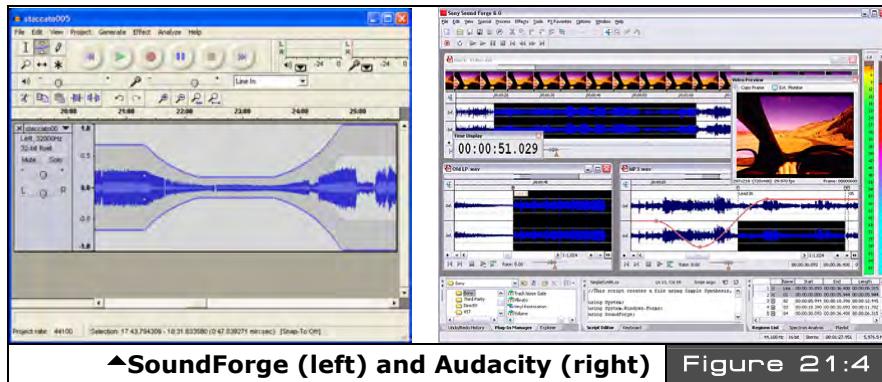
**CD\_ROOT:\HYDRA\MEDIA\SOUNDS\**

Simply look for all the files with the file extension .RAW on them, these are the originals, so you can play with them if you wish; however, I have taken the liberty to save you some time and converted all of them to Spin format files for you with the same root names, but with the file extension .SPIN,

Also, in the **CD\_ROOT:\HYDRA\SOURCES\** directory you will find two particular files named **GAMEOVER\_11\_8.RAW** and **GAMEOVER\_11\_8\_SPIN** respectively, the Spin version can be used immediately in your demo work as a test file.

If you want to experiment with audio design then you need a good sound editor that allows you to import, record, modify, and save sounds in RAW format at very least. There are hundreds of programs that do this, but there are two I like the best depending on your

budget: **SoundForge** is one of the premier sound effects programs available and is from \$69 to \$299 depending on version, while **Audacity** is open source and free and runs on a lot of platforms, both are shown in Figure 21:4. You can download both from the links below.



▲**SoundForge (left)** and **Audacity (right)** | **Figure 21:4**

**Sound Forge Audio Studio & Sound Forge 8** (30 day fully functional demos available)  
<http://psp.sonymediasoftware.com/products/soundforgefamily.asp>

#### **Audacity Open Source Audio Editor**

<http://audacity.sourceforge.net>

I suggest reading through the online documentation a bit to figure them out, they have a lot of features, but the bottom line is that you need to make sure whatever file you import, when you export or save it you do so in RAW, 8-bit, 11 KHz, SIGNED, PCM, MONO format if you want the RAW2SPIN or XGSBMP conversion tools to work.

#### **21.3.3.2 PCM Driver API**

Alright, assuming you have a sample that you have created and converted to Spin code (or simply will use the **GAME\_OVER\_11\_8.SPIN** file found in the source directory), then there is a single API function you need to know to play PCM samples:

##### **Function Name:**

PUB PlaySoundPCM (arg\_channel, arg\_pcm\_start, arg\_pcm\_end, arg\_volume)

##### **Description:**

Plays an unsigned 8-bit 11KHz PCM sound once. If a sound is already playing, then the old sound stops and the new sound is played.

**Parameters:**

- arg\_channel:** The channel on which to play the sound (0-5).
- arg\_pcm\_start:** The address of the PCM buffer.
- arg\_pcm\_end:** The address of the end of the PCM buffer.
- arg\_volume:** The desired volume (1-255).

**Example(s):**

OBJ

```

snd      : "NS_sound_drv_050_22khz_16bit.spin"    'Sound driver
snd_data : "gameover_11_8.spin"                  'PCM Sound Effect "Hydra"

' .. in the main event loop...
' play a PCM sound on channel 0 with a volume of 255
snd.PlaySoundPCM(0, snd_data.ns_hydra_sound, snd_data.ns_hydra_sound_end, 255)

```

That's all there is to playing PCM sound! And you can play as many PCM sounds through as many channels as you wish.

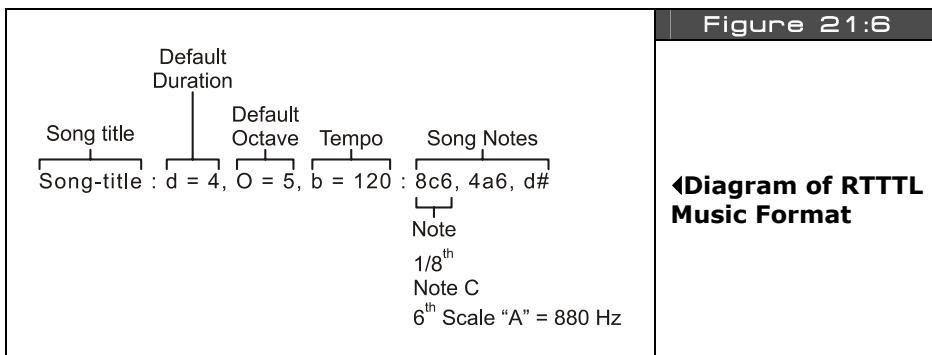
**21.3.4 Piano Driver Demo**

As a final example to put everything together, load and run **NS\_SOUND\_DEMO\_051.SPIN** located in **SOURCE\**. This demo was put together by **Nick Sabalausky** to show off all the features of the sound driver (including FM and PCM). It supports both the keyboard and the mouse, so make sure to have them plugged in and the volume turned up. This demo shows how to create an entire electronic organ and could be the basis of a much more advanced sound synthesis program. Figure 21:5 is a screen shot of the demo in action.



## 21.4 Playing RTTTL Files

As mentioned earlier, **RTTTL** stands for ***Ring Tones Text Text Transfer Language***. It's a simple monophonic (single channel) music format that is used on cell phone to play music. Originally invented by Nokia the format is very popular and there are millions of RTTTL files free on internet. The reason it was invented was that although numerous music formats exist such as MIDI, MIDI is very complex and designed for professional recording and playback. Simple cell phones are lucky to be able to play music at all, so Nokia needed a format that would work, was ASCII text, short, and single-channel, and RTTTL was the answer. In this section, we will look at the format itself and then write a player and demo based on it.



### 21.4.1 RTTTL File Format

The RTTTL file format consists of ASCII text with a header section, followed the notes of the musical score as shown in Figure 21:6. The format supports only a single channel, but does support four octaves, timing support, and has no limit to musical piece length. Before showing the format formally, it's sometimes easier just to see an example, here's one of the Star Wars themes:

#### *Star Wars Imperial Theme*

```
Imperial:d=4, o=5, b=120:e, e, e, 8c, 16p, 16g, e, 8c, 16p, 16g, e,
p, b, b, b, 8c6, 16p, 16g, d#, 8c, 16p, 16g, e, 8p
```

This example illustrates the basic format of an RTTTL file (referring to Figure 21:6 for reference), the format starts off with a text string that identifies the ***name*** of the song this is supposed to be no longer than 10 characters; however, most RTTTL files hardly follow this rule, so parsers must be able to handle longer names with embedded spaces and punctuation. Moving on, the name is followed by a colon ":" delimiter, which indicates the ***defaults*** section which consists of three default settings:

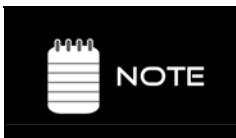
- ▶ “d=duration [1|4|8|16|32]” – Default note duration.
- ▶ “o=octave [4|5|6|7]” – Default octave/scale.
- ▶ “b=beats per minute” – Default beats per minute.

The defaults section is delimited by another colon “:” and the song begins which is a sequence of notes separated by commas “,”. Each note has three major parts as shown in Figure 21:6.

- ▶ Duration – How long to play the note (modifier, if omitted uses default).
- ▶ Note (pitch) – The note frequency itself.
- ▶ Octave (scale) – Which octave or “scale” to play the note in (modifier, if omitted uses default).

If only the note is listed then the defaults from the default section will be used to play the note, otherwise the optional modifiers modify the notes parameters for playback. The first optional field is the duration of the note, where duration can be a whole note, half note, quarter note, sixteenth note, and thirty-second note indicated by the numbers 1,2 ,4, 8, 16, and 32 respectively. Next is the note itself, which consists of ASCII characters “C”, “D”, “E”, “F”, “G”, “A”, “B”, along with “H” to represent “B” (don’t ask me), lastly the note can also be a pause indicated by “P.” Pauses are used to help timing, if a lone “P” is in the data stream it will have the length of the default duration set in the defaults section or the duration given to it as if it were a note. For example, “8C” would mean play an eighth note “C” while “8P” would mean pause for an eighth note, but make not sound.

Additionally, the notes “C”, “D”, “F”, “G”, and “A” can have sharps optionally concatenated to them resulting in ““C#”, “D#”, “F#”, “G#”, and “A#” respectively. The last part of the note definition is the octave or scale modifier and can range from 4-7. If the scale is omitted then the default scale previously defined in the header section’s “o=octave” section will be used. The meaning of octave/scale “4” is middle C scale (A=440 Hz), “5” is one octave above, “6” is the next octave and so forth. Thus, a song can range over four octaves.



I have seen many definitions of RTTTL, all “official” they all are more or less the same, but there is confusion over some things like scale and some RTTTL songs use octave “5” to indicate middle C scale. Thus, some songs you play might be one octave off plus or minus, to remedy this simply change the default by 1 and of course edit each note’s octave modifier as well.

The last part of the note definition is to support “**dotted rhythms**” which in musical theory are a way to play a note duration for an extra half time of itself. For example, if you played a quarter note dotted and the quarter note was 1 second, then the dotted quarter note would be  $1 + (0.5) \times 1 = 1.5$  seconds. So, by “dotting” a note you simply add a little more time

to the note's duration. A dotted note is indicated by a trailing period ".." For example, an 8<sup>th</sup> note, C sharp, in octave 7, dotted would look like:

#### C sharp, 8th note, played in 7th octave and dotted

"8C#7."



**Be warned though, many RTTTL songs have the dot in the wrong place (which I have supported in the parser for it), for example: "8C#.7". Thus, once again, file formats always get confused, thus write your parser such that it can handle slightly erroneous formats and still "interpret" them as best it can with elements out of order.**

#### 21.4.1.1 A Quick Note on Timing and Musical Theory

If you play music then you are very comfortable with the concepts of **beats per minute**, **duration**, **notes**, **scale**, **registers**, **quarter notes**, **half notes**, **syncopation**, and many other music concepts. However, if this is the first time you are seeing some of these music terms you are probably a little lost. Everyone is at first – I am still lost! I highly suggest reading a little online about music theory and simply searching for "RTTTL specification" online and reading a few articles to get a better understanding of these terms, and how it all fits together. The only thing we are going to discuss is the math behind the timing since that really is our only challenge, let me explain.

The format looks easy enough to understand, we read in the header, store the values, and then parse the notes. The problem is playing the notes with correct timing. This is not as easy as it seems. The fundamental problem is that music is not rigorous in its roots thus there are a lot of assumptions about timing etc. and a lot of "chained" timings. The first thing is that when a piece calls for a quarter note, half note, 8th note etc., what does it mean? Well, it means to play the note for one quarter, one half, or 1/8<sup>th</sup> a normal note duration. Ok, great, but what's a normal note duration? Well, this has to do with the concept of "**tempo**", that is, how fast a piece of music is played. Tempo is related to "beats per minute", and if we play a piece at 60 beats a minute then there is 1 beat a second. Given that, the magical connection is between beats per minute and notes, and here it is:

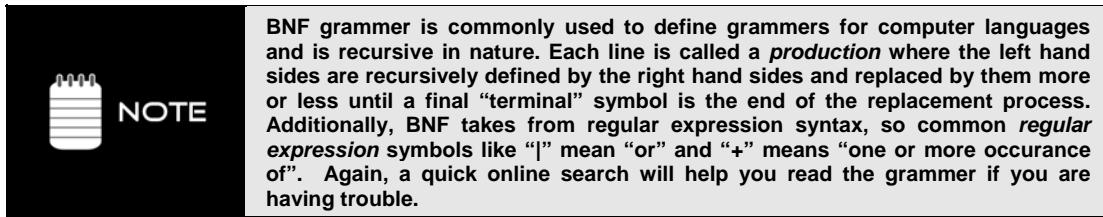
**Adhoc Musical Timing Law:** *"A quarter note usually has the duration of a single beat in music."*

This simple relationship helps us do everything. For example, if we have a song that we want to play at 120 beats per minute, then this means there are 2 beats per second, or 500 ms per beat. So far so good, then we take the law into consideration and we know that one quarter note equals 1 beat time, in this case 500 ms, and presto we have our timing relationship. Thus, when we parse a note to be played a quarter note, we play it for 500 ms,

if we see one to play for an 8<sup>th</sup> note, we play it 250 ms. Similarly, if we see a half note then that should be 2× as long as a quarter note or 1000 ms. This timing math is the fundamental problem (other than parsing the file format) to writing the RTTTL player or any music player for that matter. Your brain will not tolerate timing errors in music, trust me! With that in mind, let's take a look at the formal RTTTL specification.

#### 21.4.2 RTTTL Specification

RTTTL was originally conceived by Nokia and like any computer language "**grammar**" is described in a loose form of BNF (Backus Naur Form).



Below is the RTTTL specification in rather compact BNF form:

```

<ringing-tones-text-transfer-language> := <name> <sep> [<defaults>] <sep> <note-command>+
<name>          := <char>+
<sep>           := ":" 
<defaults>       := <def-note-duration>|<def-note-scale>|<def-beats>
<def-note-duration> := "d=" <duration>
<def-note-scale>  := "o=" <scale>
<def-beats>       := "b=" <beats-per-minute>
<beats-per-minute> := integer value
<note-command>   := [<duration>] <note> [<scale>] [<special-duration>] <delimiter>
<duration>       := "1" | "2" | "4" | "8" | "16" | "32"
<note>1 := "P" | "C" | "C#" | "D" | "D#" | "E" | "F" | "F#" | "G" | "G#" | "A" | "A#" | "H"
<scale>          := "4" | "5" | "6" | "7"
<special-duration> := "."
<delimiter>       := ","

```

Now, all we need is a parser to read the specification.

#### 21.4.3 RTTTL Demo Program

I have to admit that when I started this chapter, I wasn't planning on using RTTTL format, I was going to create a custom music format somewhat loosely based on MIDI concepts, maybe something similar to "C-MIDI." In any case, like most people I have a cell phone with more computing power than all the computers combined from the late 60's, but I never use any of the features since all I want to do is make calls with it nor do I have a personal ringtone for anything. Anyway, you can't turn around these days without seeing a free ringtone for something, so when I investigated ringtone technology, I was happily pleased that there were a number of common formats available with thousands of songs for each,

especially RTTTL format. After doing some research, I found there were some really cool songs in RTTTL, so I decided why make a simple demo that just plays one when I can make a jukebox that lets you select one and play from a list? So, that's exactly what I did. Figure 21:7 shows a screen shot of the demo program in action. The program's name is **HYDRA\_RTTTL\_PLAYER\_001.SPIN** and is located in **SOURCE\** directory on the CD.

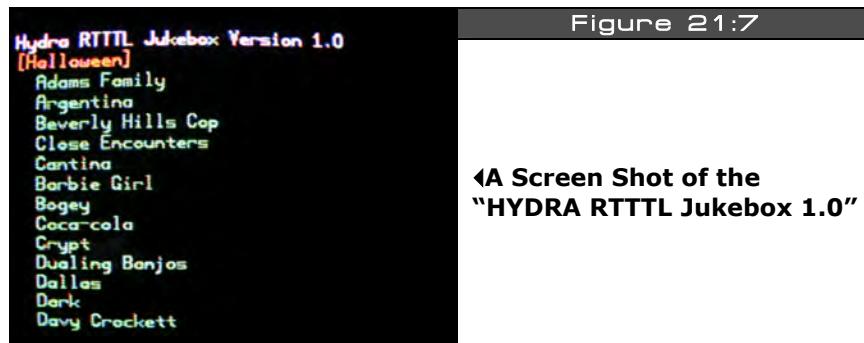


Figure 21:7

◀ A Screen Shot of the  
“HYDRA RTTTL Jukebox 1.0”

Simply load the program into your HYDRA, make sure the volume is turned up and the gamepad plugged into the left port and run the program. When the program starts it will play the “**Halloween**” theme music on load then when the song is finished you can scroll up / down and select any song to play with the game pad’s <START> button. It’s pretty cool and a bit addictive.

The demo program is pretty straightforward other than the RTTTL parser and player. The program is much too long to list, so make sure to review the source yourself. The parser was written with a lot of little “helper” functions to make it easier to understand and modify. However, a clever programmer could shorten the parser quite a bit. The program works by reading in a “play list” in the DAT section, each RTTTL song is stored as a stream of bytes with a NULL terminator at the end, this way the program can scan for each song by looking for the NULL terminator. Here’s and example of one of the songs in Spin format which identical to the RTTTL format except with a NULL terminator at the end and placed into a BYTE data statement:

```
byte "Close Encounters:d=16,o=5,b=125:d,p,e,p,c,p.,c4,p,g4,1p., d6,p,e6,p,c6,p.,c,p,g,1p.",0
```

Each song takes anywhere from a few dozen to a couple hundred bytes of ASCII text, so you surprisingly run out of memory pretty fast with graphics support drivers loaded. Nevertheless, I have chosen about 40 songs that most people have heard and can verify with their own ears the player is working right. There are more songs in the source code

commented out. Simply un-comment them and exchange them in the list, trying to keep the number of songs to no more than 40 or so, otherwise you will run out of memory.

Lastly, don't judge the sound driver by the demo. This file format is what's driving the sound engine and RTTTL is monophonic and thus sounds like a toy playing music. However, there are polyphonic ringtone formats as well as real MIDI which can easily be accommodated by the sound driver, so feel free to make better sound players based on the driver, but this is a good start, so without further ado, I am going to search for "***Whoops I Did it Again***" – just kidding, I am really trying to find "***Let the Bodies Hit the Floor***" by Drowning Pool! If you find it or make it, email it to me!



You might notice that RTTTL files are pretty short and only fragments of songs, this is not a limitation of the format, but simply that they are used for phone ring tones and people usually answer in a few seconds, alas no need to have a symphony recorded. However, there is no format-imposed limit on the length of a RTTTL song, thus you can make them as large as possible. One good way to get large RTTTL pieces is to use a MIDI-to-RTTTL conversion program which can be found on the internet. This way you can use large complete songs in MIDI, convert them to RTTTL and play them in the juke box and turn your computer into the most expensive ringtone player on the planet!

## 21.5 Summary

Sound is probably one of the most important factors in a game, if not the ***most*** important. By our very nature as humans, there is nothing that effects our emotions as much as music and sound, they can excite us, make us angry, sad, lonely, scared, and give us anxiety. Hopefully, with the sound driver in hand and some creativity some of the musically inclined readers can really make the HYDRA and the Propeller shine musically! I challenge someone to take the sound driver and based on its ideas construct a new version with 16-32 channels supporting wave table synthesis and speech support and via the USB connection turn the HYDRA into a sound card with commercial quality controlled via the PC – that would be a fun project and/or a phone answering machine of some kind?



## Chapter 22: Advanced Graphics and Animation

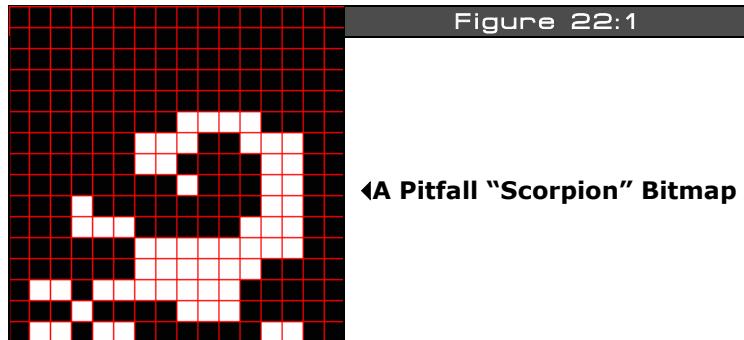
In this chapter we are going to discuss the problems associated with video game asset management along with animation and scrolling techniques. That is, given so much art, sound, music, and so forth, how does one simplify the process of getting the media into the HYDRA and doing something with it? This is the number one problem in writing games since without assets you can't make much of a game. Up to this point in the book we have manually entered in bitmaps, palettes, and data by hand, but this isn't going to cut it forever. Therefore to advance in our discussions we need tools, which are what we are going to develop in this chapter. Then with the tool chain in hand we are going to talk about scrolling techniques as well as general character animation for games and how that's done. So the primary topics in this chapter are:

- ▶ Using tool chains to build and import graphics
- ▶ Tile map scrolling
- ▶ Vector scrolling
- ▶ Parallax scrolling
- ▶ Framed animation

### 22.1 Using Tool Chains to Build and Import Graphics

Video game development is very demanding when it comes to asset generation and management. Thus far, we have more or less entered bitmap data in binary data statements that were hand drawn on graph paper or generated on the fly using a text editor. This obviously isn't going to cut it moving forward, so we need some simple tools to help us out or I am going to lose all my hair! If you recall in the last chapter on sound programming there was simply no way around building a tool to convert audio data into Spin code, it had to be done. And we are at that same turning point in the development of our graphics technology. So with that in mind, we need to develop a couple simple tools that allow us to draw imagery on the PC using a graphics painting program like **Photoshop** or **Paint Shop Pro** and then convert the bitmap data to Spin code that is somehow compatible with our current engines and technology. Secondly, we want to take advantage of the features of the tile engine, such as scrolling. To accomplish this we need to use an external tool to generate game field maps and then export them out and once again convert them to Spin-compliant code somehow. Alas, lots to do, very complicated, and details count, so let's get started!

## 22.2 Bitmap to Spin Conversion



The HEL graphics engine introduced a couple chapters ago is a tile-based engine with 4 colors per tile, where tiles are 16×16 pixels each represented by 2 bits per color, which index into the 4-BYTE color palette assigned to that tile. Thus, each tile can have 4 individual colors. The color palettes are in the form of a LONG each where BYTE 0 is Color 0, BYTE 1 is Color 1, and so forth. As an example, take a look at Figure 22:1, it depicts a “scorpion” bitmap from the classic 80’s game Pitfall (or at least it’s supposed to!) which I drew in Paint Shop Pro/Photoshop. Now, if I wanted to add this bitmap to a game or demo then it would have to be converted to our graphics tile bitmap format as shown below:

```
' a pitfall scorpion tile
scorpion_bitmap LONG %%0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0
                  LONG %%0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0
                  LONG %%0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0
                  LONG %%0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0
                  LONG %%0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0
                  LONG %%0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0_0
                  LONG %%0_0_0_0_0_1_1_1_1_0_0_0_0_0_0_0_0
                  LONG %%0_0_1_1_1_0_0_1_1_1_0_0_0_0_0_0_0
                  LONG %%0_0_1_1_0_0_0_0_1_1_0_0_0_0_0_0_0
                  LONG %%0_0_1_1_0_0_0_0_1_0_0_0_0_0_0_0_0
                  LONG %%0_0_1_1_0_0_0_0_0_0_0_0_0_0_1_0_0_0
                  LONG %%0_0_1_1_1_0_0_0_0_0_0_0_0_1_1_1_0_0_0
                  LONG %%0_0_1_1_1_1_1_1_1_0_0_0_0_0_0_0_0_0
                  LONG %%0_0_0_0_1_1_1_1_1_1_0_0_0_0_0_0_0_0
                  LONG %%0_0_0_0_0_1_1_1_1_1_1_1_0_1_1_0_1_0
                  LONG %%0_0_0_0_0_0_1_1_1_1_1_1_1_1_0_0_1_0_0
                  LONG %%0_0_0_1_1_0_0_0_0_0_0_0_1_1_0_1_1_0
```

...and the palette that goes along with this tile might look something like this:

scorpion\_palette LONG \$07 04 07 02 ' color 0 black, color 1 white



## NOTE

Notice the bitmap is mirrored on the x-axis. This is one of the quirks of the engine, the art needs to be reflected or mirrored about the x-axis since the data is read low bit to high bit when rendered on the screen. Tip: Blur your eyes to see the image better.

Additionally, if we wanted to use the bitmap tile for a sprite, then we need a **mask** of the tile which is nothing more than a copy of the tile bitmap where every entry that is non-zero is mapped to 3, and all zero entries are mapped to 0. For the scorpion bitmap above, its sprite-compliant mask would look like:

As you can see, this is tricky work! What we need is a tool that takes as an input a bitmap full of tiles regularly templated, then we can "extract" one or more tiles and the output is Spin code, so we don't have to do all this work by hand. Well, I have created such a tool called **BMP2SPIN.EXE** which is located on the CD in the **\SOURCE** directory along with the source C/C++ file **BMP2SPIN.CPP**. When writing a tool like this about a billion assumptions have to be made, otherwise you will be writing tools for months and years and not writing games. In other words, tools are hard to write and time consuming, so you have to pick your battles. First, off when doing 2D games, artists typically will "**template**" their 2D artwork into tiles that are 8x8, 16x16, 32x32 etc. This makes it easy to work with the art and of course makes it easy for tools to extract the art. So the first rule of the tool is that it works

with templated graphics. Let's discuss the process of templating graphics assets using the *Pitfall* art as an example to work with.

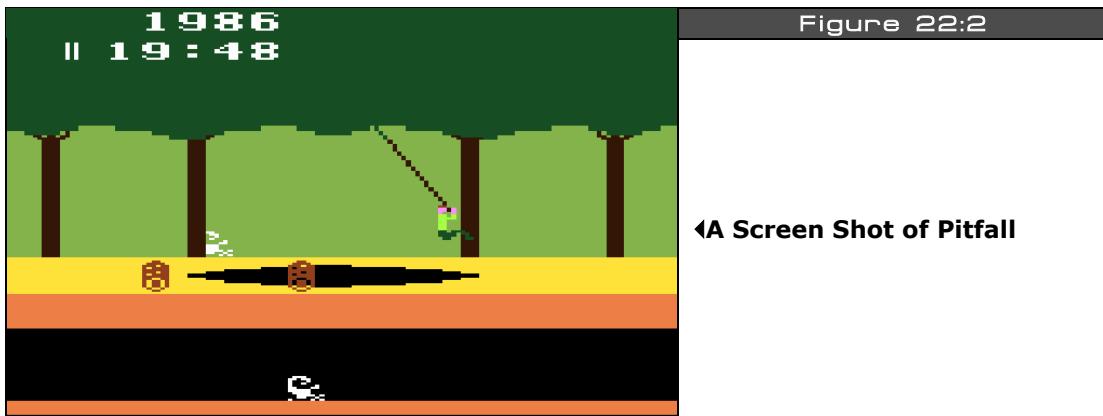
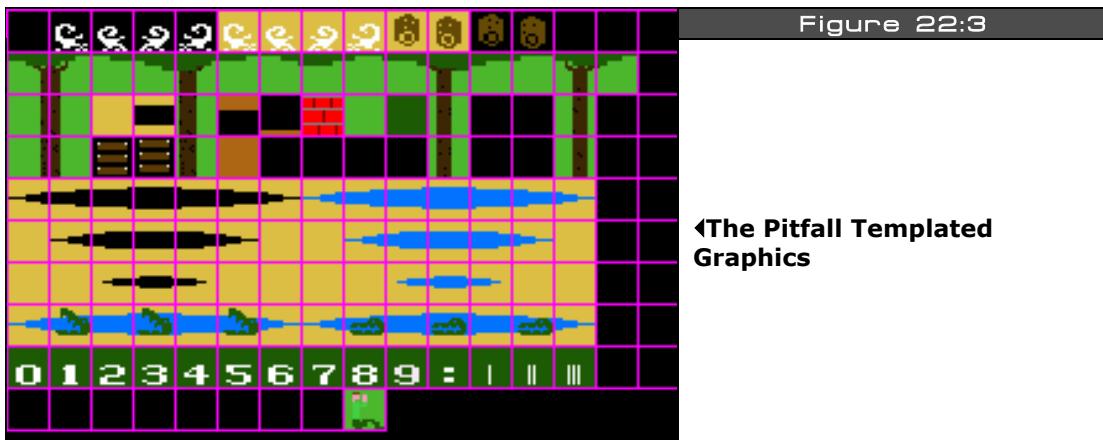
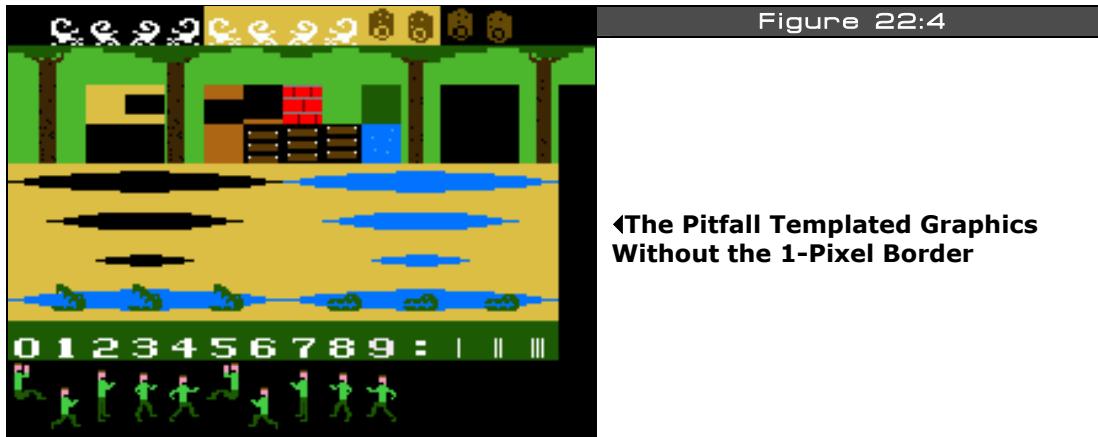
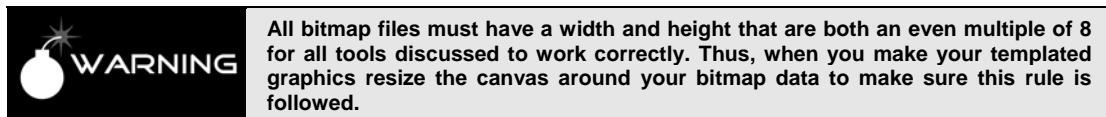


Figure 22:2 shows a screen shot of Pitfall running on my Atari 2600. Based on this screen shot, and playing the game for many years, I was able to draw all the graphics in the game (roughly) and then place them into a template. Figure 22:3 shows the templated graphics.



If course, what you see in Figure 22:3 is only a subset of the graphics from the game; I would be here for ever trying to see every little sprite in the game and then recreating it. Of course, you could always download the ROM of the game (if you own it) and pull the

graphics from it as long as it's only for experimenting like we are. In any case, the actual bitmap shown in Figure 22:3 is named **PITFALL\_TILES\_WORK\_03.BMP** and is located in the **\SOURCE** directory as well as in the **\MEDIA\GRAPHICS** directory on the CD. You can open it up and view it in your favorite paint program. The first thing you will notice about the art is that there is a 1-pixel border around each tile, this border is exactly 1-pixel wide and common practice when tiling graphics. However, some programs do not like the 1-pixel border and you must remove it. I suggest that as a convention you draw all your graphics on a "work" bitmap where they are just all over the place since its your "art" workspace. Next, you cut up your tiles into  $16 \times 16$  blocks (or whatever the size is your engine uses) and tile them into another file with a 1-pixel border. Finally, you create yet another file where the border is removed, and slide all the bitmaps together. Figure 22:4 shows the same bitmaps from Figure 22:3, but with the border removed (and a few extra tiles).



I personally prefer to work with a 1-pixel border to separate my tiles, but some third-party tools you might want to use only work with bitmaps that have no border (Mappy is one of them and we need to use it). As another example of templated art I have taken some of the royalty free tiles from **Ari Feldman's "Sprite Lib"** and tiled them as well. Figure 22:5(left) shows the tiled graphics with border while Figure 22:5(right) shows without border. The point is that you need to create your art, tile the art, and put it in a couple formats to make it easy for tools to read. The actual filenames of the two Sprite Lib based tile sets are

**SL\_BLOCKS\_02.BMP** (with border) and **SL\_BLOCKS\_03.BMP** (without border); both files are on the CD in the **\SOURCE** directory as well as in **\MEDIA\GRAPHICS\SPRITELIB\** located on the CD.



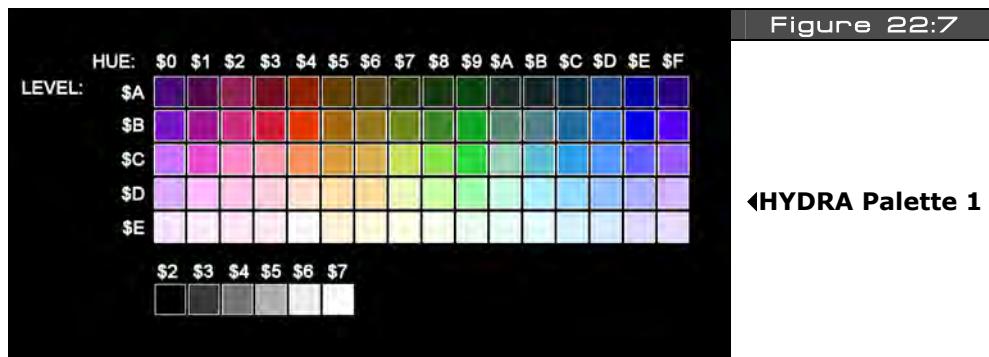
Before moving on to the tool itself and its use, there are a couple more details we need to cover. First, we haven't mentioned anything about color! We know that the Propeller only generates so many colors, so how can a 24-bit Truecolor image be represented by the HYDRA? Well, it can't, so we have to approximate colors and match or map them to the HYDRA palette. This means that bitmaps converted to the HYDRA might not look as good or vibrant as on the PC, but this is ok and standard for game graphics. To defend against graphics degradation typically what an artist does is work in 24-bit color and now and then reduce the color space to the target system's graphics palette. Every paint tool has the ability to reduce color space, so you can work with a nice 24-bit image then load the "HYDRA color palette" and see how it looks. If it looks terrible, for example, you are losing a lot of browns, then you know you need to lay off the browns and so forth. The question is, "What is the HYDRA/Propeller's palette?" It depends on the TV you hook the system up to, thus what had to be done is 10-20 TVs with "general" settings had to be connected to the HYDRA and then a complete palette rendered on the screen, then this was digitized and painstakingly ordered, labeled and numbered. The results are two palettes which I call "Palette 0" (Figure 22:6) and "Palette 1" (Figure 22:7) both of which contain 86 colors (including black). Palette 0 looks best on most TVs without adjusting the tint, but Palette 1 looks better on older "composite computer monitors" so you can take your pick.

Since this book is black and white you won't be able to see the colors from the palette, but you can look at the original bitmaps in files **HEL\_GRAPHICS\_PALETTE\_0.BMP** and **HEL\_GRAPHICS\_PALETTE\_1.BMP** which are located on the CD in the directory **\MEDIA\GRAPHICS**. Additionally, there are "color only" versions of these bitmaps with no

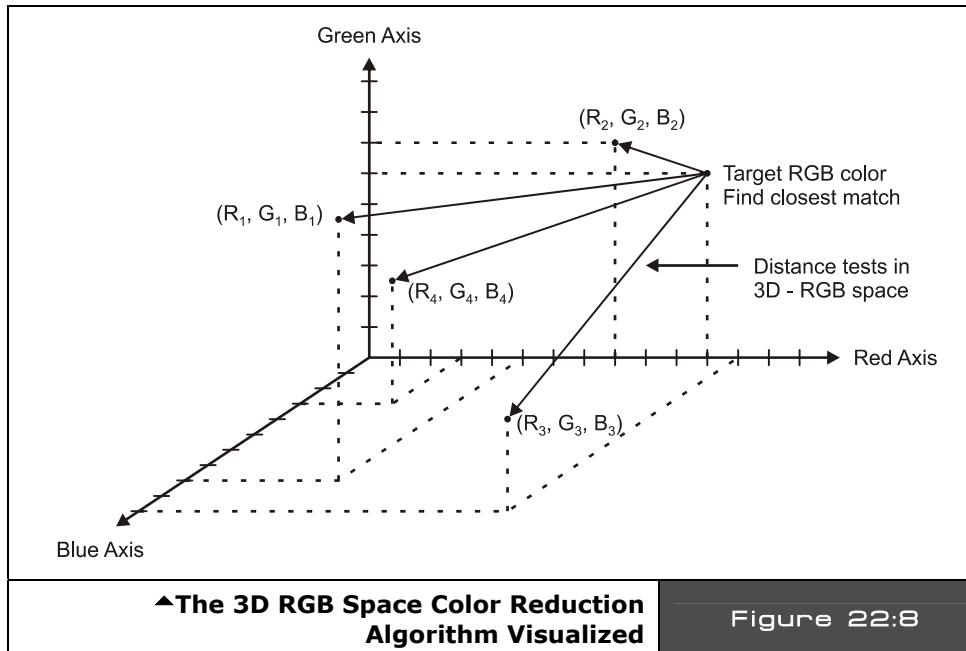
text, annotation, or other colors, so you can use them to color reduce your art with, that is use the “generate palette from bitmap function of your paint program.” Please use the following bitmaps to generate a palette to test match your art within your painting tool:

**HEL\_GRAPHICS\_PALETTE\_0b.BMP**  
**HEL\_GRAPHICS\_PALETTE\_1b.BMP**

For example, you might draw some underwater art in 24-bit color in Photoshop and you want to see how well it will map to the HYDRA palette. So load in either palette “color only” image **HEL\_GRAPHICS\_PALETTE\_0b.BMP** or **HEL\_GRAPHICS\_PALETTE\_1b.BMP** then generate a palette from it and assign it to your art, instantly you will see the art change and the colors reduce and you can focus on problem areas. When you are satisfied with your art then you can leave it in 24-bit color mode or 256 color mode and save your artwork in templated format. You will at least need the borderless version for the other tools in our tool chain, but I suggest making both a 1-pixel border version as well as a borderless version.



### 22.2.1 3D RGB Space Color Reduction Algorithm



Before moving on to the actual invocation of the tool and its parameters and use, let's take a brief aside to discuss how color matching is performed. As mentioned, the HYDRA only has 86 colors in its palette, so whatever art you want to map to the HYDRA must be mapped to these 86 colors. Moreover, for each tile there can only be 4 colors, thus the tool has to generate a histogram to select the 4 most predominant colors in each tile to build the palette for the tile. Considering all that, the setup is as follows: there is a table which contains all 86 colors the HYDRA can generate in 24-bit RGB format (8 bits for each color). Then the bitmap to be converted into Spin code first needs its colors analyzed and mapped, here are the steps to the algorithm that does it:

**Step 1:** For all pixels in the source bitmap create a histogram table of each individual color and how many times it occurs.

**Step 2:** Sort the color histogram.

**Step 3:** Select the top 4 occurring colors, If BLACK occurs at all in image, it's so important it must be part of the final palette, remove one of the top 4 colors and insert black.

**Step 4:** The “target” palette for the tile bitmap in question now contains 4 RGB colors, next step is to match each one of these RGB colors to its “best match” in the HYDRA color palette.

The color matching process then gets complex. The problem simply put is given a 3-tuple number that represents an RGB color, compare it to 86 other 3-tuples and find the 3-tuple that is the closest match. In other words, we can assume that the RGB color we are looking for is a 3D point in RGB space, then each of the 86 colors that make up the HYDRA palette are points in this space. All we need to do is find one of the 86 colors that is “closest” to the target color and that’s the color we use to match. Figure 22:8 depicts this graphically (only a few colors are shown with generic numbers assigned). So the idea is you simply run an iterative algorithm that computes the distance from your source desired color to all the HYDRA colors and try and find the best match which is simply the “closest” color in 3D RGB space. For example, here’s a snippet of code from the **BMP2SPIN.EXE** tool that illustrates the matching algorithm:

```
// for each color in HYDRA color map test if its closer to target color in 3D
// colorspace
for (index2 = 0; index2 < num_hydra_colors; index2++)
{
    // extract test r,g,b we are testing against for match?
    r_test = hydra_color_map[ index2 ].peRed;
    g_test = hydra_color_map[ index2 ].peGreen;
    b_test = hydra_color_map[ index2 ].peBlue;

    // compare test rgb to target rgb and if its closer update best match
    int rgb_dist = (r_target - r_test)*(r_target - r_test) +
                  (g_target - g_test)*(g_target - g_test) +
                  (b_target - b_test)*(b_target - b_test);

    if (rgb_dist < col_dist)
    {
        // update distance and index
        col_dist      = rgb_dist;
        best_col_match = index2;
    } // end if
} // end for index2
```

You might be asking, “How does the conversion work for 8-bit palettized bitmaps?” The tool works in almost the same way, but instead of each pixel having its own RGB value, each pixel is an index into the color lookup table which is in RGB format. There is one more step of indirection to look up a pixel’s color then the matching process is the same. Hence, you are free to use either palettized 8-bit graphics or full Truecolor bitmaps.

### 22.2.2 Using the **BMP2SPIN.EXE** Tool

Now that you have seen most of the conceptual aspects as well as the practical ones of building a tool, let’s go ahead and take a look at the tool itself. The executable is once again called **BMP2SPIN.EXE**, it has very little error handling, so if you try to break it, you won’t have to try hard, so make sure to give it valid arguments. The tool takes as input a Windows

BMP file in 8-bit palettized or 24-bit RGB format. The bitmap must not be compressed. The usage of the tool is outlined below:

**Usage:**

**BMP2SPIN.exe inputfilename [flags] > outputfilename**

**Where:**

**flags = -B -TW[1...255] -TH[1..255] -W[1..256] -H[1..256] - C[1..256] -XYx,y -M -FX -FY -V -I -P[0|1] -?**

- B = Enable 1 pixel border for templated bitmaps, default no border
- TWxx = Width of tile set on x-axis, default = 1
- THxx = Height of tile set on y-axis, default = 1
- Wxx = Width of tile, default = 16 pixels
- Hxx = Height of tile, default = 16 pixels
- Cxx = Total count of tiles to be converted, if omitted assumed to be tw\*th
- XYxx,yy = Coordinate of single tile to pull from bitmap, upper left (0,0) overrides -Cxx
- M = Enables mask write as well after each tile
- FX = Flips the output bitmap on the X axis (needed for hel engine 4.0)
- FY = Flips the output bitmap on the Y axis
- Px = Selects the color matching palette 0 or 1, 0 is default, 1 skews color hue 15 degrees approximately
- I = Enables interactive mode
- V = Verbose flag for debugging purposes
- ? = Prints help

### 22.2.2.1 Extracting a Single Bitmap

The flags are self-explanatory, so let's focus on using the tool in two different ways that are the most common. The first way you might want to use the tool is to extract a single bitmap from a larger bitmap full of templated graphics. The tool is mostly set up with defaults, so you don't have to give it many flags, but at very minimum you need to tell the tool the template width and height of your tiles. For example, in the Pitfall art there are  $16 \times 10$  tiles in the template, these values get passed as "-TW16" and "-TH10" respectively. Also, we need to mirror the output bitmaps on the X axis, so we need the "-FX" flag. Next, to extract a single bitmap tile, we need to tell the tool the tile coordinates with the "-XYxx,yy" flag which doesn't tolerate spaces, so you must type everything right next to each other. Lastly, we need to decide if we want to extract from a tile template with a 1-pixel border or not, let's assume there is a border, so we need the "-B" flag. Given all that, let's "rip" tile x=1, y=0 from the Pitfall tile set which is the scorpion if you refer to the tile bitmap artwork. The **\SOURCE**

directory has both the tool in it already as well as the bitmap file we want to work with named **PITFALL\_TILES\_WORK\_03.BMP**, so run a DOS/CMD shell, change directory into the **HYDRA\SOURCE** directory and run the following command line:

**BMP2SPIN pitfall\_tiles\_work\_03.bmp -B -TW16 -TH10 -FX -XY1,0**

You should see the following output to the console:

As you can see the tool is fairly thorough. It begins by outputting some header information to let you know what is what as well as some “getter” code if you want to import the file as a whole into your programs. The two PUB functions ***tile\_bitmaps*** and ***tile\_palette\_map*** always return the starting address of the data. The header is followed by the bitmap(s) data and at the end is the palette. In this case, there will be only one bitmap and one palette. If you want to do a little detective work then follow along: notice that if you blur your eyes, you can indeed see the scorpion. It’s made up of two colors: 0 and 1. If you look at the single palette entry, you will notice that the rightmost or low BYTE is \$02 which is BLACK and represents color index 0. Additionally, BYTE 1 which represents color 1 is \$07 which if you look at the HYDRA palette is indeed WHITE. Thus, the bitmap was scanned and converted correctly and a billion calculations were done to give us this! Of course, we didn’t indicate which palette to use, so the default Palette 0 was used. Lastly, to get the actual file output into a .txt or .Spin file simply redirect the console output like this:

```
BMP2SPIN pitfall_tiles_work_03.bmp -B -TW16 -TH10 -FX -XY1,0 > TEST.SPIN
```

...then all the text would go to **TEST.SPIN** which you could edit, or import directly into your main game program like this:

```
OBJ
bitmap_data: "test.spin" ' import external file and use getter functions.
```

Additionally, if you wanted to use this tile as a sprite, you would need its “mask.” To get mask output as well after each tile, simply add the “-M” flag like this:

```
BMP2SPIN pitfall_tiles_work_03.bmp -B -TW16 -TH10 -FX -XY1,0 -M > TEST.SPIN
```



#### NOTE

Flags can be in any order, but the source bitmap filename must *always* be the *first* parameter.

#### 22.2.2.2 Extracting Multiple Bitmaps

So far so good, now let’s try to use the tool to extract multiple bitmaps. We are going to use almost the same flags, but instead of specifying an x,y tile to extract, we are going to specify a “count” of tiles to extract. The extraction process will proceed from left to right, top to bottom in the tile template and extract however many tiles we indicate. Also, for fun, let’s use no border, and let’s request Palette 1 for the match. Here’s the command line for the multiple bitmap extraction:

```
BMP2SPIN pitfall_tiles_work_04.bmp -TW15 -TH11 -FX -C165 -P1
```

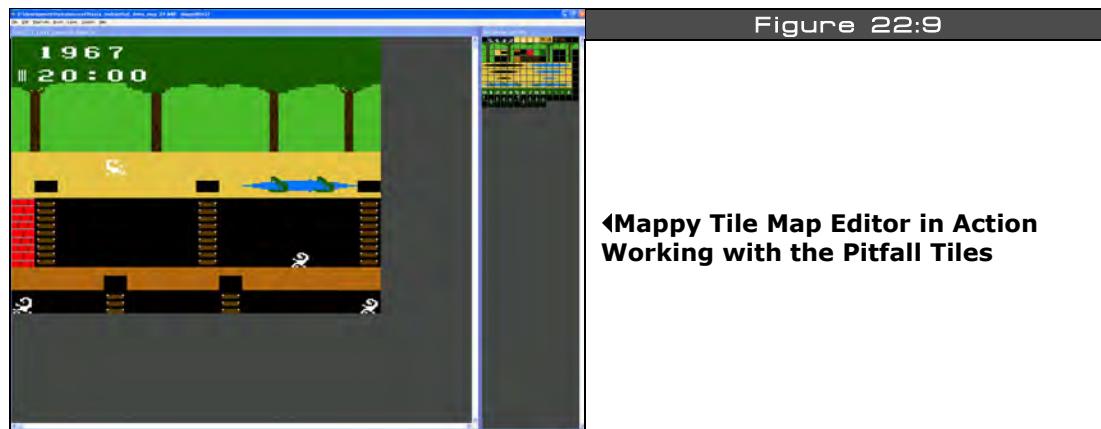
Notice the “-TH15” and “-TW11” flags have changed. This is due to the fact that the graphics template **without** the 1-pixel border is smaller and has fewer tiles horizontally, but more vertically since the graphics are slightly different. Anyway, run the program and watch all the data spew out! Of course, the HYDRA can barely hold all these 165 tiles since each tile is 16 LONGs, that’s 64 BYTES or  $64 \times 165 = 10.5\text{K}$ , which is 30% of the memory. In any event, as usual to get the output into a file you would simply redirect the console output to a file with the “>” operator.

In summary, you can use this tool to generate both bitmaps and palettes from a source tile bitmap file. The only rules are that the source file must be in .BMP format, a width and height that is a multiple of 8, and finally 8- or 24-bit color are both supported. Once you have the output from the tool in a text file you can cut and paste only the parts you need or import the entire file into a demo. The only problem is that the **BMP2SPIN** tool is only half the solution, what we really need is something that exports entire game maps.

### 22.3 Working with Tile Map Editors

Tile map editors or “map editors” are tools that allow you to use a set of bitmap tiles to “draw” a tile map representation of your game level(s). These tools are typically custom made by programmers developing their own game and usually for their own formats. You will be hard pressed to find many generic tile editors. However, there are a few that you can find on the market if you search. One such tool is called “**Mappy**” which is shown in Figure 22:9. The interface doesn’t look like much, but the program is easy to use, semi-programmable and supports a number of modes of operation and some advanced formats. You can find the program in **HYDRA\TOOLS\MAPPY** on the CD and you can always download the latest version of the program here:

<http://www.tilemap.co.uk/>



### 22.3.1 Installing Mappy

The first step is to install Mappy and get it up and running. Simply download Mappy or use the copy from the CD, the current version is around 1.4.11. There is currently no installer, so just de-compress the .ZIP file onto your harddrive somewhere. In fact, on the CD in the **\TOOLS\MAPPY** directory the program is already decompressed and ready to run. There is a single .EXE for Mappy named **MAPWIN.EXE**, to launch the program you simply click on this file. However, before you do, we need to confirm/change one thing in the MAPWIN.INI file that controls how the map files are output. Open the **MAPWIN.INI** file up, and search for the line:

**maptype="LW1H1A1-0"**

If **maptype** does not equal "LW1H1A1-0" then change it, so it does. You can save the old setting above it with a comment. Once you have confirmed this, save the file, exit and you are ready to use Mappy. Launch the program and the tool should start up with two blank windows. The one on the left is the tile map area/editor, the window on the right is the bitmap tiles area. Let's start by loading in a MAP file. On the CD in the **\SOURCES** directory there is a file name **PITFALL\_DEMO\_MAP\_04.MAP**; using the **File → Open** menu item on Mappy, load this file into the editor. Immediately, the editor will display a dialog that allows you to enter in the tile bitmap size, it will default to 32 wide, 32 high. Change these parameters to 16 wide and 16 high and click OK. The tool will then load the MAP file and display yet another file dialog querying you to select the bitmap tile file; navigate in the **\SOURCES** directory once again and select **PITFALL\_TILES\_WORK\_04.BMP** and click OK. The tool will then load everything up and you will see the tile map in the edit window along with the tiles to the right in the tile bitmap window. Now, everything is a little too small, so go to the main menu **MapTools → Zoom × 4** and select it. When you are done you should see something similar to Figure 22:9. However, the bitmap tiles to the right might look a little out of whack, try dragging the window back and forth horizontally, and resizing it until all the tile bitmaps look exactly as they do as laid out in this file: **PITFALL\_TILES\_WORK\_04.BMP**.

### 22.3.2 Using Mappy

Mappy is like any other graphics tool, the best way to learn it is to use it with the Help handy. I suggest reading the online tutorials and so on, but more or less we are only going to use Mappy in its most simple form. Here are some quick experiments to try to get the hang of Mappy:

**Experiment 1:** Drag the mouse over the tile editing area.

Simply drag the mouse over the tile editing area (large window), as you do so you will see the various statistics about the block that the mouse is selecting such as x,y, the block ID, and the layer it's in. Don't click anything, just move around a bit.

**Experiment 2:** Drag the mouse over the tile bitmaps area named “Still Blocks”.

Next, drag the mouse over the tile bitmaps on the right side of the screen. This time go ahead and click on the tile bitmaps, as you do, you will see the “block ID” for the selected block which will be highlighted. Think of this as the “brush” selected to paint with.

**Experiment 3:** Grab a scorpion and place it down on the map.

Go ahead and select one of the scorpion bitmap tiles by selecting it, then place it somewhere on the tile map editor area. Presto! That’s all there is to making tile maps. You simply “draw” the tile maps with the bitmap tiles (note you can erase with the right mouse button as well as CTRL-Z to undo).

This is exactly how I drew the Pitfall scene, tile by tile. No wonder I am going crazy!

**Experiment 4:** Creating a new map.

Now, let’s create a new Mappy map. Considering that the HYDRA tile engine supports tile maps that are 16, 32, 64, 128, and 256 wide these are our only options for width, but height can be anything greater than or equal to 12 rows, so keep that in mind. Also, the tile size is always 16×16 pixels. Keeping all that in mind, go ahead and select **File → New Map** from the main menu, the program will warn that you are about to lose your work, go ahead and click OK. Mappy will pop up the tile map dialog which is slightly different than the one you saw last time when opening a pre-existing file. In this case, we need to tell Mappy the size of the tile map and the size of the tiles, so go ahead and enter 16×12 for the tile map and 16×16 for the size of the tiles. Don’t worry about advanced options, but do make sure the color is set to truecolor mode then click OK. A little information pop-up will display and tell you that you need to import some tiles, click OK.

We can import any tile bitmaps we wish, but they must not have any pixel border, they must have an overall template size that is a multiple of 8 on width and height, and finally, so that Mappy scans the tiles correctly, you don’t want to have extra black space all over, you want the tiles to be packed as tightly as possible just like our examples. To load a bitmap tile file, from the main menu go to **File → Import** and navigate into the **\SOURCES** directory and load the **SL\_BLOCK\_03.BMP** file. The file will load into the right “Still Blocks” window. Make sure to adjust the window width with the resize bars, so the tile bitmaps all align up and the “tree” is in one piece, this makes it easier for you to work. Now go ahead and make any tile map you wish! When you are done, you can save your MAP file, but it will only save the following pieces of data based on how we modified the **MAPWIN.INI** file:

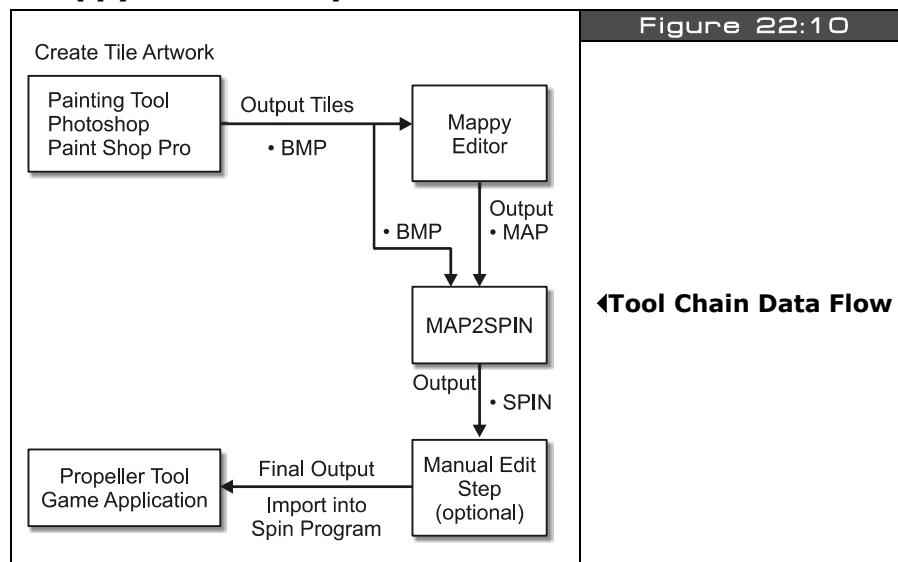
**.MAP files will contain the following information in binary format:**

**Header 2-bytes:** Width, height of tile map.

**Tile map indices:** 1 BYTE per tile map in row major form, 0-based.

Therefore, when you save your MAP file and try to reload it that's why you have to tell the tool what the bitmap size is again as well as telling it the name of the bitmap file you want to load in to represent the tiles. Thus, the MAP file is a very simple abstract representation of the tile map that only stores the original width × height of the tile map along with the indices of the tiles that are stored in each tile map entry.

## 22.4 Mappy Format to Spin Conversion



What we are working toward is a “tool chain” that allows us to create art assets and then get them into the HYDRA in a format that one or more engines understand. Take a look at Figure 22:10 to see what the grand scheme of things is. Referring to the figure, you see that we want to draw bitmap art with a paint program in BMP format. Additionally, we want to import this into the Mappy editor, then generate a MAP file which then goes into yet another conversion tool that outputs everything we need for Spin and the HYDRA tile engine 4.0. The tool that does all this is called **MAP2SPIN.EXE** and is located on the CD in the \SOURCES directory along with its source file **MAP2SPIN.CPP**. The tool is based on the **BMP2SPIN.EXE** tool, but adds the functionality of also taking a tile map from Mappy as part of its input. The final output from the tool is a HYDRA-tile-engine-compliant tile map, bitmaps, and palettes! And it generates all the header code, DAT sections, and everything else we need, so we can literally import the file into our games and use it all. Thus, we have a complete tool chain to make games!

Of course, this is a very simple and basic tool chain and 1/100<sup>th</sup> as complex as something you would see even for the most basic of modern games, but it's a start. With that in mind, let's discuss using the **MAP2SPIN** tool and how it works.

