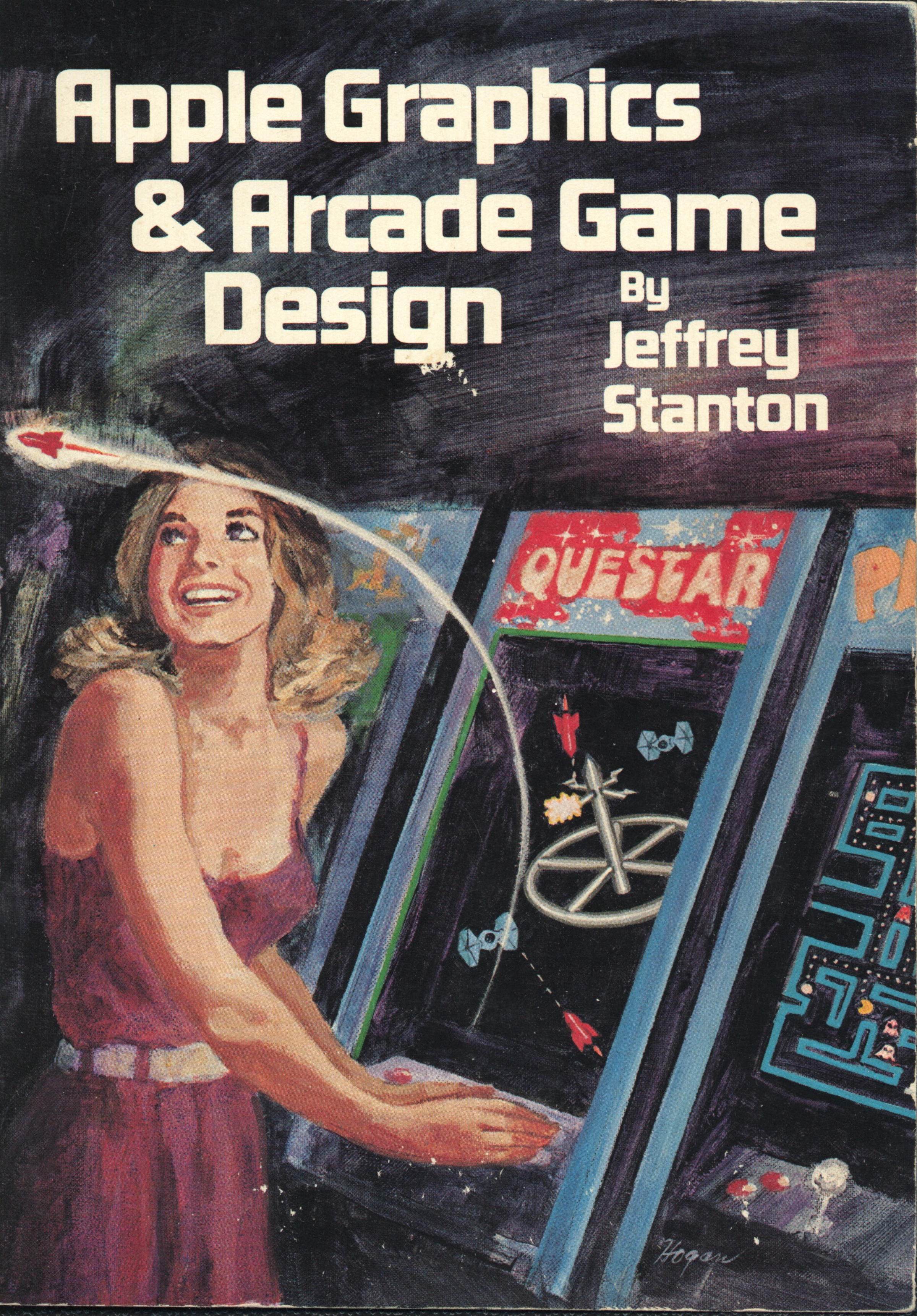
Apple Graphics & Arcade Game Design

By Jeffrey Stanton



APPLE GRAPHICS & ARCADE GAME DESIGN

BY JEFFREY STANTON

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ACKNOWLEGEMENTS

A book like this was a long and difficult undertaking. I would like to thank my publisher, James Sadlier for having faith in the book despite its long development time, Don Worth and Lou Rivas for reading the book for technical accuracy, and John Dickey and Gary Kevorkian who edited this book. I would also like to thank Dale Washlake, Phil Wasson, Jim Nitchals, and others who answered many of my graphics questions, and Shannon Hogan who did the cover art from one of my far fetched ideas.

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INTRODUCTION

A programmer's ability to create Apple graphics can be compared to an artist's ability with a sketchpad or an animator's skill with animation. Each in their own way creates images that are in some way entertaining. The viewer, however, is only interested in the final effect, not the tedious technical process that the artist or programmer had to apply to produce that effect.

The Apple II is a wonderful graphics tool, but unfortunately highly complex to use at any level other than Applesoft BASIC. The scattered magazine articles covering Apple graphics have shown the machine's complexity without presenting an adequate solution to the problem of graphics programming concepts. Those who understand the process and have mastered it are too busy writing programs to share their knowledge.

Magical references like "Raster Graphics" and "Bit Mapping" are spoken of as if they are secret techniques practiced only by the top programmers. Their games, such as "Raster Blaster", "Galaxian", "Sneakers", and "PacMan" have both awed wishful game designers and shown them the limitations of their own programming techniques.

This book will allow you to enter the world of Apple graphics, in which your most imaginative ideas can be animated. The various chapters will attempt to present a comprehensive course in Hi-Res graphics and high speed arcade animation. The major part of this material requires the ability to do assembly language programming. However, since this book was designed to increase the novice programmer's graphics skill, it assumes no prior knowledge of Apple graphics. The book begins with the bare bones graphic techniques of Applesoft BASIC and goes on to teach elementary machine language techniques that will enable the reader to program simple high speed games using the ROM's built in graphics routines.

Bit mapping (or raster graphics) and its use in high speed arcade animation will be covered in great detail. The approach throughout the book is to teach by example. The techniques required to program the three classic game types, (1) Space Invaders, (2) Asteroids, and (3) scrolling games like Defender, are explored. There are sections on paddle control, firing lasers, dropping bombs, explosions and scoring. Page