#### 22.4.1 Understanding the **MAP2SPIN.EXE** Conversion Tool.

We don't have time to cover how the tool works internally since it's like 2000 lines of code, and not important since you will have to write many of these tools to make games, and this tool is a specific example of one tool for one format for one output. You will typically write dozens of tools when you develop games. Nevertheless, let's at least cover what the inputs to the tool are and how it works.

The **MAP2SPIN** tool is a complete solution to generating all the Spin code needed, so that we can interface it with the HEL tile engine easily. If you recall, the HEL engine supports tiles, sprites, and palettes. So the tool has to take as an input the Mappy MAP file, a BMP file that represents the tile bitmap artwork and output the HEL compliant tile map, bitmaps, sprites, and palettes. And the tool has to do all this in an organized manner with proper headers, comments and formatting. The following is a general step-by-step explanation of how the tool works internally at the conceptual level:

**Step 1:** The tile map in MAP format is loaded in and analyzed. Most tile maps will only use a subset of every possible tile in the tile bitmap artwork, thus a table is generated that records how many occurrences of each tile index is used. Tiles that are not used do not need to be output as tile bitmap data later in the process.

**Step 2:** Once the Mappy tile map has been analyzed and processed it is converted to Spin-compliant code and output along with labels and an address "**getter**" function.

**Step 3:** Next, the bitmaps must be processed that are referred to by the Mappy MAP file, thus as part of the parameters to the tool the filename of the bitmap artwork file must be passed, so the **MAP2SPIN** tool can use the exact same artwork as the Mappy tool did when the tile map was generated. This is very important, otherwise the 1:1 relationship between tile indices will be lost since they are indexed left to right, top to bottom in Mappy as well as the **MAP2SPIN** tool, thus even if one tile is misplaced or the size of the graphics template file is changed, everything will be off. As the bitmaps are processed they are output in Spin-compliant code that is compatible with the HEL tile engine. At the top of the bitmaps a header and "getter" function is output as well.

**Step 4:** As the last step, the palettes generated by the bitmap analysis phase are output. A header is output along with a label once again for the "getter" function. There is a single palette for every bitmap referenced in the tile map. The final output of the tool is complete.

For example, the file **PITFALL\_TILE\_DATA.SPIN** (located on the CD in the **\SOURCES** directory) was generated by the tool (as you will see shortly) and contains everything for the

HEL engine. Below is a partial listing (please look at the full listing on CD though, and view the DAT tilemap section at a comfortable font size):

```

pitfall_tile_palette_map    LONG
    LONG $07_06_9A_02 : palette index 0
    LONG $07_07_9A_02 : palette index 1
    LONG $07_1E_9A_02 : palette index 2
    LONG $1E_07_07_9A : palette index 3
    LONG $07_07_9A_02 : palette index 4
.
.
.
```

With the right software template we could write a Spin program that imports this file as a single object, then accesses the address getter functions to get the starting address of the tile map, tile bitmaps as well as the palette map. With all those in hand they can be passed to the HEL tile engine and instantly we have a game template up and running! We will see this shortly, but now let's take a detailed look at using the tool itself.

#### 22.4.2 Using the MAP2SPIN.EXE Tool

The **MAP2SPIN** tool's parameters are nearly identical to the **BMP2SPIN** tool's, but with some slight changes and omissions. Here's the usage of the tool:

##### Usage:

```
MAP2SPIN.exe tilemapinputfile bitmapinputfile [flags] > outputfile
```

Where:

- flags = -B -TW[1...255] -TH[1..255] -W[1..256] -H[1..256] -M -FX -FY -V -P[0|1] -?"**;
- B = Enable 1 pixel border for templated bitmaps, default no border.
- TWxx = Width of tile set on x-axis, default = 1.
- THxx = Height of tile set on y-axis, default = 1.
- Wxx = Width of tile, default = 16 pixels.
- Hxx = Height of tile, default = 16 pixels.
- M = Enables mask write as well after each tile.
- FX = Flips the output bitmap's on the X axis (needed for hel engine 4.0).
- FY = Flips the output bitmap on the Y axis.
- Px = Selects the color matching palette 0 or 1, 0 is default, 1 skews color hue 15 degrees approximately.
- V = Verbose flag.
- ? = Prints help.

Since the **MAP2SPIN** tool has a much more specific purpose than the **BMP2SPIN** tool, the map tool needs fewer flags since it can make more assumptions about what the user is requesting. The the first two parameters are always the tilemap (Mappy MAP format) and the

bitmap (BMP format 8/24-bit) then are the optional flags; however, two flags are always necessary which are the tile bitmap template's width and height "-TWxx" and "-THxx." These tell the tool how to extract the tiles from the bitmap that are referenced by the tile map. As an example, let's use the tool on the **PITFALL\_DEMO\_MAP\_04.MAP** along with the bitmap that goes along with it: **PITFALL\_TILES\_WORK\_04.BMP**, and extract a single file that contains the HEL/Spin-compliant tile map, bitmaps, and palettes. Here's how:

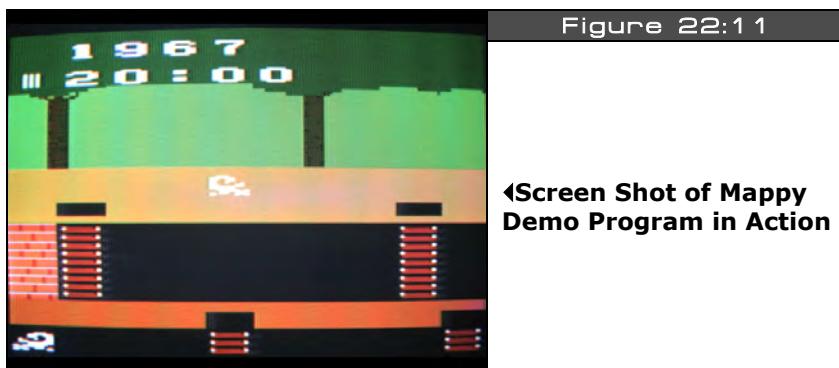
```
MAP2SPIN.EXE pitfall_demo_map_04.map pitfall_tiles_work_04.bmp -FX -TW15 -TH11
```

Execute this command from your command line shell, make sure you are in the **\SOURCES** directory, so all the files can be found. The tool should spew a ton of code out to the console which contains exactly what's in **PITFALL\_TILE\_DATA.SPIN**. Now, to get the data into a file use the command shell redirection and output the file to **MAP\_TEST.SPIN** like this:

```
MAP2SPIN.EXE pitfall_demo_map_04.map pitfall_tiles_work_04.bmp -FX -TW15 -TH11 > MAP_TEST.SPIN
```

Open the **MAP\_TEST.SPIN** file in the Propeller tool or your favorite editor and verify that at the top is the header and getter coder followed by the tile map, the bitmaps (50 of them) and the palettes (50 of them). Once you have done this, then it's time to finally use this file in a demo program.

## 22.5 Importing the MAP2SPIN Code into Demos



Things are about to get really exciting now! Take a look at Figure 22:11, this is the first Mappy-compatible demo program running showing all our hard work finally merged together. Now, the first thing to notice is that if you review the Mappy editor version of the tile map then does this image looks smaller? This is true, there are two things happening here: first our tile engine only shows the first 10 tiles horizontally from the tile map (remember this was to support a little bit of default scrolling), secondly the image looks stretched which is due to

the TV having a non-square aspect ratio at the resolution we are running at. Both issues are common to this kind of work, so just keep them in mind and draw your art slightly taller on the PC, so when it comes out on the HYDRA it looks ok. Anyway, go ahead and load the demo program into your HYDRA to see for yourself. The name of the file is **MAPPY\_TEMPLATE\_001.SPIN** and is located in the **\SOURCES** directory as usual. It will pull in the HEL graphics engine, the gamepad driver (for later use), as well as the **MAP2SPIN**-generated tile data which by default is **PITFALL\_TILE\_DATA.SPIN**. The demo program is rather short, here's an abridged listing that shows the initialization and main event loop:

```
OBJ

game_pad : "gamepad_drv_001.spin"
gfx:      "HEL_GFX_ENGINE_040.SPIN"

tile_data: "pitfall_tile_data.spin" :<--MODIFY THIS LINE - INSERT YOUR OWN
                                : MAP2SPIN OUTPUT FILE HERE!!!

'///////////////'PUBS SECTION'///////////////
'///////////////' COG INTERPRETER STARTS HERE...@ THE FIRST PUB

PUB Start
' This is the first entry point the system will see when the Propeller Chip starts
' Execution ALWAYS starts on the first PUB in the source code for
' the top level file

' start the game pad driver (will need it later)
game_pad.start

' set up tile and sprite engine data before starting it, so no ugly startup
' points ptrs to actual memory storage for tile engine
' point everything to the "tile_data" object's data which are retrieved by
' "getter" functions
tile_map_base_ptr_parm      := tile_data.tile_maps
tile_bitmaps_base_ptr_parm   := tile_data.tile_bitmaps
tile_palettes_base_ptr_parm := tile_data.tile_palette_map

' these control the sprite engine, all 0 for now, no sprites
tile_map_sprite_cntrl_parm   := $00_00 ' 0 sprites, tile map set to 0=16 tiles
                                         ' wide, 1=32 tiles, 2=64 tiles, etc.
tile_sprite_tbl_base_ptr_parm := 0
tile_status_bits_parm        := 0

' launch a COG with ASM video driver
```

```

gfx.start(@tile_map_base_ptr_parm)

' enter main event loop...
repeat while 1

    ' main even loop code here...
    curr_count := cnt ' save current counter value

    ' lock frame rate to 30-60
    waitcnt(cnt + 666_666)

    ' return back to repeat main event loop...

```

Notice there is no DAT section? This is because all the data is nicely tucked away in the imported object **PITFALL\_TILE\_DATA.SPIN**. Also, so more or less we have an entire tile engine working in about 20 lines of code! The only important thing to make sure you understand is that the HEL tile engine needs the starting address of the:

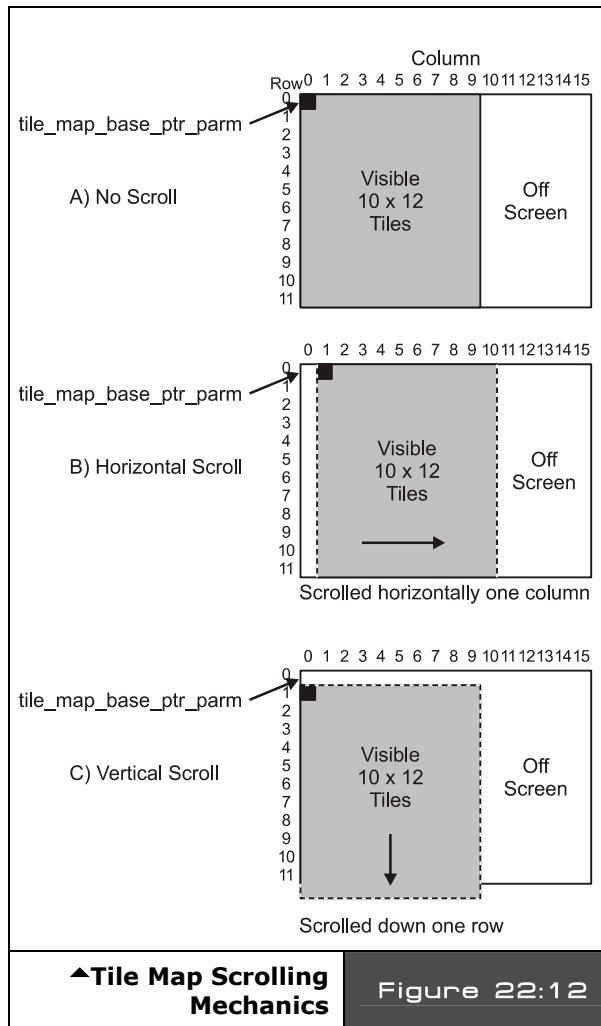
- ▶ Tile map
- ▶ Tile bitmaps
- ▶ Palettes

These are retrieved from the “**tile\_data**” object via “getter” functions with similar names. You can see this done in the assignment statements of the tile engine parameters right under the call **game\_pad.start**. Furthermore, remember than you can change these pointers on the fly to other tile maps, bitmaps, and palettes and the HEL engine will update the display within 1/60<sup>th</sup> of a second, or one frame.

Alright, now that you have the template demo program working, let's go ahead and try some things out. First, edit **MAPPY\_TEMPLATE\_001.SPIN** and change the filename of the imported Spin code loaded into the object “**tile\_data**” in the OBJ section to **MAP\_TEST.SPIN** which you should have generated in the previous experiment. Basically, it's the exact same data as the **PITFALL\_TILE\_DATA.SPIN** file. Run the program again and you should see the exact same image as before.

Now, go ahead and use the **PITFALL\_TILES\_WORK\_04.BMP** tile bitmaps and Mappy to create any number of 16×12 tile maps, export them and convert them to Spin code with the **MAP2SPIN** tool, then try them in the template. Also, remember if the colors don't look right try using the other conversion palette with the “-P1” flag to the tool. This is where things get really fun since you now have some tools to get things into the HYDRA from the PC within seconds and “see” the results.

## 22.6 Scrolling the Tile Map



In the next section, we are going to discuss scrolling at a much more technical and general level, but for now, let's see if we can get some really basic scrolling working with what we have. Scrolling, simply put, is showing only a portion of a larger game world / environment / data set on the screen and moving this window around in real-time. The screen becomes the "window" to the larger environment and can slide around horizontally or vertically. In this case, we want to look at a feature I built into the HEL engine that by default supports a little bit of scrolling horizontally without much fuss. The HEL tile engine maps we have been using (including the ones we just exported from **MAP2SPIN**) are all  $16 \times 12$  tiles. However, the screen only shows  $10 \times 12$  of these tiles, the others are off screen to the right. But, there is no reason we can't slide the tile engine rendering over and see them. This is so easy you aren't going to believe it. The trick is to realize that the HEL tile engine uses the address that is assigned to the parameter **tile\_map\_base\_ptr\_parm** as the starting address of the tile data for rendering.

If we modify this address then the image will scroll around. If you recall each tile is composed of a single WORD with the following format [tile palette index | tile bitmap index], so we need to add or subtract a multiple of 2, since there are 2 BYTES per WORD and the memory is BYTE addressed. In any case, if we want to scroll horizontally we simply want to shift the address over by 1 WORD, if we want to scroll vertically then we want to shift the address over by an entire tile row or 16 WORDs, Figure 22:12 shows this.

Of course, scrolling doesn't work if there is nothing to scroll to; however, in our case the tile data is  $16 \times 12$  and we are only viewing a  $10 \times 12$  window, so we can scroll horizontally. We can also scroll vertically if we want, but there will be garbage there now since there are only 12 rows defined in the tile map. I have modified the Mappy template program to support scrolling, the program is nearly identical, but now allows you to scroll the tile map horizontally with the gamepad's left and right directional buttons. The name of the program is **MAPPY\_TEMPLATE\_002.SPIN** and is located on the CD in the **\SOURCES** directory. Simple, load it up and give it a try.

Pretty cool huh? Of course, that's not much scrolling, but remember tile maps can be any size vertically, and can be 16, 32, 64, 128, or 256 columns horizontally, so that's a lot of scrolling room. But, we will get to that in more detail in the next section. For now, let's take a quick look at the scrolling code in the new demo to make sure you see what's going on. Here's an excerpt from **MAPPY\_TEMPLATE\_002.SPIN** that shows how the horizontal scrolling is performed:

```
PUB Start
' This is the first entry point the system sees when the Propeller chip starts,
' execution ALWAYS starts on the first PUB in the source code for
' the top level file

' start the game pad driver (will need it later)
game_pad.start

{ set up tile and sprite engine data before starting it, so no ugly startup
  points ptrs to actual memory storage for tile engine
  point everything to the "tile_data" object's data which are retrieved by
  "getter" functions }
tile_map_base_ptr_parm      := tile_data.tile_maps
tile_bitmaps_base_ptr_parm  := tile_data.tile_bitmaps
tile_palettes_base_ptr_parm := tile_data.tile_palette_map

' these control the sprite engine, all 0 for now, no sprites
tile_map_sprite_cntrl_parm  := $00_00 ' 0 sprites, tile map set to 0=16 tiles
                                         ' wide, 1=32 tiles, 2=64 tiles, etc.
tile_sprite_tbl_base_ptr_parm := 0
tile_status_bits_parm       := 0

' initialize scrolling vars
scroll_x := 0
scroll_y := 0

' launch a COG with ASM video driver
gfx.start(@tile_map_base_ptr_parm)

' enter main event loop...
```

```

repeat while 1

    ' main even loop code here...
    curr_count := cnt ' save current counter value

    ' test for scroll
    if (game_pad.button(NES0_RIGHT) and scroll_x < 5)
        scroll_x++

    if (game_pad.button(NES0_LEFT) and scroll_x > 0)
        scroll_x--

    ' update tile base memory pointer
    tile_map_base_ptr_parm := tile_data.tile_maps + scroll_x*2

    ' lock frame rate to 3-6 frames to slow this down
    waitcnt(cnt + 10*666_666)

    ' return back to repeat main event loop...

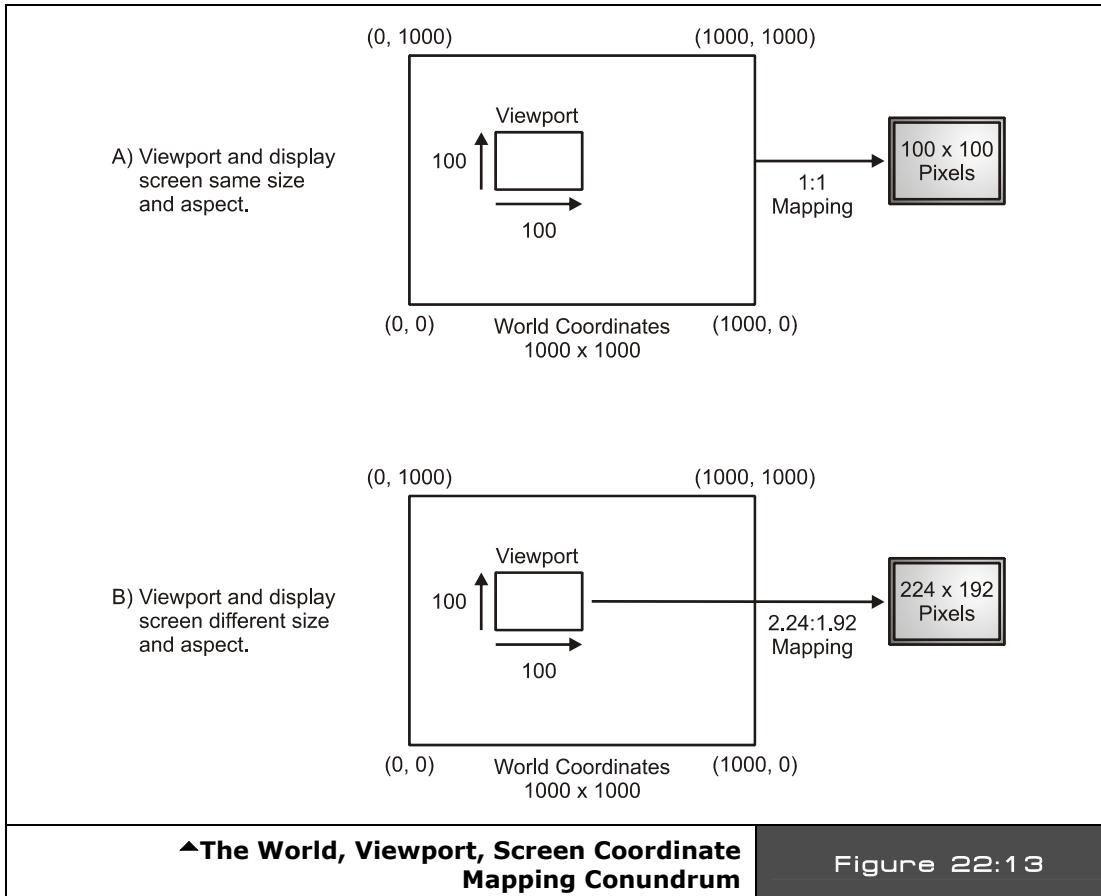
```

The scrolling is implemented by simply testing the gamepad then updating a variable **scroll\_x** which is in turn used to **offset** the base address of the tile map (notice the multiplication by 2, since there are 2 BYTES per tile entry WORD).

If you're like me then this little demo probably gives you all kinds of ideas based on huge scrolling worlds like **Nintendo's Legend of Zelda** or racing games that scroll, or adventure games, and much much more. Lastly, remember these tools are just that, "tools" and they are not going to do everything, in fact, many times you will use them to output data and still manually hack it up, change it, use a text find/replace to make global changes, nevertheless, they save a ton of time.

## 22.7 Scrolling Techniques in Games

Scrolling is to game programming as recursion is to data structures and algorithms. No matter what people always seem to have a really hard time with scrolling. I think the problem is that in most people's normal life experience nothing really scrolls? Sure computer games scroll, and Windows applications, but most people don't really have a physical analog for scrolling, so the concept is always hard for people to grasp. However, it's very easy if you just draw the problem out and understand what you're trying to do. Thus, we are going to approach this from a very technical and geometrical point of view then simplify it to the context of games and short cuts.

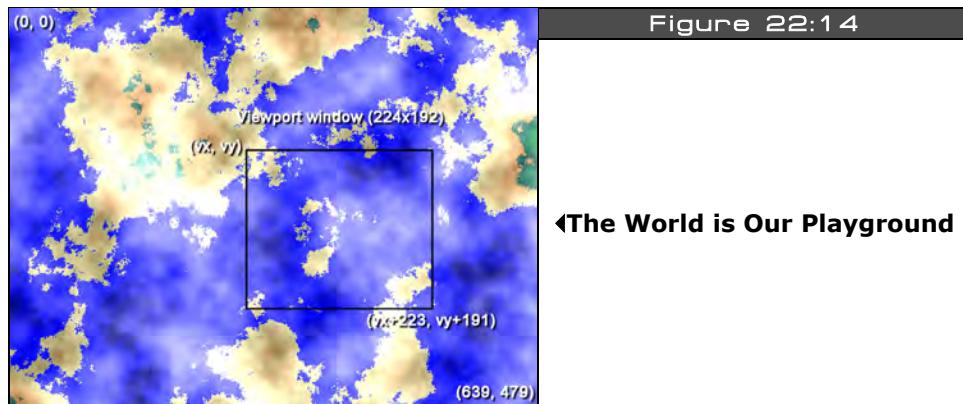


Simply put, scrolling is nothing more than mapping a "**viewport**" from a large environment to the screen. For example, say we had a world that was  $10,000 \times 10,000$  pixels and the screen (TV, monitor, whatever) is only  $100 \times 100$  pixels. This means that we can only see a "window" or "viewport" of  $100 \times 100$  at any one time. Referring to Figure 22:13(A), we see this graphically. Now, to help us describe the problem it's nice to have some terminology to refer to, so let's call the larger  $10,000 \times 10,000$  environment that we want to scroll around in the "**world coordinates,**" that is the "world" is  $10,000 \times 10,000$ . Next, we are going to call the little window that we scroll around that is  $100 \times 100$  the "viewport" coordinates. Moreover, in most cases for simple 2D the "viewport" coordinates are the same as screen coordinates; however, this need not be the case for example, we could move the viewport around the world coordinates and then map the viewport to the screen with yet another geometrical configuration.

For example, take a look at Figure 22:13(B), here we see the world coordinates, a viewport window and the screen all with different sizes. The interesting thing is that if we want to map the viewport to the screen and maintain all the image data then we must scale the image, that is if the viewport window is  $100 \times 100$  (for whatever reason), but the screen is  $224 \times 192$  (NTSC for example) then we would need to map or scale the pixels from the viewport to the screen with some math and or algorithms. But for now we will simply make sure the viewport is the same size as the screen so the transformation is 1:1 and we don't have to worry about this. Nonetheless, in more advanced graphics systems you might want to have more of these coordinate systems to help scale your imagery or make it work on any output device and so forth.

Now that we have a little common vocabulary, let's formally look at the math and programming to implement scrolling using various technologies.

### 22.7.1 Bitmap Scrolling



Bitmap scrolling is probably the simplest conceptually and practically since it's nothing more than tracking some coordinates and copying blocks of memory from one place to another. For example, let's assume that we want to make a war game of some kind and we have a nice  $640 \times 480$  bitmap of the world as shown in Figure 22:14, thus the world size is  $640 \times 480$  and the coordinates are  $(0,0)$  to  $(639,479)$  inclusive. Now, let's say that we want to create a viewport than is  $224 \times 192$  and we are going to map this viewport directly to the NTSC TV screen at some point, thus no scaling is needed. Then we simply have a memory/math problem to work out. The first calculation is how many "screenfulls" of data the viewport window can scroll over:

$$\begin{aligned} \text{screens\_x} &= 640/224 = 2.85 \\ \text{screen\_y} &= 480/192 = 2.5 \end{aligned}$$

Something like this would be perfect for little  $8 \times 8$  or  $16 \times 16$  sprite army men to run around on and kill each other, but at the same time not so big that the player couldn't move the viewport around quickly to get to the action. To scroll around the image, we need the position of the viewport window, call it  $(vx, vy)$  which is the upper left hand corner of the viewport and  $(vx+223, vy+191)$  is the lower right hand corner. Also, assuming that our ***world coordinates*** range from  $(0,0)$  at the upper left hand corner to  $(639, 479)$  at the lower right hand corner (remember computer graphics are usually up side down), Figure 22:14 shows the various coordinate labelings for reference. Given all that, what we need to do is copy the contents of the viewport to the bitmap buffer for our game engine display (usually the back buffer). Let's assume that there is 1 byte per pixel to make things easy, here's some pseudo Spin code that would do it:

```
long vx, vy           : upper left hand corner of viewport
long world_bitmap    : assume this points to the world bitmap that is 640x480
long display_buffer  : assume this points to the display buffer (could be offscreen
                      or onscreen, doesn't matter)

' copy window contents from the world bitmap to the display buffer line by line
repeat y from vy to vy+191
  bytemove(display_buffer + ((y-vy)*224), world_bitmap + (vx + y*224), 224)
```

The fragment assumes that ***world\_bitmap*** and ***display\_buffer*** have previously been pointed to the starting memory address of the world bitmap and the video display buffer respectively. The code then enters into a simple repeat loop that iterates over all 192 lines that must be copied from the viewport to the display screen. We are using the ***bytemove()*** function here to rapidly copy memory rather than copy each BYTE in yet another inner loop. Also, notice the address calculations since they are tricky. The "source" data is coming from the larger world map and the "destination" data is being copied to the display buffer, so we must continually recompute the addresses so the lines of video can be copied. This code will perfectly copy the viewport to the display buffer, however there is no error handling and typically graphics algorithms don't have any by design, thus you must make sure that  $(vx, vy)$  would never push the viewport out of the world.

Everything looks good, but can we do better? Meaning computer graphics is about speed: Spin is fast, but it will be brought to its knees if we use it to start processing bitmap data, so we have to help it out. This is a perfect example of something we can optimize. First, we are using the *bytemove()* function which only copies BYTES at a time; however, if we use the *wordmove* or *longmove* functions then we can speed up the copying process by 200-400%. The only problem is that the pointers are BYTE based and not aligned to WORD or LONG boundaries, so this won't work. However, if we were copying an off-screen buffer to an on-screen buffer, then as long as the two buffers were LONG aligned we could use a *longmove* and speed up the process, but not here. Ok, fine, is there anything else we can do? Well, looking at the inner loop, there is a lot of math there. Normally, we wouldn't care in

an optimizing compiler, but Spin is not and it will continually recompute all the math, thus we need to get the math out of the loop. This is easily done and with a little experience you can “see” the solution very quickly. The question you ask yourself is “For every incremental change in  $y$ , what is changing elsewhere?” Then take this knowledge and change the algorithm to work incrementally. Here’s the final results of that thought experiment:

```

long vx, vy      : upper left hand corner of viewport
long world_bitmap : assume this points to the world bitmap that is 640x480
long display_buffer : assume this points to the display buffer
                      (could be offscreen or onscreen, doesn't matter)

' get pointers ready for move
world_bitmap += vx + vy*224 ' now world bitmap points to upper left hand
                           corner of viewport rather than larger world bitmap

' copy window contents from the world bitmap to the display buffer line by line
repeat y from vy to vy+191
  bytemove(display_buffer, world_bitmap);
  update the pointers
    display_buffer += 224 ' 224 bytes per line
    world_bitmap   += 224 ' 224 bytes per line

```

This new algorithm is nearly optimal. The next step in optimization would be to test for source data WORD or LONG alignment and if so use a WORD or LONG copy to move the data. Otherwise, its about as fast as its going to get in Spin. The only side-effect of the code is that pointers are changed during the algorithm, thus if you wanted them to stay valid, you would make copies of them before starting the algorithm.

Unfortunately, bitmap scrolling means bitmaps, and the HYDRA only has 32K of RAM memory – not enough to make any large bitmap screens, thus we aren’t going to see any demos of this technique. However, you can always make a bitmap that is single-screen size and then scroll around a tiny window, maybe 64×64, and map it onto the screen. Of course, to do this we would need a tool to convert full bitmaps into Spin code and an engine that supports bitmaps. Right now we are going to stick to the HEL tile engine since it does tiles and sprites with very little memory.

### 22.7.2 Vector Scrolling

Bitmap scrolling is fine for computers with huge amounts of memory so full resolution bitmaps can be stored, but due to the memory limitation of the HYDRA we can’t really do much with bitmap scrolling. However, there is a work-around that supports some other effects and the idea is called **“vector scrolling.”** Vector scrolling is based on using geometrical descriptions of objects to draw them on the fly rather than actual bitmaps of the objects. For example, earlier in the book when experimenting with the Parallax reference graphics driver we drew lines, polygons, and other entities by making calls to functions. The

only memory footprint was that we needed a double-buffered display, so an offscreen and onscreen buffer. This is the idea of vector scrolling, we are going to use a bitmap display, but instead of using bitmaps to represent game entities we are going to use vector descriptions to describe the geometry of game objects and render them on the fly. Take a look at Figure 22:15, here we see two completely different games: **BattleZone** and **Defender**, both games use radically different techniques to draw the imagery. BattleZone was in fact a 3D wireframe game running on XY display hardware (not raster), and Defender was a tile-based game believe it or not! The point is that as an artist, I want to get something that looks like the mountains of each game and I want to do it with vector graphics.

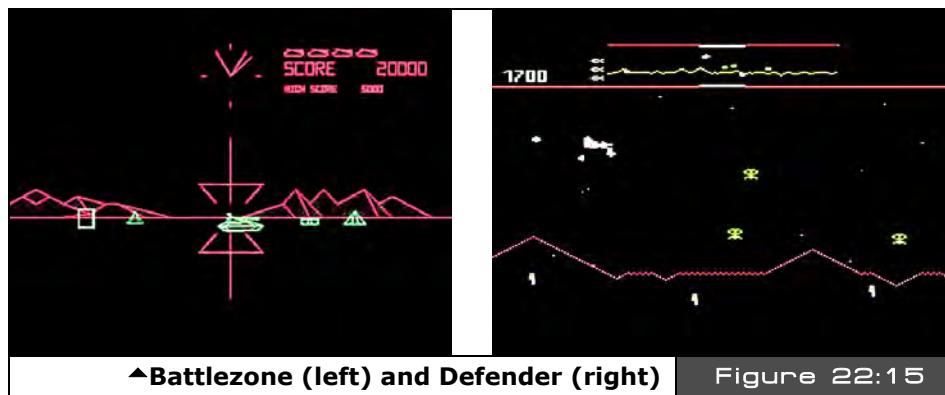


Figure 22:15

The effect is simple, we need a world coordinate system just as before, and to make it fun let's say it's  $2560 \times 192$ , that is large enough to store a 10-screen-wide world at  $256 \times 192$  per screen. Of course, a bitmap this large with 8-bit color would be enormous:

$$2560 \times 192 = 491,520 \text{ BYTES.}$$

However, the world coordinates are only virtual, we only need the memory for a back buffer and a front buffer at  $256 \times 192$  with 2 bits per pixel (Parallax graphics driver format) which equals:

$$256 \times 192 / 4 = 12,288 \text{ BYTES per buffer.}$$

Or 24576 BYTES for both the on- and off-screen video buffers, leaving us with  $32K - 24,576 = 8K$  more or less for code which must support the Parallax reference graphics driver, along with any input driver we need, plus the geometrical description of the mountains and the program in Spin that makes it all happen.

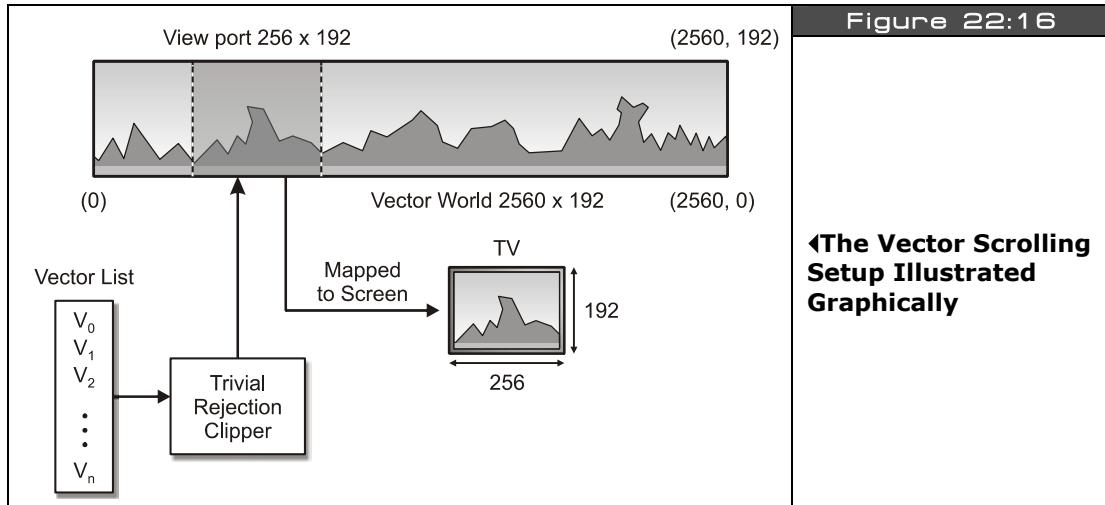


Figure 22:16

◀The Vector Scrolling Setup Illustrated Graphically

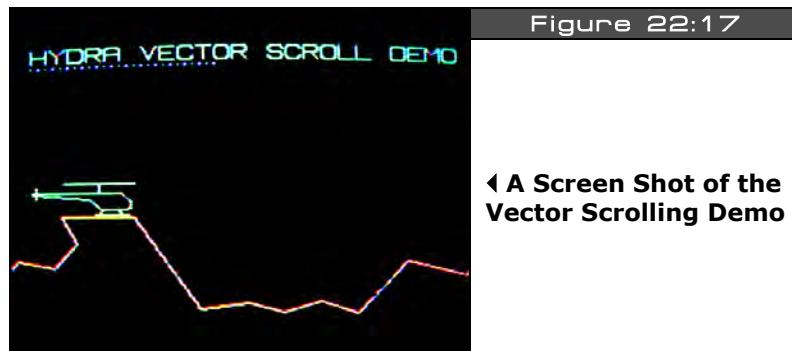
The programming plan is that the mountain geometry will consist of an array-like data structure than stores the endpoints of each line segment in the mountainscape as well as its color index (0..3), this way we can draw anything we like. As the virtual viewport moves over the world coordinates, the data structure will be scanned and any line segment where one or both endpoints lie within the viewport will be passed to the renderer for rendering. Of course, we can't just draw lines that go off the edges of the screen, someone has to clip them, but as you might recall the reference driver does this for us. Figure 22:16 shows the setup for this. The important point to understand about this type of scrolling is that we are moving the virtual viewport window over a "data set" that is purely mathematical in nature and not bitmap nor tile data, thus it's kind of an interesting setup. The viewport has coordinates of  $(vx,vy)$  to  $(vx+255,vy+191)$  and we move this rectangle around mathematically in the data set space only conceptually. All we really are going to do is test the world coordinates of each line segment in the array against the rectangle of this viewport. If any line segment is partially or wholly in then it's passed to the renderer. But, when it is passed we need to transform the data back to screen coordinates. That means that for any line segment with coordinates  $p1(x1,y1)$  to  $p2(x2,y2)$  where one or both  $p1$  and  $p2$  are within the viewport, we need to translate these points into screen space with the following transformation:

$$\begin{aligned}x1\_screen &= x1 - vx, \\y1\_screen &= y1 - vy\end{aligned}$$

$$\begin{aligned}x2\_screen &= x2 - vx, \\y2\_screen &= y2 - vy\end{aligned}$$

It's simple, but subtle. The point is that the viewport can be all over the place, but screen coordinates must always be from (0,0) to (255, 191) with our proposed setup (technically, the lines may extend beyond the screen's coordinates, but the driver will clip them for us).

The last problem is how to create the actual vector landscape. There are two options: the first option is to generate it randomly, the second option is to generate it by hand on paper or using a graphics tool and draw it on the screen and record the coordinates and colors. Either way, you need a list of 1 or more line segments that make up your mountainscape, something like 50-200 lines will suffice.



A demo of the vector scrolling setup to create a mountainscape is shown in Figure 22:17. The name of the demo is **VECTOR\_SCROLL\_DEMO\_001.SPIN** and is located on the CD in the **\SOURCES** directory, go ahead and load it up and run it on your HYDRA and give it a whirl. Use the gamepad to scroll right and left (the blue dots indicated rendered segments per frame). Note that the demo uses the Parallax reference graphics drivers, so the coordinate system is (0,0) bottom left corner, (max\_x, max\_y) top right corner.



Also, take a look at Figure 22:18 which is the entire vector terrain shown graphically; it is composed of about 125 line segments. Concentrate your attention to the left and right ends of the terrain, notice the terrain starts and ends at the bottom of the image, or in other words, the right and left side of the scolling terrain are "**tileable**," that is when you scroll around the terrain and end up at the beginning again, you don't see a "**discontinuity**" of

the geometry. This is very important if you want to repeat your terrain or geometry, the start and the end of the geometry must meet at the same place otherwise you will see a "jump" in the image when you scroll through it if you want wrap around. Let's now take a look at the section of code that does the display list process and rendering:

```
vrendered := 0 ' reset number of vectors rendered

' process vector display list
repeat index from 0 to num_vectors
    ' do a bit of pre-computation, let's make this fast!
    ' extract vector line segment properties, format[color,x1,y1,x2,y2,]
    ' also, invert y-axis to match parallax reference driver's (0,0) origin
    vbase_offset := 1 + index*5 ' pre-compute
    vcolor := terrain_vector_list[vbase_offset + 0] ' color at offset 0
    vx0 := terrain_vector_list[vbase_offset + 1] ' first point at offset 1,2
    vy0 := SCREEN_HEIGHT - terrain_vector_list[vbase_offset + 2] - 1
    vx1 := terrain_vector_list[vbase_offset + 3] ' second point at offset 3,4
    vy1 := SCREEN_HEIGHT - terrain_vector_list[vbase_offset + 4] -1

    ' now we have the line, clip to viewport

    ' is this line segment partially or wholly within viewport? (no need to test y since they are ALWAYS
    ' within viewport)
    if ((vx0 >= view_x) and (vx0 < view_x+SCREEN_WIDTH) or (vx1 >= view_x) and (vx1 < view_x+SCREEN_WIDTH))
        ' line segment is within viewport, map it to screen coords and render
        screen_x0 := vx0 - view_x
        screen_y0 := vy0 - view_y

        screen_x1 := vx1 - view_x
        screen_y1 := vy1 - view_y

        gr.colorwidth(vcolor,0)
        gr.plot(screen_x0,screen_y0)
        gr.line(screen_x1,screen_y1)

        ' show user how many vectors are rendered
        gr.colorwidth(3,0)
        gr.plot(10+vrendered*4, 175)
        vrendered++
    
```

This fragment from the demo more or less scans the vector display list and then tests each vector for inclusion in the viewport, vectors inside are rendered, otherwise discarded. Also, notice the demo shows a number of blue dots at the top of the screen. These dots represent the number of vectors rendered during each frame, these are tracked by **vrendered**. As the number of vectors increases, the speed of the display slows down markedly. This is due to the fact that the Parallax reference driver does per-pixel clipping instead of line-endpoint clipping and thus the line draw is about 10-20x slower than need be, so lines really suck a lot of time. Therefore, when using the reference driver the more lines you can remove from the rendering pass the better. Also to increase speed notice the pre-computation and caching of the array index **vbase\_offset**.



TIP

The vector display demo uses a “*display list*” of vectors to render. This technique is a very powerful concept since a display list can be thought of as an atomic object which can be copied, transformed, etc. Moreover, a game could have hundreds of display lists that represent simple objects, environments, or even animations. Early “XY” vector games and many 3D rendering engines make use of this concept.

### 22.7.2.1 The Helicopter Animation

The cool thing about vector data is how easy it is to manipulate. Since the image on the screen is generated by a list of vectors each frame, there is no reason we can't go into the list and alter the data. For example, if you scroll to the right in the demo, you will see a helicopter with its blade idling slowly. This simple animation effect was accomplished by locating the vector that makes up the blade (index 24) then writing an “animation helper” to update this vector each frame and animate the blade. The code that does this is below:

```
' animate the helicopter by going into the display list and manually updating
' the "blade" line segment index 24 of display list
' WORD 2, 334,87, 380,87
if (heli_blade_width > 30 or heli_blade_width < 2)
    dx := -dx
heli_blade_width += dx

' update vector display list
terrain_vector_list[1+24*5 + 1] := 357-heli_blade_width
terrain_vector_list[1+24*5 + 3] := 357+heli_blade_width
' end animation of helicopter
```

See if you can use this same technique to animate other parts of the environment, maybe the pyramid or the control tower to the right of the world? Or make the volcano erupt!

That's about it for this demo, as a challenge see if you can add a player ship to the game demo! **Hint:** the player's ship is in world coordinates as well, and as the viewport moves around, if the player's ship is in the window then it's drawn.

### 22.7.3 Advanced Tile Map Scrolling

Well, now we come full circle back to tile scrolling. Hopefully you have an understanding of the mathematical underpinnings of scrolling and how world, viewport, and screen coordinates all relate to each other. Now we are going to take a closer look at the HEL tile engine's scrolling support demo'd earlier. If you recall the HEL tile normally uses a  $16 \times 12$  tile screen where only the first 10 columns of tiles are visible on screen, thus the physical screen is  $10 \times 12$  and the logical screen is  $16 \times 12$ . This is shown in Figure 22:19 and thus far we have only been using the first 10 columns in our demos and not defining the remaining 6 columns that make up the whole tile screen (usually left as 0).

However, if we did put tiles into these locations and not just zero entries then we could “scroll” horizontally by simply adjusting the starting address of the tile map by 1 WORD at a time, thus we have 6 tiles of scroll horizontally already. This was shown off in:

### **MAPPY\_TEMPLATE\_002.SPIN**

...which allowed scrolling right and left with the gamepad, but only a few tiles since the tile map was still only 16×12.

The code that did the scrolling was:

```
' update tile base memory pointer
tile_map_base_ptr_parm := tile_data.tile_maps + scroll_x*2
```

...nothing more than updating the tile map base pointer in the HEL engine by the number of WORDs to scroll right/left. However, the HEL tile engine is capable of much larger tile worlds, in fact it supports 16, 32, 64, 128, and 256 tile wide maps. The height of a tile map must be at least 12 rows, but there is no limit to how many rows you can have. To tell the HEL tile engine how wide your map data is (which really tells the engine how to address rows ultimately) you need to set the proper control values in the tile map control parameter: **tile\_map\_sprite\_cntrl\_parm**. This variable is a pointer to the LONG value that holds various “control” values for the tile map sprite engine. Currently it encodes the width of map and number of sprites to process up to 8 in the following format:

**\$xx\_xx\_ss\_ww**

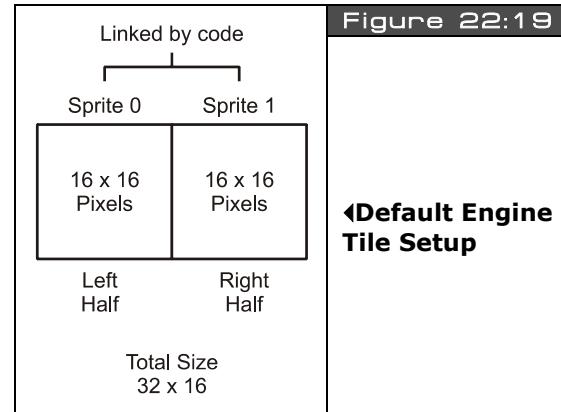
Where,

**ww** = The number of “screens” or multiples of 16 that the tile map is. For example 0 would be 16 wide (standard), 1 would be 32 tiles wide, 2 would be 64 tiles and so forth.

**ss** = Number of sprites to process 0..8

**xx** = Unused at this time

So to tell the HEL engine that the tile map is larger, the “ww” fields needs a 0,1,2,3,4... in it which indicates the width of the tile map 16,32,64,128...



**Figure 22:19**

◀Default Engine  
Tile Setup

### 22.7.3.1 Horizontal Tile Scrolling

Scrolling the tile maps horizontally is accomplished by adjusting the starting address passed into **tile\_map\_base\_ptr\_parm**. Given that each tile is one WORD, scrolling horizontally is accomplished by “sliding” the starting address in WORD multiples. As the address is adjusted the on-screen view will “scroll” to the right. If you scroll too much then you will wrap around and start drawing the next row which, unless desired, would look wrong. Thus, if you have a tile map that is 32 tiles wide then you never want to pass as the starting address any address greater than the tile map width minus the number of tiles visible (which is 10). So to scroll horizontally, in all cases you only need some code like this:

```
' update tile base memory pointer
tile_map_base_ptr_parm := tile_data.tile_maps + scroll_x*2
```

...along with some bounds checking.

### 22.7.3.2 Vertical Tile Scrolling

Vertical scrolling is nearly free with the HEL engine, we don’t even have to change the **tile\_map\_sprite\_ctrl\_parm** at all. As far as the HEL engine is concerned it needs 12 rows of tile data, that’s it, so as long as from the starting address placed in **tile\_map\_base\_ptr\_parm** there is enough data for 12 rows of tile rendering the engine will be happy. So if you have 1000 rows of data, all you need to do to scroll vertically is simply add to the base pointer the width of the row times the number of rows you want to scroll like this:

```
' update tile base memory pointer for vertical scrolling
tile_map_base_ptr_parm := tile_data.tile_maps + scroll_y*TILES_PER_ROW*2
```

...where tiles per row is 16, 32, 64, etc. and the “2” factor is because each tile is 1 WORD or 2 BYTES.

That’s all there is to scrolling with the HEL engine, so now let’s take a look at a couple demos that take advantage of scrolling.

### 22.7.3.3 Large Tile Map Scrolling Demo

As a demo of large map scrolling, I took my Pitfall artwork tile bitmap file **PITFALL\_TILES\_WORK\_04.BMP** and created a 64×24 tile world with Mappy. After 20-30 minutes of moving things around, I came up with the world shown in Figure 22:20 and saved it as **PITFALL\_DEMO\_MAP\_05.MAP**. Then with map and bitmap data in hand I ran the **MAP2SPIN.exe** tool with the following command line:

```
MAP2SPIN pitfall_demo_map_05.map pitfall_tiles_work_04.bmp -FX -TW15 -TH11 >
PITFALL_TILE_DATA2.SPIN
```

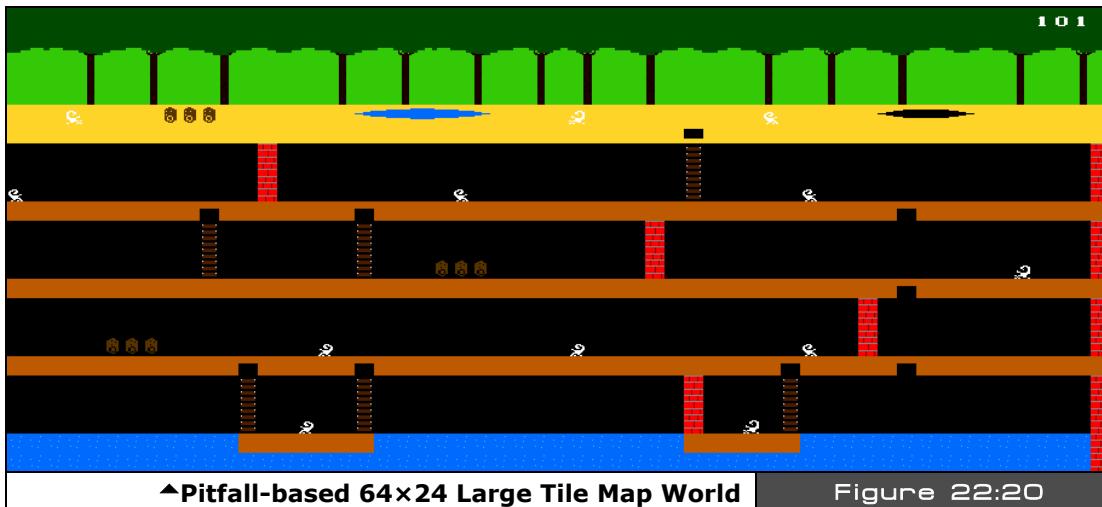


Figure 22:20

The output along with all the files are located in **\SOURCES** as usual for your reference. Then with the tile data file in hand, I modified **MAPPY\_TEMPLATE\_002.SPIN** to support the  $64 \times 24$  map and added some code to support 4-way scrolling, the resulting program is **TILE\_MAP\_SCROLL\_DEMO\_001.SPIN**. Go ahead and load it up and then use the gamepad to move around. Basically, this demo has a  $10 \times 12$  "viewport" into the  $64 \times 24$  tile map world. The program is embarrassingly simple considering what it does. First in the OBJ section we include the tile map data:

```
OBJ
tile_data:      "pitfall_tile_data2.spin"
```

Then in the main code initializes the HEL tile engine and enters the main loop:

```
{ point everything to the "tile_data" object's data which are retrieved by
"getter" functions }
tile_map_base_ptr_parm      := tile_data.tile_maps
tile_bitmaps_base_ptr_parm  := tile_data.tile_bitmaps
tile_palettes_base_ptr_parm := tile_data.tile_palette_map

' these control the sprite engine, all 0 for now, no sprites
tile_map_sprite_cntrl_parm  := $00_02 ' 0 sprites, tile map set to 2=64 tiles
                                         ' wide, 1=32 tiles, 2=64 tiles, etc.
tile_sprite_tbl_base_ptr_parm := 0        ' maps can always be any height >= 12 rows
tile_status_bits_parm       := 0

' initialize scrolling vars
```

```

scroll_x := 0
scroll_y := 0

' launch a COG with ASM video driver
gfx.start(@tile_map_base_ptr_parm)

' enter main event loop...
repeat while 1

    ' main even loop code here...
    curr_count := cnt ' save current counter value

    ' test for scroll
    if (game_pad.button(NES0_RIGHT) and scroll_x < 54)
        scroll_x++

    if (game_pad.button(NES0_LEFT) and scroll_x > 0)
        scroll_x--

    if (game_pad.button(NES0_UP) and scroll_y > 0)
        scroll_y--

    if (game_pad.button(NES0_DOWN) and scroll_y < 12)
        scroll_y++

    ' update tile base memory pointer considering scroll_x and scroll_y
    tile_map_base_ptr_parm := tile_data.tile_maps + (scroll_x + scroll_y*64)*2

    ' lock frame rate to 3-6 frames to slow this down
    waitcnt(cnt + 5*666_666)

```

The scrolling and tile map base address update is literally a few lines of code and the results are freely scrolling large worlds ready for game play logic and characters! Now, the demo is pretty boring since nothing is moving around. As an exercise let's animate one of the scorpions and make it move right to left on one of the ledges. Looking at the game map, the first scorpion under the entry point to the lower right hand (word tile coordinates (7,9) is perfect for this.

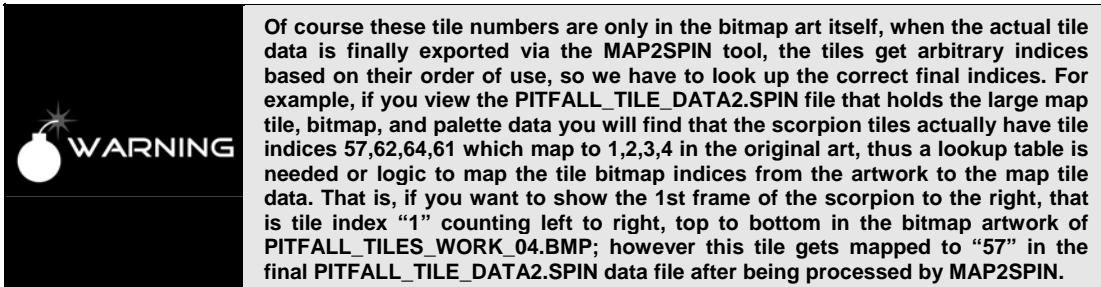
#### 22.7.3.4 Animating The Scorpion

Animating the scorpion has two elements: the “frame” or bitmap that represents the scorpion and the position or motion of the scorpion. Both of these aspects will be “animated” to create the effect. To accomplish the animation, we need some tiles that represent the scorpion walking right and left. A quick scan of the tile bitmaps in **PITFALL\_TILES\_WORK\_04.BMP** reveals that tiles 1,2,3 and 4 (top row, from left to right) represent the scorpion facing right

and left respectively with 2 frames of animation each. Thus to animate the “walking” animation set of the scorpion we need to cycle through the following frames:

Right motion: 1,2,1,2,...

Left motion: 3,4,3,4,...



However, changing the tile at location (7,9) won’t translate the scorpion, thus we need to actually move the tile as well and erase the previous tile as the scorpion moves. Furthermore, we have to have a set of rules that control the animation, and “direct” the scorpion to perform the animation we desire. For example, the animation might simply be to move right or left while animating the frame each cycle, if a wall tile is collided with then reverse direction. This type of rule results in a constant left right motion which is fine if we want the scorpion to “patrol.” However, if we want the scorpion to look a little more realistic we might create a simple finite state machine that has two states: **WALKING** and **IDLE**. In the walking state, the scorpion just walks to the right or left and reverses direction when it bumps into a wall (the tile is tested for collision); however, at some random or pre-determined time the scorpion switches into the IDLE state and while there doesn’t do anything, but sits still as if it were “thinking.”

Just some ideas, in a typical game you would create a number of these “**animation behaviors**” that you could assign to your game characters. Moreover, a tool might be created similar to the Mappy tile editor that not only lets you draw the tile world, but assign behaviors or “scripts” to each game character. This way the work is taken out of the hands of the programmer and put into the hands of the game designer where it should be. Anyway, take a look at **TILE\_MAP\_SCROLL\_DEMO\_002.SPIN**, it is more or less identical to the previous version except with the added scorpion animation (with state machine). The demo is in the **\SOURCES** directory as usual, go ahead and load it up and watch the scorpion on the start screen and follow it around with the scrolling control of the gamepad. The animation logic is nearly identical to what is discussed in the previous paragraph, take a look below for an excerpt from the guts of the animation state machine:

```

' is it time to update scorpion?
if (++scorp_anim_count > 5)
    reset counter
scorp_anim_count := 0

' process animation
case scorp_state

SCORP_STATE_WALKING:
    move
    if (scorp_dir == SCORP_RIGHT)
        WORD[tile_map_base_addr][scorp_x + scorp_y*64] := $36_36 ' write black tile (erase)

    scorp_x++ ' move scorpion
    ' test for wall collision
    if ( WORD[tile_map_base_addr][scorp_x + scorp_y*64] == SCORP_WALL_TILE_INDEX)
        scorp_x--
        scorp_dir := SCORP_LEFT
    else
        WORD[tile_map_base_addr][scorp_x + scorp_y*64] := $36_36 ' write black tile (erase)

    scorp_x-- ' move scorpion
    ' test for wall collision
    if ( WORD[tile_map_base_addr][scorp_x + scorp_y*64] == SCORP_WALL_TILE_INDEX)
        scorp_x++
        scorp_dir := SCORP_RIGHT

    ' animate
    if (++scorp_frame_index >= 2)
        scorp_frame_index := 0

SCORP_STATE_IDLE:
    ' do nothing or do something cool?

    ' update state counter
if (--scorp_state_count <= 0)
    ' select new state, direction, and counter values
    scorp_state_count := ((?random) & SF) + 10
    scorp_dir         := ((?random) & $01)*2
    scorp_state       := ((?random) & $01)

    ' draw scorpion, notice palette index is same as tile index
    ' tile entry format: [palette_index | tile_index]
    WORD[tile_map_base_addr][scorp_x + scorp_y*64] := scorp_anim_lookup[scorp_frame_index+scorp_dir]<<8+
                                                    scorp_anim_lookup[scorp_frame_index+scorp_dir]

```

*(Note that the last instruction is intended to be on a single line.)* As you play with the demo keep an eye on the scorpion by following it around with the scrolling control to verify the state machine for yourself. As an exercise see if you can simplify the animation controller and animate every single scorpion!

Of course, the motion of the scorpion is tile-based and rough. If we want the scorpion to move smoothly we would have to make it a sprite. Additionally, since we are modifying the tile memory directly, we have to “clean up” as we go, that is, we have to erase the old scorpion, then move it, then draw it right into tile memory. Another approach might be to

copy the current tile memory to a buffer then modify the buffer and let the engine draw it, this way the original data is never destroyed.



TIP

There is another way to get smooth animation with tiles. For example, say we wanted to make the scorpion walk to the right 4 steps smoothly. The trick is to take two adjacent tiles and then animate the scorpion 4 different steps within the tiles themselves. Thus the image of the scorpion actually shifts over each time. Therefore, to move the scorpion one tile now takes 4 steps and 8 tiles. This uses a lot of tile memory, but if you only have a few objects to move smoothly it's a good trick! We will see this in the framed animation section coming soon.

#### 22.7.4 Parallax Scrolling

Parallax scrolling is a method of simulating 3D by moving different layers of a 2D image at different rates based on their distances to the viewpoint. For example, when you drive in a car and look outside the window you see the road go by very quickly, but the farther objects like the mountains and clouds go by slowly. This is the "parallax" effect - near objects translate faster, farther objects translate slower. This observation is used in all kinds of 2D games to create a 3D layer effect in the action. One of the most popular 2D games that has a lot of parallax scrolling layers is **Sonic the Hedgehog**. Figure 22:21 shows a screen shot of Sonic so you can see the various layers: the spikes at the bottom of the screen, the platforms Sonic is on, the water layer, the hill areas to the rear, and finally the cloud layer. If you happen to have a copy of Sonic give the game a try so you can see how effective the parallax 3D scrolling layers are. If you don't have a copy then you can try this flash version on the web here (very impressive I might add):

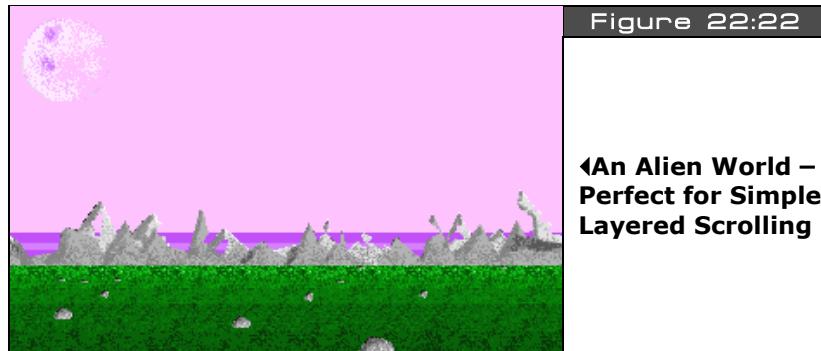
<http://www.ebaumsworld.com/sonic.html>



Figure 22:21

◀Sonic the Hedgehog  
has a lot of parallax  
scrolling layers.

To implement parallax scrolling is theoretically trivial; you simply layer either overlapping or non-overlapping y-regions and scroll them at different rates, thus creating the effect of 3D parallax. Of course, you do this in such a way that the “art makes sense,” that is, you don’t scroll the near objects slow and the far objects fast, that would make no sense. Of course, the engine needs to support either overlapping layers or at least the ability to scroll “y-bands” or regions on the screen. For example, take a look at the alien desert scene in Figure 22:22.



The good thing about this image is that we could scroll the grass region, the mountain region, and the sky with the planetoid in it and they don’t overlap on the y-axis. Thus, at very least we can go into the memory or tiles that make up the image and scroll the data horizontally to create the effect. However, if we are using a tile engine then we can only scroll the images by 1 tile which may be much too much and look too rough, but that’s the trade-off with tile graphics. As a demo of this technique of crude parallax scrolling take a look at **PARALLAX\_SCROLL\_DEMO\_001.SPIN** located on the CD in the **\SOURCES** directory. Load it up and use the gamepad to scroll right and left. Notice that the image simply repeats, and the idea is that each of the layers scroll at a rate slower/faster than the others to create the effect. The scrolling is **"out of engine"** meaning we are not using the engine to scroll, but manually going into the tile memory and scrolling the regions of the tiles ourselves. Here’s an excerpt from the code that does the actual scrolling:

```
PUB Scroll_Layer(tile_map_ptr, width, ys, ye, dx)
    . this function scrolls a layer or region of the sent tile map from ys to ye an amount dx (signed)
    . tile_map_ptr - points to beginning of tile map, 16x12 WORDs usually
    . width        - number of WORDs per row, usually 16
    . ys, ye      - start and ending y-region to scroll
    . dx          - amount to scroll horizontally (+/-)

    . do scroll in 3 steps as to not invoke built in "overlap logic" also so that as change occurs
    . user doesn't see tiles moving around
    dx := dx // width
```

```

if (dx > 0)
    repeat y from ys to ye
        ' copy left half of row to buffer
        wordmove(@tile_buffer + (dx<<1), tile_map_ptr + (y*width<<1), width-dx)
        ' copy right half of row to buffer
        wordmove(@tile_buffer, tile_map_ptr + ((y*width) + (width-dx))<<1, dx)
        ' finally copy buffer back to tile row
        wordmove(tile_map_ptr + (y*width<<1), @tile_buffer, width)
elseif (dx < 0)
    dx := -dx ' invert dx now
    repeat y from ys to ye
        ' copy right half first
        wordmove(@tile_buffer, tile_map_ptr + ((y*width) + (dx))<<1, width-dx)

        ' copy left half of row to buffer
        wordmove(@tile_buffer + (width-dx)<<1, tile_map_ptr + (y*width<<1), dx)

        ' finally copy buffer back to tile row
        wordmove(tile_map_ptr + (y*width*2), @tile_buffer, width)

```

As you can see, the function more or less is simply moving tile memory around rows at a time. As an exercise see if you can optimize the function; you should be able to make it 2-3× faster without much work. If you want to take a look at the Mappy MAP and the BMP file the demo is based on check out **ALIENPLANET\_DEMO\_MAP\_01.MAP** and **ALIENPLANET\_TILES\_02.BMP** in the **\SOURCES** directory. Also, the command line to generate the external Spin data file was simply:

**MAP2SPIN.exe ALIENPLANET\_DEMO\_MAP\_01.MAP ALIENPLANET\_TILES\_02.BMP -TW20 -TH8 -FX > ALIENPLANET\_TILE\_DATA.SPIN**

To implement full-blown parallax scrolling as in the Sonic demo, we would need to be able to overlap tile maps and “layer” them and secondly, be able to scroll sub-tile accurate or pixels at a time rather than tiles. Both of these are 100% doable on the HYDRA, but more complex graphics engines would have to be developed that take up multiple cogs to do all the work and layering.



### TIP

When starting out on game development and graphics projects, one of the last things you want to do is spend hours or days creating art to run simple tests. With this in mind, I have provided you with a good selection of stock bitmap/pixel art that I have created. Similar to Sprite Lib, my art is free for you to use, but you can't sell it or publish it, simply use it in your games and demos. You can find it inside the two main directories on the CD; \SOURCES as well as the assets directory \MEDIA\GRAPHICS.

## 22.8 Framed Animation

Animation is the magic that makes video games look like video games. One of my all-time favorite 2D games with heavy animation is **“Earthworm Jim”** (1995) by **Shiny Entertainment** shown in Figure 22:23 on the next page. The animation in this game was

gorgeous and better than cartoon quality which was a first at the time. Game developers tended to leverage technology rather than art early on, but this game did both. I highly recommend trying the game out on the PC or a game console of your choice. The point of the example is to get an idea of just how much goes into animation. There are literally thousands of frames of animation in this game, and hundreds of background sets. All this had to be generated by an artist, so the point is animation is a lot of work!



▲Screen Shots of Earthworm Jim

Figure 22:23

In this section, we are going to put together a couple demos that illustrate the idea of "**framed**" animation. Framed animation is nothing more than drawing a series of frames or images of a game character than when rapidly cycled through animates the character. Many of the demos thus far have done this to some extent, for example the scorpion had a couple frames of animation in the previous tile demo. Also, the bug blaster in the Centipede demo blinked its eyes, and so forth. Nonetheless, we are going to formalize the concept here.

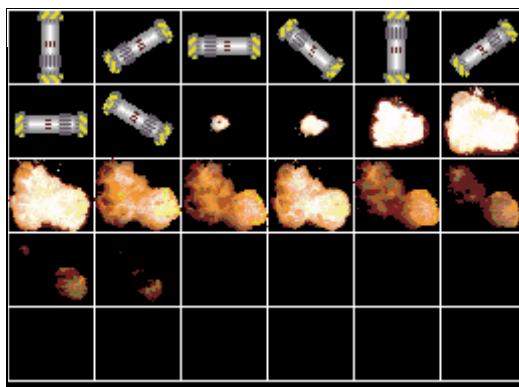


Figure 22:24

◀A Plasma Bomb Animation plus Explosion Frames

The best thing to do is show some actual animation artwork to give you an idea of animation techniques. The first plate is shown in Figure 22:24. Here I drew 8 frames of a plasma bomb rotating about its center. Then following those animation frames is the actual explosion that ensues when the plasma weapon hits its target. The size of each frame is  $42 \times 36$ , not exactly a power-of-2 tile. However, this art was originally created for a PC game, thus I didn't have the constraints of power-of-2 math. Anyway, this example is typical for a game object, you will have a single "plate" or graphics file that contains the artwork for that animation. Later, you might merge them all into a master file, or database, etc., but as an artist, it's a good idea to keep things separate. Furthermore, the technique I used for this art was to render the plasma bomb with a 3D modeler then in post processing tweak some of the details. Also, the explosion is a real explosion from stock media that I have. However, there are programs that generate explosion art, or you can try it yourself and draw it.

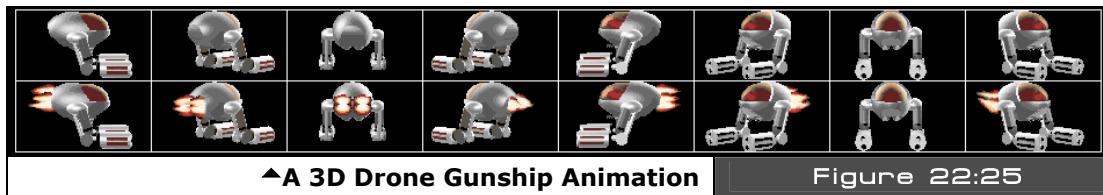


Figure 22:25

For the next example of framed animation take a look at Figure 22:25, it depicts a 3D drone of sorts. This drone can be used in a 2D game or in a 3D game as a 3D sprite. In either case, the top row of frames animate the drone rotating around the Y-axis, while the 2nd row shows the same animation, but with the engines on. I did this animation with a 3D modeler as well, but added the flames manually with a paint program.

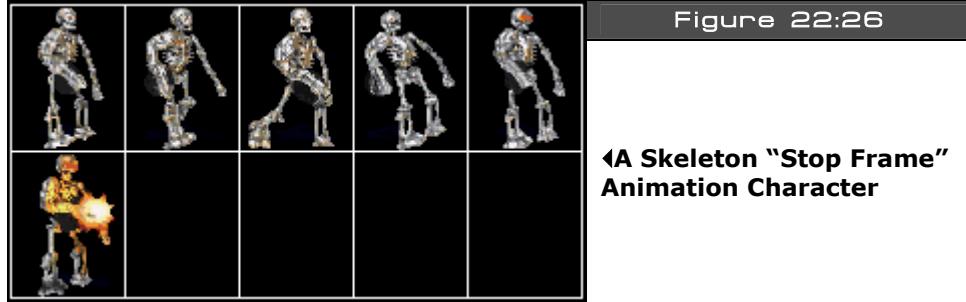


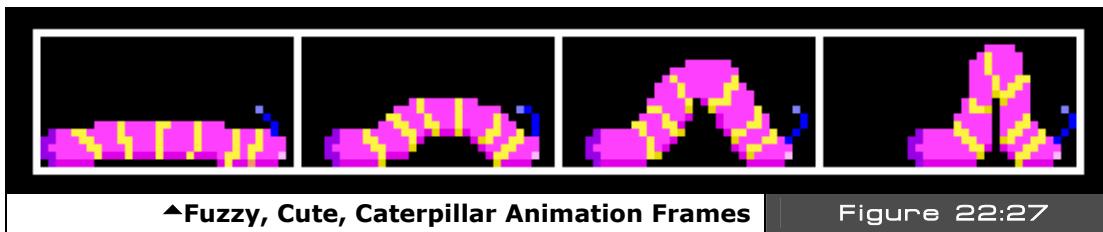
Figure 22:26

◀A Skeleton "Stop Frame" Animation Character

Sometimes when creating game art a technique used is to build miniature models and photograph them. Sometimes this is cheaper and faster than rendering or manually drawing

the art. This is the case for the animation shown in Figure 22:26. This is one slide of a very complex animation I created. Each slide shows the skeleton character walking in a certain direction, and firing his weapon (notice the muzzle flash). There are 8 of these slides, each with the skeleton walking in a different direction. Browse the **\MEDIA\GRAPHICS** directory on the CD to see all the animation frames. The original model was build at about 6" high and then mounted on a rotatabl- platform. Then the model was hand animated by myself and a photo snapped of the model building up all the animation and angles of view. The raw photography was then post processed by a paint program, lit, and cleaned up and resized. Basically, this is the same technique used in movies where you see a lot of stop frame animation. I highly recommend trying this technique since it gives you a good idea of how to animate objects physically, where to place the feet, arms, torso, etc.

Alright, now that you see what animation is and how to generate the actual art (at least theoretically), let's make some demos that show these techniques with the HYDRA. Of course, we are limited since we only have a tile engine that supports 4 colors per tile, plus sprites. Moreover, tiles/sprites can only be  $16 \times 16$  pixels. And we don't have a ton of memory, but if we use simple objects with few colors and "tile" sprites or tiles together to form larger objects we can animate just about anything.



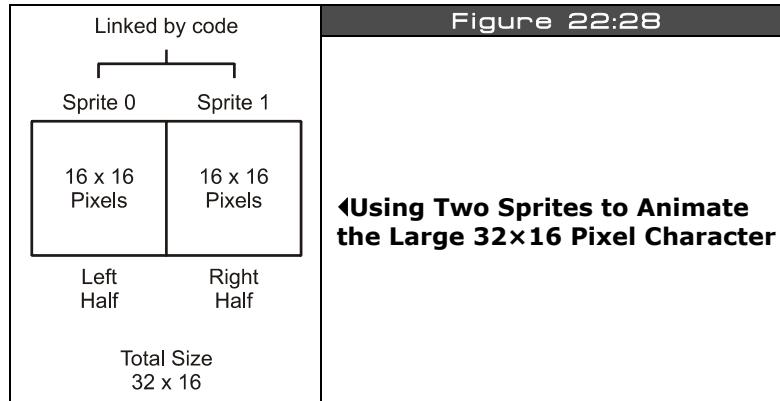
Considering my philosophy of keeping things as simple as possible, for the first demo, we are going to animate a little caterpillar (trust me it will look cool). Take a look at Figure 22:27, it shows our source media for this grand project which consists of 4 frames of animation where each frame is  $32 \times 16$  pixels. The animation was drawn by hand with me using my finger as a "model" and looking at some images of exotic caterpillars with lots of colors on them. This is a good example for us for the following reasons: the image is larger than  $16 \times 16$ , so we have to tile some sprites (or tiles together) to get the full image, next the caterpillar has few colors, so it should convert well into palettized form, and lastly, the animation is something fun to animate.



TIP

When animating objects and characters in games, the trick is not to make them look real as much as it is to make them look fun and interesting. Thus, many animators including myself will always exaggerate the animation to make the animation more visually interesting to the viewer. Also, the way something moves helps the player identify what it is. So when animating game characters make them “loud” and “obnoxious” visually – this will engage the player more!

The plan to animate this character is to use one of the templates that supports sprites that we worked with earlier and then convert it over to animate this single object. We are going to tile two sprites together side by side to fit the  $32 \times 16$  image of the caterpillar frames into the animation. This is shown in Figure 22:28.



Using two sprites means we have to keep them synced together as we move the sprite, which brings me to my next topic – motion.

We are almost ready to animate the caterpillar sprite, but there is a question at hand and that's how to actually move the caterpillar sprite? The obvious answer is to move it by a few pixels each animation frame. While surely will work, it might make the caterpillar look like its "**sliding**" rather than moving on the surface. Thus, a second aspect of animating characters that goes hand in hand with the actual animation frames, is how to move or translate the object as the frames of animation are playing or cycling? This is yet another form of art and you have to get the hang of it. For example, looking at the frames of animation in Figure 22:27 and watching some video of caterpillars moving, you will see that the caterpillar does not slide across a surface, but it arches its back then pushes off with its rear segments to translate itself on the surface. To capture this or any non-linear motion of an object a more advanced approach than simply moving objects by a constant rate each frame has to be programmed. The solution is rather simple: a ***translation-animation*** lookup table. This

table has a number of elements, usually one for each frame of animation, that indicates how far to move the object being animated. The table might have dx values, or both dx, dy values or whatever. The idea is that this table is part of the ***animation-controller*** software you need to get realistic animation. A graphical depiction of the application of the system is shown in Figure 22:29.



Referring to the figure, each frame also has a delta translation factor assigned to it creating a more realistic walk. Also, typically frames of animation are re-used in an animation to save space, for example, in the caterpillar's case, we might decide to start with the elongated frames and play frames 0,1,2,3, then play 3,2,1 and repeat, thus the animation cycle might be:

0,1,2,3,3,2,1 - repeat

If you wanted one frame to pause, you might play it twice, for example, the frame where the caterpillar is elongated on frame 0:

0,0,1,2,3,3,2,1 - repeat

The idea is to try things, have fun, and make it look cool. Considering that, a translation-animation lookup table might look like this (along with the animation frames table) in pseudo-code:

```
animation_frames [6] = {0,1,2,3,3,2,1}
animation_translation [6] = {2,2,2,3,3,2,0}
```

Notice at first the caterpillar slowly inches forward then "springs" back and pushes itself off; this is consistent with how a real one moves. The idea here is to show that no matter how the data is ordered, we can use the lookup tables to get the animation frames and motion we desire. Additionally, since the animation is "***data driven***" we can remove the programmer from the loop and once again allow the artist or game designer to control the motion data with a tool that is read by the game engine. Therefore, in a more advanced animation

system a tool might be used that not only allowed the designer to draw the art, but to assign motion and animation frames to it and then the data would be exported and loaded into the game!

As a demo of all this check out **CATERPILLAR\_DEMO\_001.SPIN** on the CD located in **\SOURCES**. Load the program up and watch the little caterpillar inch across the screen. The gamepad will scroll the world a little, other than that there are no controls of the animation itself. But, try going into the code and changing things. Specifically, here's the part of the main event loop that controls the animation:

```

' animate caterpillar if its time to do so
if (++cat_animation_counter > 1)
  ' reset counter
  cat_animation_counter := 0
  ' update frame index
  if (++cat_frame_index > cat_num_frames)
    cat_frame_index := 1 ' reset

  ' fire sound at proper moment
  if (cat_frame_index == 3)
    ' play a PCM sound on channel 0 with a volume of 255
    snd.PlaySoundPCM(0, snd_data.ns_hydra_sound, snd_data.ns_hydra_sound_end, 255)

  ' extract first frame of animation
  cat_anim_frame := animation_frames[ cat_frame_index ]

  ' translate caterpillar
  cat_x += animation_transformation [ cat_frame_index-1 ]

  ' test for wrap around
  if (cat_x > 255)
    cat_x -= 255
' end animation code block

' draw caterpillar, take into consideration scroll_x, that is "world view" position
' since sprites and tiles move independently
sprite_tbl[0] := cat_y << 24 | (cat_x-scroll_x*16) << 16 | $01
sprite_tbl[1] := tile_data.sprite_bitmaps + (cat_anim_frame*256)

sprite_tbl[2] := cat_y << 24 | (cat_x-scroll_x*16+$10) << 16 | $01
sprite_tbl[3] := tile_data.sprite_bitmaps + (cat_anim_frame*256)+128

.

DAT
' animation lookup tables

' format {number of frames in sequence, sequence...}
animation_frames      LONG    7, 0,1,2,3,3,2,1

{ list of translation factors for each frame of animation, must have same number of entries as
"animation_frames" }
animation_transformation LONG    2,2,2,3,3,2,0

```

Basically, the animation occurs whenever the animation counter overflows, at this point, the animation logic updates the current frame, retrieves the animation frame and translation factor from the lookups and then writes the sprite data to the sprite table. Also, notice the use of sound in the demo. When the animation hits a certain point a “squishy” sound is played that I recorded, processed with **RAW2SPIN** and included in the demo. The demo was based on our previous work with tile map imports as well as sprites. The real work was creating the art and using the tool chain to create a final compatible file. The steps I took were to first use the **ALIENPLANET\_TILES\_03.BMP** file for the tile work and created a tile map with Mappy named **CATERPILLER\_DEMO\_MAP\_01.MAP**, then I used the **MAP2SPIN** tool with the following command line:

```
MAP2SPIN CATERPILLAR_DEMO_MAP_01.MAP ALIENPLANET_TILES_03.BMP -FX -TW20 -TH8 >
CATERPILLAR_TILE_DATA.SPIN
```

The output file **CATERPILLAR\_TILE\_DATA.SPIN** was then put aside for a moment and I generate sprite data with the graphic file **CATERPILLER\_TILES\_WORK\_02.BMP** and processed the sprites with out **BMP2SPIN** tool like so:

```
BMP2SPIN CATERPILLAR_TILES_WORK_02.BMP -FX -M -TW8 -TH1 -C8 >
CATERPILLAR_BITMAP_DATA.SPIN
```

Then with both output files in hand, I manually merged the sprite bitmap data (and the palette(s)) used by the sprites into the **CATERPILLAR\_TILE\_DATA.SPIN** file to create a master file. With that in hand, I could load everything in and use getter functions to retrieve the tile map, tile bitmaps, sprite bitmaps and palettes! Lastly, I made a digital sample called **CATERPILLAR\_11\_8.RAW** and processed it with the **RAW2SPIN** tool with the following command line:

```
RAW2SPIN.exe CATERPILLAR_11_8.RAW > CATERPILLAR_11_8.SPIN
```

This output was then included in the final demo. A lot of steps and a lot of work, but this is what the tool chain is all about – there is simply no way to get around all these steps when developing games. The only solution is to make complex tools that do everything which I hope you do!



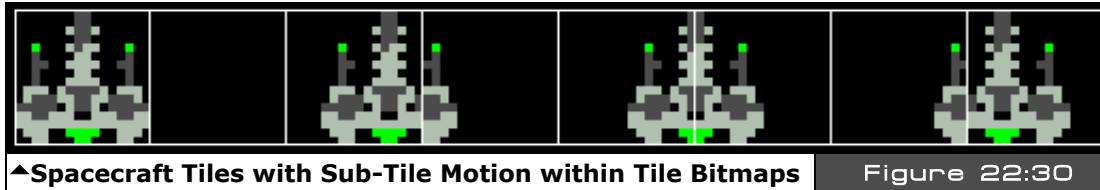
#### NOTE

As usual all the assets for the demos are in the \SOURCES directory as well as in the \MEDIA\GRAPHICS directory on the CD.

### 22.8.1 Sub-Tile Animation Techniques

“Sub-tile” animation or motion simply means performing the operation within the confines of the tile itself. For example, one of the biggest problems with tile graphics is that you can only move objects whole tiles at a time. However, if you instead represent a single 16×16 tile

image say with a two  $16 \times 16$  forming a  $32 \times 16$  pixel image, then you can animate or move the image within the tiles horizontally.



▲Spacecraft Tiles with Sub-Tile Motion within Tile Bitmaps

Figure 22:30

Figure 22:30 helps clarify this visually. Referring to the figure, there are 8 tiles total, but focus on adjacent pairs of tiles starting from the left. See how the bitmap within the tiles is slowly moving to the right within the tile art itself? This is the crux of the trick. In this case, there are 8 tiles making 4 pairs which are always rendered next to each other. If we number the tiles from left to right 0,1,2,3,4,5,6,7 then to move the ship left right, we would draw the following sequence of tiles:

Translation = 0 pixels  
Draw tiles 0,1 at tile location x=0, x=1

Translation = 4 pixels  
Draw tiles 2,3 at tile location x=0, x=1

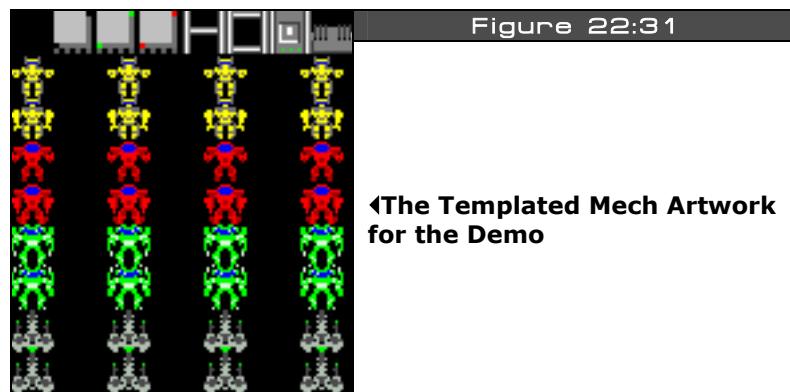
Translation = 8 pixels  
Draw tiles 4,5 at tile location x=0, x=1

Translation = 12 pixels  
Draw tiles 6,7 at tile location x=0, x=1

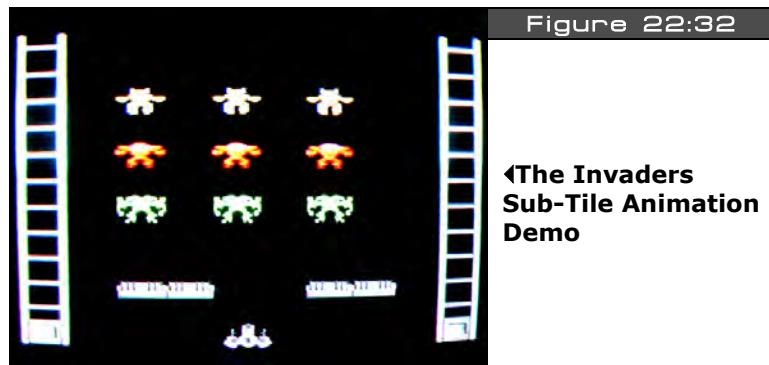
Notice, that at no time are we moving where we draw the tiles, we are only changing **which** tiles we draw. The trick is that the tiles themselves are drawn to simulate motion. Then here's the tricky part, after all 4 pairs have been drawn in sequence (the ship is moving right for example) we reset to Tiles 0,1 and move the rendering over a whole tile, so that rendering then proceeds at x=1, x=2, and the process continues. This is all there is to subtile animation and motion. With this technique you can make tiled games move very smoothly and in fact is how many early arcade games worked that had a finite number of sprites to work with.

For a change, I decided to draw some mechs and do more of a "space" based demo. I created a number of "space invader" alien mechs  $16 \times 16$  along with some barriers and the player's ship and then created smooth tile animation of the aliens and player's ship. Take a look at Figure 22:31 on the next page to see the art. The art is laid out such that there are 3

double-rows of aliens; each row of aliens has two frames of animation (arms up, arms down) and as you move to the right, the aliens move within the tile artwork 4 pixels at a time. Since the artwork is  $16 \times 16$ , each motion pair is two tiles which results in a  $32 \times 16$  space to move the art within the tiles.



Now, working with sub-tile art and multiple tiles per character is a little tricky. For example, when moving an object you have to first draw each tile pair, then at some point when the tile pair has moved the object all the way to the right, left, up, down or whatever, then you have to reset the tile pair and actually move the position the tiles are drawn at. This is really a lot of housekeeping. Also, since all  $16 \times 16$  tiles are now composed of  $32 \times 16$  pixels, it's harder to draw objects right next to each other since everything is really 2x as large as the bitmap is to support the extra tiles being drawn. These problems aren't that hard to overcome and for 25 years people have done so!



Taking all this into consideration, take a look at **INVADERS\_DEMO\_001.SPIN**, its in the **\SOURCES** directory, so load it up and give it a try. Figure 22:32 shows a screen shot of the demo in action. The demo uses the gamepad as usual; press right and left to move the ship around, notice that it collides with the walls and stays contained within the game field. Also, notice the ambient flame animation playing on the ship. Alright, now try holding down **<SELECT>** and using the dpad again, notice that you can scroll the world? Scroll all the way to the right to see the artwork all laid out for your inspection. Of course, I could have hidden another level over there as well.

The demo was generated with our tool chain primarily with Mappy and the **MAP2SPIN** program. The artwork file is called **MECH\_TILES\_WORK\_01.BMP** and the Mappy MAP file is **INVADERS\_DEMO\_MAP\_01.MAP** (both located in **\SOURCES** on the CD). The demo is a fusion of the scrolling demo along with some sprite code from our previous work. The good news is there are no “manual” steps in this demo, the final Spin tile data file was generated with the simple command line:

```
MAP2SPIN INVADERS_DEMO_MAP_01.MAP MECH_TILES_WORK_01.BMP -FX -TW8 -TW9 >
INVADERS_TILE_DATA.SPIN
```

As usual, the code is rather simple since our tool chain and HEL graphics engine are doing all the work. Below is an excerpt from the demo showing the main event loop that controls everything:

```
' test for scroll
if ((game_pad.button(NES0_RIGHT) and game_pad.button(NES0_SELECT)) and scroll_x < 32-10)
    scroll_x++

if ((game_pad.button(NES0_LEFT) and game_pad.button(NES0_SELECT)) and scroll_x > 0)
    scroll_x--


' test for player movement right?
if (game_pad.button(NES0_RIGHT) and not game_pad.button(NES0_SELECT))
    erase ship first
    WORD[tile_map_base_addr][ship_x      + ship_y*32] := $01_01 ' this is the "black" tile
    WORD[tile_map_base_addr][(ship_x+1) + ship_y*32] := $01_01 ' this is the "black" tile

    ' move player within tiles right, but first test if hitting edge?
    if (not (ship_x == 7 and ship_sub_x == 3))
        if (++ship_sub_x > 3)
            reset sub-tile and move whole tile
            ship_sub_x := 0
            ship_x++


' test for player movement left?
if (game_pad.button(NES0_LEFT) and not game_pad.button(NES0_SELECT))
    erase ship first
    WORD[tile_map_base_addr][ship_x      + ship_y*32] := $01_01 ' this is the "black" tile
    WORD[tile_map_base_addr][(ship_x+1) + ship_y*32] := $01_01 ' this is the "black" tile

    ' move player within tiles left, but first test if hitting edge?
    if (not (ship_x == 1 and ship_sub_x == 0))
        if (--ship_sub_x < 0)
            reset sub-tile and move whole tile
```

```

ship_sub_x := 3
ship_x--

' update animation of flame!
if (++ship_anim_count > 1)
    reset flame and frame
ship_anim_count := 0
if ((ship_anim_frame+=8) > 8)
    ship_anim_frame := 0

' draw player always, pay attention to how tiles are addressed and how the animation is
' performed by adding the offset to the 2nd row of tiles
WORD[tile_map_base_addr][ship_x+ship_y*32] := (SHIP_TILE_INDEX_BASE + ship_sub_x*2 + ship_anim_frame)
                                                << 8 | (SHIP_TILE_INDEX_BASE+ship_sub_x*2 +ship_anim_frame)
WORD[tile_map_base_addr][(ship_x+1) + ship_y*32] := (SHIP_TILE_INDEX_BASE + ship_sub_x*2 + 1 +
                                                       ship_anim_frame) << 8 | (SHIP_TILE_INDEX_BASE+ ship_sub_x*2+1+ship_anim_frame)

' update tile base memory pointer
tile_map_base_ptr_parm := tile_data.tile_maps + scroll_x*2

```

(Note that the WORD array assignments are each meant to be on a single line.) The code more or less begins by testing for the gamepad buttons and updates either the scrolling variable or moves the ship. If the ship is being moved, first the ship\_sub\_x variable tracks sub-tile motion, when this overflows the animation is reset and the ship is moved a whole tile. The tile map update code at the end of the loop is probably the most complex since it has to update two tiles and do a lot of arithmetic; however, the code can be simplified with shifts and pre-computations, but this would loose the steps, so I left it long and drawn out so you can see what's going on.

See if you can add a weapon to the player and/or move the alien mechs back and forth with the same technique!

## 22.9 Summary

The hardest thing about this chapter is without a doubt the tools. Unfortunately, we simply don't have the page count to go into their construction in depth, but the sources are available for you to review and modify (in the **\SOURCES** directory). Hopefully though you have enough to work with to use the tools along with the demos to start building your own tool chains for the HYDRA and have an appreciation for all the steps needed to go from art assets to final binary data on the HYDRA or any game system for that matter. Of course, we also covered some more tricks with the graphics engine like scrolling both practically and conceptually. There is so much more we could discuss, but the show must go on, so let's continue forward and talk about "AI".

*"Yes, Neo, Artificial Intelligence..."*

# Chapter 23: AI, Physics Modeling, and Collision Detection - A Crash Course!

In this chapter we are going to discuss the “glue” that ties everything we have been doing together. This glue, which controls the behavior of game objects and characters as well as makes video games what they are, is composed of **artificial intelligence** and **physics modeling**. Typically, these subjects are so vast that entire books (and graduate degrees) are dedicated to each and even then it’s only a cursory coverage. However, since we are building simple 2D games we can merge the topics together along with collision detection and discuss them all together at an introductory level. Here’s what’s in store this chapter:

- ▶ Vectors & matrices overview
- ▶ Physical intelligence
- ▶ Random motion
- ▶ Chasing algorithms
- ▶ Evading algorithms
- ▶ State machines
- ▶ Patterns and programmatic logic
- ▶ Waypoints and driving games
- ▶ Motion equations
- ▶ Gravity and wind
- ▶ Trajectory
- ▶ Simple reflections
- ▶ Collision detection techniques

## 23.1 Overview

As noted in the introductory paragraph, typically AI, physics, and collision detection are such large topics that they need entire books to give them any justice. This is true for AAA title development and state of the art technology, but for 2D games like Pac-Man and Asteroids we can get by with merging the topics together. In reality for simple games there is a lot of overlap between what one might call **artificial intelligence**, **physics**, and **collision**. For example, “AI” usually refers to the software that controls game objects whether they be characters that are “animate” like enemy aliens or objects that are “inanimate” like rocks,

debris and so forth. Racing games for example use physics models to control how the cars move, but other techniques to “drive” the cars.

However, the bottom line is that from a programming point of view an “AI” might formally use state machines, lookup tables, fuzzy logic and other exotic techniques or an “AI” might be as simple as a deterministic rule based on physics modeling. Therefore, we are going to take advantage of the fact that the games we are making are simple in nature and the models needed to create the behaviors to control the objects are either programmatic or physical. That is, an algorithm or technique can be used to come up with the desired behavior, or the behavior is clearly physical and a crude physics model can be used. The trick to building good “AI” in games is having an arsenal of techniques and layering them to create believable and realistic models for your particular needs, thus we are going to cover a number of techniques and ideas to give you some ideas that you can take further. Hopefully you find this chapter the most fun so far!

## 23.2 Quick Vectors and Matrices Overview

Before getting started on the material at hand, we should briefly review **vectors** and **matrices** since vector/matrix operations will make our work shorter, especially when we talk about physics modeling and collision detection. If you have never worked with vectors or matrices then I suggest Googling for it, or get your hands on one of my favorite books on the subject: **“Elementary Linear Algebra”** by Howard Anton. In any event, we are going to briefly discuss these concepts, so at least you have some idea of what is going on if you’re rusty or have never seen this material before. I will try to keep the explanations non-formal and intuitive.

### 23.2.1 Understanding Vectors

A **vector** is simply a short-hand method of representing a collection of independent values that relate to some object or concept. A **scalar** is a single value like 12 or 45.6 or -1/2 and so forth. Thus a vector in mathematics is a collection of scalars where each item is called a **“component.”** Although, we are going to talk about mathematical vectors that mostly represent things like **velocity**, **direction**, and **position**, vectors can represent other things that are lists of abstract objects or symbols. Also, vectors can hold a single value and thus are mappable to scalars in that case.

Typically, vectors are used to represent lists of numbers that relate to positions in 2D or 3D space, velocities, or other mathematical concepts. Figure 23:1 shows a pair of vectors **u** and **v**. The vector **u** starts at the origin and terminates at the point <5,6> while the vector **v** starts at the origin and terminates at the point <3,2>. Where the vector starts is called the **“initial point”** and where the vector ends is called the **“terminal point”** and is usually denoted with an arrow. The vectors **u** and **v** are written down computing the difference between the terminal point minus the initial point, component by component:

$$\mathbf{u} = \langle 5 - 0, 6 - 0 \rangle = \langle 5, 6 \rangle = \langle u_x, u_y \rangle$$

$$\mathbf{v} = \langle 3 - 0, 2 - 0 \rangle = \langle 3, 2 \rangle = \langle v_x, v_y \rangle$$

Where  $\langle u_x, u_y \rangle$  are the "**components**" of  $\mathbf{u}$  and  $\langle v_x, v_y \rangle$  are the components of  $\mathbf{v}$  respectively.

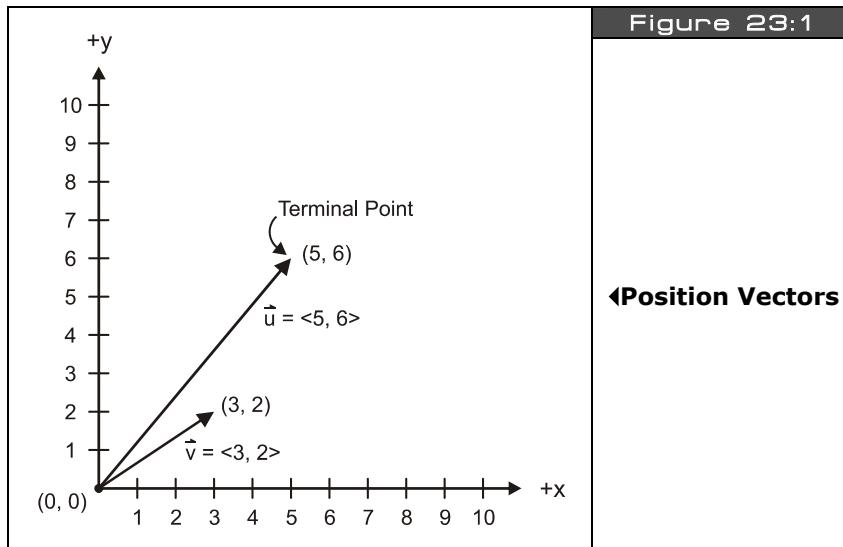


Figure 23:1

## ◀Position Vectors



## NOTE

All vectors start at the origin (0,0) in 2D space or (0,0,0) in 3D space.

Notice that I am using "**boldface**" lower case letters to represent vectors, this is simply a notational convention. Other conventions are to put an arrow above the vector identifier (used in the figures). Later we will use uppercase boldface letters to represent matrices. Anyway, moving on, the significance of  $\mathbf{u}$  and  $\mathbf{v}$  in Figure 23:1 is that  $\mathbf{u}$  and  $\mathbf{v}$  give us a shorthand method to represent the points  $\langle 5, 6 \rangle$  and  $\langle 3, 2 \rangle$  (which might be positions or velocities, whatever), so we can write  $\mathbf{u}$  or  $\mathbf{v}$  and not the coordinates themselves.

Also, you have probably heard people describe vectors as entities that represent magnitude as well as direction. This can be true, but need not be true. That is, if the vectors you are talking about are spatial vectors then yes, but if they are vectors of DNA or personal records then there is no concept of "magnitude." However, in our case these concepts *do* apply. So

what if we wanted to know the length of the vector  $\mathbf{u}$ ? This is a common operation and denoted by placing vertical bars on either side of the vector like so:

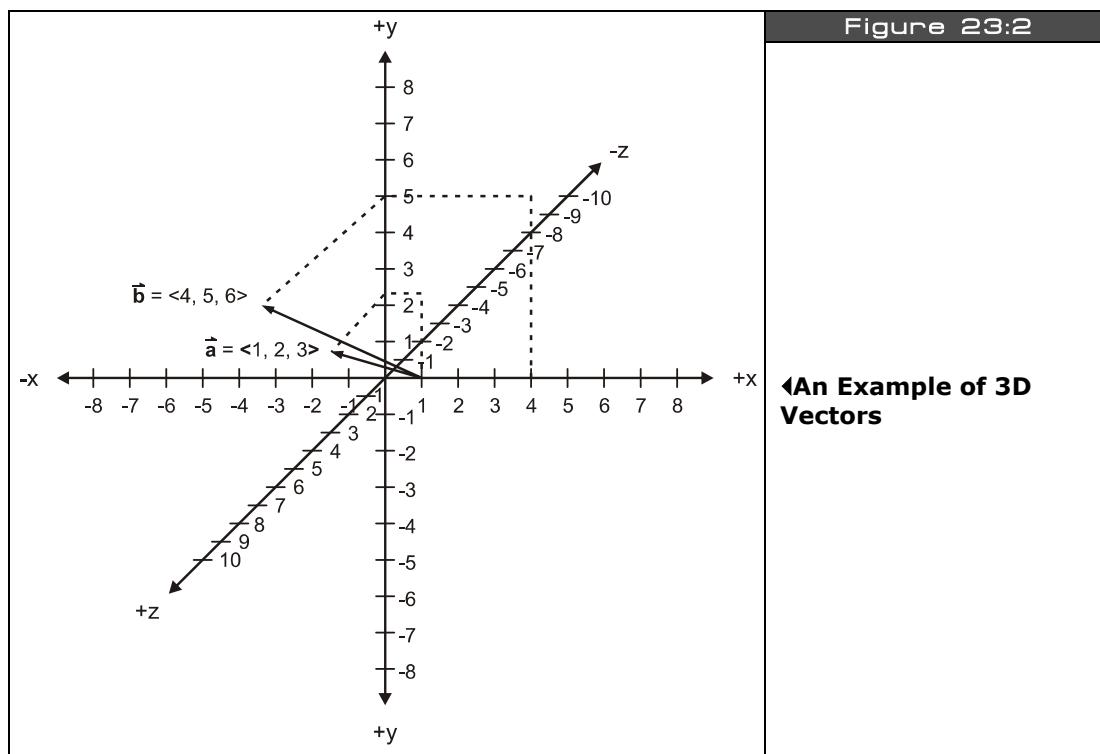
$$|\mathbf{u}| = \text{Length of } \mathbf{u}$$

The actual length of  $\mathbf{u}$  can be computed by the "**Pythagorean theorem**" like so:

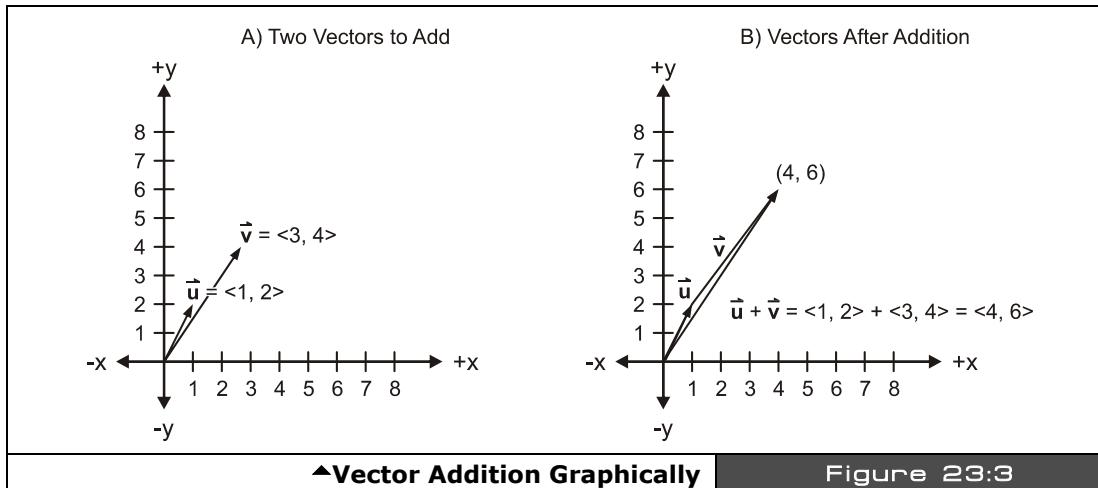
$$|\mathbf{u}| = \sqrt{(u_x^* u_x + u_y^* u_y)} = \sqrt{(5^* 5 + 6^* 6)} = \sqrt{25 + 36} = 7.81$$

In other words, the length or magnitude of **any** vector is the square root of the sum of the squares of the components that make up the vector. It doesn't matter if your vector has one or one million components.

Alright hopefully you are starting to see that vectors can be visualized by drawing them on graphs. In fact, we used a 2D X-Y graph to represent the vectors  $\mathbf{u}, \mathbf{v}$  in the example of Figure 23:1. This is no accident; vectors are very helpful in problems of geometry and typically people think of vectors as geometrical entities, either 2D or 3D.



As an example of this, take a look at Figure 23:2, here we see two vectors **a** and **b** in 3D space. Each is represented geometrically in the figure just as before. However, a little imagination is needed to "see" the 3D vectors on the 2D page, but you get the idea. In this case, if you look at the figure and imagine it in 3D you can see that  $\mathbf{a} = \langle 1, 2, 3 \rangle$  and  $\mathbf{b} = \langle 4, 5, 6 \rangle$ . And of course each of these vectors has three components representing the x,y, and z components of the vector respectively. So far so good, but next we need to learn how to add, subtract, and multiply vectors to make them more useful. Let's begin with addition.



Referring to Figure 23:3(A) we see two vectors  $\mathbf{u} = \langle 1, 2 \rangle$  and  $\mathbf{v} = \langle 3, 4 \rangle$ . To add these vectors algebraically, simply add the components like so:

$$\mathbf{u} + \mathbf{v} = \langle 1, 2 \rangle + \langle 3, 4 \rangle = \langle 4, 6 \rangle$$

...which makes sense. But, what's even cooler is that they add geometrically as well. Take a look at Figure 23:3(B). Here we see the addition in action. A copy of vector **v** is placed at the tip of vector **u**, then the result vector is the vector from the origin (0,0) to the tip of the copy of **u** which is indeed  $\langle 4, 6 \rangle$  if you inspect the figure. Thus, to add vectors graphically you simply translate the vector's tail you want to add to the tip of another vector and then wherever the tip of the addend vector winds up relative to the origin is the sum.

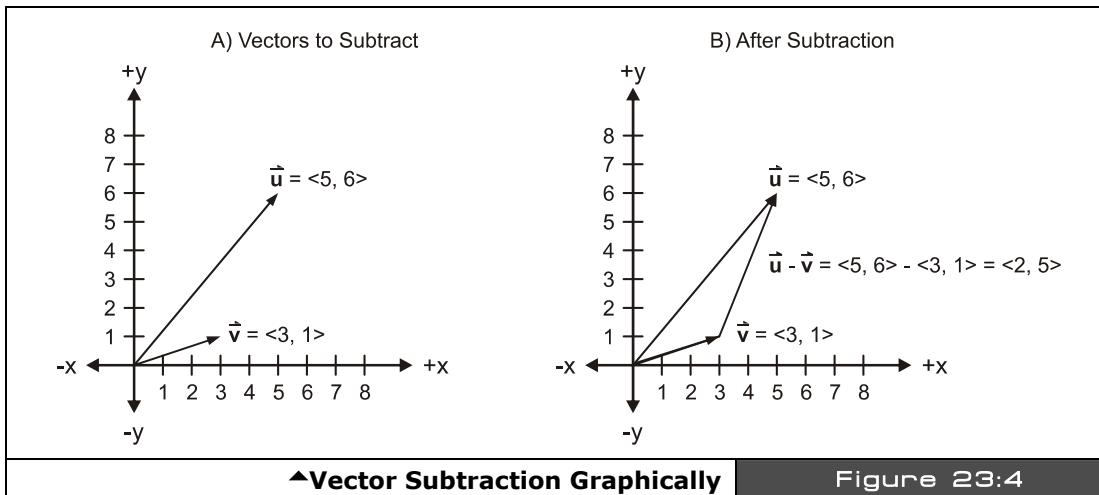


Figure 23:4

Vector subtraction can be performed algebraically just like vector addition. Take a look at Figure 23:4(A), here we see two vectors  $\mathbf{u} = \langle 5, 6 \rangle$  and  $\mathbf{v} = \langle 3, 1 \rangle$ . To subtract these vectors we simply subtract components like so:

$$\mathbf{u} - \mathbf{v} = \langle 5, 6 \rangle - \langle 3, 1 \rangle = \langle 2, 5 \rangle$$

Now take a look at Figure 23:4(B). To subtract vectors geometrically you draw a new vector between the vectors being subtracted with the terminal end at the first vector in the difference and the initial end at the second vector in the difference. Thus, in this case to subtract  $\mathbf{u} - \mathbf{v}$ , you draw a vector from  $\mathbf{v}$  to  $\mathbf{u}$  with the arrow at the end.

Vector addition and subtraction are useful to translate objects around. For example, let's say that an alien ship is located at position vector  $\mathbf{p} = \langle px, py \rangle$  and we want to move the alien ship at a velocity of  $\mathbf{v} = \langle vx, vy \rangle$ ; the vector operation is trivial:

$$\mathbf{p} = \mathbf{p} + \mathbf{v}$$

...which then when we expand out into components is:

$$\langle px, py \rangle = \langle px, py \rangle + \langle vx, vy \rangle = \langle px+vx, py+vy \rangle$$

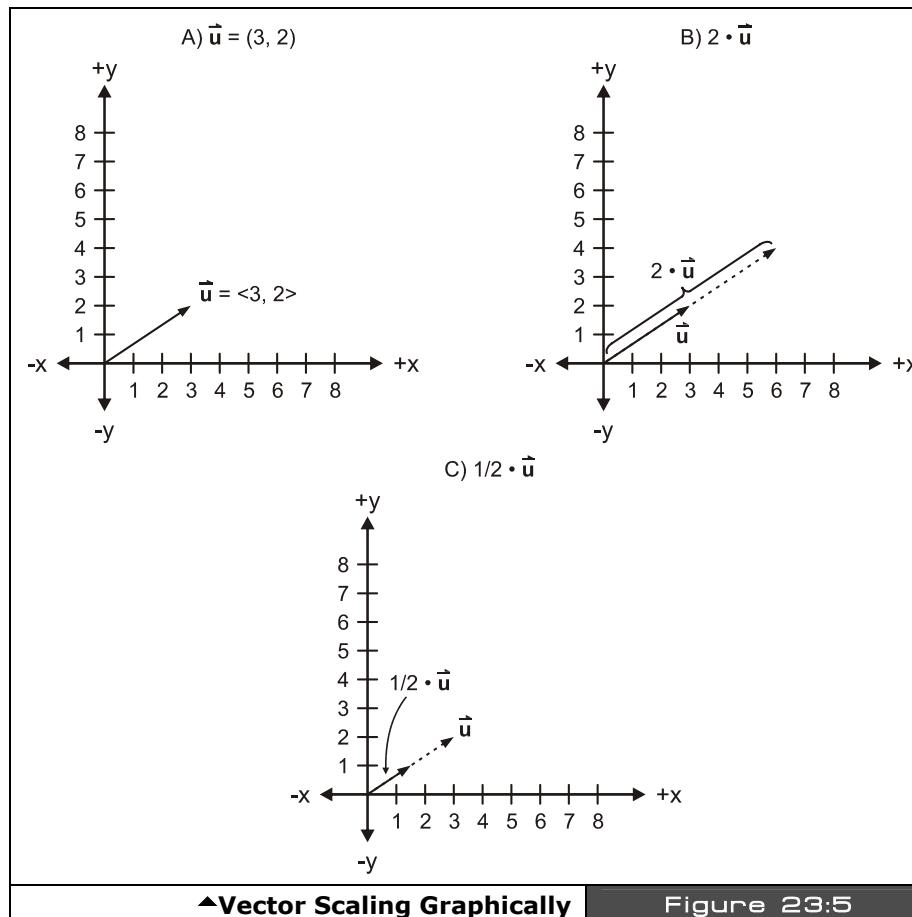
That is,

$$px = px + vx$$

$$py = py + vy$$

...which is indeed a translation. So vectors do not save you any computational effort, they are simply a more compact format to perform calculations on points, velocities, geometries,

etc. And vectors follow many of the same rules that standard scalars do since vectors are just collections of scalars. However, vectors have some other multiplicative rules that normal scalars do not. Let's take a look at these now.



▲Vector Scaling Graphically

Figure 23:5

Vector multiplication is where the standard rules of scalar multiplication start to diverge. For example, you might think that to multiply two vectors together you simply multiply the components together, but this is not the case. The reason why is that multiplying the numbers together doesn't really result in anything interesting or helpful. However, if you multiply the numbers together and sum the results, the resulting scalar is interesting, and we

will get to that in a moment, but before we do let's look at what's called "***scalar multiplication.***"

Scalar multiplication is performed by multiplying all the components of a vector by a single scalar number as shown in Figure 23:5(A), (B) and (C). The operation is denoted by placing a number in front of the vector with a multiplication sign like so:

$$k \cdot \mathbf{u} = k \cdot \langle u_x, u_y \rangle = \langle k \cdot u_x, k \cdot u_y \rangle$$

Thus, you simply multiply the scalar times each component and the result is still a vector with the same number of components. Figure 23:5 shows this for a vector in 2D space (3D space is the same idea). As you can see the operation of scalar multiplication is more or less scaling the vector, or its length. The direction stays the same, but its length or magnitude changes. For example, say we have a velocity vector  $\mathbf{v} = \langle 1, 0 \rangle$  which on the X-Y plane is moving to the right. If we were to scalar multiply this by 3 then the velocity vector would triple in length; in other words the velocity would be  $3 \times$  as much (if the vector represented velocity):

$$3 \cdot \mathbf{v} = 3 \cdot \langle v_x, v_y \rangle = 3 \cdot \langle 1, 0 \rangle = \langle 3, 0 \rangle$$

Thus, if we are using vectors to control the velocity of a ship we can simply scale them to change speed or change direction. For example, multiplying a vector by -1 inverts its direction, while maintaining its length or magnitude as shown in Figure 23:6.

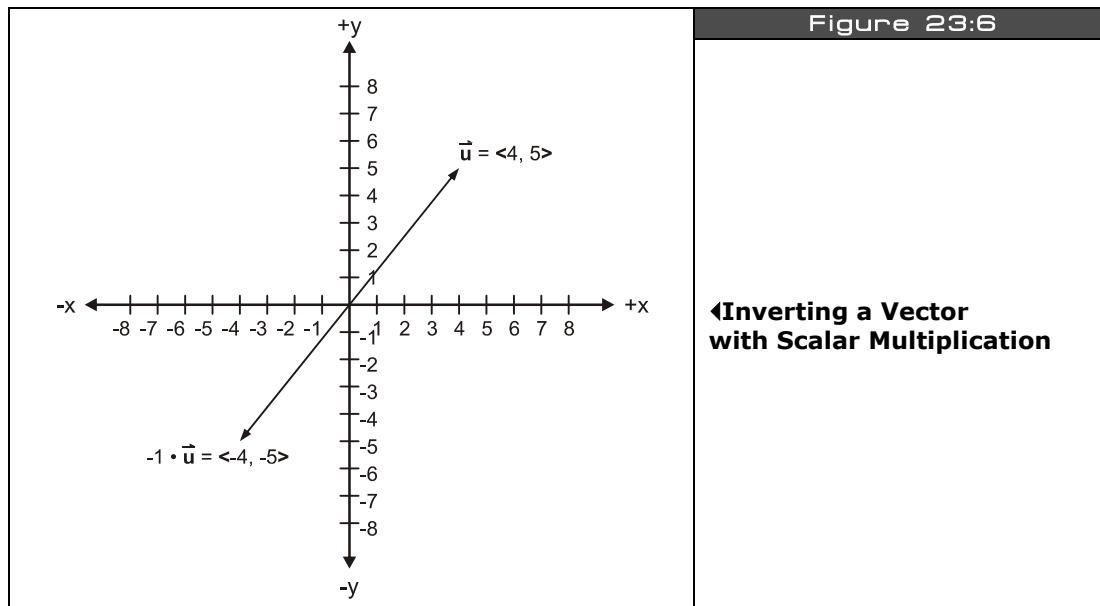
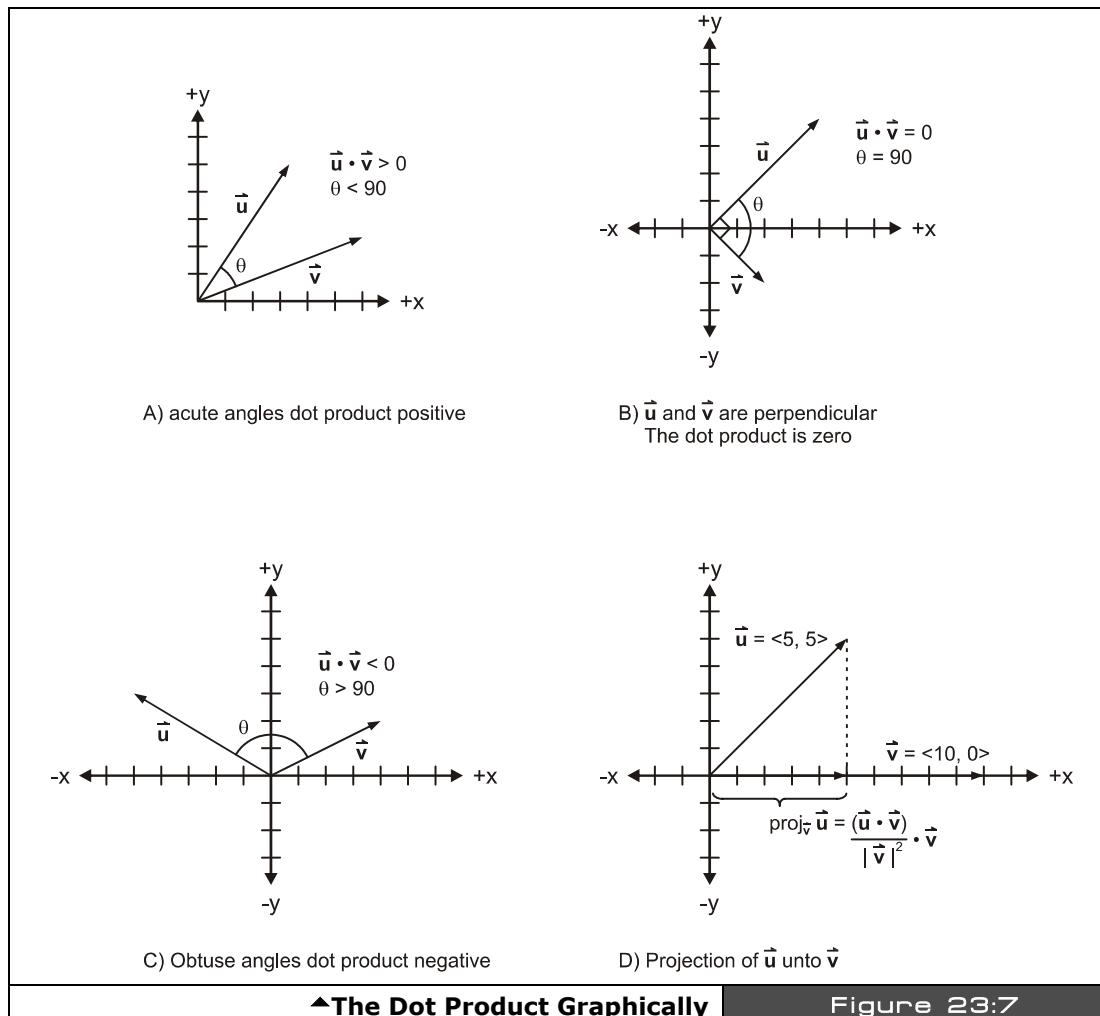


Figure 23:6

◀ Inverting a Vector  
with Scalar Multiplication

### 23.2.1.1 Advanced Vector Operations

Vectors are to computer graphics as words are to a writer, so knowing vector math inside and out can make the most complex operation trivial. To that end, there are so many cool things you can do with vectors that you could spend a lifetime studying them, but "**X-Files**" is on in 17 minutes, so I have to be brief. We are going to take a look at two more vector operations that will come in handy in our work; the "**dot product**" and computing "**unit**" vectors.



▲The Dot Product Graphically

Figure 23:7

### The Dot Product

If there is one operation that pervades computer graphics then it would be the "dot product." Computer graphics is nothing more than billions of dot products, thus its good to know what it is, how to do it, and how to do it fast! The dot product between two vectors  $\mathbf{u}$ ,  $\mathbf{v}$  is:

$$\mathbf{u} \cdot \mathbf{v} = \langle ux, uy \rangle \cdot \langle vx, vy \rangle = ux \cdot vx + uy \cdot vy$$

Surprisingly, the result is a scalar which is the sum of the component by component products of the vectors. The scalar result has a number of interesting properties as shown in Figure 23:7 which are:

### Properties of the Dot Product

- ▶ If the angle between  $\mathbf{u}$  and  $\mathbf{v}$  is less than 90 degrees (acute) then the dot product will be positive.
- ▶ If the angle between  $\mathbf{u}$  and  $\mathbf{v}$  is greater than 90 degrees (obtuse) then the dot product will be negative.
- ▶ If the angle between  $\mathbf{u}$  and  $\mathbf{v}$  is 0 degrees then the dot product will be 0.

The dot product also has the additional property than given the vectors  $\mathbf{u}$  and  $\mathbf{v}$ ,  $(\mathbf{u} \cdot \mathbf{v})/|\mathbf{v}|$  is the length of the vector projection of  $\mathbf{u}$  onto  $\mathbf{v}$ , this can be seen in Figure 23:7(D). Thus, the dot product helps to compute how much one vector is "**pointing**" in the direction of another vector which is a very useful operation. Lastly, the dot product can also be written in terms of the lengths of  $\mathbf{u}$  and  $\mathbf{v}$  as well as the cosine between them like so:

$$\mathbf{u} \cdot \mathbf{v} = |\mathbf{u}| * |\mathbf{v}| * \cos \theta$$

Combining both forms of dot product we get the equality:

$$\mathbf{u} \cdot \mathbf{v} = |\mathbf{u}| * |\mathbf{v}| * \cos \theta = ux \cdot vx + uy \cdot vy$$

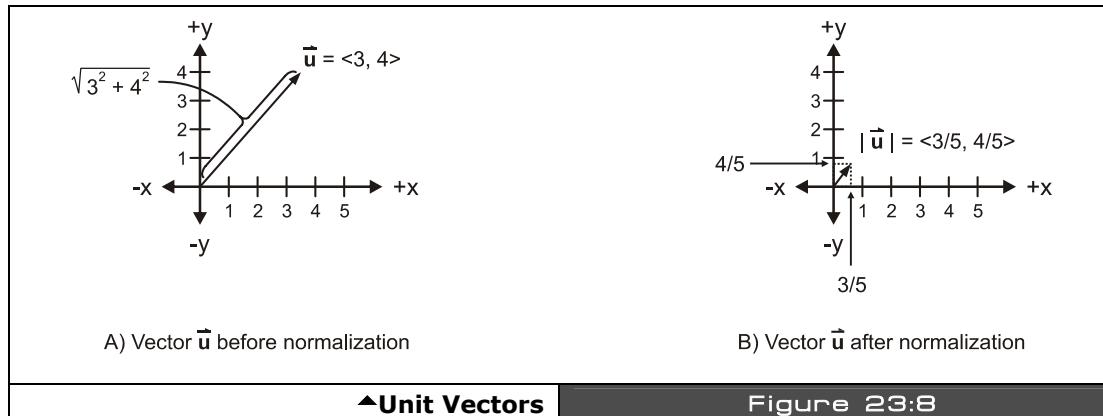
...which is useful if you want to compute the angle between two vectors.

### Computing Unit Vectors

A unit vector is nothing more than a vector with length 1.0. In other words, given any vector  $\mathbf{u}$ , then its length  $|\mathbf{u}| = 1.0$ . Many times its useful to convert a general vector into a unit vector, so we can manipulate the unit vector. This can be accomplished by finding the length of the vector and then dividing it into the vector's components (scalar multiplication). Referring to Figure 23:8(A) we see the vector  $\mathbf{u} = \langle 3, 4 \rangle$ , this is not a unit vector, it has the length  $|\mathbf{u}| = \sqrt{(3*3 + 4*4)} = 5$ . But, what if we wanted unit vector version of  $\mathbf{u}$  with the same direction, but a magnitude of 1.0? The following operations can be used to compute this:

$$\mathbf{u}' = \mathbf{u} / |\mathbf{u}| = \langle 3, 4 \rangle / 5 = \langle 3/5, 4/5 \rangle$$

Notice the prime symbol “'” or single quote is used to denote unit vectors as our convention, some texts use a hat on the vector “ $\hat{u}$ ”.



▲Unit Vectors

Figure 23:8

### 23.2.2 Welcome to the Matrix

Matrices are the Holy Grail of higher mathematics. They allow extremely complex mathematical operations and computations to be performed, and can represent all kinds of abstract mathematical entities. We aren't going to delve into all the uses of matrices, but rather focus on a single use of them and that's to represent geometrical transformations. However, as an aside I want to briefly review where most people have seen matrices used before.

Given a set of linear equations like this:

$$\begin{aligned} 2x + 5y &= 9 \\ 3x - 2y &= 10 \end{aligned}$$

Solve for  $x$  and  $y$ . Does this ring any bells? Well, if you don't do this for a living you might have a bit of a time doing it. However, if you recall there are techniques like "substitution" and "simplification" etc. to solve for  $x$  and  $y$ , here's a quick solution for you:

**Eq. 1:**  $2x + 5y = 9$

**Eq. 2 :**  $3x - 2y = 10$

Rewrite Eq.1 in terms of  $x$ :

$$\begin{aligned} 2x &= 9 - 5y \\ x &= (9/2 - 5y/2) \end{aligned}$$

Now, substitute x into Eq.2:

$$\begin{aligned} 3 * (9/2 - 5y/2) - 2y &= 10 \\ 27/2 - 15y/2 - 2y &= 10 \end{aligned}$$

Collect like terms:

$$(15/2 + 2)y = -10 + 27/2$$

Solve for y:

$$y = (2/19) * (7/2) = 7/19 = 0.368$$

And Y can be plugged into Eq.1 or 2 to solve for x, let's plug into Eq.1:

$$\begin{aligned} 2x + 5 * (7/19) &= 9 \\ x = (9 - (35/19)) / 2 &= 3.578 \end{aligned}$$

I bet that brings back horrible memories! Anyway, the point is that it's a messy process, but with matrices this process can be converted into a mechanical algorithm. The trick is to represent all the coefficients of x and y with a matrix as well as the constants on the right side of the "=" signs. Therefore, the linear system of equations above in matrix form is:

$$\left| \begin{array}{cc|c} 2 & 5 & x \\ 3 & -2 & y \end{array} \right| = \left| \begin{array}{c} 9 \\ 10 \end{array} \right|$$

**A**                    **X**                    **B**

...where, **A** is the "**coefficient**" matrix, **X** is the "**variable**" matrix, and **B** is the "**constant**" matrix as noted under each matrix. Now, for a moment let's forget about the numbers in each matrix and focus on the matrix variables themselves, **A**, **B**, and **X** (remember matrices are written as uppercase bold) and write the linear system of equations once again in matrix form alone:

$$\mathbf{A}^*\mathbf{X} = \mathbf{B}$$

See how compact the form is? No numbers, just matrices. Moreover, there are all kinds of rules of matrix math, so we can solve for X without doing all that work. It's simple, let's just multiple both sides of the matrix equation by the inverse of A, like this:

$$\begin{aligned} (\mathbf{A}^{-1})^*\mathbf{A}^*\mathbf{X} &= (\mathbf{A}^{-1})^*\mathbf{B} \\ \mathbf{X} &= (\mathbf{A}^{-1})^*\mathbf{B} \end{aligned}$$

Thus, if we knew how to find the inverse of a matrix and how to "multiply" then we could solve this matrix system and be done. This is just one way to use matrices, however, it's not the way we are going to use them, as that's beyond the scope of our discussion. Nonetheless, matrices are very useful for other types of operations like translation, rotation,

scaling, and other operations that we might want to apply to points or vectors that represent things in our games, so let's take a look at this use of matrices.

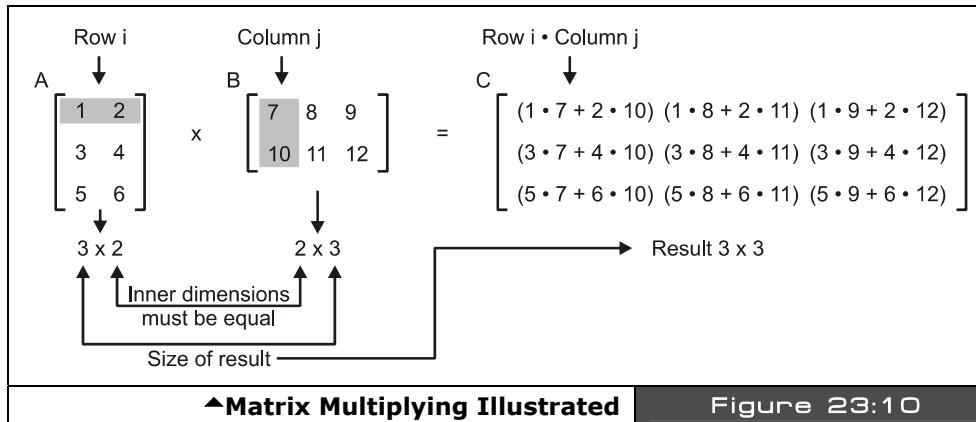
|  |   | Figure 23:9                    |
|--|---|--------------------------------|
| $M_{3 \times 2} = \begin{bmatrix} 1 & 2 \\ 3 & 4 \\ 5 & 6 \end{bmatrix}$<br>A) $3 \times 2$ Matrix | $M_{1 \times 1} = [5]$<br>B) $1 \times 1$ Matrix                      | <b>Some Annotated Matrices</b> |
| $M_{4 \times 1} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$<br>D) $4 \times 1$ Matrix        | $M_{1 \times 3} = [1 \ 2 \ 9]$<br>C) $1 \times 3$ Matrix (row vector) |                                |

To begin with all matrices are going to be represented by uppercase bold letters like **A**, **B**, **X**, **M**, etc. Next, a matrix has a number of rows and a number of columns. Typically, mathematicians refer to the row first then the column, so if someone said the matrix is "3×2" that means it has 3 rows and 2 columns; however, this is just a convention and you can surely refer to columns first then rows (as many programmers are used to). But for now we will use the row×column format. Next, any element in a matrix is referred to by its (row, column) in the matrix (either 0 or 1 based). For example, take a look at Figure 23:9(A), here we see a  $3 \times 2$  matrix,  $\mathbf{M}_{3 \times 2}$  (notice that I have put its dimensions as a subscript, another common convention). The upper left hand entry (0,0) is 1, the upper right hand entry (0,1) is 2, and finally the lower right hand entry (1,2) is 6. One notation to locate entries is to use the name of the matrix then subscripts i,j that are the row, column of the entry referred to. For example,  $\mathbf{M}_{3 \times 2}(1,1)$  means the element or entry located at row 1, column 1 (0 based of course). Lastly, matrices do not need to be 2D, in fact they can be a single column or single row for example  $1 \times n$ , or  $n \times 1$ .

Matrices can be used to perform just about geometrical transformation you might want to do to points, vectors, velocities, whatever. We just have to get everything in the proper format. Then it's a matter of "matrix multiplying" things together, thus before we can do anything, we need to review matrix multiplying.

Similar to vectors, matrix multiplying isn't as simple as multiplying elements against each, that would be mostly meaningless. In fact, to multiply matrices we are going to break the matrices down into vectors and perform dot products! Now, before you can multiply any two

matrices **A** and **B**, there are some constraints that the matrices must follow. Referring to Figure 23:10, we see matrix **A** and **B** next to each other. **A** is  $3 \times 2$  and **B** is  $2 \times 3$ , notice that they have a “**common inner dimension**” that is the number of columns of **A** is equal to the number of rows of **B**. This must **always** be true to multiply two matrices. Thus, we can multiply **A\*B**, but not **B\*A** since their inner dimensions don’t match. Moreover, the dimensions of the resulting product matrix is always the outer dimensions, thus  $\mathbf{A}_{3 \times 2} * \mathbf{B}_{2 \times 3} = \mathbf{C}_{3 \times 3}$ .



▲Matrix Multiplying Illustrated

Figure 23:10

Matrix multiplication is best shown graphically, so take a look at Figure 23:10 to see an example of a multiplication. In the figure a  $3 \times 2$  matrix is multiplied against a  $2 \times 3$  and the resulting matrix is  $3 \times 3$ . Hopefully, you see the pattern to perform the matrix multiplication; for every row of the first matrix you multiply it against every column in the second matrix. The multiplication is a dot product operation actually. Thus if you were multiplying the matrices **A\*B** to compute the result matrix entry  $C(i,j)$  you would compute the dot product between the  $i^{th}$  row of **A** and  $j^{th}$  column of **B**. It’s a little confusing at first, but after a while you get the hang of it.



**TIP** There is a cool interactive site that shows matrix multiplying here, you hover over the matrices and it will show you how the results are computed:  
<http://www.mai.liu.se/~halun/matrix/>

### 23.2.2.1 Using Matrices for Geometrical Transformations

Now, that you know how to multiply matrices, what good is it? Well, if you have a vector that represents something like position or velocity, you can use a matrix to perform very complex

operations on it. For example, say that you want to rotate a point around the origin defined by the vector  $\mathbf{p}(x,y)$ , you crack open a math book and look up rotation and you will find something like this:

$$\begin{aligned}x' &= x \cdot \cos \theta - y \cdot \sin \theta \\y' &= x \cdot \sin \theta + y \cdot \cos \theta\end{aligned}$$

What if you could write this with matrices? We would need a matrix  $\mathbf{R}$  that when multiplied by a point  $\mathbf{p} = \langle x, y \rangle$  gives us the results above, take a look below:

$$\mathbf{R} = \begin{vmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{vmatrix}$$

And if we write the vector / matrix equation:

$$\mathbf{p}' = \mathbf{p} * \mathbf{R}$$

Where  $\mathbf{p}'$  is the rotated point, we get:

$$\mathbf{p}' = \langle x, y \rangle * \begin{vmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{vmatrix}$$

And following the rules for matrix multiplication,  $\mathbf{p}$  is really like a  $1 \times 2$  matrix (called a row vector), and the rotation matrix is  $2 \times 2$ , so it's valid to multiply, moreover, the result should be  $1 \times 2$  which is also a row vector. Carrying out the multiplication we get:

$$\mathbf{p}' = \langle x \cdot \cos \theta - y \cdot \sin \theta, x \cdot \sin \theta + y \cdot \cos \theta \rangle$$

...which component for component is exactly what we want! Now, you might be saying so what? We do the exact same amount of work – true. However, the cool thing about matrices is they can represent almost any transformation, so we can not only use a simple multiplication procedure to rotate, scale, translate, shear, etc. our data, we can also **concatenate** matrices together. That is pre-multiply a bunch of transformations together off-line, then take our data vectors and multiply them by the concatenated matrix. This way a single matrix can represent a number of transformations and the same algorithm can compute the result in your code with a single matrix-multiply.

As a last example, let's look at how to perform translation using a matrix. Say you have a point  $\mathbf{p} = \langle px, py \rangle$  and you want to translate it by  $\mathbf{v} = \langle vx, vy \rangle$ , in other words:

$$\begin{aligned}px &= px + vx \\py &= py + vy\end{aligned}$$

This is trivially accomplished with the vector operation:

$$\mathbf{p} = \mathbf{p} + \mathbf{v}$$

But, what if we wanted to represent this operation with a matrix? Well, the first thing we need to do is add a 1 to our points as a 3<sup>rd</sup> component. For example, if a vector  $\mathbf{p}$  represents a point  $\langle px, py \rangle$ , we would simply add a "dummy" 1.0 to the vector making it  $\langle px, py, 1 \rangle$ . Now, to translate  $\mathbf{p}$  by vector  $\mathbf{v} = \langle vx, vy \rangle$ , we use this matrix:

$$\mathbf{T} = \begin{vmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ vx & vy & 1 \end{vmatrix}$$

...which is 3×2, this is why we need to add the dummy "1" to the point we want to translate. Considering that, here's the final vector/matrix math to translate the vector point  $\mathbf{p}$ :

$$\mathbf{p}' = \mathbf{p} * \begin{vmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ vx & vy & 1 \end{vmatrix} = \langle px, py, 1 \rangle * \begin{vmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ vx & vy & 1 \end{vmatrix}$$

Performing the matrix multiplication, we multiple the single row vector  $\mathbf{p}$  against each column of  $\mathbf{T}$ , resulting in:

$$\mathbf{p}' = \langle 1*px + 1*vx, 1*py + 1*vy, px*0 + py*0 + 1*1 \rangle = \langle px+vx, py+vy, 1 \rangle$$

...which indeed is the translation of the point  $\mathbf{p}$  by  $\mathbf{v}$ . The extra 1 at the end can be ignored and is only needed since we need a 3×3 transformation matrix. This tactic of adding 1 to the coordinate is called making it "**homogenous**," and is nothing more to facilitate these kinds of transformations. Putting it all together, we can use a single matrix  $\mathbf{M}$  to both translate and rotate a point:

$$\mathbf{M} = \begin{vmatrix} \cos \theta & \sin \theta & 0 \\ -\sin \theta & \cos \theta & 0 \\ vx & vy & 1 \end{vmatrix}$$

Well, that's it for our little impromptu review of vectors and matrices. Hopefully, if you were rusty it helped a bit, and if you have never seen this material before, at least you have some insight into what vectors and matrices are. In either case, AI, physics and collision detection rely heavily on using these ideas, so they are good to know. Otherwise, code tends to be overly complicated to accomplish manually what can be represented more elegantly and compactly with vectors and matrices. At least that's what the brochure says!

### 23.3 Physical/Deterministic Intelligence

In simple 2D games there is a distinct blur between "artificial intelligence" and "**physics modeling**." For example, if you were to write an Asteroids-type game and were writing the code to move the asteroids, you would use the following simple physics model:

```
asteroid_x := asteroid_x + dx
asteroid_y := asteroid_y + dy
```

Although this is a crude physics model, you might refer to it as the “asteroid AI” when describing the code to a fellow programmer. You might say something like “the asteroids AI is just a simple translation.” The point is that sometimes the “AI” needed for a games object is so simple or deterministic that a simple physics model or analogy will suffice.

As another example, say we wanted to make a Space Invaders-type game where the invaders moved right to left and simply bounced off the edges of the screen and moved down a line. This again is so basic that the combination of a very crude physical interpretation of “collision and response” and some conditional logic can be used to arrive at the following “AI”:

```
' move invader by constant velocity
invader_x := invader_x + invader_dx

' test for screen edge?
if (invader_x > SCREEN_RIGHT or invader_x < SCREEN_LEFT)
    invader_dx := -invader_dx      ' invert velocity
    invader_y := invader_y + INVADER_HEIGHT ' move down a row
```

So the first tier of AI in games is to leverage very simple rules that are either physical in nature or algorithmic and can be described in a few short lines. This type of AI is typically used in a lot of “arcade shooters” to control enemies or to control background objects in games that don’t have a lot to do with the game play. For example, a bird that flies across the screen doesn’t need more AI than:

```
bird_x := bird_x + bird_speed
```

So the first weapon in your arsenal of AI techniques is simply to see if you can come up with some simple rule(s) to control the game characters that result in the desired game play or behavior. These rules might be deterministic and coded with a few conditionals, or might be a couple lines of physics code. With that in mind, now we are going to cover a number of AI techniques to complement your toolbox. With them in hand you should be able to code just about any AI you need for your game characters.

## 23.4 Random Motion

Random motion is one of the most useful AI techniques around. Of course, you have to use it appropriately, you can’t have objects just move around randomly all the time! However, judicious use of random variables and random motions is exactly the behavior that’s desired in many cases. For example, in the next section we will learn about tracking and evasion algorithms. But these algorithms are pretty relentless and no fun since the player simply doesn’t have a chance if they are used solely to control game characters. However, if tracking and evasion is mixed with a little randomness, then characters start to take on a

more realistic or "***organic***" set of behaviors. With that in mind, let's take a look at the most basic of random algorithms: ***random motion***.

To move an object randomly in the plane we can approach the problem in a couple ways. We could simply select a random dx, dy each cycle and move the object:

```
object_x := object_x + rand(-2, 2)  ; rand( ) function returns a random integer from
                                         ; parm1 to parm2 inclusive
object_y := object_y + rand(-2, 2)  ; rand( ) function returns a random integer from
                                         ; parm1 to parm2 inclusive
```

This technique results in a motion that looks like molecules under an electron microscope; useful, but not too exciting. Another more interesting method of random motion is to first select a random direction vector and then apply this vector for some fixed or random amount of time or frames.

```
' compute random vector
object_dx := rand(-2,2)  ; rand( ) function returns a random integer from parm1 to
                         ; parm2 inclusive
object_dy := rand(-2,2)  ; rand( ) function returns a random integer from parm1 to
                         ; parm2 inclusive

' compute number of times to perform motion
object_motion_iterations := rand(5,10)
```

In this case, a random vector direction (object\_dx, object\_dy) is selected then the assumption is that the motion will occur ***object\_motion\_iterations*** times which has been selected to be from [5,10] iterations. Let's go ahead and implement this algorithm with a demo.



Figure 23:11 shows the a screen shot of the demo **BEE\_DEMO\_001.SPIN** which implements the ideas discussed above. The demo creates an array of "bee" records, where

each bee has position, velocity, current frame, and a timer. When the timer expires on any particular bee, a new random direction is selected along with a random time to fly in that direction. The effect looks reasonably realistic. The demo uses the artwork found in **BEE\_TILES\_WORK\_02.BMP** as well as the Mappy map file **BEE\_DEMO\_MAP\_01.MAP**, both files as well as the source file itself are in **the \SOURCES** directory as usual. The tile data file was exported with the following command line to the **MAP2SPIN** tool:

```
MAP2SPIN BEE_DEMO_MAP_01.MAP BEE_TILES_WORK_02.BMP -FX -TW6 -TH2 >
BEE_TILE_DATA.SPIN
```

Other than the AI implementation, which is rather trivial, there are a number of techniques used in the demo that are of note. First and most importantly, the demo uses a true double-buffered tile display for rendering to minimize flicker. The setup is as follows: the tile data is loaded in as usual, then a tile buffer is allocated that is the same size as the tile map data, then during each frame the original tile data is copied into the tile buffer, the tile buffer is rendered on, manipulated and then passed to the tile engine for rendering. This way the original tile data isn't destroyed during rendering and we can have objects drawing on top of the tile maps without worrying about losing the tile map data. Secondly, I had to write a random number function that generates random numbers in a range, which is very useful when you start doing AI programming:

```
Pub Rand_Range(rstart, rend) : r_delta
  ' returns a random number from [rstart to rend] inclusive
  r_delta := rend - rstart + 1

  result := rstart + (?random_var & $7FFFFFFF) // r_delta

  return result
```

...and it's initially seeded like this:

```
' initialize random variable
random_var := cnt*171732
random_var := ?random_var
```

The mod operator “//” is very slow and usually I don't recommend it, but for these demos it will suffice. However, if you need to compute thousands of random numbers at a time in a particular range, more efficient means of bounds containment must be used. Lastly, the demo uses fixed-point math for the position and velocity of the bees. The fixed-point math is in 24.8 format. In other words, 24 bits of whole part and 8 bits of decimal part. If you're not familiar with fixed-point math, it's rather simple actually: you scale all your numbers by some factor (usually a power of 2), then do all the math in fixed-point format, and finally when you need integers you shift the results destructively. For example, here's how you would initialize two fixed-point values for 1 and 100 in (24.8) format:

```

long x, y, z

x := 1 << 8    ' same as 1*256 = 000000000000000000000001.0000000 base 2
y := 100 << 8   ' same as 100*256 = 00000000000000000000001100100.0000000 base 2

' ' compute result
z := x+y

```

At this point z will equal  $1*256 + 100*256$  which is not equal to 101, however, if we want to convert the fixed-point number to an integer we reverse the process:

```

z := z >> 8 ' same as z / 256

```

...and since  $(101*256) / 256 = 101$ , the answer is correct. Similarly, if we were to divide x by 2 we should get 0.5:

```

x := x >> 1 ' same as x / 2

```

Now, if we convert x back to an integer it will be zero! So, what good is this? Well, if we leave x in fixed point format it is:

$000000000000000000000000.1000000_2$

...and if we were to add x to y then we would get:

$0000000000000000000000001100100.1000000_2$

...which, if you look to the right of the fixed point, is the number 1/2 (since the digits to the right of the decimal are the 1/2, 1/4, 1/8, etc. place). And to the left of the decimal is 10110 which is the whole part of the number. So the fixed-point number retains the information. And to extract the whole part you just need to shift to the right 8 times. Thus, to use fixed-point math you convert all your numbers to a fixed point by shifting to the left, perform any addition and subtraction you want as usual, and then when you want the whole part, you shift back to the right and that's it. To support multiplication is slightly more complex since when you multiply two-fixed point numbers you are multiplying the scaling factors as well, so the result either has to be pre-shifted down, or double-precision multiplication has to be used and the result shifted back to 24.8 format (or whatever format you are using, eg. 16.16). Division is a little more complex and requires shifting as well to place the dividend/divisor in the right format. Anyway, we will use fixed-point math more and more, so it's good to know.

Getting back to the random motion, there are a lot of things you can do with this demo to experiment. For example, all the bees are moving randomly, but say you want some "wind" to blow them from a certain direction, no problem, just add a wind factor to their position

each cycle, or to the velocity of each, and the wind will superimpose on their motion. This way you can “layer” motions.

## 23.5 Tracking Algorithms

If there is a “hello world” of AI for games then it has to be the chasing/evasion algorithm below:

```
if (player_x > alien_x)
    alien_x++
elseif (player_x < alien_x)
    alien_x-

if (player_y > alien_y)
    alien_y++
elseif (player_y < alien_y)
    alien_y-
```

This algorithm shadows the motion of the player, and the “alien” will track the player and hunt him down constantly. Although this AI is very efficient, it’s not much fun since the alien literally does whatever the player does. However, in some case this might be what you want. For example, a homing missile or something of that sort. The interesting thing about this algorithm is that if we flip the signs around then the algorithm turns into an “evasion” algorithm like so:

```
if (player_x < alien_x)
    alien_x++
elseif (player_x > alien_x)
    alien_x-

if (player_y < alien_y)
    alien_y++
elseif (player_y > alien_y)
    alien_y-
```

Both algorithms on their own are too aggressive, but are very powerful when used as “tools” in other algorithms. For an example of both algorithms in a single demo, check out **TRACKING\_DEMO\_001.SPIN** located in the **\SOURCES** directory, its based on the artwork from **MECH\_TILES\_WORK\_01.BMP** and **INVADERS\_DEMO\_MAP\_02.MAP**. The assets were ran through the **MAP2SPIN** tool as usual, and then the output file **INVADERS\_TILE\_DATA2.SPIN** was manually modified to allow using some of the tiles as sprites (I manually added masks). In any event, give the demo a try and then lets discuss it. Use the gamepad to control the player and the **<SELECT>** button to toggle the AI mode

between chase and evade. The first thing you will notice about the demo is how fast the alien locates and tracks the player (you).

The demo uses both tiles and sprites since I needed smooth motion for the player and alien characters. Some things to note about the demo are that the sprites always use the tile palette index they are on. In this case, all the tiles palettes in the game field use a "red" palette of colors, so both game characters are made of reds. However, if you move into the right and left extreme areas of the screen, you will see the characters take on the gray palettes of the "space station superstructure." The code is too long to list in its entirety, but here's a fragment from the main event loop where the most action happens:

```
' test player movement first?
if (game_pad.button(NES0_RIGHT))
    player_x+=2
elseif (game_pad.button(NES0_LEFT))
    player_x-=2

if (game_pad.button(NES0_UP))
    player_y-=2
elseif (game_pad.button(NES0_DOWN))
    player_y+=2

' test for ai mode change
if (game_pad.button(NES0_START))
    repeat while game_pad.button(NES0_START)  ' let user release button first
        if (ai_mode == AI_MODE_EVADE)
            ai_mode := AI_MODECHASE
        else
            ai_mode := AI_MODE_EVADE

' update animation frames
if (++player_frame_counter > 15)
    player_frame_counter := 0
    if (++player_frame > 1)
        player_frame := 0

if (++alien_frame_counter > 15)
    alien_frame_counter := 0
    if (++alien_frame > 1)
        alien_frame := 0

' now test ai mode and apply ai method
if (ai_mode == AI_MODECHASE)
    begin chase ai
    if (player_x > alien_x)
        alien_x++
    elseif (player_x < alien_x)
```

```

alien_x--  

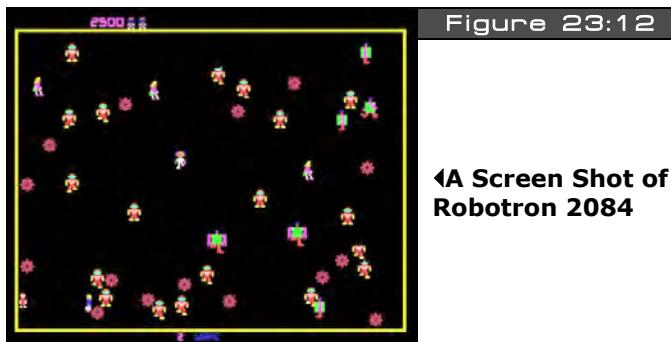
if (player_y > alien_y)
    alien_y++
elseif (player_y < alien_y)
    alien_y--
else
    begin evade ai
    if (player_x > alien_x)
        alien_x--
elseif (player_x < alien_x)
    alien_x++  

if (player_y > alien_y)
    alien_y--
elseif (player_y < alien_y)
    alien_y++

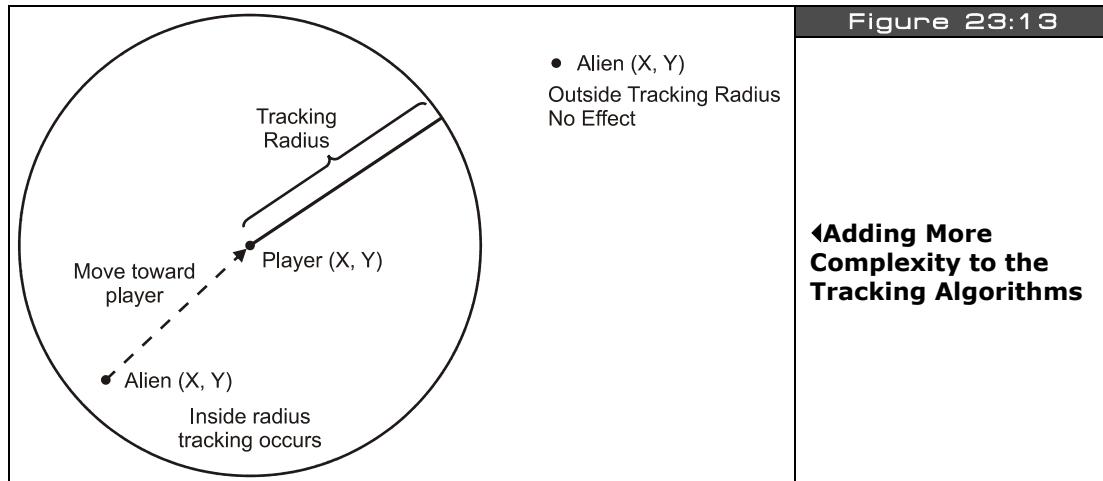
```

The code begins by testing the gamepad and moving the player, then checking for an AI mode toggle, and finally moving into the actual algorithms themselves. The interesting thing here is to realize that the ***ai\_mode*** could potentially be anything, not just chasing and evading modes. Keep this in mind when designing games, many times you want to keep the AI code separated and pluggable so you can select which kind of AI drives the game characters.



Anyway, if you play with the demo for a few moments it gets boring really quick. This type of AI is pure "***shooter***" AI, and not found in many games that have any strategy. One place you will find an AI very similar to this is in the game "***Robotron 2084***" by ***Williams***. This was a great game, but really nothing more than run and gun! Figure 23:12 shows a screen shot. If you have access to the game, give it a try, so you can see the AI in action. However, there are a couple added features to the basic chase/evade algorithm in Robotron 2084 which are very useful for other games as well. Instead of relentlessly coming toward the

player (or moving away), a timer is used that selects a direction to track the player and then continues on that path until the time is up. This way, every couple seconds or so the bad guys “re-evaluate” their trajectories toward the player and select a new targeting vector (maybe on at 90 degree angles as well). This “loosens” the algorithm a little and gives the player some time to react and get away. Secondly, another tactic is to only turn the tracking “on” when the player and the bad guys are within some vicinity or some radius of influence. Figure 23:13 shows these ideas graphically.



Adding these simple two features to the basic tracking (evasion algorithm) create a much more interesting AI behavior than before. As an example of this, take a look at **TRACKING\_DEMO\_002.SPIN** which implements these new ideas. When you run the demo you will start at the middle of the screen and the alien (bad guy) starts somewhere randomly. If he is too far away he won't do anything, so get close to him and the moment you get close enough (**MIN\_AI\_REACTION\_DIST**) the alien will come charging toward you! But, notice if you change directions, the alien will not react immediately, so you have time to get away!

Now, there are some interesting things to note about this second implementation: first if you come within range of the alien then the alien will attack, but you will notice it "**overshoots**" your position. This is because the trajectory is not constantly updated as before, thus there is an "**oscillation**" effect that results. The amount of oscillation can be minimized by changing the update rate to the trajectory. Of course, if the trajectory updates every frame then we are back to where we started and the tracking is dead on! So this new implementation lets you tune the reaction rate. Also, if you do not like the oscillation effect, then you can add another

layer of software that tests if the alien is within a very close proximity of the player and if so, then all motion is stopped. This way, the alien tracks the player (but not constantly) and stops when it gets close enough to the player (maybe to fire weapons). Anyway, here's the new AI code augmented with the distance and motion control updates:

```

' update ai counter
if (--ai_counter <= 0)
    ' re-evaluate AI if player is within range
    dx := player_x - alien_x
    dy := player_y - alien_y
    dist := (dx*dx + dy*dy), compute dist^2
    ' re-vector trajectory if player is close
    if (dist < MIN_AI_REACTION_DIST)
        reset behavior counter
    ai_counter := Rand_Range(5, 25)

    ' now test ai mode and apply ai method to compute trajectory vector
    if (ai_mode == AI_MODECHASE)
        ' begin chase ai
        if (player_x > alien_x)
            alien_dx := 1
        elseif (player_x < alien_x)
            alien_dx := -1

        if (player_y > alien_y)
            alien_dy := 1
        elseif (player_y < alien_y)
            alien_dy := -1
        else
            ' begin evade ai
            if (player_x > alien_x)
                alien_dx := -1
            elseif (player_x < alien_x)
                alien_dx := 1

            if (player_y > alien_y)
                alien_dy := -1
            elseif (player_y < alien_y)
                alien_dy := 1
        else
            ' player not in reaction distance, kill trajectory vector, reset counter
            alien_dx := 0
            alien_dy := 0
            ai_counter := 5
    ' move alien on last set trajectory vector
    alien_x += alien_dx
    alien_y += alien_dy

```

See if you can add some code that tests if the player is within a second closer radius than ***MIN\_AI\_REACTION\_DIST*** and if so, all motion is stopped.

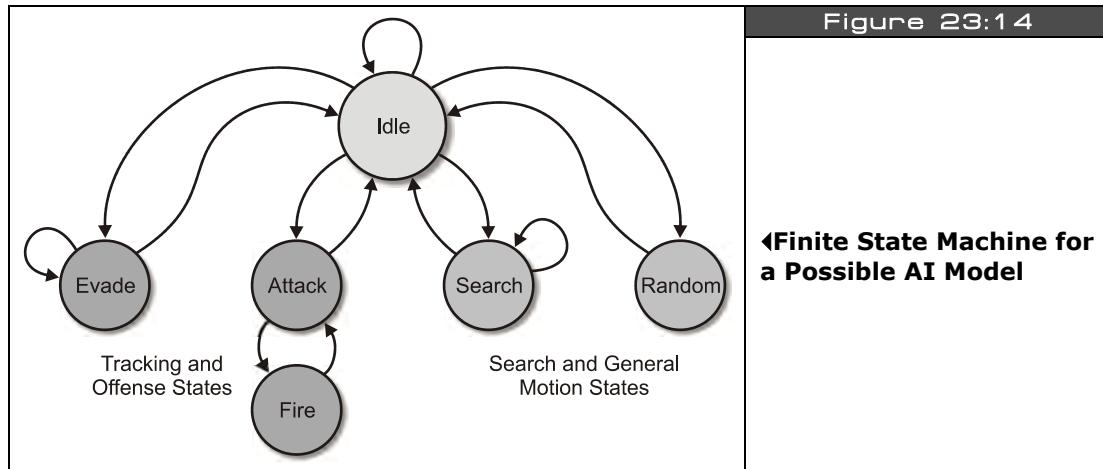


Figure 23:14

◀ Finite State Machine for a Possible AI Model

## 23.6 Finite State Machines

**Finite state machines** (FSM's) are one of the most useful programming objects there are. If you're not an expert on them, finite state machines are an organized set of rules used to transition from one "**state**" to another based on the current state and various inputs. At any given state, the FSM can have one or more outputs associated with the state.

Even if you didn't realize it, nearly all of the programming we have been doing thus far is nothing more than FSM's in one form or another, we simply haven't formally made note of it. However, to take the next step in AI, we want to start thinking of the AI in terms of states, and then these states themselves can either be deterministic AI, physical AI, and so forth. Thus, we are going to start to "layer" the AI techniques to build complex behavioral models (at least complex for this beginners guide). Take a look at Figure 23:14; it depicts a potential game character AI model FSM (the arcs are simply potential ideas, the final state machine might be different). This AI is composed of a FSM with the following states:

- ▶ **ATTACK**
- ▶ **EVADE**
- ▶ **FIRE**
- ▶ **SEARCH**
- ▶ **IDLE**
- ▶ **RANDOM**

Each of the “states” can be implemented with simple deterministic logic, a physical algorithm, random logic, a combination of techniques, or yet another finite state machine. The idea here is to create a “model” of the character AI that has distinct states and then code each state. Continuing with the example, let’s see how we might code an AI model with these states:

- ATTACK** Based on the coordinates of the player and the AI character, vector the AI character toward the player. Additional inputs such as distance to player and weapons status of player and AI might be taken into consideration.
- EVADE** Based on the coordinates of the player and the AI character, vector the AI character away from the player. Additional inputs such as distance to player and weapons status of player and AI might be taken into consideration.
- FIRE** Fire weapon at selected target.
- SEARCH** Search for selected target.
- IDLE** Do nothing, give player time to react.
- RANDOM** Select a random motion or state.

To code the state machine, any number of architectures can be used. For example, below is a pseudo code framework you might use to implement your game AI character:

```

long ai_state      ' current ai state
long ai_state_counter ' used to count how long a state is in
long ai_x, ai_y ' position of AI controlled character

long px, py ' position of player ai is working against

{ enter into state machine, process current state, make transitions to other
states potentially, etc. }
case ai_state
  ATTACK:
    ' vector toward player until counter has timed out
    if (--ai_counter > 0)
      ' run tracking code..
      if (px > ai_x)
        ai_x++
      if (px < ai_x)
        ai_x--
    .
  else
    ' attack state is over, select a new state
    ai_state := New_State_Select
  
```

```

EVADE:
    ' vector away from player until counter has timed out
    if (--ai_counter > 0)
        ' run tracking code..
        if (px > ai_x)
            ai_x--
        if (px < ai_x)
            ai_x++
        .
    .
else
    ' evade state is over, select a new state
    ai_state := New_State_Select

FIRE_WEAPON:
    ' fire weapon at player
    Fire_Weapon
    ai_state := New_State_Select

SEARCH:
    ' search for target
    if (--ai_counter > 0)
        Search
    else
        ' search state is over, select a new state
        ai_state := New_State_Select

IDLE:
    if (--ai_counter > 0)
        ' do idle animation?
    else
        ' idle state is over, select a new state
        ai_state := New_State_Select

RANDOM:
    if (--ai_counter > 0)
        ' move ai randomly
    else
        ' random motion is, select a new state
        ai_state := New_State_Select

```

As you can see, each state has its own code and in some cases calls other functions. For example, each state runs for a period of time counted down by ***ai\_counter*** (in this case), and then a call is made to **New\_State\_Select**. This is completely arbitrary and need not be the case, that is, the state control could be coded inline and the state termination could be affected not only by the ***ai\_counter*** but other external stimuli such as the state of the

player, other AIs' in the game and so forth. But, for this simple example, the idea is that you might need an external function that takes all that information in and selects a new state for your AI.

The thing to remember about this type of architecture is that it must be real-time and that the state machine must run a single cycle each time the game loop runs, so the AI isn't "starved." Also, care must be taken that when one state transitions to another any loose ends are tied up, meaning variables are reset or initialized and so forth. Considering all that, I think you can see how powerful this technique is! You can literally build software brains with layers and layers of complexity, embedded state machines within state machines where each atomic AI element might be random, deterministic, physical, or use some other technique. This is exactly how state-of-the-art AI is made in modern games, not with one technique but a collection of them, and state machines are the glue to organize it all.



### NOTE

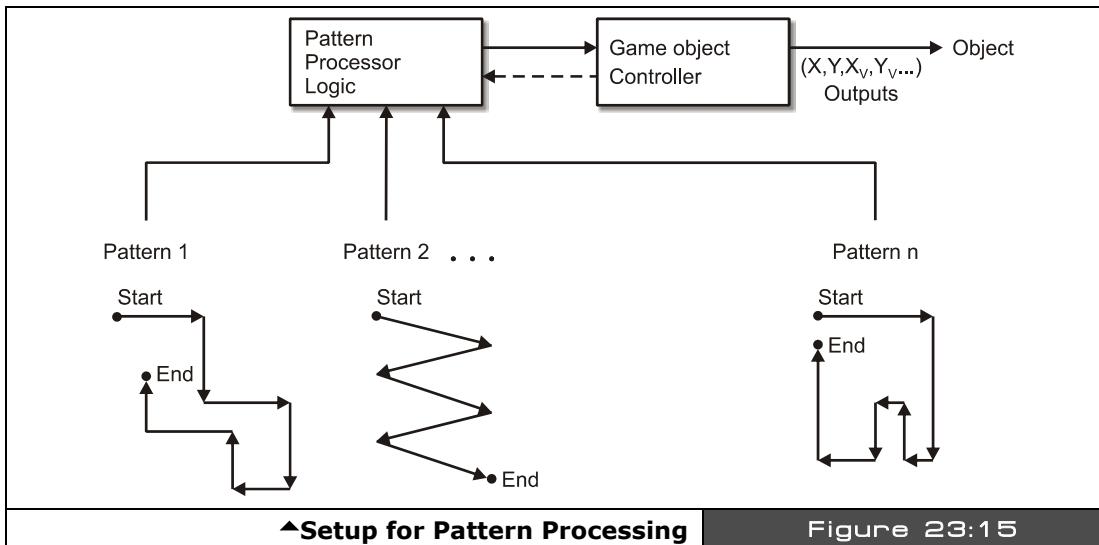
Since Spin has no support for data structures and encapsulation of data, the examples thus far have been using globals and very little parameter passing is going on. These techniques are for illustration purposes only. If you are making professional games and/or systems, you should try to emulate data structures with indexed arrays, and try to use functions that are totally parameter-driven so as not to rely on globals as much as we are to keep things short and simple.

Now that we made a formal discussion of finite state machines, it's just in time for our next discussion on pattern following where we can put them to practical use.

## 23.7 Pattern/Programmatic Logic Control

Although the techniques we have outlined thus far are very useful, they are very simple as well. We aren't going to get any "intelligent" looking behavior out of a few lines of tracking code. What we need is to take things to the next level with a very cool concept: "**programmable AI.**" In the realm of 2D games especially, the game AIs' follow patterns that are either randomly selected or triggered by some event. For example, **Pac-Man** is a game full of nothing but patterns. The ghosts run around executing patterns most of the time, unless the player gets too close which sometimes transitions the ghosts into chase mode. Another example of patterns in 2D games are space shooters such as **Galaxians** which features waves of alien invaders that follow very specific attack/flight patterns when attacking the player. These techniques all fall under **pattern** or **programmable logic** and are the topic of this section.

A pattern is a pre-recorded sequence of states or instructions that the game AI's or characters "**read**" in some fashion and then execute.



For example, take a look at Figure 23:15, here we see a setup for motion control of game characters. There are a set of pre-recorded flight or motion patterns, a **pattern processor** state machine that reads the patterns and then sends the information to the game AI's. So in essence the patterns themselves are really "**programs**" and the pattern processor logic is really the "**interpreter**." This is a very powerful paradigm as you might imagine. With it we can basically through programmatical control create huge arrays of patterns, motions, flights, whatever, store them as patterns and, using some logic, select and play them through the AI's. This is exactly how 90% of all sports games work. For example, the designers of the latest football, basketball, baseball, hockey, etc. games spend weeks, if not months, recording "plays" for the game AI characters to execute. Of course, these plays are far more complex than what we are going to do, but the ideas are the same: to come up with a "**language**" or instruction set of sorts that a pattern processor or interpreter reads and executes. In essence, we are creating a "**virtual machine**" in software that has an instruction set, program, and executes resulting in control of our game characters!

### 23.7.1 Pattern Languages Primer

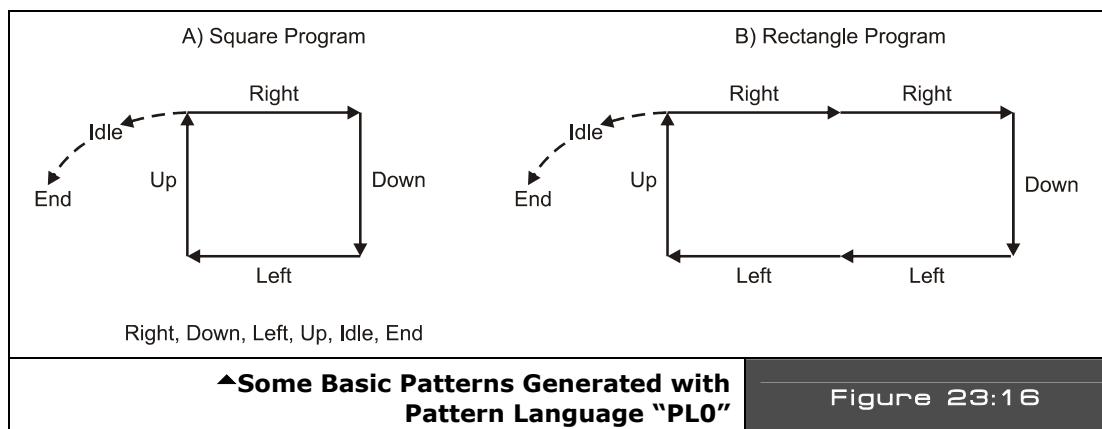
There are no rules here, the idea is to come up with a simple language then write some code that reads it and can control the motion/behavior of a game character. With that in mind, let's start with something really easy. Let's say that we have a shooter game with enemies that fly around in space; we don't want to even try to code a bunch of flight patterns, so let's see if we can come up with a language and support software to do the job.

The first step is to outline what the language or control instruction set will be. Let's say the commands are: {RIGHT, LEFT, UP, DOWN, IDLE, END}. We will call the language or instruction set "PL0" (**P**attern **L**anguage **0**), where each of the instructions has the following meanings:

- RIGHT** – Move right some pre-determined distance
- LEFT** – Move left some pre-determined distance
- UP** – Move up some pre-determined distance
- DOWN** – Move down some pre-determined distance
- IDLE** – Sit idle and do nothing for some pre-determined amount of time
- END** – End of pattern program sentinel, must be placed at end of each pattern program

The first thing you will notice is that PL0 has no operands, it's a pure opcode-only instruction set, thus its use is limited and not very flexible. For example, all the movements are fixed since they are not parameterized, but as a start this is fine. Anyway, take a look at Figure 23:16, here we see couple patterns and behaviors coded with this language. The square pattern in Figure 23:16(A) would be:

Square Program = "RIGHT, DOWN, LEFT, UP, IDLE, END"



Of course, this is just one square program, there are an infinite number of them, say we wanted a rectangle with width > height. That's easy, we just use the RIGHT and LEFT instructions more:

Rectangle Program = "RIGHT, RIGHT, DOWN, LEFT, LEFT, UP, IDLE, END"

So as you can see, even with this simple language there are all kinds of cool possibilities. But, we can do a lot more by supporting other types of instructions along with operands. However, before getting to that, let's take a stab at coding some of this software needed for the language and pattern processing.

First, we have to decide on a format for the instruction set, so let's represent each instruction as a single BYTE with the following constant definitions:

```
' opcode definitions
OP_IDLE      = 0
OP_END       = 1
OP_RIGHT     = 2
OP_LEFT      = 3
OP_UP        = 4
OP_DOWN      = 5
```

Next, we need some kind of storage to store a pattern, let's use a simple array that might look like this:

```
DAT
' a simple square pattern
pattern byte OP_IDLE, OP_RIGHT, OP_UP, OP_LEFT, OP_DOWN, OP_IDLE, OP_END
```

With the constants in hand and the data for a pattern, we need some code that reads the pattern and processes it, here's a pseudo-code loop that handles the job:

```
' vars for pattern processing and alien position
long alien_x, alien_y ' position of alien controlled by pattern processor

byte opcode          ' the opcode currently being processed
long opcode_index    ' the index into the pattern program where the next opcode is
                      ' being fetched (like instruction pointer)
long opcode_counter ' a general counter/timer that is used to control state

opcode_index := 0      ' initialize program fetch index to 0
opcode := pattern[ opcode_index ] ' fetch first instruction
opcode_index++         ' advance instruction index
opcode_counter := 0   ' reset counter, used to track state, time, etc.

repeat while 1
  ' somewhere in the main event loop..

  case opcode ' process instruction
    OP_IDLE:
      if (++opcode_counter > 10) ' waits for 10 cycles/frames, fetches next instr.

      Fetch ' fetch next instruction
```

```

OP_END:
    ' program is over, either restart program or do something else...

OP_RIGHT:
    ' move alien right some number of cycles, say 5
    if (++opcode_counter < 5)
alien_x++
    else
        Fetch ' fetch next instruction

OP_LEFT:
    ' move alien left some number of cycles, say 5
    if (++opcode_counter < 5)
alien_x--
    else
        Fetch ' fetch next instruction

OP_UP:
    ' move alien up some number of cycles, say 5
    if (++opcode_counter < 5)
alien_y--
    else
        Fetch ' fetch next instruction

OP_DOWN:
    ' move alien down some number of cycles, say 5
    if (++opcode_counter < 5)
alien_y++
    else
        Fetch ' fetch next instruction

PUB Fetch
' fetches next instruction from program
opcode := pattern[ opcode_index++ ] ' fetch instruction, advance pointer
opcode_counter := 0      ' reset counter, used to track state, time, etc.

```

Of course this is only pseudo-code and there is a lot missing, but the main idea is that the pattern program is processed by a state machine of some sort and each of the actions are executed. As noted, this technique is very powerful and gives the game designer the flexibility to control the AI of characters using “programs” written in tools rather than programmed in code. Once again, the idea is to move the design of a game into the designer’s hands and not force a designer to have to actually program the AI. Also, if you have say 100 different patterns or behaviors and then come up with a set of rules used to select the patterns (maybe based on the state of the game, player, statistics, etc.) then the behaviors of the game AI characters will virtually be indistinguishable from human opponents for all intents and purposes.

### 23.7.2 Advanced Concepts in Pattern Languages

Hopefully, you see how exciting the concept of AI characters processing little programs via software virtual machines is! But let's see if we can add some more functionality to our pattern language "PL0" to make it more robust, so that more advanced and useful programs can be written with it that do everything we need. First, let's brainstorm a bit and list some features and shortcomings that "PL0" currently has that we want to add and improve on.

Right now there are no operands; all opcodes have fixed implied operands. The ability to add 1 or more operands to opcodes is needed, so we can parameterize the instructions. Next, the instruction set thus far only controls motion, why not add the ability to fire weapons, change states to various tracking modes, and even fire off function calls? What about adding conditionals? And even loops and/or gotos to the language? Also, it would be cool to have a set of global values that could be used as operands as well. For example, giving the language access to the player x,y position:

**GBL\_PLAY\_X** If used as an operand queries that x position of player which is then uses as the operand of the instruction.

**GBL\_PLAY\_Y** Same.

With just these simple ideas we can create a new language "PL1" that can create almost any behavior we might need. Of course, the language must relate to the functionality or control of some in game characters, thus there is no need to have language elements that make no sense to the characters themselves. For example, if we were to use the language to control asteroids in a game that would be overkill since 4 lines of code can do that. The point is the game objects controlled by the language should be appropriately selected. Considering that, here's a new version draft of the language PL1 shown in Table 23:1.

Referring to Table 23:1, you can see that there are a lot of things this new language can do and a lot of details we would have to deal with to implement it. For example, the exact implementation of the flow control and loop opcodes would have to be defined, such as how to code the **OP\_GOTO** opcode. One possible idea would be to simply allow a positive or negative number as the operand, and then offset that number of instructions plus or minus from the **OP\_GOTO** instruction itself. Thus, this code would be an infinite loop back to itself:

```
OP_GOTO, -1, OP_END
```

Since "**OP\_GOTO, -1**" means jump back 1 instruction, the instruction index is reset right back to the **OP\_GOTO** instruction again. But, keep in mind the offset is not how many BYTES, or WORDs, or LONGs, but how many "instructions." The **OP\_GOTO** has some brains that know how to count forward and backward instructions.

| Version 1.0 of Pattern Language "PL1"▼ |                               |   |
|--|-------------------------------|---|
| Instruction                            | Operand(s)                    | Description   |
| <b>Directionals</b>                    |                               |   |
| OP_RIGHT                               | velocity, time                | Moves right at given velocity for given time  |
| OP_LEFT                                | velocity, time                | Moves left at given velocity for given time   |
| OP_UP                                  | velocity, time                | Moves up at given velocity for given time   |
| OP_DOWN                                | velocity, time                | Moves down at given velocity for given time   |
| <b>Actions</b>                         |                               |   |
| OP_FIRE                                | target #                      | Fires weapon at object identified by value target#  |
| OP_IDLE                                | time                          | Sit idle for given time   |
| OP_ATTACK                              | time                          | Attack player for given time  |
| OP_EVADE                               | time                          | Evaude player for given time  |
| OP_RANDOM                              | time                          | Move in random direction for given time   |
| <b>Flow Control and Loops</b>          |                               |   |
| OP_LOOP                                | iterations, # of instructions | Execute the instructions immediately following the loop instruction for the requested number of iterations. |
| OP_GOTO                                | instruction offset            | Goto instruction based on offset (+/-).   |
| OP_IF_FUNC_EXE                         | func index, # of instructions | Execute function requested, if result is TRUE execute the following # of instructions, else jump them       |
| OP_END                                 | none                          | Ends program.   |

Another interesting instruction is the **OP\_IF\_FUNC\_EXE** instruction. The idea here is that you would use the instruction to call a list of global information "getter" functions that all returned Boolean TRUE/FALSE values then, based on the result, the code block under the instruction would be executed or jumped. Here's an example:

```
OP_IF_FUNC_EXE, 3, 5
```

This would be interpreted as "call the global information function number 3, if the result is TRUE then execute the next 5 instructions, else jump over them." Moving on, the other instructions more or less are "what you see is what you get." The only thing that isn't well-defined is what "time" means in many of the instructions. Well, it could be real-time, or frames, or cycles, or something in between. The idea is that it's a parameter that represents how long to perform the operation.

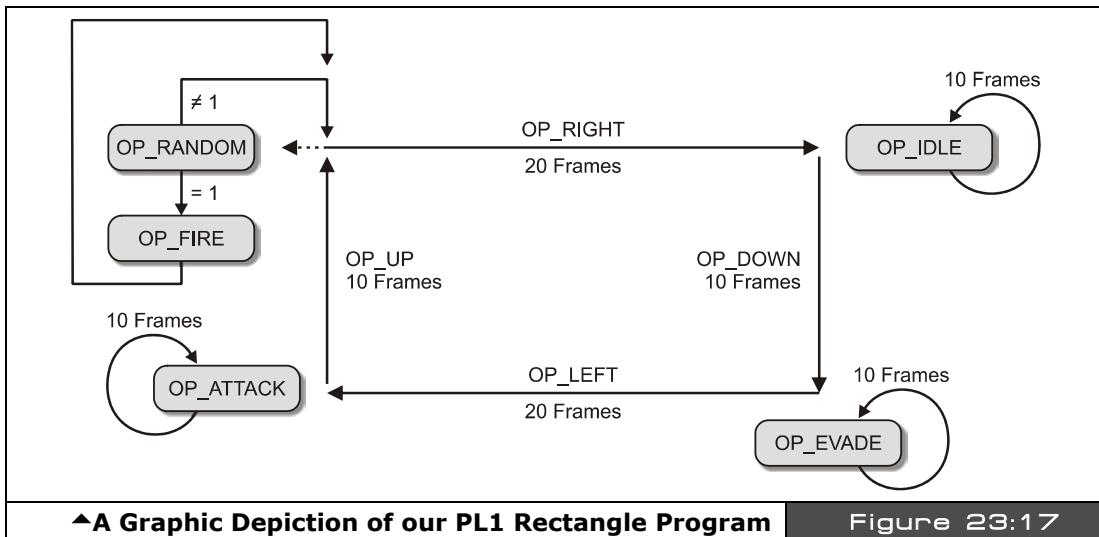


Figure 23:17

Taking all that in, let's write a little program with PL1 that does something. How about this: we write a program that constantly moves a character in a rectangle, but at each corner we want to attack, evade, idle, and move randomly. Also, we want the program to repeat over and over, and once each cycle. We will make a call to one of the built-n functions which returns a random TRUE/FALSE (say it's index 4) and we will use this to fire the weapons at the player which is target number 0! Figure 23:17 shows the program graphically for reference. Here's the program with some line numbers and comments to help sort it out:

```

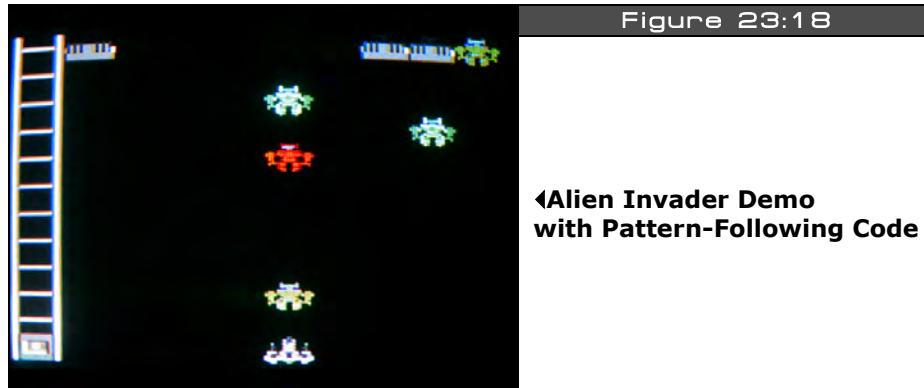
0: OP_RIGHT, 1, 20 ; move right at speed of 1 pixel/frame for 20 frames
1: OP_IDLE, 10 ; do nothing for 10 frames
2: OP_DOWN, 1, 10 ; move down at a speed of 1 pixel/frame for 10 frames
3: OP_EVADE, 10 ; evade the player for 10 frames
4: OP_LEFT, 1, 20 ; move left at a speed of 1 pixel/frame for 20 frames
5: OP_ATTACK, 10 ; attack the player for 10 frames
6: OP_UP, 1, 10 ; move up at a speed of 1 pixel/frame for 20 frames
7: OP_RANDOM, 10 ; move randomly for 10 frames
8: OP_IF_FUNC_EXE, 4, 1 ; call random number function, if TRUE (1) then execute the
                           ; next (1) instructions
9: OP_FIRE, 0 ; fire at the player (will be jumped if above call was FALSE)
10: OP_GOTO, -11 ; go back 11 instructions including the OP_GOTO
11: OP_END ; will never be reached

```

Reviewing the program, it does exactly what we want it to do. Moreover, it's totally relocatable since the **OP\_GOTO** and **OP\_IF\_FUNC\_EXE** instructions use relative addressing. Thus, with a little work, sub-routines can be added and a high-level tool can be written that allows you to code either with text or graphically could be written to generate all these "programs." More or less you can literally create an entire programming language with the

pattern language and at some point the programming language starts to blur with a full blown “scripting language.” Nonetheless, the idea is to create an instruction set that is robust enough to move your game characters around as well perform some rudimentary processing once in a while. Let’s take everything now and build a simple demo that takes advantage of some of our work here.

### 23.7.3 Pattern Following Demo



As a demo of the pattern interpreter technology we have been discussing, take a look at **INVADERS\_DEMO\_002.SPIN**. The gamepad is used to control the ship as usual, also you can fire with the <A> or <B> action buttons. Figure 23:18 shows a screen shot of the demo in action. The demo is based on the map file **INVADERS\_DEMO\_MAP\_03.MAP**, and the bitmap file **MECH\_TILES\_WORK\_02.BMP**. The final Spin compliant data file was generated with the following MAP2SPIN command line:

```
MAP2SPIN INVADERS_DEMO_MAP_03.MAP MECH_TILES_WORKS_02.BMP -FX -TW8 -TW10 >
INVADERS_TILE_DATA3.SPIN
```

The map and bmp files are nearly identical to the last invaders demo except that the art has been augmented with some laser pulses, but that’s about it. All the files are located in **\SOURCES** as usual. The demo more or less implements a pattern language similar to PL1, but not as complete. The following is an excerpt from the opcode listing in the demo:

|            |     |                         |                               |
|------------|-----|-------------------------|-------------------------------|
| PCMD_IDLE  | = 0 | format: {PCMD_IDLE, n}  | - idles for n frames.         |
| PCMD_FIRE  | = 1 | format: {PCMD_FIRE}     | - fires straight down.        |
| PCMD_RIGHT | = 2 | format: {PCMD_RIGHT, n} | - moves right n frames.       |
| PCMD_LEFT  | = 3 | format: {PCMD_LEFT, n}  | - moves left n frames.        |
| PCMD_UP    | = 4 | format: {PCMD_UP, n}    | - moves up n frames.          |
| PCMD_DOWN  | = 5 | format: {PCMD_DOWN, n}  | - moves down n frames.        |
| PCMD_TRACK | = 6 | format: {PCMD_TRACK, n} | - tracks player for n frames. |

|  |                                 |
|--|---------------------------------|
| PCMD_EVADE = 7 ' format: {PCMD_EVADE, n} | - evades player for n frames.   |
| PCMD_JMP = 8 ' format: {PCMD_JMP, n}     | - set pattern IP or index to n. |
| PCMD_END = 9 ' format: {PCMD_END}        | - ends program.                 |

The demo consists of the invaders environment, a group of alien robots that are controlled by the pattern interpreter along with the player's ship. The program is totally dynamic, so you can add more alien robots and patterns at will via constants and data. The pattern interpreter is rather large and is very similar to what we have discussed, so I am not going to list the complete code; however, here is the header into the interpreter along with "idle" and "fire" instruction handlers:

```

repeat bot_index from 0 to NUM_BOTS - 1
    process each bot
    if (bot_state[bot_index] <> BOT_STATE_DEAD)
        process alive and dying states

    ' test state of bot vm - fetch or execute?
    if (bot_vestate[bot_index] == BOT_VMSTATE_FETCH)
        ' fetch next opcode, leave instruction index on opcode though
        bot_opcode[bot_index] := byte[bot_pattern_ptr[bot_index]] [bot_pattern_index[bot_index] ]

    ' now process (or continue processing current opcode)
    case (bot_opcode[bot_index])

        PCMD_IDLE:           ' format: {PCMD_IDLE, n} - idles for n frames.
            ' if instruction was just fetched, then fetch operand and prepare to execute
            if (bot_vestate[bot_index] == BOT_VMSTATE_FETCH)
                ' fetch path
                ' need to retrieve parameter and store in counter
                bot_counter[bot_index]:= byte[bot_pattern_ptr[bot_index]] [bot_pattern_index[bot_index]+1]
                ' set vestate to execute
                bot_vestate[bot_index] := BOT_VMSTATE_EXECUTE
            else
                ' execute path
                ' decrement frame counter
                if (bot_counter[bot_index]-- < 1)
                    ' time is up, done with instruction, fetch another, next time around
                    bot_vestate[bot_index] := BOT_VMSTATE_FETCH
                    ' advance instruction index past opcode and operand
                    bot_pattern_index[bot_index] += 2

        PCMD_FIRE:           ' format: {PCMD_FIRE} - fires straight down.
            ' if instruction was just fetched, then fetch operand and prepare to execute
            if (bot_vestate[bot_index] == BOT_VMSTATE_FETCH)
                ' fetch path
                Fire_Missile(bot_x[bot_index], bot_y[bot_index], MISSILE_STATE_FIREDBYENEMY)
                ' advance instruction index past opcode, leave in fetch mode to get next instruction
                ' since we can immediately process the fire command
                bot_pattern_index[bot_index] += 1

```

Upon inspection of the code you will see that the pattern interpreter “virtual machine” has two states: **“fetch”** and **“execute.”** In the fetch state, the next pattern opcode is fetched and passed to the appropriate instruction handler in the case statement. In the execute state, the instruction handler processes the instruction and performs the requested logic and controls the bot. Thus, each of the instruction handlers have both a “fetch” and “execute” control path. This is a very clean way to do things and it keeps you from going crazy. Also, notice that some instructions can be instantly executed like the “fire” handler while the “idle” handler has to wait a number of frames before issuing another fetch request.

The next interesting thing about this demo is the way that the graphics are handled. This demo uses a true page flipped double buffer system with the following setup: the original tile graphics in a  $32 \times 12$  WORD tile set, along with two  $32 \times 12$  WORD buffers, call them ***tile\_map\_buffer1***, and ***tile\_map\_buffer2***. These two buffers are used as the off-screen back buffer, and the on-screen front buffer. The animation loop works as follows:

**Step 1:** The original tile data is copied into the current back buffer (which could be *tile\_map\_buffer1* or *tile\_map\_buffer2*).

**Step 2:** All rendering is then done destructively on this back buffer.

**Step 3:** The back buffer and front buffer are swapped.

**Step 4:** The HEL engine is pointed to the front buffer and rasterizes it to the TV.

Thus, all graphics rendering is done on the off-screen buffer so there is no flicker, plus we never see any of the updates to the tile map graphics and the animation is clean and stable. The code that “flips” the pages and sets the HEL engines tile graphics pointer is as follows:

```
' flip pages
if (back_tile_buffer == @tile_map_buffer1)
    back_tile_buffer := @tile_map_buffer2
    front_tile_buffer := @tile_map_buffer1
else
    back_tile_buffer := @tile_map_buffer1
    front_tile_buffer := @tile_map_buffer2

' update tile base memory pointer
tile_map_base_ptr_parm := front_tile_buffer + scroll_x*2
```

The demo is a good starting point for a complete game. See if you can add more patterns, explosions, and levels to the game.

## 23.8 Waypoints, Pathing and Driving Games

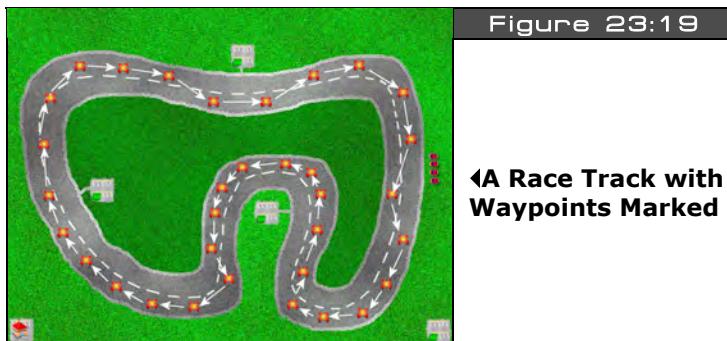


Figure 23:19

◀ A Race Track with Waypoints Marked

So far the technologies we have looked at are perfect for most arcade games and even sports games. However, racing games is one class of games that can benefit from yet another technique – “**waypoint following**.” Take a look at Figure 23:19, here we see an overhead view of a race track that is marked with what are called “**waypoints**.” These waypoints are further annotated by lines or paths connecting each. Now, imagine you want to write a racing game that has a bunch of race cars on a track that the player races against. How would you approach it? Well, once approach would be to write a really complicated rule-based AI that, based on the position of the car the AI is driving, the position of the other cars, the geometry of the road, etc., controls the car and makes it drive on the road. This will work of course, but is a ton of work. Instead, a simpler method is to create an “invisible” track of waypoints that the AI car must follow. And to make it interesting we might have 10-20 different tracks or lanes that the AI can drive in.

Thus we have turned what potentially could be a programming nightmare into nothing more than making the AI car follow a path of points around a track. Wherever the points go, the car should follow. The algorithm to perform the tracking is the only real challenge, but we will get to that in a moment. For now, let’s talk about other ideas for waypoint and pathing technology. The idea of having vector lists that compose “paths” for game AI characters to follow is very powerful and one the primary technologies used in modern games. For example, take a look at Figure 23:20, here is an image of a war game. The problem is that we want to get our AI characters from the left side of the game world to the right side, but we want them to go over the bridge and be able to end up at one of the three waypoints on the right side. With waypoints and paths this is trivial. A set of vector lists or paths full of waypoints is generated on paper or with a tool, then some code is written that instructs the AI characters to select one of the paths, follow the waypoints until the AI character is over the bridge and has reached the goal waypoint.

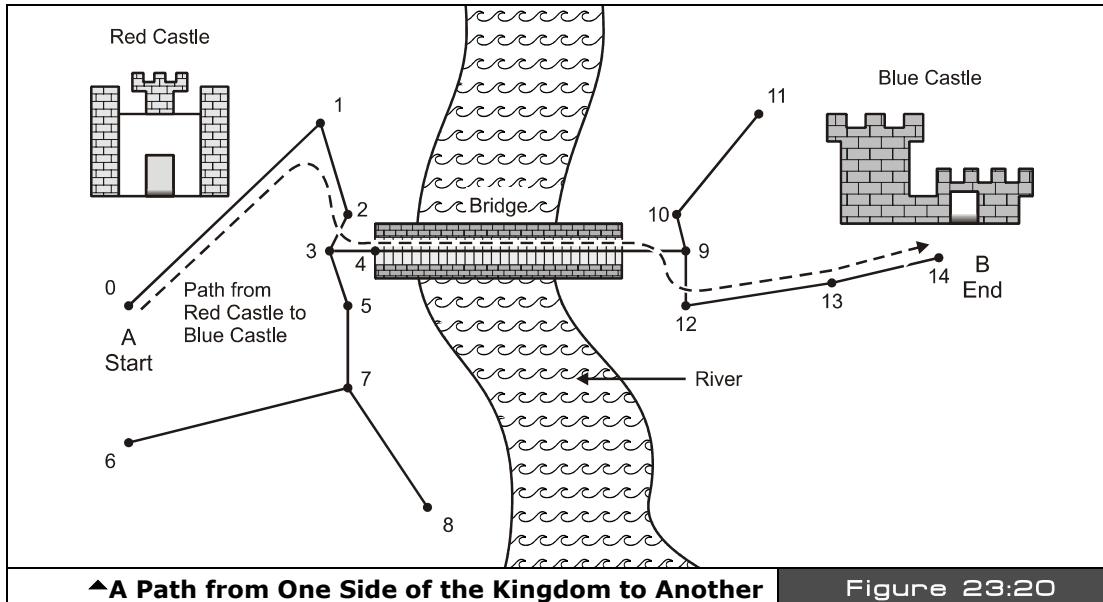


Figure 23:20

Thus, under normal conditions maybe the game AI is simple evade, chase, random, pattern code, but when an AI character needs to **get somewhere**, the pathing code is executed and the character gets from point A to B via a list of waypoints. Considering that, let's re-visit the simple driving game example. In this case, we want to get around a track via a single path which consists of a set of waypoints. When the last waypoint is reached, we simply start over again. So we have a number of considerations: first we need a data structure to represent the waypoints, then we need a motion algorithm that moves the game character in the appropriate manner. Let's discuss these considering the data set shown in Figure 23:21.

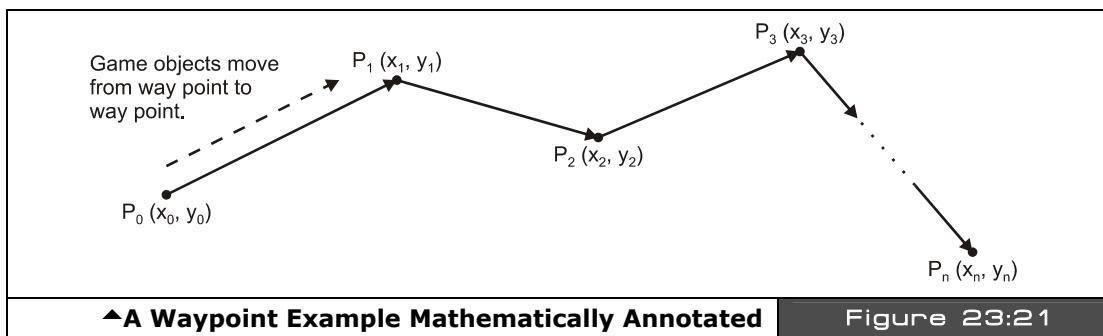


Figure 23:21

The figure depicts a number of waypoints labeled as  $\mathbf{p}_0(x_0, y_0)$ ,  $\mathbf{p}_1(x_1, y_1)$ ,  $\mathbf{p}_2(x_2, y_2)$ , ...,  $\mathbf{p}_n(x_n, y_n)$ . We already have almost all we need to follow the waypoints from one to another, but we need to discuss the details about how the “look and feel” of the motion should be implemented for a racing game. For example, we could use a tracking algorithm that starts the car off at  $\mathbf{p}_0$  and then uses the tracking algorithm to move to  $\mathbf{p}_1$ , once at  $\mathbf{p}_1$ , the tracking algorithm is used to move to  $\mathbf{p}_2$  and so forth. This is a reasonable solution; however, the dynamics of the results won’t look right since cars tend to turn, they don’t make 45° or 90° sudden direction changes plus they slowly accelerate and decelerate. Therefore, we not only have to come up with an algorithm to control the motion, but a physical “**model**” that we plug the control input into.

In the case of a car or racing game, the “model” might be a crude representation of a car’s position, velocity, and other attributes. For example, we might draw a car sprite that has 8 directions only, so visually it can look like its going in 8 different directions. Next, we need a math model of the car which might consist of the following:

- Position:**  $\mathbf{p}(x, y)$
- Direction:** (theta)
- Speed:** (s)

With this model, we would map theta (the angle the car is pointing in) into the 8 visual images of the car sprite. Thus, assuming a 360 circle, each directional change represents 45 degrees. We can compute the trajectory/velocity vector  $\mathbf{v}(vx, vy)$  of the car with the following math:

$$\begin{aligned} vx &= s * \cos(\text{theta}) \\ vy &= s * \sin(\text{theta}) \end{aligned}$$

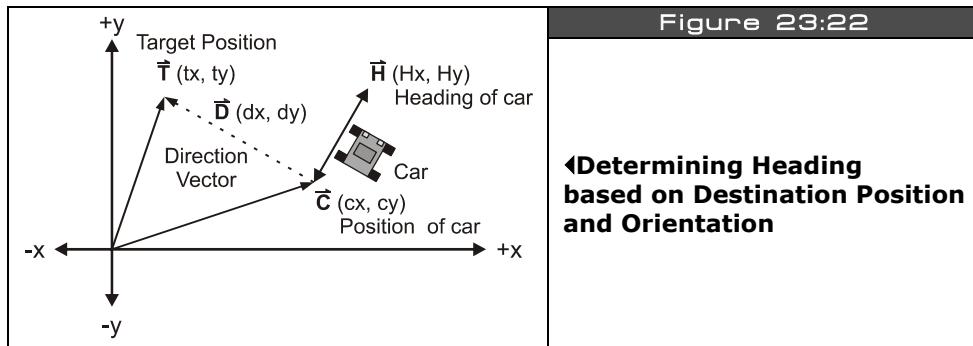
...and then each animation frame we could update the position vector of the car  $p(x,y)$  as follows:

$$\mathbf{p} = \mathbf{p} + \mathbf{v} = (px+vx, py+vy)$$

So far, so good. But, there are a lot of things missing. First, there is no friction, secondly, the car can be pointed in 8 directions, but there is no modeling of the wheels turning to induce a turn with the tail following and so forth. Thus, you can see a lot of work would have to be done to make the car model very realistic (we will discuss modeling in more depth in the physics discussion in the next section). The point is that, aside from the realistic nature of the model, we at least have a model! Next, the question is can we “drive” the model with our waypoints in a more realistic manner than just using the brute force tracking algorithm? The answer is of course yes, with this new model we have the ability to turn the car, then we let the math compute the trajectory of the car. Thus, we want to turn the car toward the waypoint, let the math do its thing, then when we reach the waypoint, we turn the car toward the next waypoint.

Considering that, the problem seems that we need a way to "turn" the car toward any waypoint, which is more or less a vector geometry problem. We need some math that can drive the turning algorithm based on the target waypoint, the current location of the car, and its orientation. Referring to Figure 23:22, we see the setup in terms of vectors:

- t(tx, ty)** – The target position vector, in other words, the waypoint we want to get to.
- c(cx, cy)** – The current position of our car that we want to drive to the target position.
- h(hx, hy)** – The heading vector of the car, that is, what direction it is pointing in currently.
- d(dx, dy)** – The direction vector from the car to the target point we are trying to get to. Note that d is also equal to (t-c).



Looking at the diagram for a moment, the idea is that we want to turn the car toward the target, in other words, we want to make vectors **h** and **d** parallel. One solution to this is to imagine **d** as an infinitely long line, and we want to determine which "side" **h** is pointing to relative to this line, or technically speaking which "half space" or "half plane" **h** is in. For example, in the figure, **h** is to the right, or pointing clockwise of **d**, so we want to turn the car to the opposite direction. Similarly, if **h** was on the left side or counterclockwise side of **d** then we would want to turn the car the other way. Therefore, it looks like if we could just figure out which side of **d** the vector **h** was on, then we simply would turn the opposite way and be done. There are a billion ways to compute this, but one operation that will compute this result is called "**cross product**" denoted by "×" and whose **determinate** is defined by the following formula in 2D space:

$$\mathbf{u} \times \mathbf{v} = (ux, uy) \times (vx, vy) = (ux*vy - uy*vx)$$

...which is a scalar and the sign of which tells us which side  $\mathbf{u}$  is relative to  $\mathbf{v}$ ! Take a look at Figure 23:23 to see some examples to see this for yourself. Now, we take this information and plug it back into our algorithm, so we only need to compute the cross product ( $\mathbf{h} \times \mathbf{d}$ ) and look at its sign to determine which way to turn the car. Putting everything together, we get the following algorithm:

Given we have a vector list of waypoints that make up the track and we have a car located at  $\mathbf{c}$  with a heading  $\mathbf{h}$  that we want to follow the road.

**Step 1:** Create a vector list of waypoints  $\mathbf{p}_0 \dots \mathbf{p}_n$  that make up the track .

**Step 2:** Find the nearest waypoint using a distance calculation, set it as the target vector  $\mathbf{t}$ .

**Step 3:** Compute the cross product ( $\mathbf{h} \times \mathbf{d}$ ), then based on the sign turn the car clockwise or counterclockwise.

**Step 4:** Move the car forward at speed s.

**Step 5:** Test how close car is to waypoint, once a threshold is reached select next waypoint in list and target it, continue simulation until you run out of virtual gas!

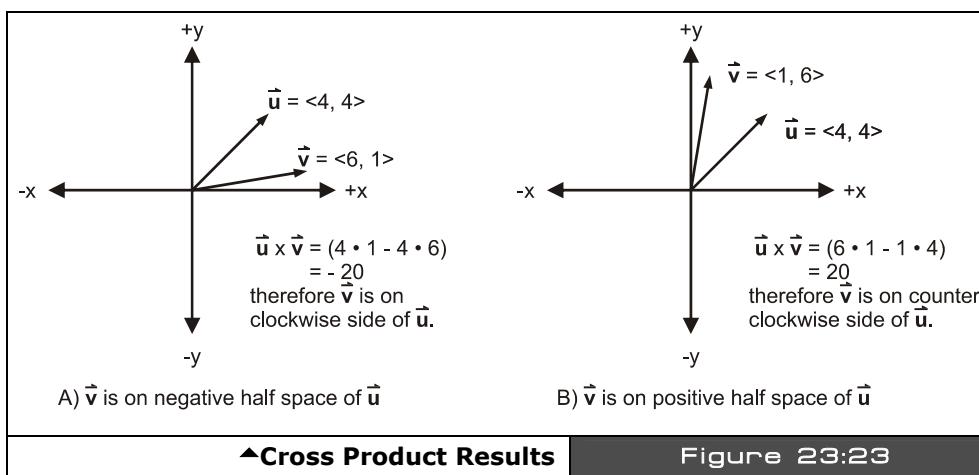


Figure 23:23

## 23.9 Advanced AI Topics

No discussion on AI is complete without some mention of the cutting-edge technologies used in practice and in science fiction! So let's briefly take a look conceptually at what some of the more interesting technologies are.

**INFO**

For interested readers, check out my book *Tricks of the Windows Game Programming Gurus 2nd Edition*, it has one of the most detailed coverages of general AI techniques applied to games including all the subjects below. Also, on the CD in \DOCS\NETWARE, I have placed an introductory article on neural networks you might be interested in perusing.

### 23.9.1 Neural Nets

If any AI technique gets the most press it's "**neural nets**" otherwise known as "**artificial neural networks**." There is nothing artificial about them though. Neural nets or **NNs** as they are called are models loosely (and I mean loosely) based on human neural pathways. The idea behind NNs is to model how our brain cells process information rather than use typical computational models based on predicate logic that computer programs are more commonly based on.

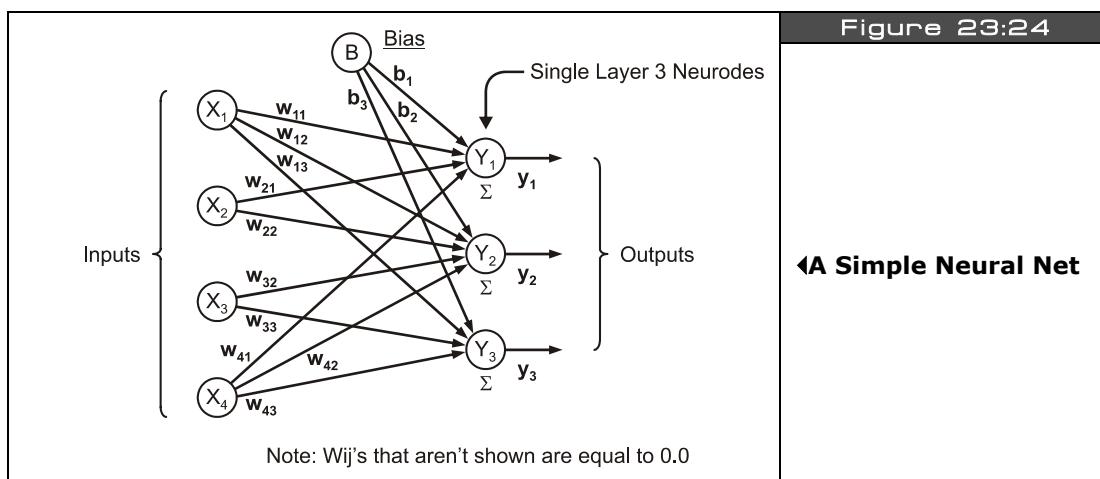


Figure 23:24 shows a typical neural net. As you can see the neural net is represented by a number of inputs and outputs. Each of the nodes or "**neurodes**" process information. But, unlike a computer that performs logical or mathematical operations on the inputs, neural nets take a much more organic point of view. If you have ever studied a little brain biology then you know that each brain cell or **neuron** consists of a **soma** (the main processor), the **axon** (the interface or conduit), and **dendrites** (the I/O ports). Signals come in through the dendrites and are processed by the soma, and sent out through the axon to other neurons.

The interesting thing about the entire process is that it's of course electro-chemical in nature, that is, concentrations of chemicals (primarily sodium, chloride, and potassium) are used to

move charge and send the electrical signals. Information is encoded not as bits or voltages, but by the frequency and concentration of these signals. Neurons process information by thresholding data inputs and outputting data when the threshold is reached. For example, you might have a million neurons that are all good at recognizing circles, and a million that are good at recognizing squares in your visual cortex. Now, a signal comes in from your optic nerve and starts getting processed by the visual cortex. There is no high-level cognition such as "this is a square or circle" that you brain relies on, but it's more of an accumulative operation, the circle and square neurons are all excited and the output of the set with the greatest signal wins. This process continues on adinfinitum until you realize that you are looking at a "**Circle K Stop and Go**" and you are at your destination! So your cognition is ultimately the sum of 10-100 billion little neurons, each without any knowledge of anything, but themselves. Put, them all together and you have an conscious being – you. So we are the sum of billions of nothings that make something – interesting?

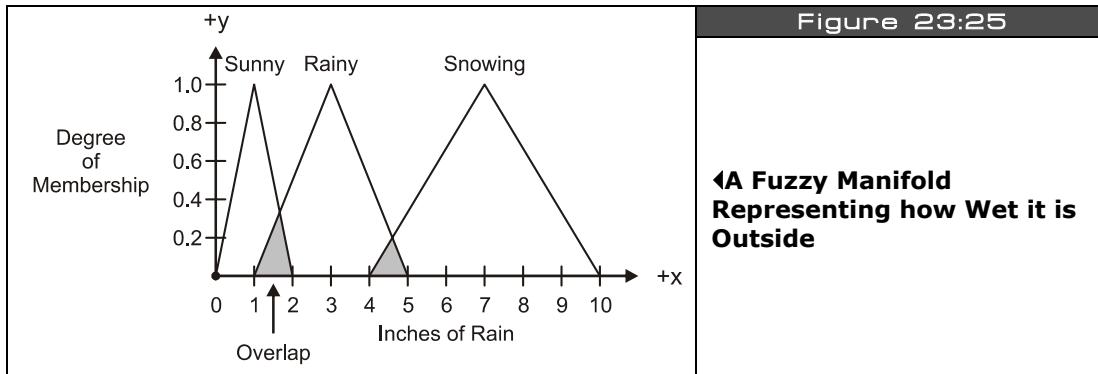
Artificial neural nets try to make an analogy to this, but using computer models. The idea is that we create a network in a computer with nothing more than math (using matrices and vectors primarily), then we excite the network with an input, and then a lot of matrix multiplying goes on (where the numbers in the matrices represent weights in the network and its architecture), and the output of the operations are the "strength" of the results. Thus, neural networks more or less are really good at **pattern recognition** problems, and that's about it. They can take multidimensional data and "separate" it into results. One really common example for artificial neural nets is character recognition. First, a neural net is designed (which really means a lot of numbers and coefficients are arrived at) and that when exciting by a target symbol (a bitmap of a letter for example) causes the network to output a value. Then 26 of these networks are built, and for every input each network is excited, the winner with the highest output is the result and the character is recognized.

### 23.9.2 Fuzzy Logic

**Fuzzy logic** is one of those things that became popular a few years back by the media, books, and even game programmers "discovering" it for the first time. But, like anything else its like hundreds of years old! In fact, neural nets are half a century old! In any case, fuzzy logic is simply a form of mathematics that deals with "**fuzzy set theory**." Fuzzy set theory is a very real method of performing set operations with mathematical objects that have partial containment in the set.

For example, if I created three sets: raining, sunny, and snowing, and asked you to assign today's weather into one of those categories, maybe you could, maybe you couldn't. What if today was partially sunny with light showers? Well, then there is no exact insertion point, thus we might say that today is 80% sunny, and 30% rainy, and 10% snowing, for a total of 120% - which is ok in fuzzy logic! Thus, the idea of fuzzy logic is to have partial set inclusion for inputs and then based on a sequence of operations determine a final output that is crisp. So fuzzy logic takes "**fuzzy**" non-exact inputs and outputs a "**crisp**" signal which can be

used as a final output. Figure 23:25 shows what's called a "**fuzzy manifold**" that represents how the various weather states might overlap.



Fuzzy logic is one of the most powerful AI techniques you can use in games since it's simple to implement and by building a fuzzy controller model you can use a tool(s) to create AI behaviors that are very organic. Moreover, fuzzy controllers are everywhere – from your transmission, to elevator controllers, to traffic lights. Some processors even have fuzzy logic support opcodes like the **Motorola 68HC12**.



### INFO

For interested readers, look on the CD in \DOCS\FUZZY, where I have placed an introductory article on fuzzy logic and a PowerPoint presentation I made on the subject.

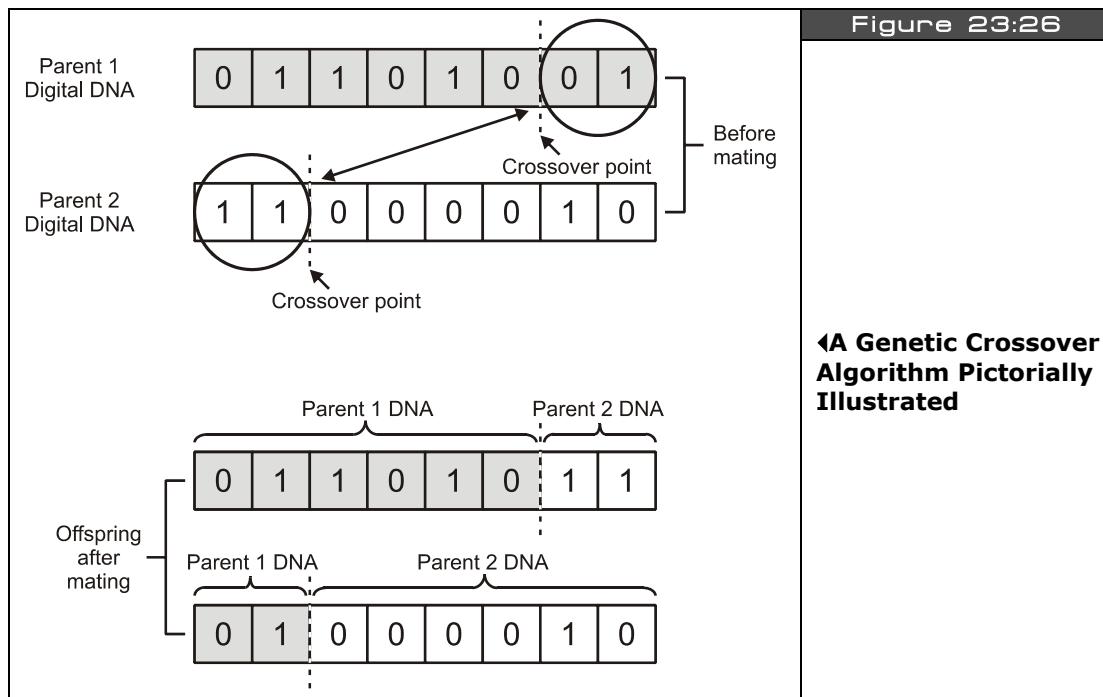
#### 23.9.3 Memory and Learning

**Memory and learning** are nothing more than data logging when it comes to games. For example, say you have an army of bad guys and they are running around in a world looking for the player, food, weapons, whatever. If you don't give them "god-like" knowledge of the map, that is, they only know what they come close to, then memory and learning is very easy to implement. As a simple example, let's say we are making an adventure game, and the game AI characters need to find ammo just like the player does. But, since we are not allowing them to be "god" they can't see through walls, or access the global data base, they only "know" about the rooms they have visited. Thus, as the game AI characters run through the world, they record the amount of ammo and the **time** that they recorded the ammo in any particular room. Then when a game AI passes another game AI in the hallway, they can communicate or "**share**" memories! This is done by summing their knowledge or potentially randomly picking one element from each memory and adding it to the other AI's memory.

However, during the sharing of knowledge, the time stamp on each individual memory is used as a gauge of the validity of the memory. For example, if AI Character 1 saw some ammo in the crystal chamber 5 minutes ago, but AI Character 2 saw that the ammo was gone 1 minute ago, then the smart thing to do is to take the newer information as more valid. Another method is to sum the knowledge using the time stamp as the weighting factor. The possibilities are limitless.

Using this technique, the knowledge and experience of other game AI's can be leverage by each other even if the AI's themselves haven't had the experience. Many times the results of implementing memories in game AI are "**emergent behaviors**," that is, behaviors that were not directly planned or programmed.

#### 23.9.4 Genetic Algorithms



Genetic algorithms are another exciting field of study. The idea is rather simple in theory: computer programs or solutions to problems are looked at as genetic vectors or information. If we have two good solutions to a computer program then isn't it reasonable to think if we "**mate**" these solutions then potentially the offspring might be even better solutions? The

test of how good a solution is based on what's called the "***fitness function***" which is a measure of how well the solution solves the problem (whatever it may be). Sounds crazy? Well, it's one of the most important techniques in AI there are and everything from HALO to your refrigerator cooling cycle might have some genetic algorithms in them. Figure 23:26 shows the process in action: just like in normal biological reproduction one information vector from the father and one information vector from the mother are mated. The mating process consists of selecting a random ***crossover*** point to snip the vectors apart and then re-assembling them. Additionally, just like in nature, genetic algorithms on computers add in random mutations and other disturbances, to give evolution a chance and not drive down the "***best***" path always since "***best***" sometimes might miss "***better***."

The problem though is mapping a "computer program" into some kind of information vector. However, here's a good example to show how this can be done with an Electrical Engineering-based problem for fun. Imagine you have a very complex filter you have designed and the filter has 4 stages. Each stage is constructed of 2 capacitors and 2 resistors. How they are hooked up is irrelevant. All we know is that by experimentation we have found that we get the desired results with the following two vectors **a** and **b** (that represent the values of the capacitors and resistors for each filter solution):

$$\mathbf{a} = ca1, ca2, ca3, ca4, ca5, ca6, ca7, ca8, ra1, ra2, ra3, ra4, ra5, ra6, ra7, ra8$$

$$\mathbf{b} = cb1, cb2, cb3, cb4, cb5, cb6, cb7, cb8, rb1, rb2, rb3, rb4, rb5, rb6, rb7, rb8$$

Now, to mate **a** and **b** all we need to do is select a crossover point on one and then swap genetic material. Of course, in this example, we have to select two crossover points, since we don't want to mix resistors with capacitors, so let's select the following crossover points:

$$\mathbf{a} = ca1, ca2, ca3, \underline{ca4, ca5, ca6, ca7, ca8}, \quad ra1, ra2, ra3, ra4, ra5, ra6, \underline{ra7, ra8}$$

$$\mathbf{b} = \underline{cb1, cb2, cb3}, \quad cb4, cb5, cb6, cb7, cb8, \quad \underline{rb1, rb2, rb3, rb4, rb5, rb6}, \quad rb7, rb8$$

Merging the data, we get two offspring:

$$\mathbf{ab} = \underline{cb1, cb2, cb3, ca4, ca5, ca6, ca7, ca8}, \quad \underline{rb1, rb2, rb3, rb4, rb5, rb6, ra7, ra8}$$

$$\mathbf{ba} = ca1, ca2, ca3, cb4, cb5, cb6, cb7, cb8, \quad ra1, ra2, ra3, ra4, ra5, ra6, rb7, rb8$$

Let's call **ab** "**Jimmy**" and **ba** "**Michelle**." And then we might decide to mutate little Jimmy and Michelle a little as well and come up with yet 2 more variants. Then these variants are tested by the fitness function and, if above a certain threshold of performance, they are saved, else, they are thrown back into the digital oblivion.

Genetic algorithms can be used in games to "learn." Say that you vectorize a parameterization that controls the various state machines of a fighting character AI in a

game. Then you play the AI 1,000 times and let it learn from you by updating its control vector by means of a genetic algorithm. Then after 1,000 plays or so, the evolved AI can beat you, but you didn't have to program it directly, you simply played it to learn! This is exactly how many fighting games work. They come with a few dozen (or hundred) canned AI's and when you play the character many levels over and over, the AI will learn your techniques and be able to adapt to your personal game play. Thus, the game experience is different for everyone.



INFO

Check out Dr. Koza's *Genetic Programming* as well as *Turtles, Termites, and Traffic Jams* by Resnick. Both will blow your mind...

## 23.10 Physics Modeling



Figure 23:27

◀Half Life 2 in Action

**"Physics modeling"** as it pertains to video game development is the modeling of game object behaviors by using real-world physical models or approximations thereof. In the past, computers didn't have the horsepower needed to perform realistic physics models for games, but today many games show off amazing physics. One of my favorites is **Half Life 2** by **Valve**. This game not only has some of the most realistic physics modeling in a video game, but when objects have real physics, the game takes on a life of its own. Objects interact with each other in permutations you could never imagine. Plus, it's a lot of fun heaving refrigerators at enemies using the "zero point energy" weapon!

We aren't going to create physics engines even 1/100<sup>th</sup> as advanced as those seen in Half Life 2 (since they took over 10 years and \$25M in R&D), but we are going to create physics models that are based on real-world physics and math. I have chosen a set of commonly

used physics models in games: motion, gravity, friction, and projectiles, to showcase some of the ideas. Now, before we get started, here's two things to remember: first these models are quick and dirty to get the job done, and secondly we are simulating physics response in discrete time, that is, time is continuous in the real-world, but in the computer it's quantized. More accurate physics simulators take this into consideration, but in our case we are going to think of a single frame as a unit of "time" and our simulations will run accordingly. Before we start let's review a few physics concepts in case you are rusty. Although we don't really care about units of measure in a computer program (since it's all virtual anyway), at least having some review of these units and their relationships will help glue the concepts together as we explore them.

### 23.10.1 Basic Units of Measure

Let's briefly introduce the concepts of mass and time. Although everyone knows what time is, many people don't exactly know what "mass" is; they confuse it with weight. So just to make sure we are all on the same page, let's review these two important concepts and their relationship to games.

#### 23.10.1.1 Mass (m)

All matter has mass. Mass is a measure of how much matter is present. It doesn't have anything to do with weight. Many people have mass and weight confused. For example, they might incorrectly say that they weigh 75 kilograms (165 pounds on Earth). First, kilograms (kg) are a metric measure of mass, that is, how much matter, while pounds (lbs.) is a measure of force or more loosely weight (mass in a gravity field). The measure of weight or force in the metric system is called a Newton (N). Furthermore, matter has no weight per se, it only can be acted upon by a gravitational field to produce what we refer to as weight. Hence, the concept of mass is a much more pure idea than weight (which changes from planet to planet).

In games, the concept of mass is only used abstractly in most cases as a relative quantity. For example, I might set the spaceship equal to 100 mass units and the asteroid equal to 10,000. I could use kilograms, but unless I am doing a real physics simulation then it really doesn't matter. All I need to know is an object that has a mass of 100 has twice as much matter as an object that has 50 mass units. I'll revisit mass in a bit when I talk about force and gravity, but that should be enough to give you a feel for it. Mass is the measure of how much matter an object is made of and is measured in kilograms in the metric system or – ready for this – "**slugs**" in the English system!

#### 23.10.1.2 Time (t)

Time is one of the most abstract concepts to comprehend. Think about it. How would you explain time without using time itself in the explanation? Time is definitely an impossible concept to convey without using circular definitions and a lot of hand waving. Luckily,

everyone knows what time is, so I won't go into it, but I do want to talk about how to relate to time in a game.

Time in real life is usually measured in seconds, minutes, hours, and so forth. Or if you need to be really accurate then it's measured in milliseconds (ms,  $10^{-3}$  seconds), microseconds ( $\mu\text{s}$ ,  $10^{-6}$ ), nano ( $10^{-9}$ ), pico ( $10^{-12}$ ), femto ( $10^{-15}$ ), etc. However, in most video games there isn't a really close correlation to real time. Algorithms are designed more around the frame rate than real-time seconds (except for time-modeled games). For example, most games consider one frame to be one virtual second, or in other words, the smallest amount of time that can transpire. Thus, most of the time you won't use real seconds in your games and your physics models, but virtual seconds based on a single frame as the fundamental time step.

On the other hand, if you're creating a really sophisticated 3D game then you probably will use real time. All the algorithms in the game track real-time and, invariant of the frame rate, adjust the motion of the objects so that say a tank is moving 100 feet per second even if the frame rate slows down to 2 fps or runs at 60 fps. Modeling time at this level of accuracy is challenging, but absolutely necessary if you want to have ultra realistic motion and physical events that are independent of frame rate changes. In any case, we'll measure time in seconds (s) in the examples or in virtual seconds which simply means a single frame.



#### NOTE

For the physics readers with us: if time was really continuous we could never move forward in time, thus time must be discrete and quantum in nature similar to matter and space. What do you think?

### 23.10.2 Kinematic Motion Concepts

The study of objects in motion is called "kinematics". And this is what we are keenly interested in when it comes to games. The three quantities that we want to really get a handle on are **position** (s), **velocity** (v), and **acceleration** (a). Based on these concepts we can introduce others in a civilized manner.

#### 23.10.2.1 Velocity (v)

Velocity is the instantaneous rate of speed of an object and is usually measured in meters per second m/s or in the case of the automobile miles per hour or mph. Whatever units you prefer, velocity is the change in position **s** per change in time **t** or mathematically in a 1 dimensional case:

$$\text{Velocity} = v = ds/dt.$$

In other words the instantaneous change in position (ds) with respect to time (dt). As an example, say you are driving down the road and you just drove 100 miles in one hour then your average velocity would be:

$$v = ds/dt = 100 \text{ miles}/1 \text{ hour} = 100 \text{ mph.}$$

In a video game the concept of velocity is used all the time, but again the units are arbitrary and relative. For example, in a number of the demos I have written thus far I usually move objects at some rate, say  $\mathbf{v}=(4,4)$  in the X and Y axis per frame, with code something like:

```
x_position := x_position + x_velocity;
y_position = y_position + y_velocity;
```

That translates to 4 pixels/frame. But frames aren't time are they? Actually, they are as long as the frame rate stays constant. In the case of 30 fps which is equal to 1/30 seconds per frame the 4 pixels/frame translates to:

$$\begin{aligned}\text{Virtual Velocity} &= 4 \text{ pixel} / (1/30) \text{ seconds} \\ &= 120 \text{ pixels per second.}\end{aligned}$$

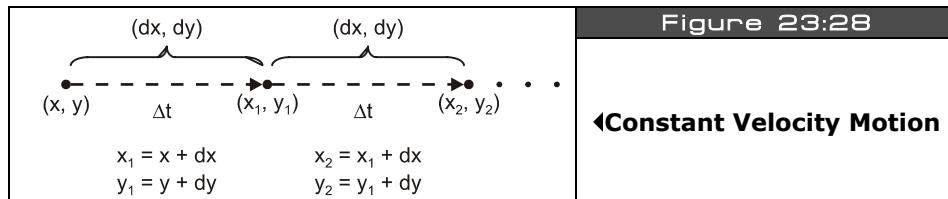
Hence, the objects in our game have been moving with velocities that can be measured in pixels/second if we wanted to work out the math. Then if you wanted to get crazy then you could estimate how many virtual meters were in one pixel in your game world and do the computation in meters/second in cyberspace. In either case, now you know how to gauge where an object will be at any give time or frame if you know the velocity. For example, if an object was currently at position  $x_0$  and it was moving at 4 pixels/frame, when 30 frames go by the object will be at:

$$\text{New Position} = x_0 + 4 * 30 = x_0 + 120 \text{ pixels.}$$

This leads us to our first important basic law:

$$\begin{aligned}\text{New Position} &= \text{Old Position} + \text{Velocity} * \text{Time} \\ &= x_t = x_0 + v*t.\end{aligned}$$

...which states that an object moving with velocity  $\mathbf{v}$  that starts at location  $x_0$  and moves for  $t$  seconds will move to the position equal to its original position plus the velocity times the time. Take a look at Figure 23:28 to see this more clearly.



### 23.10.2.2 Acceleration (a)

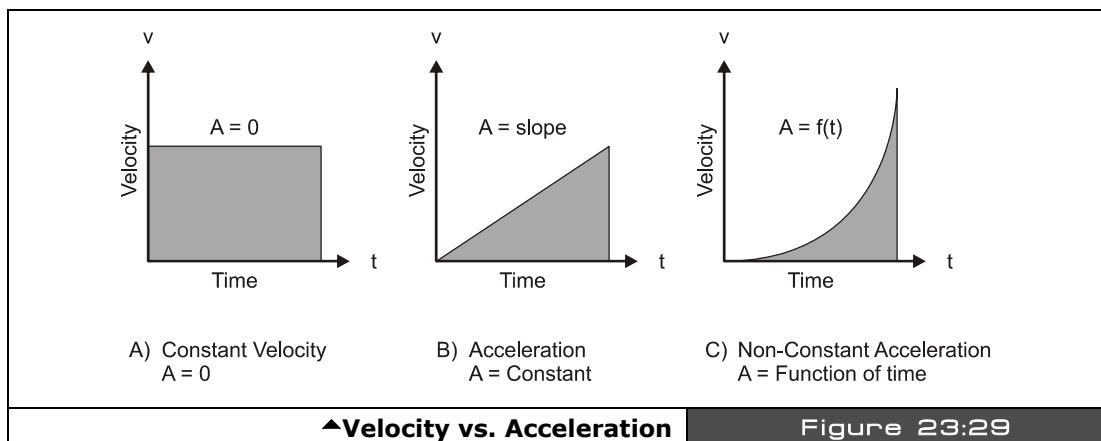


Figure 23:29

Acceleration is similar to velocity, but it is the measure of the rate of change of velocity rather than the velocity itself. Take a look at Figure 23:29, it illustrates an object moving with a constant velocity as well as with a changing velocity. The object moving with a constant velocity has a flat line (slope of 0) for its velocity as a function of time, but accelerating objects have non-zero slopes since their velocities are changing as a function of time.

Figure 23:29(B) illustrates constant acceleration. There is also non-constant acceleration. In this case the line would be a curve in Figure 23:29(C). Pressing the accelerator in your car will give you the feeling of non-constant acceleration, while jumping off a cliff will give you the feeling of constant acceleration (gravity). Mathematically, acceleration is the rate of change of velocity with respect to time or:

$$\text{Acceleration} = a = dv/dt.$$

The units of acceleration are a little weird also. Since velocity is already in units of distance per second, acceleration is in units of distance per second\*second or in the metric system  $\text{m/s}^2$ . If you think about this it makes sense since acceleration is the change of velocity ( $\text{m/s}$ ) per second. Furthermore, our second motion law relates the velocity, time, and acceleration:

$$\begin{aligned}\text{New Velocity} &= \text{Old Velocity} + \text{Acceleration} * \text{Time} \\ &= v_t = v_0 + a*t.\end{aligned}$$

...which states that the new velocity at some time  $t$  in the future equals the starting velocity plus the acceleration times the amount of time the object has been accelerating for.

Acceleration is a fairly simple concept and can be modeled in a number of ways, but let's take a look at a simple example. Imagine that an object is located at (0,0) and it has a starting velocity of 0. If we were to accelerate it at a constant velocity of 2 m/s then we could figure out the new velocity each second simply by adding the acceleration to the last velocity as shown in Table 23:2.

| <b>Table 23:2</b>   |   |                           |
|---|---|---------------------------|
| <b>Velocity as a Function of Time for Acceleration 2 m/s<sup>2</sup>▼</b> |   |                           |
| <b>Time (t = s)</b>   | <b>Acceleration (a = m/s<sup>2</sup>)</b> | <b>Velocity (v = m/s)</b> |
| 0   | 2   | 0                         |
| 1   | 2   | 2                         |
| 2   | 2   | 4                         |
| 3   | 2   | 6                         |
| 4   | 2   | 8                         |
| 5   | 2   | 10                        |

Taking the data in the table into consideration, the next step is to figure out the relationship among position, velocity, acceleration, and time. This takes a bit of Calculus, but even if you don't know Calculus you should be able to follow along since the derivation makes a lot of sense intuitively. Forgetting acceleration for a moment, we know that position is equal to initial position plus velocity multiplied by time:

$$x_t = x_0 + v \cdot t.$$

What this equation really does in the discrete case is "add up" the change in distance each unit of time  $t$ . Thus, position is really the time sequence sum of changes in distance. In other words this leads us to the fact that position is the integral of velocity. And we know that velocity is equal to:

$$v_t = v_0 + a \cdot t.$$

Thus,

$$x_t = \int v_t \cdot dt = \int (v_0 + a \cdot t) \cdot dt$$

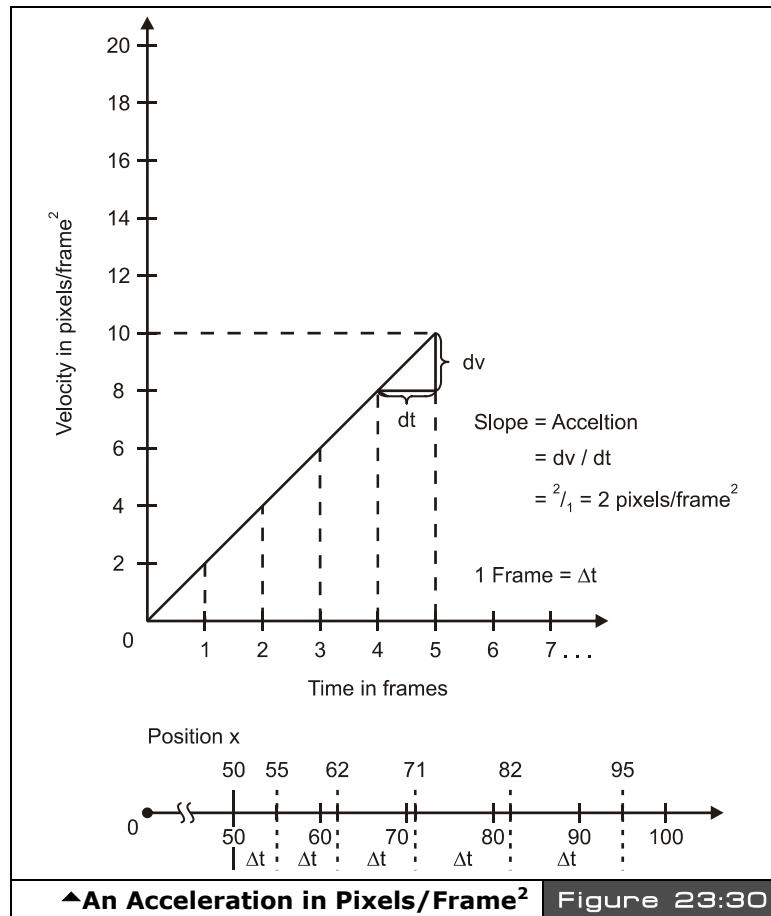
Integrating this, results in:

$$x_t = x_0 + v_0 \cdot t + 1/2 \cdot a \cdot t^2.$$

...where  $x_0$  is technically the constant of integration which happens to be the initial position of the object. Thus, the formula above is the final piece of the puzzle that relates position, velocity, and acceleration. This equation states that the position of an object at some time  $t$  is equal to its initial position plus its initial velocity times time plus one half the acceleration times time squared. The  $1/2*a*t^2$  term is basically the time integral of the velocity. Also, we don't have to use the entire formula if some of the terms are 0. For example, if the acceleration is 0, then the formula reduces to:

$$x_t = x_0 + v_0 * t$$

Let's see if we can use the equation in our game world of pixels and frames. Take a look at Figure 23:20 for an example:



Assume these initial conditions: the object is at  $x=50$  pixels, the initial velocity is 4 pixels/frame, and the acceleration is 2 pixels/frame<sup>2</sup>. Finally, assume that these are the conditions at frame 0. Then to find the position of the object at any time in C/C++, here's what you would do:

$$x = 50 + 4*t + (0.5)*2*t*t;$$

Where t is simply the frame number. Table 23:3 lists some examples for  $t = 0, 1, 2, \dots, 5$ .

| <b>Table 23:3</b>                                   |                           |   |
|---|---------------------------|---|
| <b>An Object Moving With Constant Acceleration▼</b> |                           |   |
| <b>Time/Frame (t)</b>                               | <b>Position (x)</b>       | <b>Delta(x)=x<sub>t</sub> - x<sub>t-1</sub></b> |
| <b>0</b>  | 50                        | 0   |
| <b>1</b>  | $50+4*1+(0.5)*2*1^2 = 55$ | 5   |
| <b>2</b>  | $50+4*2+(0.5)*2*2^2 = 62$ | 7   |
| <b>3</b>  | $50+4*3+(0.5)*2*3^2 = 71$ | 9   |
| <b>4</b>  | $50+4*4+(0.5)*2*4^2 = 82$ | 11  |
| <b>5</b>  | $50+4*5+(0.5)*2*5^2 = 95$ | 13  |

There's a lot of interesting data in the table, but maybe the most interesting data is that the change in position each time frame is constant and equal to 2. Now this doesn't mean that the object moves 2 pixels per frame, it means that the change in motion each frame gets larger by 2 pixels. Thus on the first frame the object moves 5 pixels, then on the next frame it moves 7, then 9, 11, then 13, and so on. And the delta between each change in motion is 2 pixels which is simply the acceleration!

Although we have been modeling acceleration in many of our demos, let's look at it more formally and how we have been doing it. First, you set up an acceleration constant and then each frame you add it to your velocity, basically modeling:

$$v_t = v_0 + a*t.$$

This way you don't have to use the long equation which is in terms of position. Then you simply translate your object with the resulting velocity as a second step. Here's an example:

```
long acceleration, velocity, x
long acceleration = 2    ' 2 pixels per frame
long velocity      = 0    ' start velocity off at 0
long x             = 0    ' start x position of at 0 also

{ then you would execute this code each cycle to move your object with a constant
acceleration }
```

```
' update velocity
velocity += acceleration

' update position
x += velocity
```

In essence, the program is integrating the position formula since it's running in time and computing 1 frame increments.



### NOTE

Of course this example is 1 dimensional. You can upgrade to 2 dimensions simply by adding a y position (and y velocity and acceleration if you wish).

#### 23.10.2.3 Force (F)

One of the most important concepts in physics is **Force**. Figure 23:31 depicts one way to think of force. An object with mass  $m$  is sitting on a table with gravity pulling it toward the center of the Earth; the acceleration is  $a=g$  (force of gravity). This gives the mass  $m$  weight and hence if you try to pick it up then you will feel resistance. The relationship between force, mass, and acceleration is defined by **Newton's Second Law**:

$$F = m \cdot a.$$

In other words, the force exerted on an object is equal to its mass times the acceleration of the object. Or rearranging terms:

$$a = F/m$$

...which states that an object will accelerate an amount equal to the force you place on it divided by its mass. Now let's talk about the units of measure. But, instead of just blurting it out, let's see where it comes from in the metric system at least. Force is equal to mass times acceleration or kg's multiplied by  $m/s^2$  ( $m$  stands for meters not mass). Hence, a possible unit of force is:

$$F = kg \cdot m/s^2 \text{ or "Force equals kilograms times meters per second squared"}$$

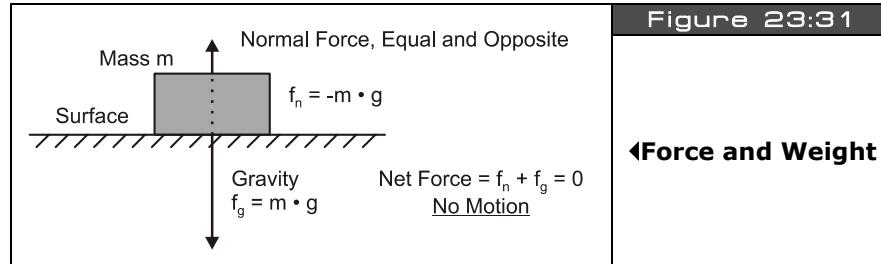
This is a bit long, so after Isaac Newton, we just call it – **Newton (N)**. As an example, imagine that a mass  $m$  equal to 100 kg is accelerating at a rate of  $2 m/s^2$  then the force that is being applied to the mass is exactly equal to:

$$F = m \cdot a = 100 \text{ kg} \cdot 2 \text{ m/s}^2 = 200 \text{ N.}$$

This gives you a bit of a feel for a Newton. A 100 kg mass is roughly equivalent to the force of 220 lbs. on Earth, and  $1 m/s^2$  is the acceleration of a small motorized vehicle like a moped

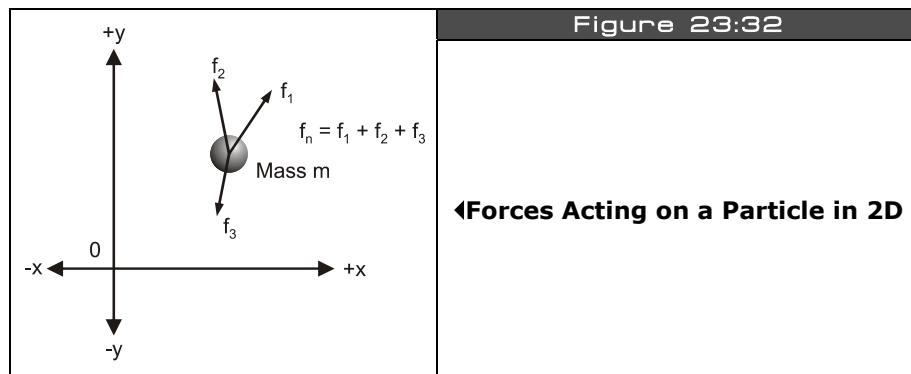
where anything over 3-4 m/s<sup>2</sup> is like a race car accelerating away. In a video game the concept of force is used for many reasons, but a few that come to mind are:

- ▶ You want to apply artificial forces like explosions to an object and compute the resulting acceleration.
- ▶ Two objects collide and you want to compute the forces on each.
- ▶ A game weapon only has a certain force, but it can fire different virtual mass shells and you want to find the acceleration they would feel on firing.



#### 23.10.2.4 Forces in Higher Dimensions

Of course forces can act in all three dimensions, not just in a straight line. For example take a look at Figure 23:32, it depicts 3 forces acting on a particle in a 2-D plane. The resulting force that the particle p “feels” is simply the sum of the forces that are acting on it. However, in this case it's not as simple as adding scalar numbers together since the forces are vectors. Nevertheless, vectors can be de-composed into components and then the forces acting in each axis can be computed. The result is the sum of the forces acting on the particle.



In the example shown in Figure 23:32 there are 3 vector forces:  $\mathbf{F}_1$ ,  $\mathbf{F}_2$ ,  $\mathbf{F}_3$ . The final force  $\mathbf{F}_{\text{final}} = \langle f_x, f_y \rangle$  that object p feels is simply the sum of these forces in component form:

$$\begin{aligned} f_x &= f_{1x} + f_{2x} + f_{3x} \\ f_y &= f_{1y} + f_{2y} + f_{3y} \end{aligned}$$

With that in mind, it doesn't take much to deduce that in general; the final force F on an object is just the vector sum of forces, or mathematically:

$$\mathbf{F}_{\text{final}} = \mathbf{F}_1 + \mathbf{F}_2 + \dots + \mathbf{F}_n$$

Where each force  $\mathbf{F}_i$  can have 1, 2, or 3 components, that is, each vector can be a 1D (scalar), 2D, or 3D.

### 23.10.2.5 Momentum (P)

Momentum is one of those quantities that's hard to define verbally. It's basically the property that objects in motion have. Momentum was invented as a measure of both the velocity and mass of an object. Momentum is defined as the product of mass (m) and the velocity (v) of an object:

$$p = m * v.$$

...and the units of measure are kg\*m/s, kilogram times meters per second. Now the cool thing about momentum is its relationship to force – watch this:

$$F = m * a$$

or substituting p for m:

$$F = (p * a) / v$$

But,  $a = dv/dt$ , thus:

$$F = \frac{p * dv/dt}{v} = \frac{d(p) * v}{dt * v} = dp/dt$$

Thus, force is the time rate change of momentum per unit time. Hmm – interesting. That means if the momentum of an object changes a lot then so must the force acting on the object. Now, here's the clincher. An apple can have as much momentum as a train – how? An average apple has mass of 0.200 kg while a train made of 20 cars might have the mass of about 100,000 kg. But, if the train is going 1 m/s and the apple is moving 1,000,000 m/s (that's one fast apple) then the apple will have more momentum:

$$\begin{aligned} m_{\text{apple}} * v_{\text{apple}} &= 0.200 \text{ kg} * 1,000,000 \text{ m/s} = 200,000 \text{ kg*m/s} \\ m_{\text{train}} * v_{\text{train}} &= 100,000 \text{ kg} * 1 \text{ m/s} = 100,000 \text{ kg*m/s} \end{aligned}$$

And thus if either of these objects came to an abrupt stop, hit something for example, that object would feel a whole lot of force, in other words *energy transfer!* That's why a fat bumblebee hitting you on a motorcycle is so dangerous. It's not the mass of the bee, but the velocity of the bee that gets you (or rather the relative velocity of the bike). Combined the momentum is huge and can literally throw a 200 lb. guy off the bike.

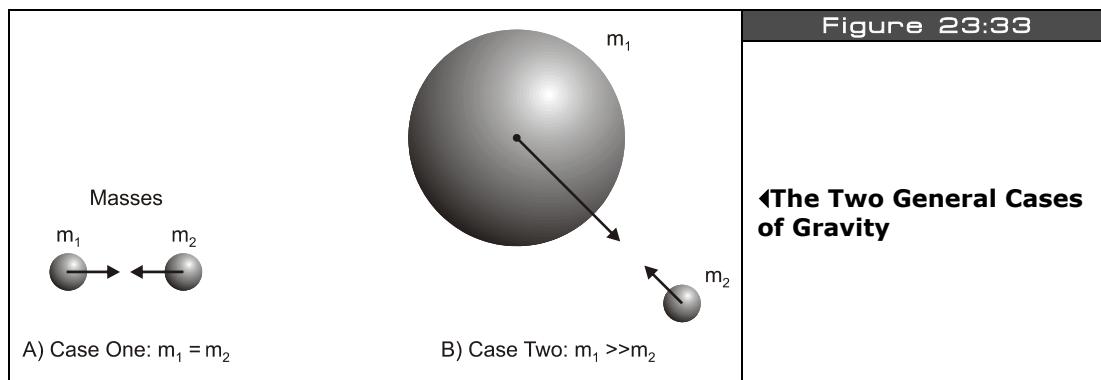
### 23.10.2.6 Kinetic Energy

This shotgun physics review wouldn't be complete without some mention of "**kinetic energy.**" To start, energy is the ability to perform **work**. Work is **force times distance** and **power** is **work done per unit time**. So the bottom line is "energy" is the ability to transform a system, that's the best I can put it. In any case, when objects are in motion, they possess kinetic energy since if there were to ever stop it would result in energy transfer (heat and friction usually). The equation for kinetic energy for a mass  $m$  moving at a velocity  $v$  is:

$$ke = \frac{1}{2} * m * v^2$$

...and momentum was just  $m * v$ , so you see kinetic energy is very similar. In fact, it's the integral of momentum which makes sense. Additionally, "energy" is always positive and measured in  $\text{kg} * \text{m}^2/\text{s}^2$  which in the Meter-Kilogram-Second system we just call **Joules (J)**. Alright, now the cool part is that the kinetic energy of any closed system is always the same before and after any collisions, changes, etc. This fact can help you compute velocities after a collision for example since the total kinetic energy of a closed system must **never** change, never. Well, that's about it for our little physics review, let's put the knowledge to use with some cool demos!

### 23.10.3 Gravity and Friction (Demo)



Gravity and friction are both forces, thus cause accelerations. Therefore, gravity and friction are simply special cases of general forces that occur so commonly we simply named them. Gravity in the general sense is what keeps us on the ground. It's the force between the mass of the planet Earth and each mass on the surface (like you). There are really two cases that you need to consider when modeling gravity, these are shown in Figure 23:33:

**Case 1:** Two or more objects with relatively the same mass

**Case 2:** Two objects where the mass of one object is much greater than the other

Case 2 is really a sub-case of Case 1. For example, in school you may have learned that if you drop a baseball and a refrigerator off a building they will both fall at the same rate. The truth of the matter is they do *not!* But the difference is so infinitesimal (on the order  $10^{-24}$ ) that you could never see the difference. Of course, there are other forces that might make a difference like wind shear and friction, hence, a baseball is going to fall faster than a piece of paper since the paper is going to feel a lot of wind resistance. The gravitational force between any two objects with mass  $m_1$  and  $m_2$  is:

$$F = G * m_1 * m_2 / r^2.$$

...where  $G$  is the gravitational constant of the universe equal to  $6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2 \cdot \text{kg}^{-2}$ . Also, the masses must be in kg and the distance  $r$  in meters. So let's try out an example, say that you want to find out what the gravitational attraction is between two average sized people of 70 kg (155 lbs.) at a distance of 1 meter:

$$F = 6.67 \times 10^{-11} * 70 \text{ kg} * 70 \text{ kg} / (1 \text{ m})^2 = 3.26 \times 10^{-7} \text{ N}.$$

Not even a micro Newton, that's not much is it? However, let's try the same experiment with a person and the planet Earth at 1 meter given the Earth has a mass of  $5.98 \times 10^{24} \text{ kg}$ :

$$F = 6.67 \times 10^{-11} * 70 \text{ kg} * 5.98 \times 10^{24} \text{ kg} / (1 \text{ m})^2 = 2.79 \times 10^{16} \text{ N}.$$

Obviously,  $10^{16}$  Newtons would crush you into a pancake, so we must be doing something wrong? The problem is that we are assuming that the Earth is a point mass that is 1.0 meters away. A better approximation would be to use the radius of the Earth (the center of mass) as the distance which is  $6.38 \times 10^6 \text{ m}$ :



MATH

You may assume that any spherical mass of radius  $r$  is a point mass as long as the matter the sphere is made of is homogenous and any calculations must place the other object at a distance greater than or equal to  $r$ .

$$\begin{aligned} F &= 6.67 \times 10^{-11} * 70 \text{ kg} * 5.98 \times 10^{24} \text{ kg} / (6.38 \times 10^6 \text{ m})^2 \\ &= 685.93 \text{ N}. \end{aligned}$$

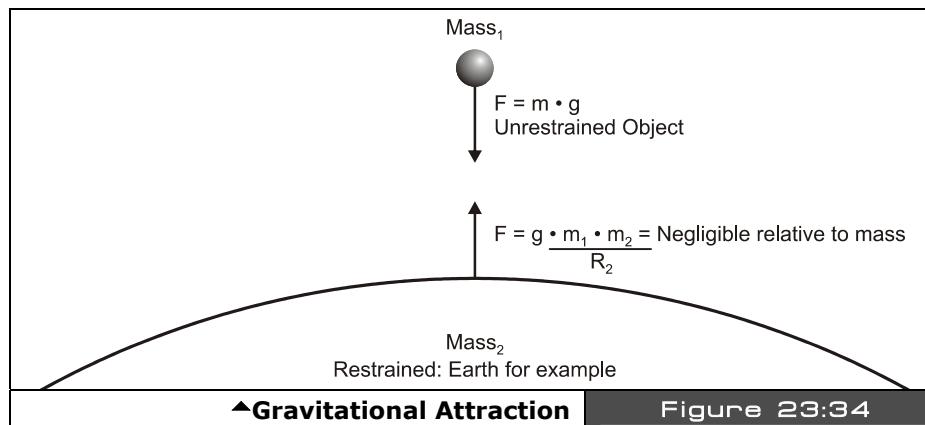
Now that seems more reasonable. As a sanity check, on Earth 1 lb. is equal to 4.45 N, so converting the force to lbs., we have:

$$685.93 \text{ N} / (4.45 \text{ N} / 1 \text{ lb.}) = 155 \text{ lb.}$$

...which was the starting weight! Anyway, now that you know how to compute the force between two objects you can use this simple model in games. Or course, you don't have to use the real gravity constant  $G = 6.67 \times 10^{-11}$ , you can use whatever you like – remember you are "god" in your game world. The only thing that is important is the form of the equation which states that the gravity between two objects is proportional to a constant times the product of their masses divided by the distance squared between the objects' centers, that's all the matters. Moreover, you can even simplify more by making  $G=1$  in your calculations.

Using the above formulation is the key to modeling a black hole in a space game. For example, you might have a ship that is flying around on the screen and you have black holes (or planetoids) on the screen and you want the ship to get sucked in if it gets too close. Using the above equation it's a snap. You would make up a constant  $G$  that worked well in the virtual game world (based on screen resolution, frame rate etc.) and then simply set an arbitrary mass for the ship and one for the black hole that was much larger. Then you would figure out the force and then convert the force to acceleration with  $F=m*a$ , that is,  $a = F/m$ . Then you would simply vector the ship directly toward the black hole each frame. As the ship got closer the force would increase until the player couldn't get free! We will actually see this in a demo shortly.

The next use of gravity in games is to simply make things fall from the sky or off buildings at the proper rate. This is really the special case that we talked about before, that is, one object has a mass much greater than the other. However, there is one more constraint and that is that one object is fixed – the ground. Take a look at Figure 23:34; it depicts the situation that I am describing.



▲Gravitational Attraction

Figure 23:34

### 23.10.3.1 Modeling Gravity

In this case, there are a number of assumptions that we can make that will make the math work out easier. The first is that the acceleration due to gravity is constant for the mass that is being dropped which is equal to  $9.8 \text{ m/s}^2$  or  $32 \text{ ft/s}^2$ . Of course, this isn't really true, but true enough to about 23 decimal places. Hence, if we know that the acceleration of any object is simply  $9.8 \text{ m/s}^2$  then we can just plug that into our old motion equation for velocity or position. Thus, the formula for velocity as a function of time with Earth gravity is:

$$v(t) = v_0 + 9.8 \text{ m/s}^2 * t.$$

...and position is:

$$y(t) = y_0 + v_0 * t + 1/2 * 9.8 \text{ m/s}^2 * t^2.$$

In the case of a ball falling off a building we can let the initial position  $y_0$  be equal to 0 and the initial velocity  $v_0$  also 0. This simplifies the falling object model to:

$$y(t) = 1/2 * 9.8 \text{ m/s}^2 * t^2.$$

Furthermore, you are free to change the constant 9.8 to anything you like and  $t$  represents the frame number (virtual time) in a game which is coupled to frame rate. Taking all that into consideration, here's some pseudo-code showing how to make a ball fall from the top of the screen:

```
long y_pos, y_velocity, gravity

y_pos      := 0 ' top of screen
y_velocity := 0 ' initial y velocity
gravity    := 1 ' do want to fall too fast (at 60 fps will be 1 pixel/sec*sec)

' perform gravity loop until object hits bottom of screen at SCREEN_BOTTOM
repeat while (y_pos < SCREEN_BOTTOM)
    ' update position
    y_pos += y_velocity

    ' update velocity due to gravity by constant acceleration
    y_velocity += gravity
```



**TIP** I used the velocity to modify the position rather than modifying the position directly with the position formula. This is an easier calculation.

You may be asking how to make the object fall with a curved trajectory? This is simple, just move the x position at a constant rate each cycle and the object will seem as if it was thrown off rather than just dropped. The code to do this is:

```

long y_pos, x_velocity, y_velocity, gravity

y_pos      := 0 ' top of screen
y_velocity := 0 ' initial y velocity
x_velocity := 2 ' initial x velocity      (constant)
gravity     := 1 ' do want to fall too fast (at 60 fps will be 1 pixel/sec*sec)

' perform gravity loop until object hits bottom of screen at SCREEN_BOTTOM
repeat while (y_pos < SCREEN_BOTTOM)
    ' update position
    x_pos += x_velocity
    y_pos += y_velocity

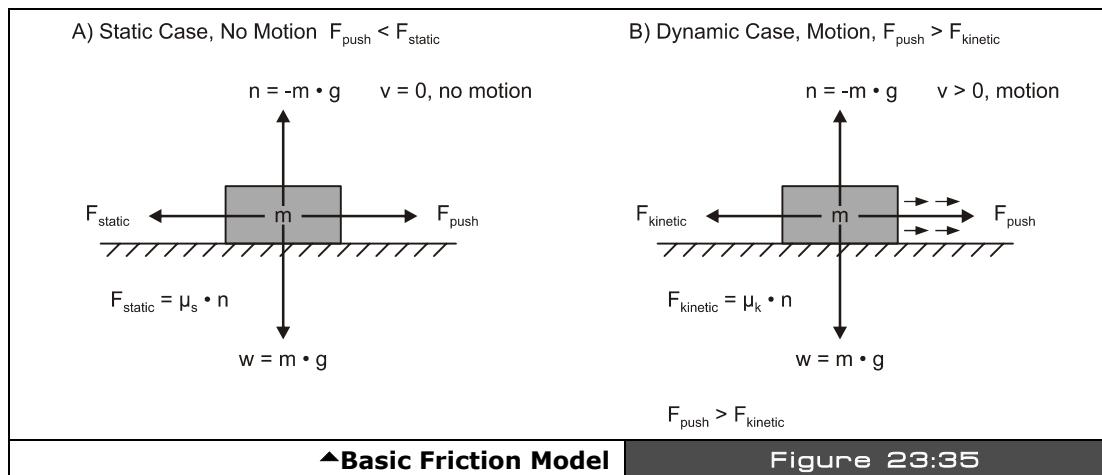
    ' update velocity due to gravity by constant acceleration
    y_velocity += gravity

```

Of course, sign convention is very important with these models. You have to keep track of what is up, what is down, the coordinate system you are using, and be consistent!

### 23.10.3.2 Modeling Friction

The next topic of discussion is friction. **Friction** is any force that retards or consumes energy from another system. For example, automobiles use internal combustion to operate; however, a whopping 30-40% of the energy that is produced is eaten up by thermal conversion or mechanical friction. On the other hand, a bicycle is about 80-90% efficient and probably is the most efficient mode of transportation in existence. But, the most efficient form of transportation is a significant other who drives you everywhere!



Friction is basically resistance in the opposite direction of motion and hence can be modeled with a force usually referred to as the frictional force. Take a look at Figure 23:35, it depicts the standard frictional model of a mass  $m$  on a flat plane. If you try to push the mass in a direction parallel to the plane you will encounter a resistance or frictional force that pushes back against you. This force is defined mathematically as:

$$F_{\text{static}} = m * g * \mu_s$$

...where  $m$  is the mass of the object,  $g$  is the gravitational constant (9.8 m/s<sup>2</sup>) and  $\mu_s$  is the static frictional coefficient of the system which depends on the conditions and materials of the mass and the plane. If the force  $F$  you apply to the object is greater than  $F_{\text{static}}$  then the object will begin to move. Once the object is in motion then its frictional coefficient usually decreases to another value which is referred to as the coefficient of kinetic friction  $\mu_k$ .

$$F_{\text{kinetic}} = m * g * \mu_k$$

Then when you release the force, the object will slowly decelerate and come to rest since friction is always present. To model friction on a flat surface all you need to do is apply a constant negative velocity to all your objects that is proportional to the friction that you want. Mathematically, we have:

$$\text{Velocity New} = \text{Velocity Old} - \text{friction}$$

The results of this will be objects that slow down at a constant rate once you stop moving them. Of course, you have to watch out for letting the sign of the velocity go negative or in the other direction, but that's just a detail. Here's an example of an object that is moved to the right with an initial velocity of 16 pixels per frame and then slowed down at a rate of 1 pixel per frame due to virtual friction:

```
long x_pos, x_velocity, friction

x_pos      := 0   ' starting position
x_velocity := 16  ' starting velocity
friction   := -1  ' frictional value

' move object until velocity <= 0
repeat while (x_velocity > 0)
    ' move object
    x_pos += x_velocity;

    ' apply friction
    x_velocity+=friction;
```

The first thing you should notice is how similar the model for friction is to gravity. They are identical almost. This isn't luck. The truth is that both gravitational forces and frictional forces act in the same way. In fact, all forces can be modeled in the exact same way, we just like to

name things! Also, you can apply as many frictional forces to an object as you wish. Just sum them up vectorially.

### 23.10.3.3 Space Demo

As an example of modeling thrust, friction, gravity, and what we have learned thus far, take a look at Figure 23:36, it depicts **SPACE\_DEMO\_001.SPIN** running. This demo can be found in the **\SOURCES** directory and is based on the previous Parallaxaroids demo as a starting point. The demo illustrates a number of concepts we have discussed and integrates them all together. First, there is the ship which is controlled by the mouse. Move the mouse right/left to rotate the ship, and use the **<RIGHT>** mouse button to engage the thrusters. The **<LEFT>** mouse button toggles the asteroid field which is not part of the simulation and the physics models don't apply to them (they are in a quantum time flux).



As you play, you will notice 3 animating stars, these are actually black holes or suns, or whatever you want to call them. But, the bottom line is they have really strong gravity modeled with the gravity formula. Additionally, it's assumed there is a bit of friction, so if you fly the ship around and release the thruster, the ship will slowly come to a stop. The entire model is executed each frame and the resulting response controls the ship's motion. The model is rather straightforward, but when converted to fixed-point math to support the accuracy needed, the code becomes a little ugly. Nevertheless, it's well commented and you should be able to experiment with it. The entire program is too long to list, but below is an excerpt of the physics modeling section.

```
' all calculations for ship thrust and position model are performed in fixed point math
if (mouse.button(THRUST_BUTTON_ID))
    ' compute thrust vector, scale down cos/sin a bit to slow ship's acceleration
    thrust_dx := SinCos(COS, ship_angle) ~> 1
    thrust_dy := SinCos(SIN, ship_angle) ~> 1

    ' apply thrust to ships current velocity
    ship_dx += thrust_dx
```

```

    ship_dy += thrust_dy

    ' apply friction model, always in opposite direction of velocity
    ' frictional force is proportional to velocity, use power of 2 math to save time
friction_dx := -ship_dx ~> SPACE_FRICTION
friction_dy := -ship_dy ~> SPACE_FRICTION

    ' apply the friction against the ships current velocity
ship_dx += friction_dx
ship_dy += friction_dy

    ' now compute the acceleration toward the black hole, model based on F = (G*M1*M2)/r^2
    ' in other words, the force is equal to the product of the two masses times some constant G divided
    ' by the distance between the masses squared. Thus, we more or less need to accelerate the ship
    ' toward the black hole(s) proportional to some lumped constant divided by the distance to the
    ' black hole squared...
    ' sum the accelerations up (resulting in velocity changes to the ship)
repeat i from 0 to NUM_BLACK_HOLES-1
    ' compute each force direction vector d(dx,dy) toward black hole, so we can compute its length
    dx := (black_x[i]) - (ship_x ~> 16)
    dy := (black_y[i]) - (ship_y ~> 16)
    r_squared:=(dx*dx+dy*dy)  ' no need to compute length r, when we are going to use r^2 in a moment

    ' now compute the actual force itself, which is proportional to accel
    ' which in this sim will be used to change velocity each frame
    f := ((GRAVITATIONAL_CONSTANT * black_gravity[i]) << 9) / r_squared

    ' f can be thought of as acceleration since its proportional to mass
    ' which is virtual and can be assumed to be 1
    ' thus we can use it to create a velocity vector toward the black hole now in the direction
    ' of the vector d(dx, dy)
    dx := dx << 16 ' convert to fixed point
    dy := dy << 16

    ' compute length of d which is just r, careful to compute fixed point values properly
    r := (^^(r_squared << 16)) ' square root operation turns 16.16 into 24.8

    ' normalize the vector and scale by force magnitude
    dx := f*((dx / r) << 8)
    dy := f*((dy / r) << 8)

    ' update velocity with acceleration due to black hole
    ship_dx += dx ~> 3
    ship_dy += dy ~> 3

    ' clamp maximum velocity, otherwise ship will get going light speed due to black holes
    ' when the distance approaches 0!
dx := (ship_dx ~> 16)
dy := (ship_dy ~> 16)

    ' test if ship velocity greater than threshold
v := ^^(dx*dx + dy*dy)

    ' perform comparison (to squared max, to make math easier)
if (v > MAX_SHIP_VEL)
    ' scale velocity vector back approx 1/8th
    ship_dx := MAX_SHIP_VEL*(ship_dx / v)
    ship_dy := MAX_SHIP_VEL*(ship_dy / v)

    ' finally apply the velocity to the position of the ship

```

```

ship_x += ship_dx
ship_y += ship_dy

' screen bounds test for player
if (ship_x > (SCREEN_WIDTH/2)<<16)
    ship_x -= SCREEN_WIDTH<<16
elseif (ship_x < (-SCREEN_WIDTH/2)<<16)
    ship_x += SCREEN_WIDTH<<16

if (ship_y > (SCREEN_HEIGHT/2)<<16)
    ship_y -= SCREEN_HEIGHT<<16
elseif (ship_y < (-SCREEN_HEIGHT/2)<<16)
    ship_y += SCREEN_HEIGHT<<16

```

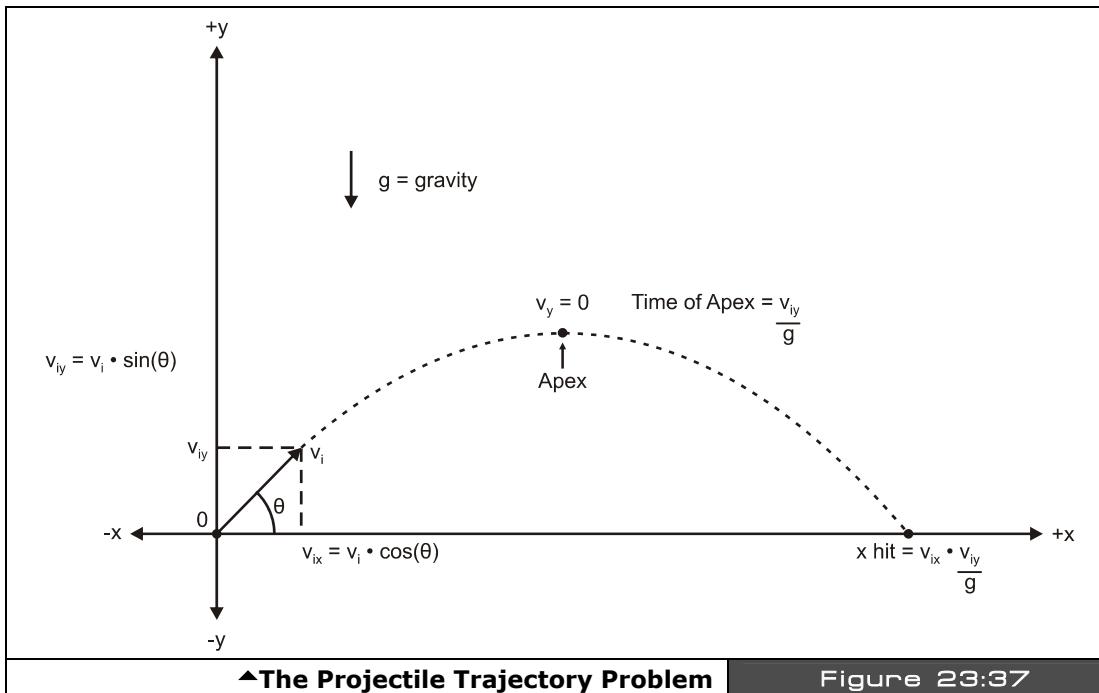
The physics modeling section begins with applying the thrust from the engines. This is modeled as increasing the velocity of the ship due to the thrust acceleration. Next, comes the friction modeling section which is interesting since the frictional vector direction must be in the opposite direction of the ship's motion. Thus, first the ship's velocity vector has to be normalized and then this is used for the direction to apply the retarding frictional force (which results in a decrease in velocity).

Next, comes the contribution of the black holes. A loop sums the forces up from each black hole that is exerted on the ship. Then based on the vector from the ship to each black hole, the acceleration is computed and then the velocity updated, driving the ship toward each black hole the appropriate amount. Finally, at the end of the code we test for maximum velocity and clamp it as well as test for off -the-screen boundaries and wrap the ship around.

This example physics model is rather complete and contains everything you need to model quite a bit of interesting physical phenomena in your games (including racing games like **Atari Sprint**). Probably the most irritating thing is the support of fixed-point math to perform the calculations and keeping track of all the shifting operations. This can lead to errors. One important thing to remember in Spin is that when performing a shift right make sure to use the "`~>`" or "`~~>`" operators to shift WORDs and BYTEs respectively and maintain the sign bits. Anyway, play with the demo, try changing the simulation constants and see what you can make happen.

#### 23.10.4 Projectile Modeling

Falling objects are fairly exciting, but let's see if we can do something a little more appropriate for video game programming. With that in mind, let's work out how to compute trajectory paths since shooting things is the main goal in most games! Take a look at Figure 23:37 on the next page, here you see the general setup for the problem. We have a ground plane, call it  $y=0$ , and a tank located at  $x=0$ ,  $y=0$ , with a barrel pointed at an angle of inclination  $\theta$  (theta) with the X-axis. The question is, if we fire a projectile with mass  $m$  at with initial velocity  $v_i$  then what will happen?



We can solve the problem by breaking it up into its X-Y components. First, let's break the velocity into an (x,y) vector:

$$v_{ix} = v \cdot \cos \theta$$

$$v_{iy} = v \cdot \sin \theta$$

This is nothing more than using plane geometry and resolving the opposite and adjacent sides of the triangle formed by the vector trajectory. Ok, now forget about the x part for a minute, and think about the problem in the Y-axis alone. The projectile is going to go up and down and hit the ground. How long will this take? Take a look at our previous gravity equations:

$$v(t) = v_0 + 9.8 \text{ m/s}^2 \cdot t.$$

And position for the Y-axis is:

$$y(t) = y_0 + v_0 \cdot t + \frac{1}{2} \cdot 9.8 \text{ m/s}^2 \cdot t^2.$$

The first one tells us the velocity relative to time. That's what we need. We know that when the projectile reaches its maximum height, the velocity will be equal to 0. Furthermore, the amount of time that the projectile takes to reach this height will be the same amount of time it takes to fall to the ground again (referring to Figure 23:37). Therefore, plugging in our values for initial y velocity of our projectile and solving for time t, we have:

$$v_y(t) = v_{iy} - 9.8 \text{ m/s}^2 * t$$

Note, I flipped the sign of the acceleration due to gravity since down is negative and matters in this case. And in general when the velocity equals 0:

$$0 = v * \sin \theta - a * t \text{ (a is just the acceleration)}$$

Solving for time t:

$$t = v_{iy} * (\sin \theta) / a$$

Alright, now the total time of flight is simply the time up added to time down which equals  $t+t = 2*t$  since the projectile must go up then down. Therefore, we can revisit the x component now. We know that the total flight time is  $2*t$  and we can compute t from  $(v_{iy} * (\sin \theta) / a)$ , therefore, the distance that the projectile travels in the X-axis is just:

$$x(t) = v_{ix} * t$$

...which plugging in our values is:

$$x_{hit} = (v * \cos \theta) * (v * (\sin \theta) / a)$$

...or:

$$x_{hit} = v_{ix} * v_{iy} / a$$

Of course, this is only helpful if you need to know where the trajectory will wind up. However, there are many cases where this is important. Say you have an AI character that is shooting at a player, the AI can instantly gauge where a projectile will hit and adjust its weapons accordingly.



MATH

Note that I replaced the 9.8 value of acceleration with a. I did this to reinforce that the acceleration is just a number, and you can make it whatever you wish.

Now, that's the physics behind everything, but how to model it in a program? Well, all you do is apply constant X-axis velocity to the projectile and gravity in the Y-axis and test for when the projectile hits the ground or something else. Of course, in real life the X and Y velocities would diminish due to air resistance, but throwing that out the algorithm I just described

works great. Here's some C/C++ pseudo-code to do it since Spin doesn't support floating-point directly and fixed-point makes the math so ugly for this example:

```
// Inputs
float x_pos      = 0,           // starting point of projectile
      y_pos      = SCREEN_BOTTOM, // bottom of screen
      y_velocity = 0,           // initial y velocity
      x_velocity = 0,           // constant x velocity
      gravity    = 1,           // do want to fall too fast
      velocity   = INITIAL_VEL, // whatever
      angle      = INITIAL_ANGLE; // whatever, must be in radians

// compute velocities in x,y
x_velocity = velocity*cos(angle);
y_velocity = velocity*sin(angle);

// do projectile loop until object hits
// bottom of screen at SCREEN_BOTTOM
while(y_pos < SCREEN_BOTTOM)
{
    // update position
    x_pos += x_velocity;
    y_pos += y_velocity;

    // update velocity
    y_velocity += gravity;
} // end while
```

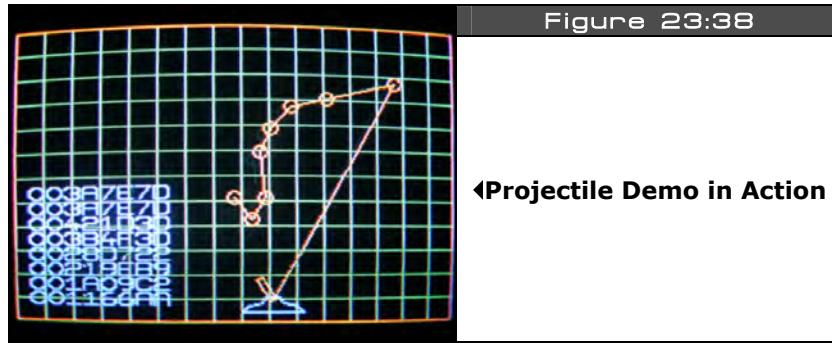
That's all there is to it! And of course we can add more forces like "wind". We would just model it as a small acceleration in whatever direction we wanted (usually a crosswind in the X-axis). Assuming that the wind force creates a constant acceleration against the projectile, you simply need to add this line of code in the projectile loop:

```
x_velocity := x_velocity - wind_factor
```

Where **wind\_factor** would be something like 0.01, something fairly small, so wind doesn't blow everything too much.

#### 23.10.4.1 Projectile Demo

As a demo of the projectile implementation and modeling, check out the file **PROJECTILE\_DEMO\_001.SPIN** located on the CD in **\SOURCES**. This demo is one of the most impressive HYDRA demos in my opinion since it shows off real-time physics modeling with the Propeller chip and simply looks really cool as shown in Figure 23:38. In the demo, you are in control of a base turret that can move right to left as well as rotate the turret. Additionally, you can control the initial velocity or energy of the projectiles as well. The demo has some rather complex controls and uses the gamepad.

**Gamepad controls:**

- <RIGHT>** Move turret base right
- <LEFT>** Move turret base left
- <A>** Rotate turret cannon clockwise (right)
- <B>** Rotate turret cannon counter-clockwise (left)
- <START>** Fire projectile
- <UP>** Increase initial velocity of projectile
- <DOWN>** Decrease initial velocity of projectile
- <SELECT>** Toggle through various display modes including velocity magnitudes, and chain linked mode

The demo starts off in full display mode where it prints the magnitude of all projectiles bottom to top, and chains all the projectiles together. To get the program to speed up, toggle the display modes with **<SELECT>** until only the turret and the projectiles render. Try increasing or decreasing the initial velocity of the projectiles with **<UP>/<DOWN>** as well as firing them at the ground. It's a lot of fun!

The demo itself contains a variety of interesting physics modeling including projectile trajectory as well as collision, wind, and tactics to determine when objects are at rest. For example, when you fire a projectile, how do you determine when it's at rest? Your first inclination might be to say when its x,y velocity are both equal to 0. This is **wrong!** This is not necessarily an indication that the projectile is at rest on the ground. For example, when the projectile is shot straight up, there is a moment when it is suspended in midair at the apex of its trajectory. Thus, testing for zero total velocity or momentum isn't enough, since while suspended in the air with its net velocity equal to 0, the projectile has "**potential**" energy. Thus, the complete test strategy is to test that the projectile is on the ground ( $y=0$ ) and there is no momentum. These are the kinds of details that you have to work out when

physics modeling. Many times your intuition might be wrong, but the physics never lie. Thus, it's counterintuitive that if the momentum is zero the projectile is at rest, but in the example above we realized that the projectile has potential energy due to its position above the ground at the apex of its trajectory straight up and down.

These types of problems are where the real fun of physics modeling comes in, that is, making all the "corner cases" work in the simulation, so the model not only looks real, but works and doesn't get "stuck." In any event, the simulation loop of the projectile is shown below and it's quite a bit simpler than the space demo physics model:

```

' projectile physics
repeat i from 0 to NUM_PROJS-1
    ' process each projectile
    if (proj_state[i] == 1)
        ' apply acceleration of gravity to y component of velocity
        proj_yv[i] := proj_yv[i] + GRAVITY

        ' apply acceleration due to wind force to x component of velocity
        proj_xv[i] := proj_xv[i] + WIND

        ' apply velocity to projectile
        proj_x[i] := proj_x[i] + proj_xv[i]
        proj_y[i] := proj_y[i] + proj_yv[i]

        ' test for collisions with walls, every collision absorbs some percentage of the energy that
        ' decreases the momentum of the ball. this is due to the inelastic collision, and heat that is
        ' produced to deform the ball and friction of the surfaces, this way the ball will
        ' come to rest, thus step 1 is to compute the collision, step 2 is to decrease velocity a bit
        if ((proj_x[i] => SCREEN_WIDTH << 16) or (proj_x[i] <= 0))
            ' reflect ball
            proj_xv[i] := -proj_xv[i]

            ' apply velocity to projectile
            proj_x[i] := proj_x[i] + proj_xv[i]
            proj_y[i] := proj_y[i] + proj_yv[i]

            ' now model energy loss due to collision, all of it will be lumped into "FRICTION"
            proj_xv[i] := (proj_xv[i] * FRICTION) ~> 8
            proj_yv[i] := (proj_yv[i] * FRICTION) ~> 8

        if ((proj_y[i] => SCREEN_HEIGHT << 16) or (proj_y[i] <= (PROJ_MASS << 16)))
            ' reflect ball
            proj_yv[i] := -proj_yv[i]

            ' apply velocity to projectile
            proj_x[i] := proj_x[i] + proj_xv[i]
            proj_y[i] := proj_y[i] + proj_yv[i]

            ' now model energy loss due to collision, all of it will be lumped into "FRICTION"
            proj_xv[i] := (proj_xv[i] * FRICTION) ~> 8
            proj_yv[i] := (proj_yv[i] * FRICTION) ~> 8

        ' test for "dead ball", we need to compute the magnitude of the velocity is 0 AND
        ' the ball is at rest at bottom of screen
        if ( ||(proj_y[i] ~> 16) <= PROJ_MASS and
            (((proj_xv[i]~>8 * proj_xv[i]~>8) + (proj_yv[i]~>8 * proj_yv[i]~>8)) < EPSILON) )
            proj_state[i] := 0

```

The simulation loop begins by applying gravity to each projectile, then applying wind to the projectile. Both of these forces are modeled as velocity changes per frame. Next, the velocity of the projectile is used to translate it to its next location discretely. Let's take a quick aside for a moment. There is a problem with this approach and collision detection. The problem is that we are moving the projectile discretely through space based on 1 second or 1 frame intervals, but we are not examining what is happening "between" these discrete jumps. That is, maybe the projectile hit something as it instantly warped through space. This is a serious problem in high-end physics simulations! The trick is to "**project**" trajectories from each discrete time step and compute if there is even the remote possibility of collision, if not, then the discrete step can be taken. Otherwise, the point in between where the discrete step is missing the event must be computed and dealt with.

Moving on, after the projectile is translated in the code, then the collision response tests are made with the bounding box of the screen. If there is a collision then we simply invert the velocity and then re-apply the translation transformation (this helps to "push back" the projectile if it pierced the surface impossibly during its motion). Finally, the last test is a bit nasty. It's the "dead ball" test that checks if the projectile is not moving. We need to test both the total velocity vector as well as the position of the ball. If the ball is at the bottom of the screen and not moving, then it's a "dead ball" and is removed from the simulation queue.

Finally, the initial conditions of the projectile are the position of the turret's barrel base and the initial velocity, calculated with the following code:

```
' find an available project
repeat i from 0 to NUM_PROJS-1
    if (proj_state[i] == 0)
        initialize the projectile
        proj_state[i] := 1 ' set to active

    ' compute initial position base/turret position, convert to fixed point as well
    proj_x[i] := base_x << 16 ' since turret is mounted at base_x, base_y
                                and projectile would start its trajectory at this interface
    proj_y[i] := (base_y + base_yoff) << 16

    ' now compute initial trajectory (note sin/cos already in fixed point format)
    proj_xv[i] := (turret_power+(11-PROJ_MASS))*SinCos(COS, turret_angle)
    proj_yv[i] := (turret_power+(11-PROJ_MASS))*SinCos(SIN, turret_angle)
    quit
elseif (gp.button(NES0_START)==0) ' debounce fire button
    fire_debounce := 0
```

The code searches for an available projectile then initializes it to the physics model we discussed in the sections above for trajectory velocity. Notice the use of the **turret\_power** and **PROJ\_MASS** in the model scaling. These are used to give "reasonable" initial results visually. Note that the larger **turret\_power** is, the faster the projectile, but the larger the **PROJ\_MASS** the slower the projectile. These parameters as well as others can be found in the constants section of the code.

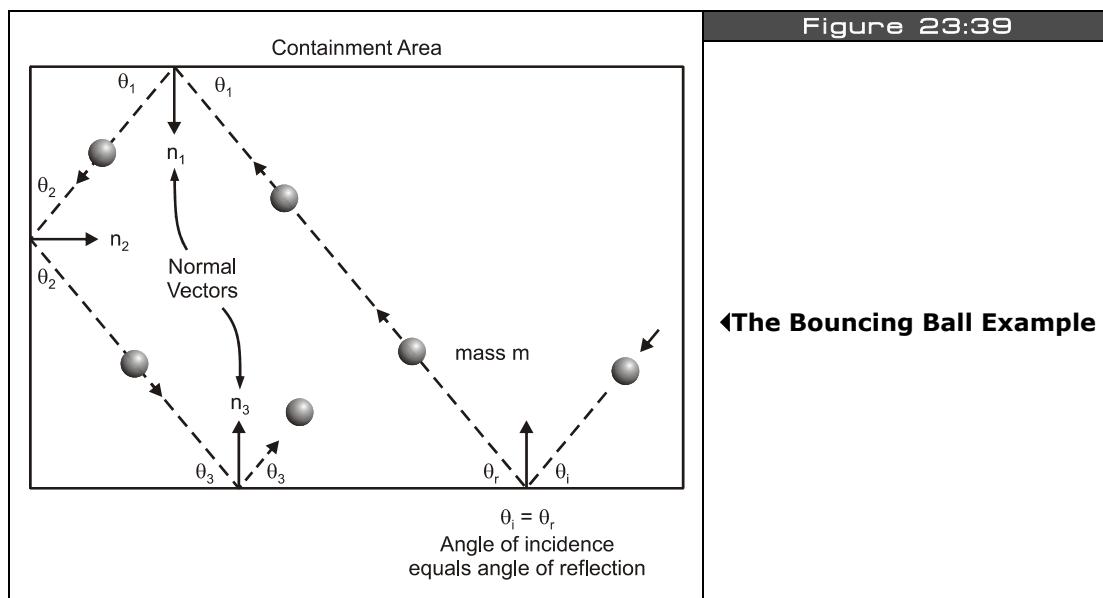
Also, I apologize for all the fixed-point math, but it's a necessary evil. I have tried to make the calculations lengthy to show all steps, but some optimizations were necessary, thus some steps of the physics simulation will be a little hard to follow. However, ignore scaling and shifting, and try to focus on what the code is generally trying to accomplish by reading the comments.

Lastly, the demo uses some interesting rendering techniques for the polygon meshes such as vector lists that describe the shape of the base and turret. These polygon meshes are transformed each frame, and linked together using relational positioning, thus the turret moves with the base, the turret rotates relative to the base. But, both the base and the turret cannon are defined in their own local coordinate system.

## 23.11 Collision Detection Techniques

Video games are about doing everything fast and collision is no exception. The problem is that if you approach it in the wrong way you can easily hit a computational wall that is quadratic or even cubic (in other words for  $n$  objects, on the order of up to  $n^3$  calculations have to be performed!). So in this section we are going to look at some common methods used in basic 2D collision detection algorithms and finish off with some advanced "***spatial partitioning***" techniques for building "divide and conquer" algorithms to compute collisions.

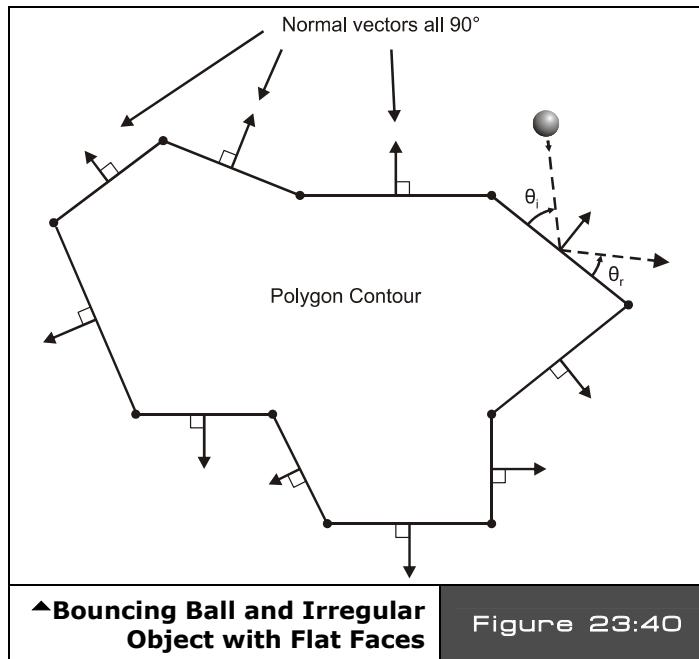
### 23.11.1 Simple Reflections



Take a look at Figure 23:39, it depicts a fairly common collision problem in games, that is bouncing an object off the boundaries of the screen which we have done many times. Given the object has initial velocity ( $xv,yv$ ), the object can hit any of the 4 sides of the screen. When a ball hits one of the sides then it always reflects off the side at an angle equal and opposite to its initial trajectory as shown in Figure 23:39. Although we have just stated the problem in terms of angles of incidence and reflection, the bottom line is if the object hits a wall to the east or west then we want to reverse its X velocity while leaving its Y velocity alone. And similarly on the north and south walls, we want to reverse the Y velocity and leave the X velocity alone. Here's the code which we have seen in one form or another before:

```
' given the object is at x,y with a velocity if xv,yv
' test for east and west wall collisions
if (x > EAST_EDGE || x < WEST_EDGE)
    xv=-xv ' reverse x velocity

' now test for north and south wall collisions
if (y > SOUTH_EDGE || y < NORTH_EDGE)
    yv=-yv ' reverse y velocity
```



Of course, this simplification only works well for horizontal and vertical barriers. You'll have to use the more general angle calculation for walls or barriers that aren't co-linear with the X and Y axes. This brings us to the more general problem of how to solve the collision of a ball and a barrier that has a surface at any orientation.

For example, take a look at Figure 23:40, it shows an irregular shaped object with the property that all the sides are flat facets. The question is how to bounce a ball off this type of object?

To solve this problem we have to look macroscopically at one of the collisions at any orientation. The ball comes in at the angle of incidence  $\theta_i$  and reflects at the angle of reflectance  $\theta_r$ . Now, the interesting thing is that  $\theta_i = \theta_r$  relative to the "**normal**" of the surface (which is the perpendicular). Thus, if we turn the problem into a general vector problem and represent the trajectory of the ball as a vector and the plane of the surface as a vector (flat on the screen in 2D), then we should be able to do some vector math to compute the final trajectory for a ball hitting a surface on any orientation.

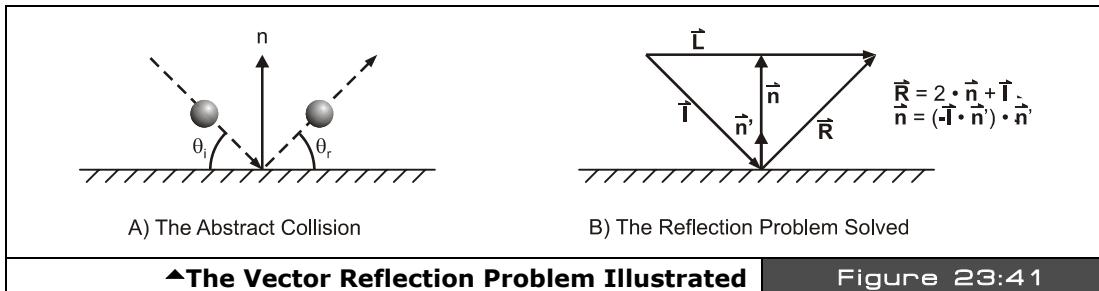


Figure 23:41 shows the setup for the solution of the problem at hand. Given that the ball is traveling along the vector  $i$  and the normal to the surface is  $n$  and  $n'$  (unit vector) and we want to find  $r$ , then a little vector algebra gives us the following results:

$$n = (-I \cdot n') * n'$$

That is, the vector  $n$  in the diagram is equal to  $-i$  dot  $n'$  times  $n'$ , then

$$r = 2 * n + i$$

Let's try this result for the X-axis. If we want to collide with the X-axis, then the normal to the X-axis is the Y-axis, which means  $n' = <0,1>$ , and let's say that our incidence or trajectory vector  $i = <4,-2>$ , that is, moving right and down on a normal Cartesian coordinate system. Common sense tells us that the trajectory vector's Y-component would be inverted in the collision resulting in  $<4,2>$ , let's see what the math says:

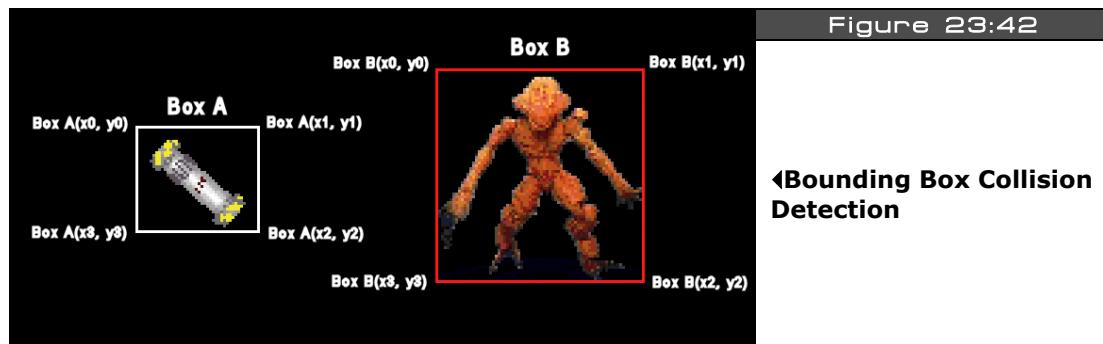
The resulting reflectance vector  $r$  is:

$$\begin{aligned} r &= 2 * n + i \\ &= 2 * (-I \cdot n') * n' + i \\ &= -2 * (<4,-2> \cdot <0,1>) * <0,1> + <4,-2> \\ &= -2 * (4 * 0 + -2 * 1) * <0,1> + <4,-2> \\ &= 4 * <0,1> + <4,-2> \\ &= <4,2> \end{aligned}$$

Therefore, you can use this construction when you want to collide a point mass with any irregularly-shaped object. Of course, when balls hit balls the collision response is much more complex, you have to take into consideration the mass of each ball, the trajectory and so forth. This is beyond the scope of this book, but for most purposes in a video game when two objects collide **A** and **B** you can momentarily represent object **A** by a bounding rectangle with flat sides (or a multisided object), then represent object **B** as a single point, then perform the collision calculation to find the response of **A**, then redo the problem with **A** and **B** swapped to find the response of **B**. Furthermore, you can use the mass of **A** and **B** (virtual mass) to adjust how much the trajectory of each will change. The object with larger mass and larger momentum will not change trajectory as much as the object with smaller mass and smaller momentum.

### 23.11.2 Rectangle/Bounding Box Collision Determination

If you play a lot of games, I am sure you have been blown up countless times by a missile that didn't hit you. Similarly, I am sure you have fired at something, hit it visually, but missed. How can these things happen? Well, the problem with collision detection in games is that true **pixel accurate** collision detection is too costly computationally on small systems. To perform pixel accurate collision detection with bitmap objects you would literally have to logically AND the bitmaps together row by row and test if there was any overlap, this a huge amount of computation. Thus, faster methods are usually employed such as **bounding box collision detection**.



Referring to Figure 23:42, two game objects are shown with bounding boxes drawn around them. Although the game objects themselves might have a lot of detail, the bounding boxes are rough estimates of the area covered by each object. To test for collision the bounding boxes themselves are tested for overlap. This is an easy operation and can be carried out in a number of ways. For example, one method is to test each point from box A to see if it's within box B. This test might look like:

```

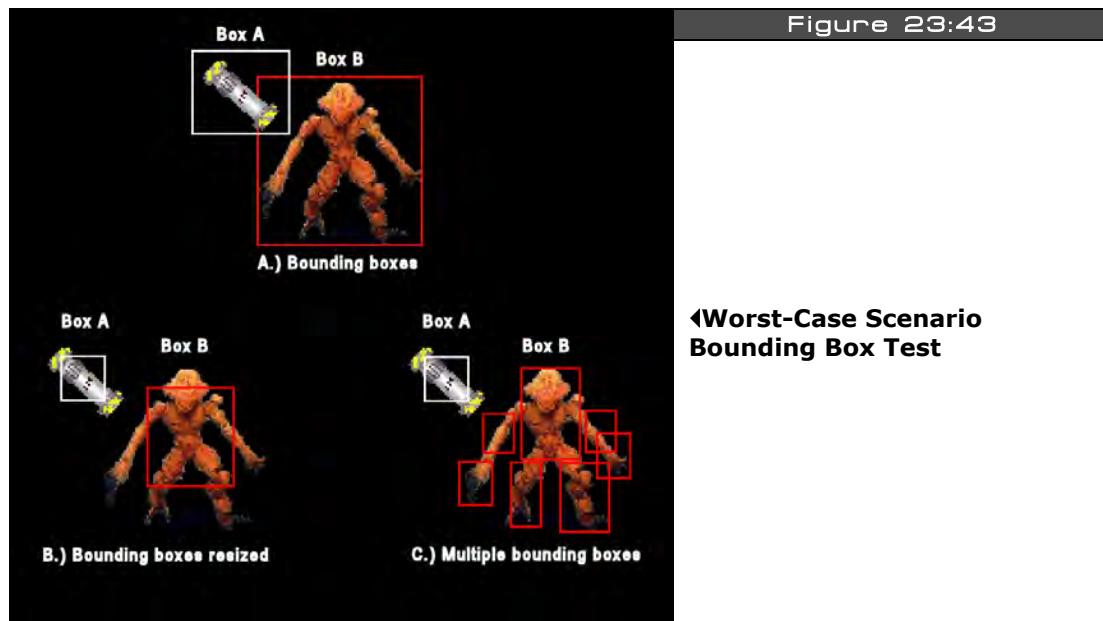
long boxA_x[4], boxA_y[4] ' holds x,y coords of box A in clockwise order
long boxB_x[4], boxB_y[4] ' holds x,y coords of box B in clockwise order

' iterate through each vertex in box A and test if its within box B
repeat index from 0 to 3
    ' extract next vertex
    test_x := boxA_x[index]
    test_y := boxB_y[index]

    ' test if point (test_x, test_y) is within boxB
    if (test_x > boxB_x[0] and test_x < boxB_x[1])
        if (test_y > boxB_y[0] and test_y < boxB_y[2])
            ' collision detected process and quit...
quit

```

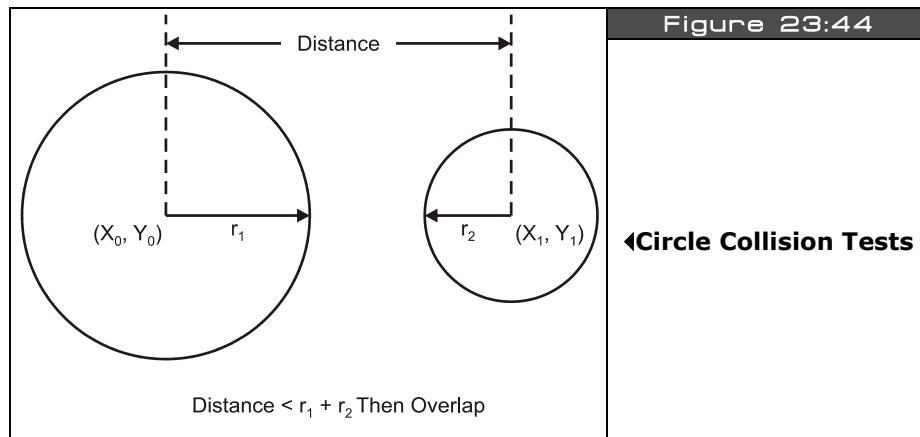
Of course there are numerous ways to optimize this, for example, if the bounding boxes are represented by the upper left hand corner along with a width and a height then we can subtract the positions of the bounding boxes to come up with a dx and dy. If dx and dy are both less than the sum of the width and the height of each bounding box then the bounding boxes must be overlapping. The important thing is to find a representation that is efficient and fast for testing.



Lastly, the obvious problem with bounding boxes is that they will indicate a collision when there is none. For example, Figure 23:43 shows a worst-case scenario using bounding box collision detection. Referring to the Figure 23:43(A), object A is a small plasma bomb where its bounding box is a good representation of object since the bomb spins around constantly; however, the bounding box around the monster contains a lot of area that is not part of the object. And as you can see the plasma bomb can be within the bounding box of object B and not hitting it! This is definitely bad. Once solution is to artificially make the bounding box smaller and concentrate on the centroid of the object as shown in Figure 23:43(B). This solution is ok, but then collisions might not registered on the extremities like the arms, legs and head. Yet another solution is to use multiple bounding boxes as shown in Figure 23:43(C). Here the most important parts of the monster have collision surfaces, so everything can be hit. Moreover, the second advantage of this setup is that if the head, or body etc. are hit it can be detected, so more accurate damage reporting can be done! The downside of course is the computation needed for the added boxes.

As an aside, another possible solution is to first perform a gross bounding box collision test as in Figure 23:43(A), which may or may not mean a true collision. Then if there is a potential collision, that is, the bounding boxes have at least overlapped, then a pixel accurate bitmap mask (or polygon mesh collision test) can be performed which is much more time consuming, but doesn't occur all the time, so it's a trade off for accuracy.

### 23.11.3 Circle Collision Determination



Another collision surface that can be used other than the bounding box is a **bounding circle**. The idea is the exact same, but the idea is that the object being tested has more of a circular geometry, thus the circle is a better collision surface to represent the collidable

region. Figure 23:44 shows the setup, and of course the circles are only imaginary. The collision test simply performs the following operation:

```
' compute distance from center of each circle
dx := (x1-x0)
dy := (y1-y0)

dist := ^^ (dx*dx + dy*dy) ' note in Spin "^^" is the square root operator

' test dist against radii
if (dist < (r1+r2))
  ' collision!
else
  ' no collision
```



TIP

The square root operation is computationally very expensive, but there is a trick to get rid of it. Instead of computing the distance between two objects, one can always compute the square of the distance. That is, leave out the square root operation and if you wanted to test the distance less than say 100, instead you square the 100 (which is a constant usually or a simple multiply) and then test again  $100*100 = 10,000$  instead. The code in the block below shows this.

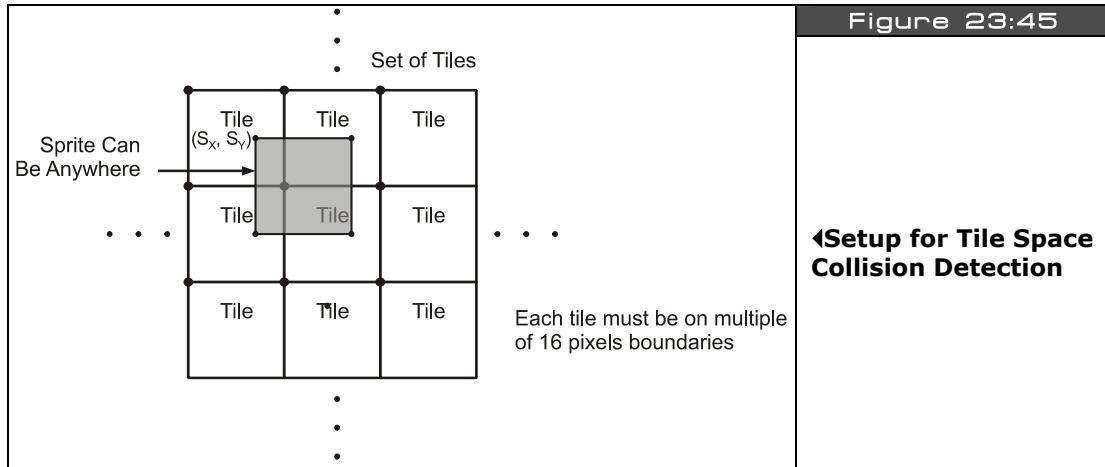
```
' fast collision test using squared distances
dx := (x1-x0)
dy := (y1-y0)
r12 := r1+r2

dist := (dx*dx + dy*dy) ' this is the distance squared

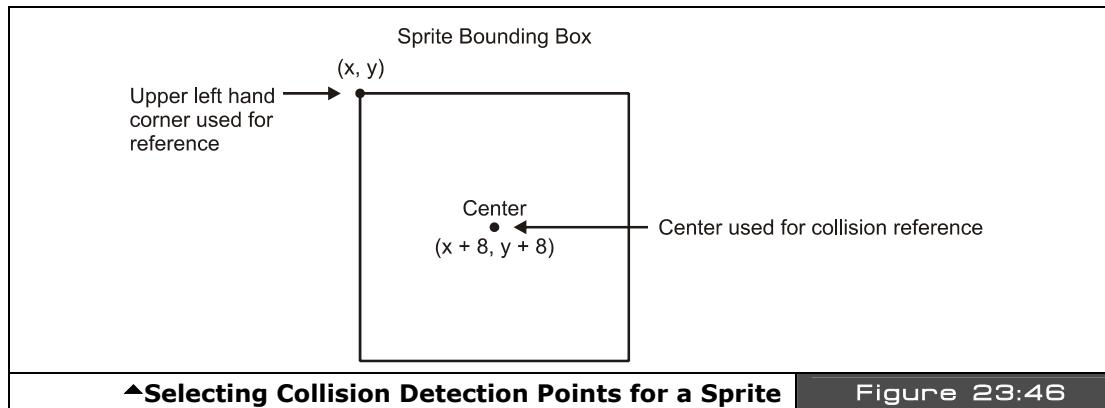
' test dist^2 against radii sum ^ 2
if (dist < (r12*r12))
  ' collision!
else
  ' no collision
```

#### 23.11.4 Tile Space Collision Detection

When developing games that mix tile, pixel, and sprite graphics, simple collision tests become difficult since you have to deal with multiple geometrical representations. For example, the tile engine demos that we have been working with represent the screen as a matrix of tiles;  $10 \times 12$ ,  $16 \times 16$ , or whatever, where each tile is usually  $8 \times 8$  or  $16 \times 16$  in most cases. The problem is how to integrate sprite graphics and tile graphics collisions when you have both systems on the screen at once. A common example is the top-down adventure game as shown in Figure 23:45.



Here, the screen is represented by  $16 \times 16$  tiles, but the player and game objects might all be sprites and thus can be drawn anywhere. So the question is how to perform collision detection between the sprites and the tile world? The solution is very simple; first you have to decide on the center of the sprite representation, that is, do you want to use the center of the sprite or the top-left corner or the bottom-right corner etc. as the collision detection point? This is shown in Figure 23:46.



In many cases, the best approach will be to use the 4 points of the bounding box of the sprite, but for a quick example, let's use the center of the sprite as the collision point. With this setup the sprite is  $16 \times 16$  pixels, the tiles are  $16 \times 12$  ( $16 \times 16$  each), and the coordinate

system is (0,0) at the top left corner for the tile space and (16,16) for the top left corner for the sprite space (if we are talking about the HEL tile engine, other tile engines would be similar). The problem to solve is to determine where the center of the sprite is in tile space. Here's the math:

```
long sprite_x, sprite_y ' the upper left hand corner of the sprite
word tile_map[16*12]    ' tile map memory in format where each WORD entry = b15
[palette index | tile index] b0

' compute tile coordinates that sprite is sitting on
tile_x := (sprite_x - 16) / 16
tile_y := (sprite_y - 16) / 16

' extract tile index that sprite is sitting on
tile_index := tile_map[tile_x + tile_y*16] ' 16 columns per row, but only 10 are
                                                visible currently (leaves scrolling room)

' perform collision tests with this tile index...
```

With this technique all kinds of cool tricks can be used. For example, you can draw 10 different "road" tiles with different inclinations, then you can test what tile the sprite is on and adjust its trajectory based on the virtual angle of the bitmap that represents the tile. This is how "**terrain following**" can be accomplished in tile games. The NES game "**ExciteBike**" shown in Figure 23:47 uses this very technique to follow the road.



### 23.11.5 Divide and Conquer Techniques for Collision Determination

When you start writing collision detection algorithms for your games, the first problem is simply testing two objects to see if they collide. However, once that problem is solved you quickly realize that if you have 100 alien ships and the player, and alien ships can each fire 100 bullets, then potentially you have to compute 300 object-to-object collision tests! This is a really big number, in fact it's "300 choose 2" which is 44850! This is totally unacceptable. Moreover, even if we decreased the number of aliens and bullets the number of tests is still large. For example, let's say there are 10 aliens, the player, and only 10 bullets that can be in flight. Moreover, we are only going to test bullets against the player and aliens, and aliens against player, but not bullets against bullets. This computation still has the following number of tests:

$$\text{Alien/Player collision tests: } 10 * 1 = 10$$

$$\text{Alien/Bullet collision tests: } 10 * 10 = 100$$

$$\text{Player/Bullet collision tests: } 10 * 1 = 10$$

$$\textbf{Total} = \mathbf{120}$$

And if each test takes 100-1000 assembly language instructions (depending if you are programming directly in ASM or Spin) then this is a huge number of cycles. Luckily, there is a way out of this seemingly impossible situation and that is based on the concept of "***spatial partitioning.***" The idea behind spatial partitioning is that you break the space of the world and position of objects into cells or cubes (in 3D) and then only the objects that fall within each cell can potentially collide and thus need to be tested! This can reduce the collisions down to nearly nothing.

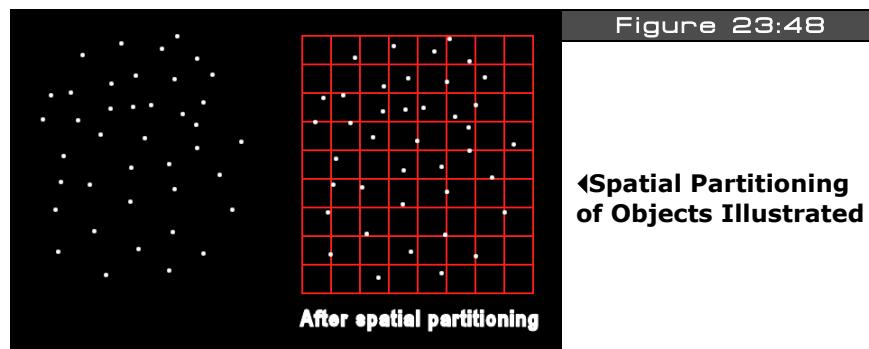


Figure 23:48 shows an abstract representation of the spatial partitioning problem. On the left of Figure 23:48 we see a number of white dots representing objects we want to test for collision. Assuming every single object must be tested against every other, this would be a lot of tests. However, now take a look on the right of Figure 23:48. In this case, we have

partitioned the 2D space into regular cells where each cell contains a specific set of objects. Only objects in each cell can potentially collide with each, thus the tests are reduced to the maximum number of objects per cell. The algorithm can be stated as follows:

**Step 1:** For every object in the collision list partition it into a cell size  $m \times n$ , this is done simply by dividing the coordinates of each objects by  $m, n$  and using the results as the cell index. Insert the object index or pointer into the cell's container.

**Step 2:** For every cell in the partition, test all objects against each other for collision.

The algorithm is very straightforward, and very fast. You can tune it by performing some experimentation to find the optimal cell size to organize the objects into. And of course if the cell size becomes the size of the game world then you have the original problem and all objects must be tested against each other. Now, before moving on, there is something I want to bring your attention to and that's Step 2 of the algorithm. In this step, for every cell in the spatial partition we test all the objects against each other. However, there is no reason why we can't further divide individual cells up even more in a recursive manner. This addition to the algorithm is referred to as the "**quadtree algorithm**" and the 3D version is "**octree**." In any case, the advantage further partitioning has is that if there are too many objects in any one cell you further divide the cell up more to reduce the objects that must be tested against each other for collision to a manageable number.

## 23.12 Summary

AI and physics are one of my personal favorite subjects in Computer Science. They are literally the key to the universe. If you can model AI and physics with near-reality precision then you can not only create machines that can think, but potentially virtual simulations that are near reality ala "**The Matrix**." The possibilities are endless! Hopefully, this chapter has given you some basic ideas of just how simple AI can be, and more importantly, it's not a "**single solution**" science, but more of an organic science where you layer and apply the techniques you need in your game, thus creating "**brains**" for your game characters that exhibit all the behaviors you need. For interested readers, I suggest reading "**The Age of Spiritual Machines**" by **Ray Kurzweil**. It's an exposition on a number of possibilities relating to AI, computing, nanotechnology, and other cutting edge technologies that within the next 20-30 years are going to change everything about the human race, so check it out!

## Chapter 24: Graphics Engine Development on the HYDRA

In this chapter we are going to discuss the inner workings of the HEL tile and sprite engine that we have been using in the demos throughout the book. The HEL engine is a very complex, high-performance assembly language program and to explain every bit of it would take a couple hundred pages of text. Alas, what I am going to try to do is discuss architectural decisions, overall design, and important techniques used within the engine. Along with these discussions we will look at fragments of the code, but readers are urged to review the source itself which is heavily commented and located in the source file **HEL\_GFX\_ENGINE\_040.SPIN**. Hopefully this chapter gives you an idea of the thought process that went into the engine, so you can take it to the next level. Here's what's in store:

- ▶ Design goals of the HEL engine
- ▶ Engine Architecture overview
- ▶ Engine code analysis and deconstruction
- ▶ Advanced engine design concepts

### 24.1 Design Goals of the HEL Engine

The HEL engine was designed to be the simplest possible graphics engine that could be written on the Propeller and that could support both tiles and sprites. Moreover, I wanted to fit it into a single cog and support a **memory mapped** interface rather than a complex API. Thus, the HEL engine looks like a piece of virtual hardware to the programmer rather than a software API coupled with some hardware.

These constraints meant that a lot of tricks and clever organization of data had to be used to make things work with the confines of a single cog, but some concessions had to be made. First, due to the complex scanline setup calculations, this version of the engine uses an unusually long Hsync pulse. This works fine on CRT-based displays, but on modern LCD and plasma displays, the display might have a hard time syncing to the engine's timing. Nonetheless, I have tested the engine on 50 or so CRTs from different manufacturers and it works fine. Additionally, I have found that if you are willing to sacrifice some of the sprite processing, you can adjust the timing parameters at the header of the code and the engine will work fine on LCDs and plasmas as well.

Next, using a single cog and doing both tiles and sprites means that a lot of computation has to be done each scanline and pixel this means that its nearly impossible to support **high**

**color modes** per pixel. That is, it's possible to support all 86 colors or 256 different pixel values per pixel (as you will see in the advanced demos next chapter). But, to accomplish this takes at least 2 cogs and most of the time 3 or 4 to get the job done right. And since I wanted to stick with a single cog, the HEL engine supports only 4 colors per tile. Nonetheless, each tile **does** support its own palette of any 4 colors. Furthermore, the sprites must use the palettes of the tiles they overlap.

At the end of the day, the HEL engine is short, fast, runs on virtually every CRT-based TV and is a great starting point for you to make your own engines. It supports tiles, sprites, paging, and scrolling. Those features pretty much sum it up for most circa 80's hardware which means anything you see on your Atari 800, Commodore 64, or Apple II you should be able to pull off with the HEL engine with a little work! On the other hand, it's really easy to modify the engine for higher resolution, more or less sprites, and different tile sizes.



The HEL engine is 100% assembly language, so readers not familiar with ASM will have a tough time following the code, but the explanations should give you an idea of what's going on theoretically, so you can follow along. Not to mention, the code is heavily commented.

## 24.2 Engine Architecture Overview

The HEL engine is a good example of a "**memory mapped**" I/O device. In other words, there are no API calls, you simply change memory locations and pointers in global memory and the engine reacts to it and draws what you tell it to. This is the best setup since you can always write an API on top of it. With that in mind, let's look at the overall architecture of the engine in relationship to the client cog (running your game), main memory, and the driver cog (that the engine runs on). Since we already covered the use of the engine in Chapter 19 (which you should review), our discussion here is going to focus on more the internals of the engine rather than using the engine. However, let's review the different pieces of the engine before we get started. Take a look at Figure 24:1 for the discussion that follows.

The HEL engine is composed of the following components/assets:

- ▶ Parameter passing area
- ▶ Tile map
- ▶ Palette map
- ▶ Tile bitmaps
- ▶ Sprite records
- ▶ Sprite bitmaps
- ▶ Sprite masks

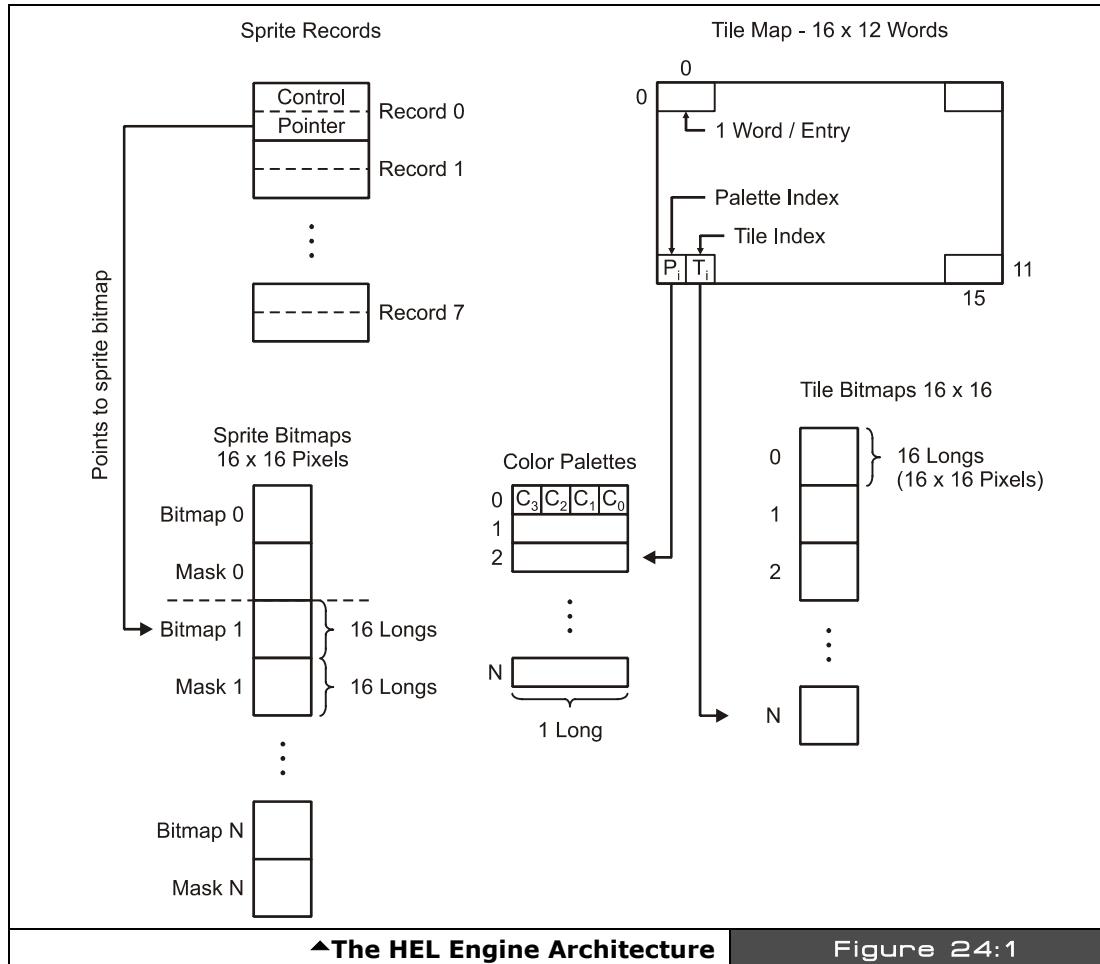


Figure 24:1

The **parameter passing area** is the interface to the outside world. This is where the HEL engine gets its information to do what it does. The parameter passing area is defined in main memory and is composed on the following 6 variables in the following order (from the engine code itself):

```

long tile_map_base_ptr_parm      ' parm 0: ptr to tile map (16x12 array, row major, 2-bytes per entry)
long tile_bitmaps_base_ptr_parm  ' parm 1: ptr to the base of the bitmap data, each 16x16
long tile_palettes_base_ptr_parm ' parm 2: ptr to the base of the palettes array, each palette 1 long
long tile_map_sprite_cntrl_parm  ' parm 3: ptr to various control values for the tile map/sprite engine
long tile_sprite_tbl_base_ptr_parm ' parm 4: ptr to the base of the 'sprite table'
long tile_status_bits_parm       ' parm 5: ptr to status word - vsync, hsync, etc.

```

The base of the table is passed to the HEL engine on startup and the PAR assembly register is used to index into the values.

The **tile map** is the  $16 \times 12$  array of tiles that the engine renders each frame. Each tile is 2 BYTEs and consists of a palette index and a tile index into the tile bitmaps themselves. The tile map itself is in row-major form and can actually be 16, 32, 64, 128, or 256 tiles wide to support horizontal course scrolling. Only 10 tiles are visible each scanline to keep color aliasing down to a minimum (since there are only 160 true color clocks per line for active video).

The **palette map** is an array of 1 to 256 LONG palette entries that each represent a set of 4 colors. These are indexed by the tile palette indices in each tile entry.

The **tile bitmaps** are the bitmaps that are drawn for each tile. They are  $16 \times 16$  pixels represented by 16 LONGs and horizontally mirrored to make access of the tile engine faster.

The **sprite records** are an array of 8 entries that define each sprite, one record per sprite. The engine refers to these records for the position of each sprite as well as the pointer to the sprite bitmap data itself.

The **sprite bitmaps** are  $16 \times 16$  pixel bitmaps that represent each sprite. Similar to tiles, they are 16 LONGs each flipped horizontally. Additionally, each sprite bitmap has a **sprite mask** that goes along with it to help render the sprite faster.

The operation of the engine is straightforward: you set up the parameters passing area, start the tile engine and then the tile engine starts processing the data. Each frame, the parameters are read from main memory which instructs the engine where to get all the assets. Let's begin by reviewing the engine's operation at the level of information flow then we will drill down and look at the code elements section by section.



For all the discussions that follow, you might want to keep track in the source with the Propeller Tool. Line numbers help to do this. To toggle line numbers press <CTRL+N> in the Propeller Tool.

#### 24.2.1 HEL Engine Frame Processing

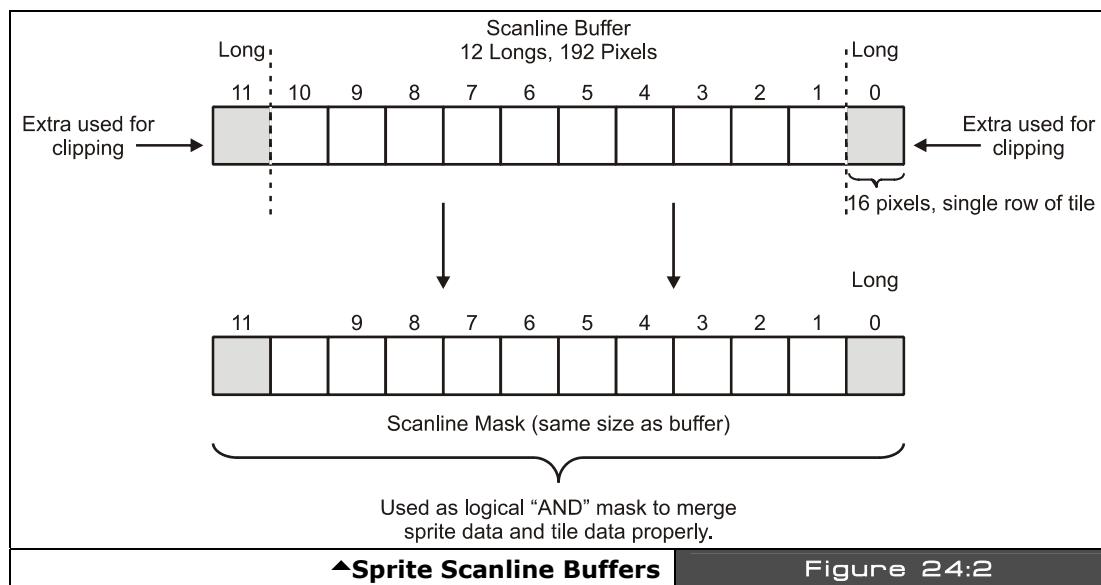
Referring to Figure 24:1, the engine begins by caching the main memory sprite records into a local cog memory **sprite cache**. It does this regardless if sprites are in the scene or enabled. This step is necessary since anything inside the inner loops of the engine we want to cache in local cog memory (if possible), so we don't have to go to main memory. Once the sprite records are cached the frame begins and the blank scanlines are rendered which isn't very interesting; however, during this time one could perform many calculations since there is a

lot of dead time. The frame processing then begins in earnest and is composed of two major components:

- ▶ Sprite processing
- ▶ Tile processing and rendering

#### 24.2.1.1 Sprite Processing

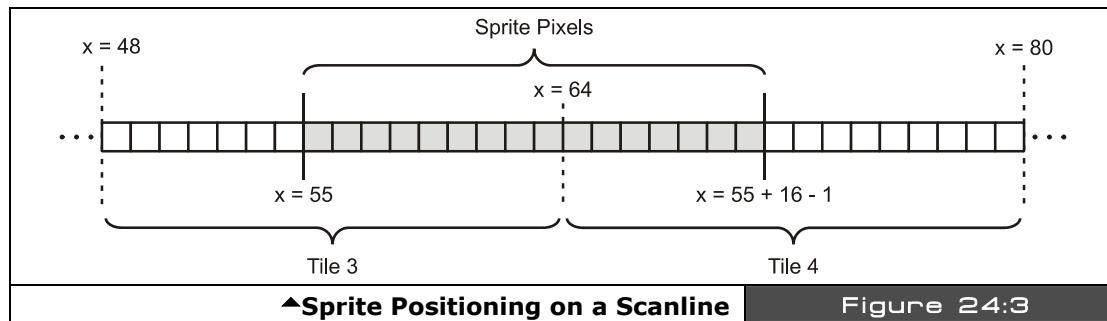
The sprite processing is the most complex of the two phases and where all the performance and cycles are needed. The problem simply put is that we have up to 8 sprites that need to be rendered on the current scanline. This is where things get complicated. The problem with sprites is that they are supposed to be magical, that is, you position them and they simply show up on the screen at the proper location without disturbing anything under them. This is quite challenging to code. The problem is that the sprites ultimately have to be drawn on top of the tile maps, moreover, sprites can overlap with each other, so all these issues have to be considered. The solution is to create what's commonly known as a "**scanline buffer**" to perform the processing. A scanline buffer is really a 1-dimensional bitmap that represents a single scanline on the screen. Thus, if we perform our rendering algorithms a scanline at a time, we can think of the screen as a collection of scanlines. And if we can solve the rendering problem for a single scanline, then we simply loop to draw the screen. The HEL engine uses this approach.



▲Sprite Scanline Buffers

Figure 24:2

The sprite processing algorithm begins by setting aside two scanline buffers: one to hold the actual bitmap data for the sprite on that scanline and another buffer which is used as a **mask** or **stencil** for the sprite scanline, these buffers are shown in Figure 24:2. Once the buffers are initialized the sprite list is looped through. For any sprite in the list from 0..n that is on the current scanline, that sprite is processed, sprites that are not intersected by the scanline are discarded.

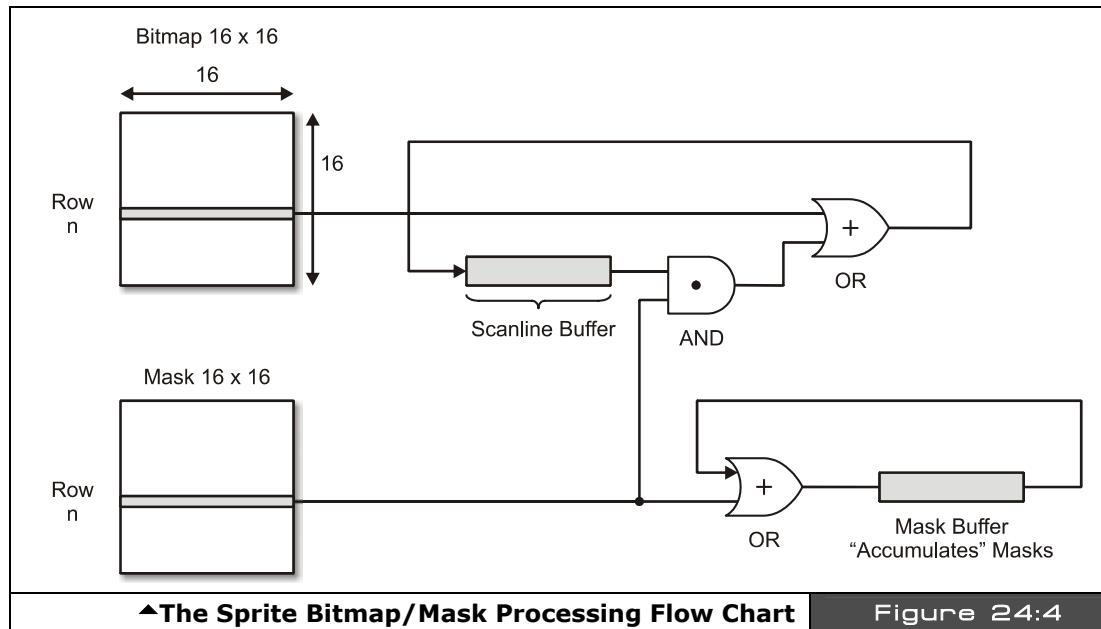


The sprite processing begins by locating where the sprite is in tile space, that is, the sprite bitmap data must ultimately be rendered with the tile data, so the sprite location has to be ascertained relative to a 16 tile (or 32, 64, 128, 256) wide screen. So say the sprite was at  $x=55$  ( $y$  is irrelevant), then  $55/16 = 3$  with a remainder of 7. This means that the sprite is located on tiles 3 and 4 (0 based) straddling them by 7 pixels. This is shown in Figure 24:3. Thus, the trick is to read the sprite bitmap and write half of it on tile 2 and the other half of it on tile 3. This is accomplished by first taking the sprite bitmap's 32-bit pixel definition for the 16-pixel line and performing a 64-bit shift to position it. The two LONGs that make up the results can be written into the scanline buffer at position 3,4. Then we would have the sprite data buffered in the correct position. But, not so fast! The problem is that when we process the next sprite, what happens if it ends up overlapping the current sprite? We can't just OR the color data, we can't AND it, we can't XOR it. All of those operations would manipulate the color index bits since they are 2-bit pairs. What we need to do is cut a "**hole**" out of the sprite scanline buffer first, then OR the sprite bitmap data into it. This is what the scanline mask buffer is for, shown in Figure 24:2.

The scanline mask buffer accumulates the total mask that indicates where sprite data is on a scanline. This is where the sprite bitmap masks come into play. As the sprite is being processed, not only is the bitmap data being shifted but the mask data for the particular line is as well. Then before the sprite bitmap is written to the scanline buffer, the sprite mask is used to cut a hole in the scanline buffer for the sprite bitmap data itself, and the mask is OR'ed with the scanline buffer mask. This way the sprite can be written into the scanline

bitmap buffer with a final OR operation and the scanline buffer mask becomes an accumulation of all sprite masks.

This process continues until all the sprites have been processed. The results are a single scanline that represents the sprite data for the scanline. Additionally, there is the scanline mask buffer that can be used as an AND mask to clear out the target tile bitmap data to make the hole for the sprite scanline data to be OR'ed in. Figure 24:4 shows the sprite processing of bitmaps and masks as a flowchart.



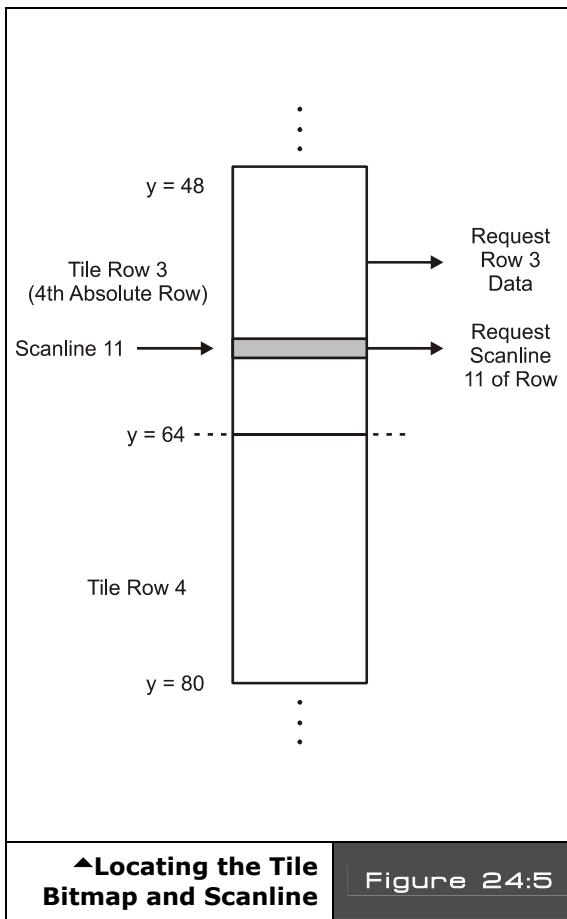
### 24.2.1.2 Tile Processing

The tile processing part of the engine is the easy part. To render the tiles, more or less the algorithm is as follows:

**For the current scanline compute the tile row.**

**For the current tile row access the tile indices for each tile as well as palettes.**

**For each tile, draw 16 pixels of tile and loop until tile row is complete.**



So the tile processing more or less works scanline by scanline just like the sprite engine. Thus we can resolve the problem into solving single scanlines once again. For example, let's say that the next scanline to be drawn is 59 and we are starting at the left edge of the screen. First we need to compute the tile row which is  $59/16 = 3$  (4th absolute row) with a remainder of 11. Thus, we need to access the 4<sup>th</sup> row in the tile map, and the 11<sup>th</sup> scanline of that row. This is shown in Figure 24:5. The first step is to retrieve the actual bitmap data and palette data for the tile. Thus, we use the tile row to access the tile map along and retrieve the tile palette and bitmap indices which are then used to retrieve the palette for the tile and to locate the actual bitmap for the tile. The bitmap for the tile is found by multiplying the tile index by 64 BYTES (since there are 64 BYTES per tile bitmap) and adding this value to the base memory of the tile bitmaps themselves. Then the last step is to grab the 11<sup>th</sup> row of the tile bitmap data. At this point, we have the palette entry and the pixel data to render the 16-pixel span.

If there were no sprites, then the 16-pixel span could be rendered by setting up the pixels and colors and passing them to the **waitvid** instruction, then moving to the next tile on the X-axis and repeating the process until the entire scanline was processed. However, the sprites add a whole other dimension of pain. We need to overlay the sprites onto the tile bitmap data; this is where the sprite scanline buffer and scanline mask come into play. For every tile row we render from left to right on the screen we simply need to merge the sprite data into each row of 16 pixels. Referring to Figure 24:6, the merging process begins with retrieving the mask from the scanline buffer mask and logically ANDing it with the tile pixels. This creates the hole for the sprite data itself. Once the hole is created, the scanline buffer is accessed and the actual sprite bits are retrieved and logically OR'ed into the tile bits and

finally the data is written to the screen. The results are exactly what is desired: tiles in the background, sprites in the foreground without any color distortion.

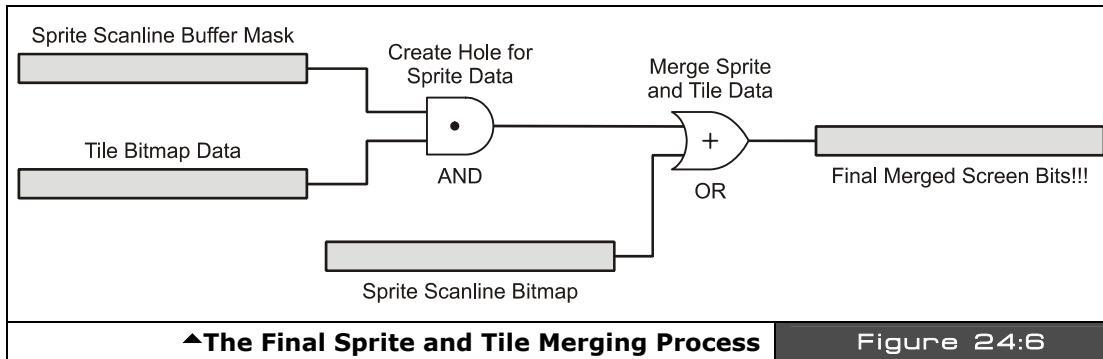


Figure 24:6

Summing up, the process of rendering both sprites and tiles is rather complex in a single cog. However, by judicious use of caching and accessing the main memory efficiently, it **is** possible. The only downside is that the engine uses an extended horizontal sync pulse which may be incompatible with some LCD/plasma sets, but on CRT based monitors you should have no problem. With all that in mind, let's briefly review some of the code itself.

### 24.3 Engine Code Analysis and Deconstruction

In this section we are going to more or less review each important section of the code, list code fragments, and discuss important parts of the ASM code itself. This won't be a complete listing since the code is over 1000 lines long (including comments). Therefore, please make sure to review the complete code for the HEL engine **HEL\_GFX\_ENGINE\_040.SPIN** located on the CD in the **\SOURCES** directory. I am going to leave simple things out like the blanking lines and vertical sync in the deconstruction. Also, in the listings to save space I am going to remove 20-30% of the vertical comments, so once again the full annotated listing is on the CD.

#### 24.3.1 Setup

The first thing that happens when the HEL engine starts up is that it must set up the VSU with the proper counter modes and settings. This is performed on entry into the driver based on the constants in the driver's CON section. Here's the code listing that sets up the timing chain:

```

HEL_GFX_Driver_Entry

    ' VCFG: setup Video Configuration register and 3-bit TV DAC pins to outputs

    movs    vcfg, #VIDEO_PINMASK      : vcfg S = pinmask (pin31 ->0000_0111<-pin24), only want lower 3-bits
    movd    vcfg, #VIDEO_PINGROUP    : vcfg D = pingroup (HYDRA uses group 3, pins 24-31)
    movi    vcfg, #VIDEO_SETUP       : vcfg I = controls overall setting, want baseband video on bottom nib
                                : 2-bit color, enable chroma on broadcast & baseband
    or     dira, tvport_mask        : set DAC pins to output 24, 25, 26
                                : CTRA: setup Frequency to Drive Video
    movi    ctra, #VIDEO_CNTR_SETUP : pll internal routed to Video, PHSx+FRQx (mode 1) + pll(16x)
                                : needn't set D,S fields since they set pin A/B I/Os, but mode 1 is
                                : internal, thus irrelevant

    ' compute the value to place in FREQ, so final counter is NTSC and PLL output is 16*NTSC
    mov     r1, v_fred              : r1 <- TV color burst frequency in Hz, eg. 3_579_545
    rdlong  r2, #CLKFREQ_REG       : r2 <- CLKFREQ is register 0, eg. 80_000_000
    call    #Dividefract          : perform r3 = 2^32 * r1 / r2
    mov     frqa, r3                : set freq for counter, so bit 31 is toggling at rate of
                                : color burst (2x actually)

    mov     r0, par                 : copy boot parm value and read in parms from main memory
    add    r0, #20                 : status bit is 5 longs out or 20 bytes
    mov     tile_status_bits_ptr, r0 : ptr to status bits, so tile engine can pass out status

```

#### 24.3.2 Starting the Next Frame and Retrieving the Parameters

Once the timing chain is set up, the engine immediately begins drawing the next frame of video. To do this, the engine needs to retrieve the pointers to all the assets such as the tile map, the bitmaps, sprites, palettes, and sprite records. This is done in real-time each frame. Thus, the engine updates everything at 60 fps always. Below is the listing showing the beginning of the frame and the retrieval on the parameters from main memory:

```

Next_Frame      start of new frame of 262 scanlines

    ' read run-time parameters from main memory, user can change these values every frame
    mov     r0, par                 : copy boot parm value and read in parms from main memory
    rdlong  tile_map_base_ptr, r0   : base ptr to tile map itself
    add    r0, #4
    rdlong  tile_bitmaps_base_ptr, r0 : base pointer to array of 16x16 bitmaps, each 64 bytes
    add    r0, #4
    rdlong  tile_palettes_base_ptr, r0 : base pointer to array of palettes, each 4 bytes/1 long
    add    r0, #4
    rdlong  tile_map_sprite_cntrl, r0 : read tile map	sprite engine control word, format xx_xx_ss_ww

    ' copy control words into width and number of sprites
    mov     tile_map_width, tile_map_sprite_cntrl
    mov     tile_num_sprites, tile_map_sprite_cntrl
    and    tile_map_width, #$FF      : map width encoded in byte 0 (lowest byte), $xx_xx_ss_ww
    shr    tile_num_sprites, #$08    : number of active sprites to render encoded in byte 1
                                : (2nd from right most low byte), $xx_xx_SS_ww
    add    r0, #4
    rdlong  tile_sprite_tbl_base_ptr, r0 : base pointer to sprite table

```

### 24.3.3 Caching the Sprite Records

When writing graphics engines and algorithms, the more data you can cache in local fast memory the better! Thus, as an example of this technique, the HEL engine caches the sprite records so they don't have to be accessed from memory to be interrogated. Actually, much more data could have been cached locally, for example a few sprites, or tiles, or palettes. But, although that would have sped the engine up considerably, it would have limited the amount of graphics. However, a demand page caching system that scanned the sprites and tiles needed each frame could potentially cache them during the vertical blank for the next frame, as long as the cache wasn't overflowed. In any case, the HEL engine only caches the sprite records themselves which is a good starting point. Here's the code:

```
' read the sprite table into the local cog memory sprite table cache
mov      r1, tile_sprite_tbl_base_ptr    ' r1 = tile_sprite_tbl_base_ptr, byte ptr, main memory
mov      r2, #sprite_table_cache        ' r2 = @sprite_table_cache, long ptr, cog memory

mov      r3, #16                      ' 16 Longs to copy from main memory to cog memory to fill
                                         ' the sprite table cache, 8 sprites, each sprite 2 longs

Sprite_Table_Cache_Loop

    movd    Write_Cache, r2          ' overwrite destination on rdlong instruction
    nop                            ' wait for pre-fetch, so we don't execute
                                   ' self modifying code too quickly
    Write_Cache rdlong  0, r1        ' *r2 = *r1
    add    r1, #4                  ' r1+=4, move to next LONG, byte addressing in main memory
    add    r2, #1                  ' r2++, move to next LONG, long addressing in cog memory
    djnz   r3, #Sprite_Table_Cache_Loop ' if (--r3 > 0) then loop
```

### 24.3.4 Sprite Processing

The next part of the code is where all the action happens and the sprites are processed. The code is rather complex, has a lot of self-modifying going on, and all kinds of tricks, so take your time reviewing it. The code more or less begins by testing if a sprite is on the current scanline and if the sprite is enabled. If both statements are true, then the sprite is processed beginning with locating the sprite in tile space, then shifting the sprite and mask into position, and finally writing out the sprite data and mask data to the scanline buffers. Here's the code (full annotation is on the CD source file as usual):

```
mov      r2, tile_num_sprites      ' the more sprites to process, the more time it takes to render
test    r2, #$FF wz
if_z   jmp    #Tile_Map_Processor

    mov      r3, #sprite_table_cache ' r3 = @sprite_table_cache, local cog memory
    ' clear scanline buffers out, no memory fill!!!!!
    ' first clear out 12 LONGs of scanline bitmap buffer since only 10 tiles are visible, plus 1
    ' extra on either side
    mov sprite_scanline_bitmap+0, #0
    mov sprite_scanline_bitmap+1, #0
    mov sprite_scanline_bitmap+2, #0
    mov sprite_scanline_bitmap+3, #0
    mov sprite_scanline_bitmap+4, #0
    mov sprite_scanline_bitmap+5, #0
```

```

    mov sprite_scanline_bitmap+6, #0
    mov sprite_scanline_bitmap+7, #0
    mov sprite_scanline_bitmap+8, #0
    mov sprite_scanline_bitmap+9, #0
    mov sprite_scanline_bitmap+10, #0
    mov sprite_scanline_bitmap+11, #0

    ' now clear out the scanline mask buffer (Set to $FFFFFF)
    mov sprite_scanline_mask+0, MAX_INT
    mov sprite_scanline_mask+1, MAX_INT
    mov sprite_scanline_mask+2, MAX_INT
    mov sprite_scanline_mask+3, MAX_INT
    mov sprite_scanline_mask+4, MAX_INT
    mov sprite_scanline_mask+5, MAX_INT
    mov sprite_scanline_mask+6, MAX_INT
    mov sprite_scanline_mask+7, MAX_INT
    mov sprite_scanline_mask+8, MAX_INT
    mov sprite_scanline_mask+9, MAX_INT
    mov sprite_scanline_mask+10, MAX_INT
    mov sprite_scanline_mask+11, MAX_INT

    mov r7, r1      ' copy scanline # into r7
    add r7, #16     ' add 16 to support sprite clipping
                    ' r1 holds "real" scanline, r7 holds offset scanline by 16

Sprite_Processing_Loop

    ' extract the nth sprite state/ptr from sprite_table_cache
    movs Read_State, r3          ' r3 is pointing at sprite record's offset 0 field for nth
                                ' sprite - the state/control word
    add r3, #1                  ' advance to ptr field of sprite record, plus give self modify
                                ' time to complete
Read_State    mov sprite_state, 0 ' read the sprite_state out of this sprites record

    ' next read the sprite pointer in prep for processing algorithm, eventhough we may pass on it
    movs Read_Ptr, r3            ' r3 is pointing at sprite records offset 1 field for nth sprite -
                                ' the bitmap pointer
    add r3, #1                  ' advance to ptr field of sprite record, plus give self modify time to complete
Read_Ptr      mov sprite_bitmap_ptr, 0 ' read the sprite_bitmap_ptr out of this sprite record

    ' now we've encoded sprite_state, sprite_x, sprite_y and r3 pointing to NEXT sprite record
    ' r2 is the sprite index, r1 is scanline
    test sprite_state, #%00000001 wc, wz ' test enabled bit?
if_z jmp #Next_Sprite           ' this sprite is disabled, ignore!

    ' else sprite is enabled, continue processing....
    ' at this point we have everything, we can start interrogating...
    ' copy the sprite_state into x,y since they are encoded within
    mov sprite_x, sprite_state   ' x is encoded in 2nd byte of state
    shr sprite_x, #16            ' now yx are in lower 16-bits
    and sprite_x, #$FF           ' mask lower byte which is x position

    mov sprite_y, sprite_state   ' y is encoded in 3rd byte of state
    shr sprite_y, #24            ' now y is in lower 8-bits

    ' if sprite intersects current scanline then process it...
    mov r4, sprite_y             ' r4 = sprite_y
    add r4, #16                  ' r4 = sprite_y+16, bottom of sprite since it's 16x16 pixels

    ' perform bounds test

```

```

Test_Sprite_Top
    cmp    r7, sprite_y  wz      ; compare scanline to sprite_y, if (scanline>=sprite_y) then
                                    ; test bottom
    if_ae jmp    #Test_Sprite_Bottom
    jmp    #Next_Sprite          ; r7 is used tho (r1+16) to support sprite clip at top of screen
                                    ; compare scanline to sprite_y+16
                                    ; scanline not within sprite process next sprite

Test_Sprite_Bottom
    cmp    r7, r4      wz, wz   ; compare scanline to sprite_y+16
                                    ; r7 is used tho (r1+16) to support sprite clip at top of screen
    if_ae jmp    #Next_Sprite          ; if (scanline >= sprite_y+16) then sprite is NOT on this
                                    ; scanline, process next sprite

    ; else, sprite IS on scanline, here comes the really icky part...extracting its data and mask
    ; first compute the sprite tile and offset
    mov    sprite_tile_x, sprite_x      ; compute tile offset, or 16 pixel boundary
    shr    sprite_tile_x, #4            ; sprite_tile_x = sprite_x/16
    mov    sprite_offset_x, sprite_x      ; compute pixel offset to shift sprite data within tile
    and    sprite_offset_x, #$0F          ; sprite_offset_x = sprite_x mod 16

    ; compute the row of the sprite we need to render, that is the (current line - sprite_y), this
    ; would fail if we hadn't already determined
    ; the current scanline is intersecting the sprite at some y
    mov    r5, r7      ; r1 holds current scanline (r7 is used though which is
                        ; r1+16 to support sprite clip at top of screen)
    sub    r5, sprite_y          ; r5 = r1 - sprite_y, equals dy or intersection row from 0-15

    ; retrieve row of sprite from bitmap
    shl    r5, #2      ; r5 = (r1 - sprite_y)*4, 1 long per line, 4 bytes per long, byte
                        ; offset from top of sprite
    add    r5, sprite_bitmap_ptr      ; r5 = sprite_bitmap_ptr + (r1 - sprite_y)*4, ptr to long that
                                    ; holds bitmap line

    ; read 16 pixels / 32-bit data row of sprite from memory into local bitmap buffer
    rdlong sprite_bitmap_buffer, r5      ; sprite_bitmap_buffer[0] = mm[r5] = mm[sprite_bitmap_ptr +
                                            ; + (r1 - sprite_y)*4]
    mov    sprite_bitmap_buffer+1, #0      ; sprite_bitmap_buffer[1] = 0

    ; get mask from memory.... rather than construct it, it is precomputed by us, and exists 16 longs
    ; after the bitmap itself, or 64 bytes down
    add    r5, #16*4
    rdlong sprite_mask_buffer, r5      ; sprite_mask_buffer[0] = mm[r5] = mm[sprite_bitmap_ptr +
                                            ; + (r1 - sprite_y)*4 + 16]
    mov    sprite_mask_buffer+1, #0      ; sprite_mask_buffer[1] = $00000000

    ; now we have the sprite's 16 pixels in sprite_bitmap_buffer[0] and
    ; and the positive sprite mask in sprite_mask_buffer[0]
    ; now we need to shift these to make them pixel accurate based on offset of sprite within a tile
    cmp    sprite_offset_x, #0      wz, wz
    if_z jmp    #Sprite_No_Shift        ; if (sprite_offset_x ==0 ) then jump out...

Sprite_Do_Shift
    mov    r6, sprite_offset_x      ; we need to perform a 64-bit shift, do in two parts...
    shl    r6, #1      ; r6 = sprite_offset_x*2 (# of bits to shift rather than pixels)
    mov    r0, #32            ; again another 64-bit shift is needed
    sub    r0, r6            ; r0 = 32 - sprite_offset_x*2
    mov    sprite_bitmap_buffer+1, sprite_bitmap_buffer      ; copy sprite bitmap buffer
    shl    sprite_bitmap_buffer, r6            ; shift 16 pixels to the left via two seperate shifts
    shr    sprite_bitmap_buffer+1, r0

```

```

    mov    sprite_mask_buffer+1, sprite_mask_buffer      ' copy sprite mask buffer
    shl    sprite_mask_buffer, r6   ' shift 16 pixels to the left via two seperate shifts
    shr    sprite_mask_buffer+1, r0

Sprite_No_Shift
    now that the mask shift operation is complete we can invert the mask to a NEGATIVE, we needed
    to keep in POSTIVE form
    since shift operations shift in 0's not 1's, and the shifting would alter our mask erroneously
    xor    sprite_mask_buffer, MAX_INT
    xor    sprite_mask_buffer+1, MAX_INT

    ' and now merge the final data into the screen sized scanline buffers!!! Its about time!
Sprite_Merge_Data
    step 1: AND the mask into scanline bitmap buffer and overwrite any pixels that are there
    and make a "hole" for new sprite data
    sprite_scanline_bitmap[sprite_tile_x]    &= sprite_mask_buffer[0]
    sprite_scanline_bitmap[sprite_tile_x+1]  &= sprite_mask_buffer[1]
    mov    r0, #sprite_scanline_bitmap        r0 = @sprite_scanline_bitmap
    add    r0, sprite_tile_x                 ' r0 = @sprite_scanline_bitmap + sprite_tile_x
    movd   :Write0, r0 ' modify destination address of AND opcode downstream to hold address in r0
    nop                            wait for pre-fetch, so we don't execute self modifying code too quickly
:Write0 and 0, sprite_mask_buffer          AND the mask against the scanline buffer

    add    r0, #1                           ' r0 = @sprite_scanline_bitmap + sprite_tile_x + 1
    movd   :Write1, r0 ' modify destination address of AND opcode downstream to hold address in r0
    nop                            wait for pre-fetch, so we don't execute self modifying code too quickly
:Write1 and 0, sprite_mask_buffer          AND the mask against the scanline buffer

    ' step 2: now write the bitmap bits into the scanline buffer by ORing the source data from sprite
    into the scanline buffer
    sprite_scanline_bitmap[sprite_tile_x]  |= sprite_bitmap_buffer[0]
    sprite_scanline_bitmap[sprite_tile_x+1] |= sprite_bitmap_buffer[1]
    mov    r0, #sprite_scanline_bitmap      r0 = @sprite_scanline_bitmap
    add    r0, sprite_tile_x               ' r0 = @sprite_scanline_bitmap + sprite_tile_x
    movd   :Write2, r0 ' modify destination address of the OR opcode downstream
    nop                            to hold address in r0
    ' wait for pre-fetch, so we don't execute self modifying code too quickly
:Write2 or 0, sprite_bitmap_buffer        OR the bitmap data into scanline buffer (in hole created
                                         by the mask, so color bits dont get yucky)

    add    r0, #1                           ' r0 = @sprite_scanline_bitmap + sprite_tile_x + 1
    movd   :Write3, r0 ' modify destination address of the OR opcode downstream
    nop                            to hold address in r0
    ' wait for pre-fetch, so we don't execute self modifying
    ' code too quickly
:Write3 or 0, sprite_bitmap_buffer        OR the bitmap data into scanline buffer (in hole created
                                         by mask, so color bits dont get yucky)

    ' step 3: now write the mask to the scanline mask buffer, so it can be used to make a "hole" in
    the tiles to write the sprite data into
    and    sprite_scanline_mask[sprite_tile_x],  sprite_mask_buffer[0]
    and    sprite_scanline_mask[sprite_tile_x+1], sprite_mask_buffer[1]
    mov    r0, #sprite_scanline_mask           r0 = @sprite_scanline_mask
    add    r0, sprite_tile_x                 ' r0 = @sprite_scanline_mask + sprite_tile_x
    movd   :Write4, r0 ' modify destination address of the AND opcode downstream
    nop                            to hold address in r0
    ' wait for pre-fetch, so we don't execute self modifying code too quickly
:Write4 and 0, sprite_mask_buffer          ' r0 = @sprite_scanline_mask+ sprite_tile_x + 1

```

```

    movd  :Write5, r0          ; modify destination address of the AND opcode downstream
                                ; to hold address in r0
    nop   ; wait for pre-fetch, so we don't execute self modifying code too quickly
:Write5 and 0, sprite_mask_buffer+1

    ; at this point the sprite data has been written into the scanline buffer as well as the mask
    ; been written to the mask scanline buffer
    ; when this loop finishes then the sprite_scanline_bitmap will hold the entire scanline of the
    ; sprite data and the scanline mask will hold the AND mask to AND into the destination tile data
    ; to make a "hole" for the sprite data
Next_Sprite

    djnz  r2, #Sprite_Processing_Loop  ; if (- -r2 > 0) the loop

```

### 24.3.5 Tile Map Processing

The last step in the processing and rendering of a single scanline is of course the tile map itself. This is actually easy compared to the sprite processing step. The tile map processing draws a single scanline of tiles while at the same time overlaying the sprite data for the scanline. Here's the main code that performs this step:

```

Tile_Map_Processor
    ; select proper sub-tile row address
    mov   r2, r1          ; r1 holds current video line of active video (0..191)
    and   r2, #$0F        ; r2 = r1 mod 16, this is the sub-row in the tile we want to render

    ; access main memory can get the bitmap data
    shl   r2, #2           ; r2 = r2*4, convert to BYTE based row offset of pixels
    add   r2, tile_bitmaps_base_ptr  ; r2 = tile_bitmaps_base_ptr + r2

    ; compute tile index itself for left edge of tile row, inner loop will index across as the
    ; scanline is rendered
    ; new code with support for playfields 16, 32, 64, 128... in size which then allows scrolling to
    ; be supported
    mov   tile_map_index_ptr, r1      ; r1 = line, copy it
    and   tile_map_index_ptr, #$1F0    ; tile_map_index_ptr = [(r1 / 16) * 16..256], this is the
                                    ; starting tile index for a row
                                    ; , 0, 16, 32, ...
    shl   tile_map_index_ptr, tile_map_width
    shl   tile_map_index_ptr, #1        ; tile_map_index_ptr = tile_index*2, since each tile is 2
                                    ; bytes, we need to convert index to byte address
    add   tile_map_index_ptr, tile_map_base_ptr ; tile_map_index_ptr = [(r1 / 16) * 16..256] +
                                                ; tile_map_base_ptr
                                                ; this is a byte address in main memory now

    ; at this point we have everything we need for the pixels rendering aspect of the 16 tiles that
    ; will be rendered, the inner loop logic will retrieve the tile map indexes, and access the 16
    ; pixels that make up each row of each tile, BUT we need to get the palette(s)
    ; for each tile as well, each tile has its own palette, but the palette will change each group of
    ; 16-pixels across the screen since each 16-pixels represents a single line from a different
    ; tile. we could cache all the palettes into the local cache if we wanted.

    ; render the 16 tile lines (10 on screen only), r2 is holding proper row address, but we need to
    ; add base of actual tile we want rendered
    mov   r4, #1            ; r4 = tile_index, offset to 1, so we can index into scanline buffer one tile
                            ; to the right which makes the sprites able to scan off the left edge
Pixel_Render_Loop

```

```

    ' read next tile index and palette index from main memory
rdword tile_map_word, tile_map_index_ptr

    ' retrieve 16-pixels of current row from proper bitmap referenced by tile
mov    r3, tile_map_word
and    r3, #$FF          ' mask off upper 8-bits they hold the palette index, we aren't interested in
shl    r3, #6           ' r3 = tile_map_index*64 (bytes per tile)
add    r3, r2           ' r3 = tile_map_index*64 + tile_bitmaps_base_ptr + video_line mod 16
rdlong r3, r3          ' r3 = main_memory[r3], retrieve 32 bits of pixel data
                           ' 16 clocks until hub comes around, try and be ready, move a couple
                           ' instructions that aesthetically should be in one place between the hub reads
                           ' to maximize processing/memory bandwidth

    ' at this point we can bring in the sprite data and mask data, we need to first mask the current
    ' pixels with AND mask to make a hole then simply OR the sprite scanline data into the tile data
    ' to make the "composition"
    ' v_pixels_buffer = (v_pixels_buffer & sprite_scanline_mask[r4=tile_index] ) |
    ' sprite_scanline_bitmap[r4=tile_index]

    mov    r0, #sprite_scanline_mask      ' r0 = @sprite_scanline_mask
add    r0, r4                  ' r0 = @sprite_scanline_mask+tile_index (0..15), long address
movs   :ReadMask, r0          ' modify source operand in mov instruction downstream
nop     ' give self modify a moment to catch up...later put something here useful other than NOP
:ReadMask mov   sprite_mask_buffer, 0      ' sprite_mask_buffer = sprite_scanline_mask[tile_index]

    mov    r0, #sprite_scanline_bitmap   ' r0 = @sprite_scanline_bitmap
add    r0, r4                  ' r0 = @sprite_scanline_bitmap+tile_index 0..15), long address
movs   :ReadBitmap, r0          ' modify source operand in mov instruction downstream
nop     ' give self modify a moment to catch up...later put something here useful other than NOP
:ReadBitmap mov  sprite_bitmap_buffer, 0      ' sprite_bitmap_buffer = sprite_scanline_bitmap[tile_index]

    ' now merge sprite bitmap with tile bitmap
and    r3, sprite_mask_buffer      ' AND mask first with tile pixel data in r3
or     r3, sprite_bitmap_buffer   ' OR bitmap data into pixels
mov    v_pixels_buffer, r3        ' r3 holds pixels now, copy to pixel out buffer

    ' retrieve palette for current tile
mov    r5, tile_map_word
shr    r5, #8          ' r5 now holds palette index, we shifted out tile index into oblivion
shl    r5, #2          ' multiple by 4, since there are 4-bytes per palette entry
                           ' r5 = palette_map_index*4
add    r5, tile_palettes_base_ptr ' r5 = palette_map_base_ptr + palette_map_index*4

    ' this line moved from top of loop to eat time after previous memory read!
add    tile_map_index_ptr, #2      ' advance pointer 2 bytes to next tile map index entry, for
                           ' next pass
rdlong v_colors_buffer, r5        ' read the palette data into the buffer

    ' draw the pixels with the selected palette
waitvid v_colors_buffer, v_pixels_buffer

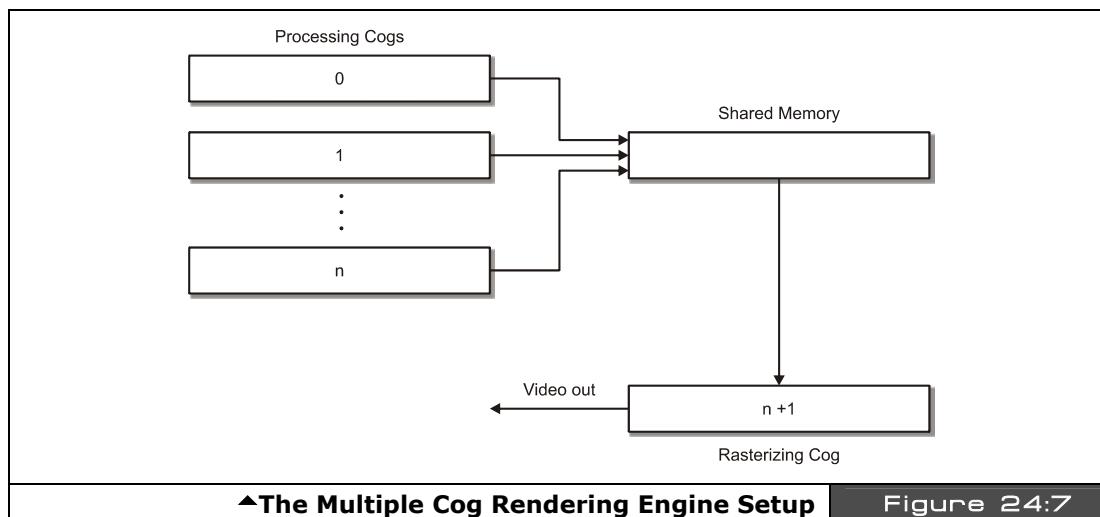
    ' reset hsync output status bit and set region and active line
    ' this code is NOT needed, can be commented out for more time in inner pixel processing loop
mov    r0, r1
shl    r0, #16          ' set the current line
or     r0, #TSB_REGION_ACTIVE_VIDEO ' set region to active video reset hsync
wrlong r0, tile_status_bits_ptr ' write out status bits to main memory
add    r4, #1           ' r4++
cmp    r4, #11         wc, wz

```

```
if_ne jmp  #Pixel_Render_Loop          ' loop until we draw 16 tiles (single pixel row of each)
                                         ' only 10 are viewable, so we loop until a net of 10
```

## 24.4 Advanced Engine Design Concepts

The HEL engine is a good baseline engine to start experimenting with. However, to take the engine to the next level it needs a couple more features, such as every single pixel can be any color you desire and many more sprites with scaling and other effects. Let's talk for a moment about how these effects might be achieved. First off, as you can see the problem with writing graphics engines is the vast amount of computation needed per pixel/line/frame. There are never enough clock cycles to do all the processing that we would like to do. The HEL engine more or less pushes a single cog near its limits, although with some optimization you could definitely get more out of it. However, we are talking about 10-50% more at max, not 3 to 5x more. Thus, another approach has to be taken to get more color, higher resolution, and more sprites on the screen.



The approach is simple: use multiple cogs to process the graphics information as shown in Figure 24:7. The idea is to separate the **processing** of tile, sprites, and geometry and **rasterization** into two different processes, then this is the perfect division of labor. For example, the Parallax reference drivers work in this fashion. There is one driver for the TV and one driver for the graphics. But, the idea is to take this to the extreme (which is done in the demos in the next chapter) and use one cog whose sole mission is life is to draw frames of video from a shared scanline memory buffer a line at a time. This shared scanline buffer is

**"fed"** by one or more cogs. For example, let's say we have one cog to rasterize the scanline buffer and one cog to generate the scanline data. So the rasterization cog only has to wait in a loop for the scanline to become "ready," read it in, and then write it out to the video stream with **waitvid** instructions. Moreover, since this producer-consumer arrangement unloads the video generation cog, you can draw only 4 pixels at a time rather than 16 and get full color since normally you pass 16 pixels and 4 colors. But, there is no reason you can't draw 4 pixels with 4 different colors, it's just that you have to feed the **waitvid** instruction constantly. But, if another processor is doing all the work then the cog that is generating video more or less is just reading from a buffer and not doing anything.

Moving back to the processing cog, we started with one. This means that by the time the video cog is done rendering a single scanline, the processing cog has to have the next scanline ready in the buffer. This means that more or less you get 64 µs to process a line. That's a good amount of time. However, by adding cogs we can double, triple, quadruple, etc. this number. For example, if Cog 1 and 2 are processing video data and Cog 3 is generating video, the processing cycle might start like this:

### System Start...

T0: Cog 1 – Generate line n  
 T1: Cog 2 – Generate line n+1

### Start Cog 3 Up....

T2: Cog 3 – Start reading and rasterizing line buffer generated by Cog 1  
 T3: Cog 3 – Start reading and rasterizing line buffer generated by Cog 2  
 T4: Cog 3 – Start reading and rasterizing line buffer generated by Cog 1

As you can see, now each processing cog has two time slices to build a scanline, since while either Cog 1 or 2 is generating a line, the rendering cog is reading from the other cog's scanline buffer. So basically, with 2-3 processing cogs and a single video cog you can more or less do anything you want with the Propeller chip graphically! Of course, the devil is in the details, and issues like double-buffering the scanlines, synchronization, and moving the buffers from cog to cog through shared global memory can be tricky. The point is that it's possible and you will see numerous demos of it in the next chapter.

## 24.5 Summary

Hopefully, you have learned your way around the HEL engine and have a starting point to either write a graphics driver from scratch or modify the engine to your needs. I have to admit that writing the engine was one of the most fun aspects of programming the HYDRA, since the engine code along with a single cog is like a "soft-GPU" and thus a very powerful paradigm (like the Atari 800/Amiga graphics **display lists**). I suggest trying to optimize the engine more, make it more compliant to LCD and plasma screens, and see if you can add

more sprites and more resolution to it. When you have mastered that then a multi-cog engine would be the next logical step. And to get you going there, in the next chapter you will see numerous graphics engines that you can use and modify yourself that are much more advanced than the HEL tutorial engine.



## Chapter 25:

### HYDRA Demo Showcase

Well, this is it, the end of a long journey. If you read this book cover to cover, I applaud you! In this last chapter, we are going to take a look a number of demos written by the "**HYDRA Demo Coder Team.**" If you know anything about computer graphics and games, you might have heard the term "demo coder" before. Demo coders are people that write "demos" for computers. So what? Well, demo coders typically write demos on computers and game systems that are simply impossible to do. That is, if you ask an above average programmer, if it's possible to do something really crazy on some very limited computer they will always say no. A demo coder will not only say "Yes!" but have it to you by the end of the night. Bottom line, demo coders are Jedi knights of programming, so there is a lot that can be learned by examining their code. On the other hand, their code is so advanced, so complex, it might as well be in an alien computer language! However, if you are patient you should be able to figure out how these demos work by playing with them and reviewing the code and comments therein.

### 25.1 The Demo Showcase

First off, the demo coders spent a lot of time working on all these demos, so I would like to once again thank them for contributing (in no particular order): **Rémi Velleux, Colin Phillips, Robert Woodring, Jay T. Cook, Nick Sabalausky, Rainer Blessing, Matthew Kanwisher and Michael Thompson.** If you would like to learn more about any particular demo coder, you can read about them in "About the Demo Coders" on page 795 at the end this chapter. I am going to present each demo and/or piece of software in a template form. All of the demos will run right out of the **\SOURCES** directory, simply load the top level source file indicated. Additionally, you will find additional sources, readme files, and other tools in the **\DEMOS** directory on the CD. The "additional sources" directory noted in each demo is the path to these files for each particular demo. Also, there will be a screen shot of each demo for reference, so you can see what the demo should look like.



If you find that the colors of a demo don't seem correct (or there is no color at all) you can either adjust the hue on your TV set or you can try adjusting the crystal frequency value in the setup of each demo. Look at the top of the main file for the demo in question and locate the line that looks like: "`_xinfreq = 10_000_000 + offset.`" The offset value added to the base frequency of 10\_000\_000 helps offset the xtal manufacturing variances. So try adding multiples of 1000 to the base of 10\_000\_000 eg. 0, 1000, 2000, 3000, 4000, or 5000 until the display looks good. Or, use negative numbers as well.

### 25.1.1 Dr. HYDRA



Figure 25:1

◀Dr. HYDRA in Action

Author: Rémi Veilleux

Top level filename: REM\_dr\_hydra\_018.spin

Additional sources in: \DEMOS\Remi\_Veilleux\REM\_dr\_hydra\_05\_11\_06

"**Dr. HYDRA**" is based on the popular "**Dr. Mario**" Nintendo puzzle game which is similar to a standard block drop game. Supports keyboard and gamepad play. Also, the game uses a high color graphics engine and assembly language overlay loader.

### 25.1.2 HYDRA Lock N Chase

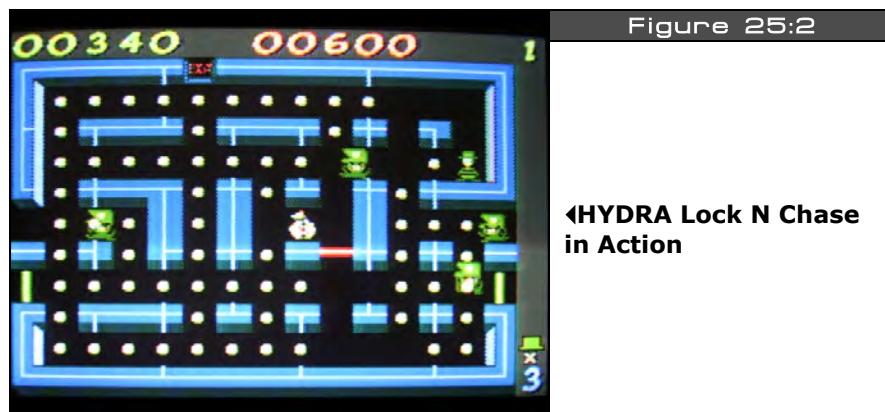


Figure 25:2

◀HYDRA Lock N Chase  
in Action

Author:

**Rémi Veilleux**

Top level filename:

**REM\_LockNChase\_012.spin**Additional sources in: **\DEMOS\ Remi\_Veilleux\REM\_lock\_n\_chase\_02\_12\_06****"HYDRA Lock n Chase"** is a retro remake of the popular 1980's game "**Lock N Chase.**"The player controls an escaped criminal and the police try to catch him. Supports keyboard and mouse. The game uses the standard Parallax reference driver **TV\_DRV\_010.SPIN** to generate the TV signal, but a custom graphics engine.

### 25.1.3 Alien Invaders



Author:

**Rémi Veilleux**

Top level filename:

**REM\_AlienInvader\_013.spin**Additional sources in: **\DEMOS\Remi\_Veilleux\REM\_AlienInvader\_02\_14\_06****"Alien Invaders"** is a two-player shooter that pushes the limits of Propeller chip to its absolute maximum. The game uses both a custom multi-cog graphics engine, overlay loader, and is in pure assembly language. Supports keyboard and both gamepads. There is no sound due to memory constraints.

#### 25.1.4 Peg Solitaire

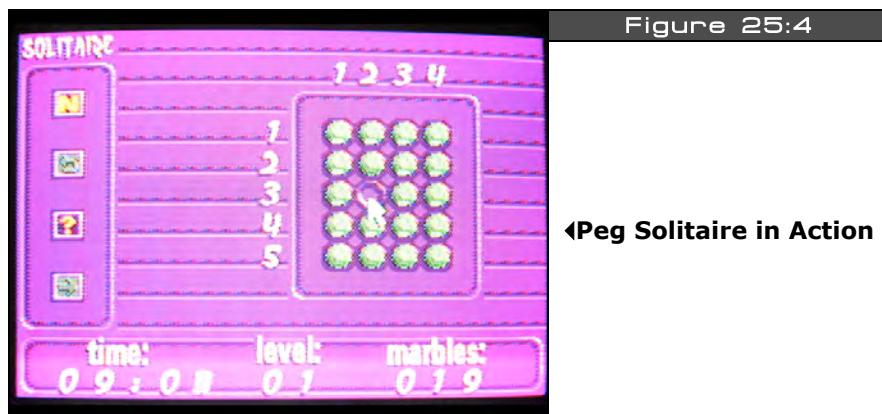


Figure 25:4

↳ Peg Solitaire in Action

Author: Rémi Veilleux

Top level filename: REM\_PegSolitaire\_016.spin

Additional sources in: \DEMOS\Remi\_Veilleux\REM\_peg\_solitaire\_02\_28\_06

"**Peg Solitaire**" is a computer implementation of the classic board game of the same name. Supports keyboard, mouse, and gamepad controls. The game is based on a custom multi-cog graphics engine and overlay loader.

#### 25.1.5 GFX Engine Demo and Tutorial

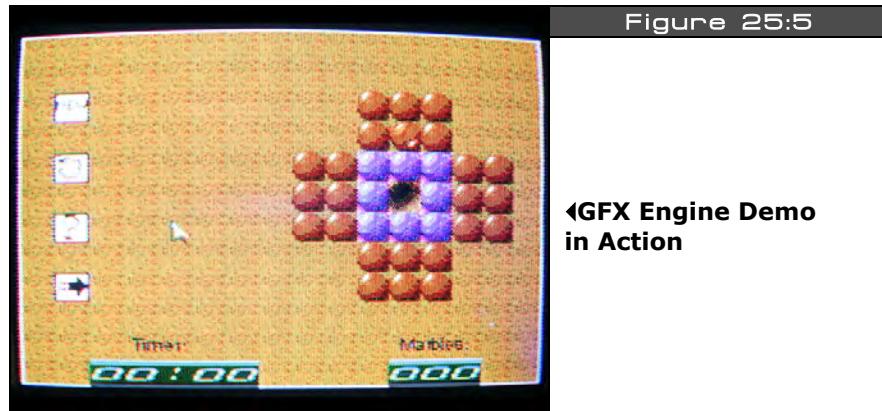


Figure 25:5

↳ GFX Engine Demo in Action

Author:

**Rémi Veilleux**

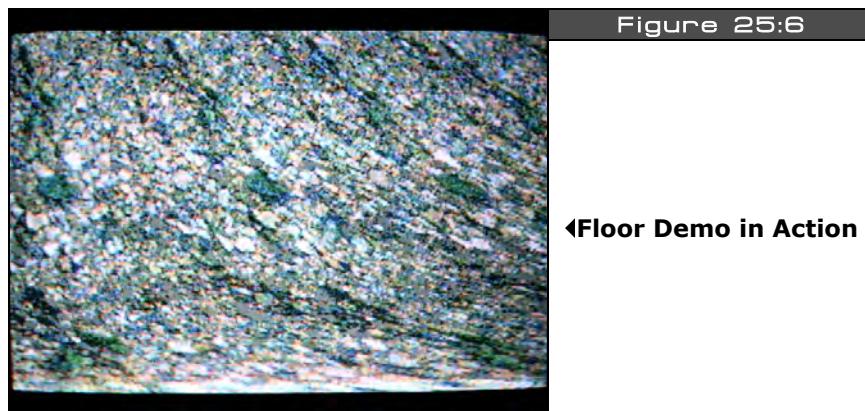
Top level filename:

**REM\_Tutorial\_017.spin**

Additional sources in: **\DEMOS\Remi\_Veilleux\REM\_tutorial\_03\_01\_06**

This graphics engine demo illustrates **Rémi Veilleux's "GFX"** graphics engine. The demo source file itself is heavily commented in tutorial style and guides you through the use of all aspects of the state-of-the-art engine for your games and applications. The demo directory contains other support source and files that you will need to use the engine in your own applications. Supports mouse, keyboard, and gamepads.

#### 25.1.6 Floor Demo



Author:

**Rémi Veilleux**

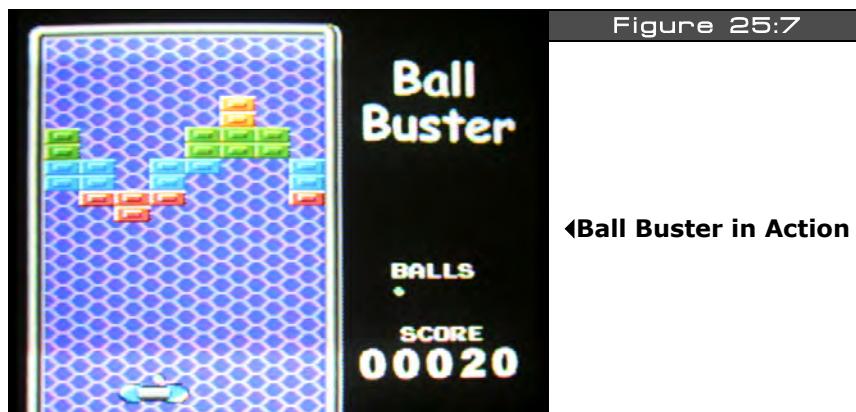
Top level filename:

**REM\_FloorDemo\_010.spin**

Additional sources in: **\DEMOS\Remi\_Veilleux\REM\_Floor\_02\_19\_06**

The "**Floor Demo**" illustrates a pseudo-3D parallax scrolling technique with a large bitmap. Use the mouse to adjust various sampling rates in the demo to see how they affect the image.

### 25.1.7 Ball Buster



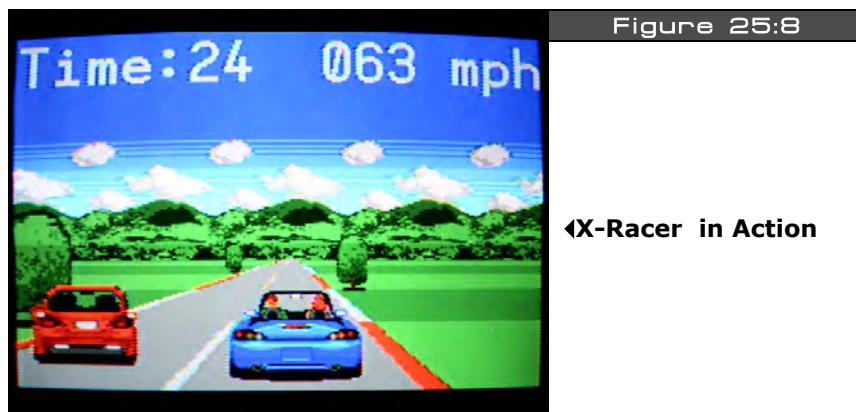
Author: **Jay T. Cook**

Top level filename: **JTC\_B\_Buster\_005.spin**

Additional sources in: **\DEMOS\JT\_Cook\JTC\_B\_Buster\_03\_09\_06**

"**Ball Buster**" is an implementation of the classic game "**Breakout**." The game uses the "**COP**" graphics engine developed by Colin Phillips as the driver. Supports mouse and gamepad inputs.

### 25.1.8 X-Racer



Author:

**Jay T. Cook**

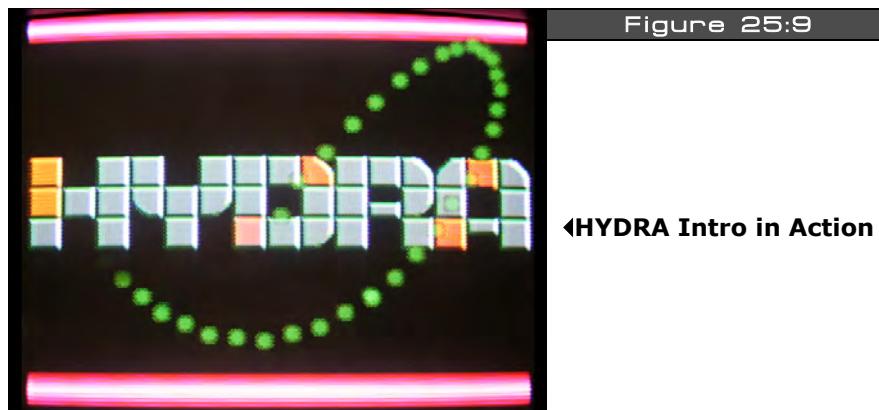
Top level filename:

**JTC\_XRacer\_010.spin**

Additional sources in: **\DEMOS\JT\_Cook\JTC\_XRacer\_08\_21\_06**

"**X-Racer**" is a 3D racing game that uses ray casting (sampling technique) and scaled sprites to create the illusion of 3D graphics reminiscent of "**Pole Position.**" This game is probably the most visually impressive of any of the demos for the HYDRA. The game's graphics engine is based on **Rémi Veilleux's** GFX engines. Supports gamepad controls.

#### 25.1.9 HYDRA Intro



Author:

**Colin Phillips**

Top level filename:

**CP\_HIADEMO\_001.spin**

Additional sources in: **\DEMOS\Colin\_Philiips\demos\CP\_HIADEMO\_02\_15\_06**

"**HYDRA Intro**" was written as a simple demo to test the "**COP**" graphics engine as well as give the HYDRA something to do when it boots from its on-board EEPROM. No controls, just looks pretty.

### 25.1.10 HydraMan

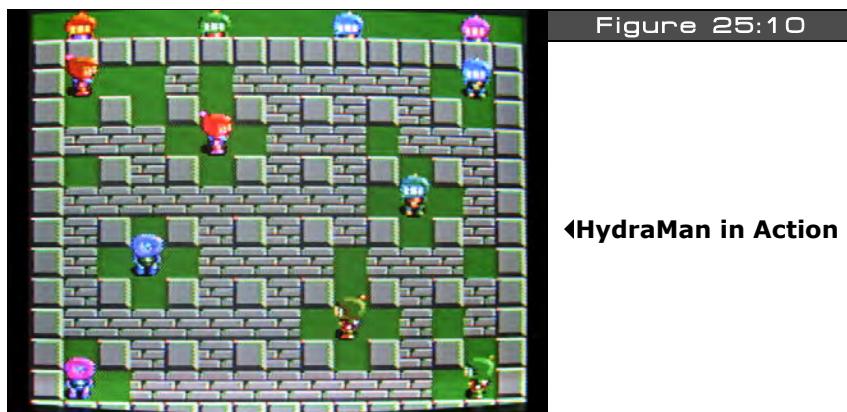


Figure 25:10

◀HydraMan in Action

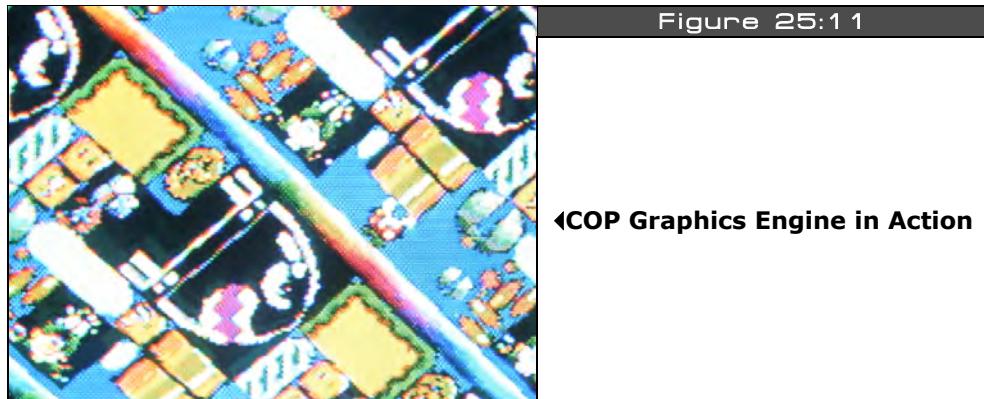
Author: **Colin Phillips**

Top level filename(s): **CP\_HYDRAMAN\_005.spin**  
**CP\_HYDRAMAN\_005b.spin**  
**CP\_HYDRAMAN\_005c.spin**

Additional sources in: **\DEMOS\Colin\_Phillips\GAMES\CP\_HYDRAMAN\_02\_14\_06**

"**HydraMan**" is based on the popular game "**BomberMan**." There are three versions of the game with various game play options up to 8 players. The graphics are based on the "**COP**" graphics engine. Support keyboard and both gamepads.

### 25.1.11 COP Graphics Engine Tests and Tutorials



Author: **Colin Phillips**

Top level filename(s): **CP\_COP\_test\_010.spin,**  
**CP\_COPGFXTEST\_001.spin,**  
**CP\_COPGFXTEST\_003.spin,**  
**CP\_COPTUT\_001.spin**

Additional sources in: **\DEMOS\Colin\_Phillips\graphics\**

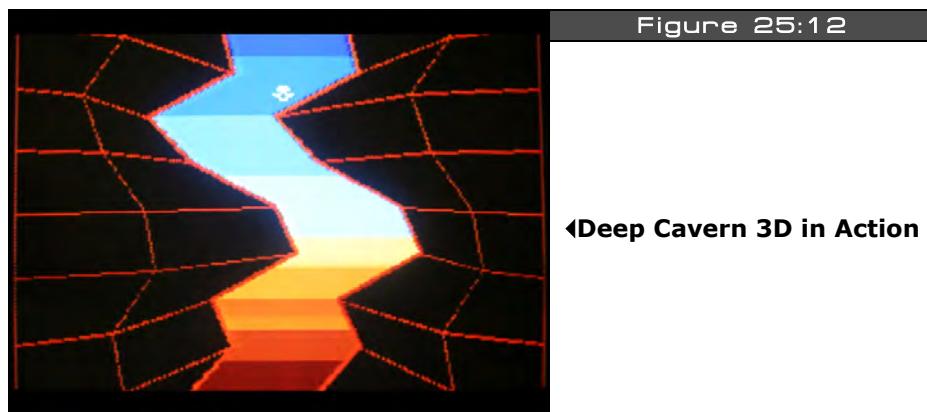
Colin Phillips experimented a great deal with the Propeller chip's graphics abilities and tried numerous performance experiments resulting in a slew of graphics engines. These engines were then later used by many of the demo coders to create their own demos on. Make sure to review all of the engines within the directory **\DEMOS\Colin\_Phillips\graphics\**. There are two classes of engines in there: the "**COP**" engines, and the second generation "**COP-GFX**" engines. Even though you could concentrate on the latest versions of each engine, I highly recommend reviewing the engines as they were developed (they are all dated) since this gives you a better chance of following how they work. The engines can be found in this directory:

**\DEMOS\Colin\_Phillips\graphics\CP\_COP\_01\_24\_06**  
**\DEMOS\Colin\_Phillips\graphics\CP\_COP\_02\_03\_06**  
**\DEMOS\Colin\_Phillips\graphics\CP\_COPGFXTEST\_03\_10\_06**  
**\DEMOS\Colin\_Phillips\graphics\CP\_COPGFXTEST\_06\_07\_06**

Finally, there is a complete tutorial on using the graphics engine which is composed of a sample demo along with sources. This can be found on the CD here:

**\DEMOS\Colin\_Phillips\graphics\CP\_COPTUT\_03\_02\_06**

### 25.1.12 Deep Cavern 3D



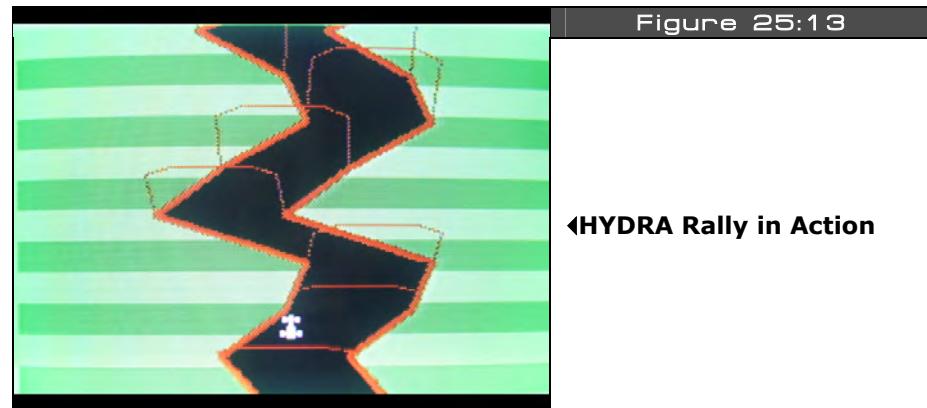
Author: **Nick Sabalausky**

Top level filename: **NS\_deep\_cavern\_020.spin**

Additional sources in: **\DEMOS\Nick\_Sabalausky\NS\_deep\_cavern\_02\_14\_06**

**"Deep Cavern 3D"** is a simple pseudo-3D demo based on perspective tricks and wireframe graphics. You control a ship which descends into the darkness. Supports keyboard and gamepad.

### 25.1.13 HYDRA Rally



Author:

**Nick Sabalausky**

Top level filename:

**NS\_hydra\_rally\_021.spin**Additional sources in: **\DEMOS\Nick\_Sabalausky\NS\_hydra\_rally\_02\_15\_06**

**"HYDRA Rally"** is a pseudo-3D experiment using wireframe graphics and perspective. You control a race car which you must keep from hitting the sides of the road. Supports keyboard and gamepad.

#### 25.1.14 Piano Demo



Author:

**Nick Sabalausky**

Top level filename:

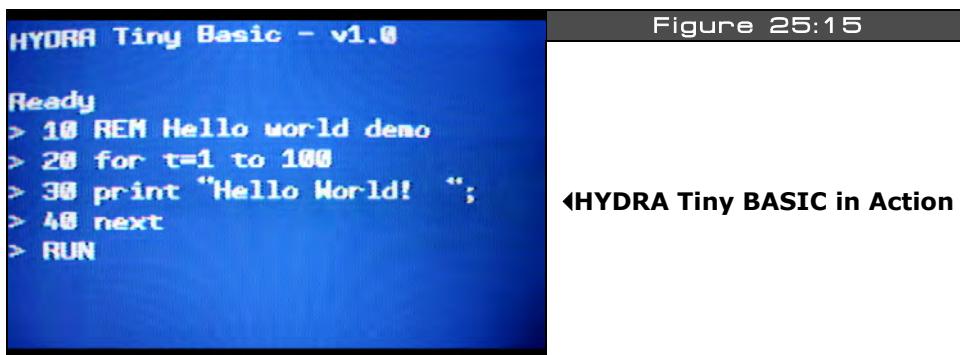
**NS\_sound\_demo\_052.spin**Additional sources in: **\DEMOS\Nick\_Sabalausky\NS\_sound\_07\_21\_06**

Nick Sabalausky did a lot of work on a full ADSR multi-channel sound driver for the HYDRA. The "**Piano Demo**" shows off the driver and what it can do. Also, the demo is a good place to start to see how to use the driver. The latest version of the driver at the time the book was printed was 5.2; however, make sure to check the CD for updates within Nick's directory as well as to see numerous other sound drivers and the development of the final product. The demo itself is more or less a piano that you can play using the keyboard and mouse. Also, <SPACEBAR> on the keyboard invokes the speech sample. Additionally, make sure to read:

**\DEMOS\Nick\_Sabalausky\NS\_sound\_07\_21\_06\NS\_sound\_drv\_writeup.doc**

...which is a rough draft of the design of the sound driver from the author's notes.

### 25.1.15 HYDRA Tiny BASIC



Author: **Robert Woodring**

Top level filename: **RGW\_TinyBasic\_010.spin**

Additional sources in: **\DEMOS\Robert\_Woodring\RGW\_HTBasic\_08\_03\_06**

**"HYDRA Tiny BASIC"** is an implementation of "**Tiny BASIC**" first presented in Dr. Dobb's Journal in 1976. The HYDRA implementation is more or less complete with its various quirks. However, it's a good example of a complete interpreter running on the HYDRA in assembly language and fun to program with a TV and keyboard and no PC. You could do worse things than review the source code line by line and figure it out. There is a document on the language itself and the keywords and so forth which can be found here:

**\DEMOS\Robert\_Woodring\RGW\_HTBasic\_08\_03\_06\Hydra\_Tiny\_Basic.doc**

This demo is probably one of the coolest things about the HYDRA since you can actually write programs with it. Moreover, the interpreter is **very** fast.



**TIP**

There is also a "mod" version of the language by Jay T. Cook that supports more characters per line. The top filename is: RGW\_JTC\_TinyBasic\_010.spin and the complete source files can be found in:

**\DEMOS\Robert\_Woodring\T\_Basic\_Mod\_08\_06\_07\**

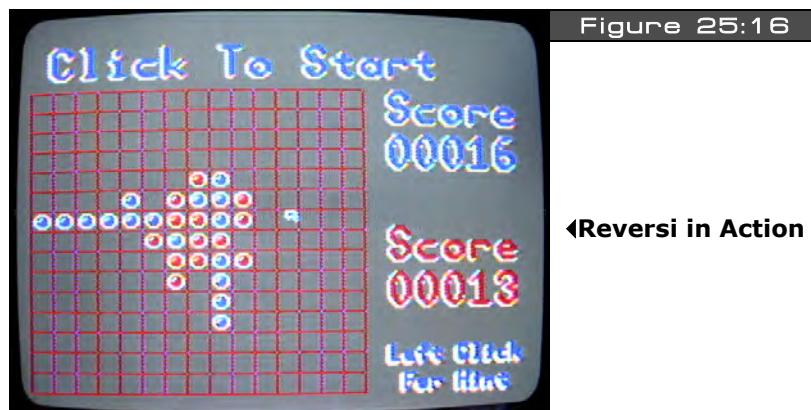
**25.1.16 Reversi**

Figure 25:16

◀Reversi in Action

Author:

**Robert Woodring**

Top level filename:

**RGW\_Reversi\_018.spin**Additional sources in: **\DEMOS\Robert\_Woodring\RGW\_Reversi\_02\_15\_06**

"**Reversi**" is an implementation of the classic board game by the same name. Use the mouse to make your moves. See if you can beat the built-in artificial intelligence (which isn't easy). Supports mouse only.

### 25.1.17 Glass Demo



Figure 25:17

◀Glass Demo 3D in Action

Author: **Robert Woodring**

Top level filename: **RGW\_Glass1\_.spin, RGW\_Glass2\_.spin**

Additional sources in: **\DEMOS\Robert\_Woodring\RGW\_glass\_sample\_05\_15\_06**

**"Glass Demo"** demonstrates a glass lensing effect that is a favorite of demo coders to implement. These demos are not 100% correct and thus a work in progress. Each demos tries a slightly different approach to obtain the lensing effect. Still they are interesting since they use large bitmaps and warp the image in real-time. No input devices supported.

### 25.1.18 Hydris

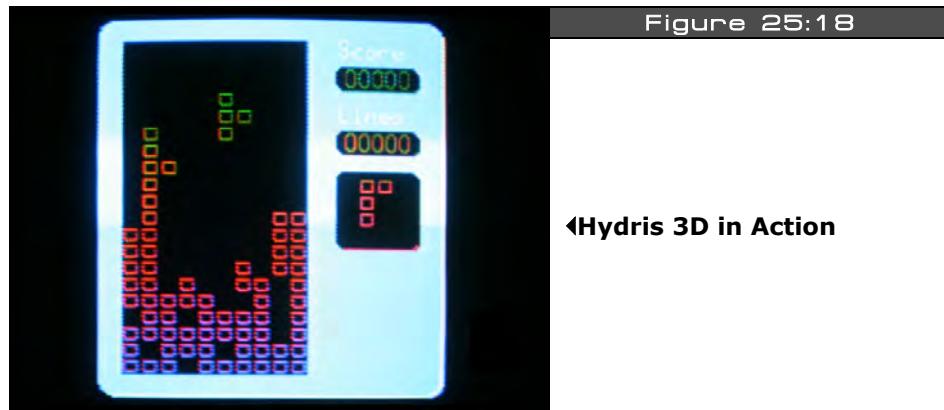


Figure 25:18

◀Hydris 3D in Action

Author:

**Rainer Blessing**

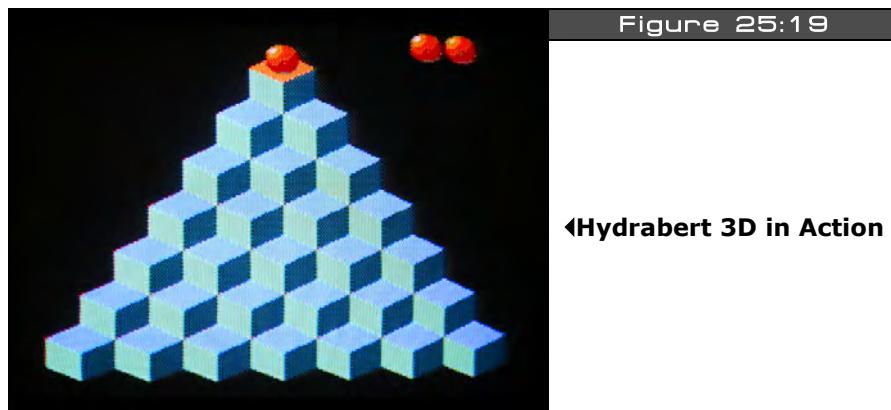
Top level filename:

**RB\_Hydrabert\_100.spin**

Additional sources in: **\DEMOS\Rainer\_Blessing\RB\_Hydrabert\_02\_14\_06**

"**Hydris**" is a variant of "**Tetris**." You rotate blocks and try to fit them together. Supports keyboard and mouse.

### 25.1.19 Hydrabert



Author:

**Rainer Blessing**

Top level filename:

**RB\_Hydrabert\_100.spin**

Additional sources in: **\DEMOS\Rainer\_Blessing\RB\_Hydrabert\_02\_14\_06**

"**Hydrabert**" is based on the idea of "**Q-bert**," that is, a 3D isometric game field that you move a character around on. This demo is in the early stages and no game play is in, but it's a good start for you to add some more elements to. Supports keyboard and gamepad.

### 25.1.20 Sub-Hunt

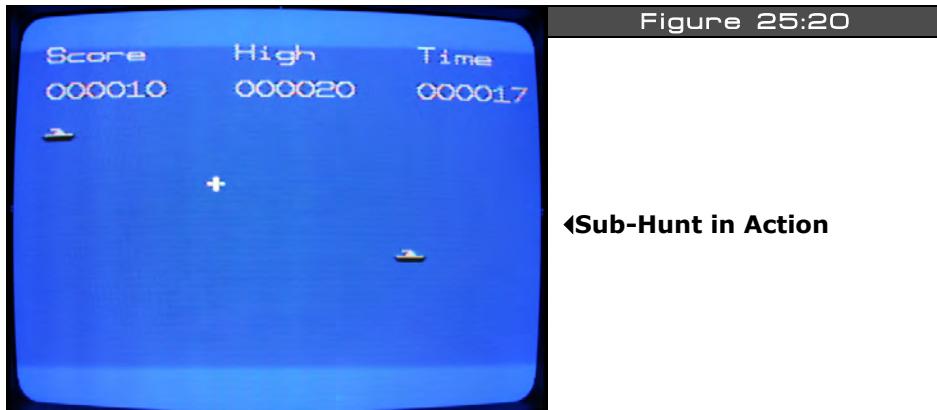


Figure 25:20

↳ Sub-Hunt in Action

Author: Matthew Kanwisher

Top level filename: MK\_SUB-HUNT\_013.spin

Additional sources in: \DEMOS\Matthew\_Kanwisher\MK\_SUB-HUNT\_02\_17\_2006

**"Sub-Hunt"** is based on the very old arcade game "**Sea Wolf**." You control a cross-hair and can fire infinite velocity projectiles at subs. Very simple game, all in Spin.

### 25.1.21 PDasm

| Location | ByteCode  | Op | Flag | Cond | Code:                         |  |
|----------|-----------|----|------|------|-------------------------------|--|
| 00000000 | 04C4B400  | i  | —ri  | 0001 | IF_NC_AND_NZ RDWORD 090, #000 |  |
| 00000001 | 0010746E  | 0  | —    | 0100 | IF_C_AND_NZ 058, 110          |  |
| 00000002 | 7B887A84  | IE | zcr- | 1010 | IF_Z 061, 132                 |  |
| 00000003 | 7B887A1C  | IE | zcri | 0110 | IF_C_NE_Z 017, #028           |  |
| 00000004 | 05B0220C  | i  | —c—  | 0000 | NOP                           |  |
| 00000005 | 00002230C | 0  | —    | 0111 | IF_NC_OR_Z 017, 012           |  |
| 00000006 | 00042549  | 0  | —    | 0001 | IF_NC_AND_NZ 018, 329         |  |
| 00000007 | 0004925AC | 0  | —i   | 0010 | IF_NC_AND_Z 018, #428         |  |
| 00000008 | 009C2B10  | 0  | —r   | 0111 | IF_NC_OR_NZ RDBYTE 021, 272   |  |
| 00000009 | 009C2F5C  | 0  | —r   | 0111 | IF_NC_OR_NZ RDBYTE 023, 348   |  |
| 0000000A | 009C3590  | 0  | —r   | 0111 | IF_NC_OR_NZ RDBYTE 026, 400   |  |
| 0000000B | 009C29C8  | 0  | —r   | 0111 | IF_NC_OR_NZ RDBYTE 060, 456   |  |
| 0000000C | 00000000  | 0  | —    | 0000 | NOP                           |  |
| 0000000D | 00000001  | 0  | —    | 0000 | NOP                           |  |
| 0000000E | 00000030  | 0  | —    | 0000 | NOP                           |  |
| 0000000F | 00000000  | 0  | —    | 0000 | NOP                           |  |
| 00000010 | 00000000  | 0  | —    | 0000 | NOP                           |  |
| 00000011 | 00000000  | 0  | —    | 0000 | NOP                           |  |
| 00000012 | 00000010  | 0  | —    | 0000 | NOP                           |  |
| 00000013 | 0000000C  | 0  | —    | 0000 | NOP                           |  |
| 00000014 | 0000000A  | 0  | —    | 0000 | NOP                           |  |
| 00000015 | 00000001  | 0  | —    | 0000 | NOP                           |  |
| 00000016 | 00000000  | 0  | —    | 0000 | NOP                           |  |
| 00000017 | 00000000  | 0  | —    | 0000 | NOP                           |  |
| 00000018 | 03938700  | 0  | zcr- | 0100 | IF_C_AND_NZ 451, 256          |  |
| 00000019 | 00000000  | 0  | —    | 0000 | NOP                           |  |

Figure 25:21

↳ PDasm in Action

**Author:****Michael Thompson****Top level filename:****pdasm.exe** (Windows command line executable)**Additional sources in:** **\DEMOS\Michael\_Thompson\MT\_PDasm\_02\_15\_06**

**"PDasm"** is a simple tool that disassembles Propeller binary files. It's a work in progress, but a good start if you need a disassembler. The C/C++ source files are all included, so you can modify and enhance the program.

## 25.2 Additional Demos and Sources

The demos presented are for the most part the most complete and impressive demos. However, as the demo coders were developing their software many of them experimented and created various tools to help their work out. Thus, make sure to take your time and look through all the sub-directories in the **\DEMOS** directory, read all the readme's, try all the tools out and so forth. There is a gold mine of additional information in there! For example, in Colin Phillips' directories under **\APPS\** you will find a PC-to-HYDRA communications application. In Nick Sabalausky's directory you will find an EEPROM driver under **\NS\_eeprom\_drv\_02\_26\_06\**.

## 25.3 About the Demo Coders

In the early days of game development it was customary to give credit on the packaging to the actual developers that created the games. Sadly, companies rarely give credit to the developers of games these days. They want us to think the CEO or marketing department made them I guess? Ya right! Typically, the developers' names are buried in the final credits of the game after it's solved. However, I want everyone to know the names and a little bit about the demo coders that created the awesome demos on the HYDRA that not only add value to the product, but have pushed the Propeller chip to its absolute limits and they deserve to be recognized.

**Rémi Veilleux** — Rémi Veilleux, born near Montreal, Canada, started programming with an Apple II and a Tandy TRS-80. Since then, he has collected numerous game consoles and old computers. He worked professionally for Ludus Design (Quadra), Microids Canada (Syberia series) and Electronic Arts (Medal of Honor, Golden Eye: Rogue Agent). Still being a passionate old-school developer, he coded games for the XGameStation Micro and more recently for the new HYDRA project.

**Colin Phillips** — Colin Phillips' interest in designing and programming games started as far back as when he was 5 years old when he was introduced to the QL Sinclair and it's SuperBasic. So, he has been programming for the best part of 20 years now. Highlights include developing an Assembler and C compiler for the Nintendo 64 at age 16, winning the Xtreme Games 128k game programming contest, and developing and maintaining numerous online gaming sites such as [www.thesnookerclub.com](http://www.thesnookerclub.com), [www.thepoolclub.com](http://www.thepoolclub.com) and the

recently launched [www.playonlinesoccer.com](http://www.playonlinesoccer.com). His company, Memir Software ([www.memirsoftware.com](http://www.memirsoftware.com)) is based in London, UK.

**Robert Woodring** — Robert Woodring lives, works and plays in Virginia Beach, VA. Robert has been a programming for more years than he can remember. Carbon dating results have yet to pin down his age conclusively. The latest gig for Robert for the past 15 years has been programming for route distribution handheld computers and trying to remember where he put his car keys. His passions are virtual machines, languages, and of course video games.

**Jay T. Cook** — "JT" Cook has been a longtime video game junkie which inspired his fascination of programming. He has been programming on various hobby projects since the late 90's with the HYDRA as his first commercial project. He currently resides in Des Moines Iowa and you can visit his website at [www.avalondreams.com](http://www.avalondreams.com).

**Nick Sabalausky** — Nick Sabalausky is interested in nearly all aspects of entertainment and computer technology, but his first passion is programming. Since grade school, he has worked with numerous languages and platforms, ranging from the common to the obscure. He is the author of the best-selling value PC breakout clones "Hyperball" and "Zarkanoid" both developed with Xtreme Games. Additionally, he runs [www.twistedpairgaming.com](http://www.twistedpairgaming.com) as well as serving as "official household system administrator" at his home in Cleveland, Ohio.

**Rainer Blessing** — Rainer Blessing is from Stuttgart/Germany. He studied computer science with a focus on networking. His day job is a Java/Database developer concentrating on application programming rather than game development. Rainer has been programming for over 20 years. The first game he wrote was Pong on the Atari 800XL, and he thinks gamewise he hasn't made much progress since then! But, he wrote a Linux IDE for the XGS ME and a complete emulator, so he is more of a system software game developer. His work can be found on [www.rainerblessing.com](http://www.rainerblessing.com).

**Matthew Kanwisher** — Matthew Kanwisher lives in Atlanta, Georgia. Currently he is attending Georgia State for a B.A in Computer Science. Matthew has worked on projects ranging from Telecommunications, Home Automation, and DJ Software. Currently he is working for BellSouth as a Senior Software developer on their Business Voice over Ip offerings.

**Michael Thompson** — Michael Thompson began programming at age 11 when he got his start in Apple IIe BASIC at an after-school program. After graduating high school he perused studies at DigiPen Institute of Technology from which he graduated in 2005 with an Associate's of Science in Real-Time Interactive Simulation. He now makes a living as a software developer in Bellevue, Washington and pursues his gaming interests in his spare time.

## 25.4 Summary

Well, hopefully you are sufficiently impressed. I know I am! The demos range from relatively simple Spin examples, to state-of-the-art, pedal-to-the-metal 3D games. If you take the time to reverse engineer every single demo and figure out the tricks and secrets of them, not only will you have mastered graphics on the HYDRA and Propeller chip, but you will have an edge against everyone else.



## **BACK MATTER**

## Epilog

It was a long time ago when I wrote my first computer program. I think it was about 1977 when I strolled into a Radio Shack and was instantly engrossed with the TRS-80. I spent many months driving my Mongoose BMX bike to play with it each day (in fact my bike was stolen one day while in the computer store programming!) I would draw my programs and graphics on graph paper, and then painstakingly type them in. Back then I was really into D&D, so all my games were D&D based. Then a few years later my parents bought me an Atari 800 (after years of lobbying for one). I doubt I left my bedroom even once during junior high or high school while I was learning the mysteries of graphics programming.

These 8-bit machines were magic. They were powerful enough to do anything you wanted them to – if you were clever enough. And all you needed to program was a TV, the computer and maybe a tape recorder. It was a lot of fun, I miss those days. It was like exploring a new planet, each day you would learn something new and everyone around was just as interested in programming as you were.

The HYDRA game console kit and book is my attempt to try and re-create this for others who can never live through those days. The ability to program in a simple language with a simple tool and see something on the screen is somehow magical to me even today. Sure, I like to keep up with the latest and greatest 3D graphics technology and shader programming, but there is something pure about programming simple computers and seeing your results instantly on the screen. Hopefully, everyone has fun with the HYDRA and all the components of it!

André LaMothe, 2006

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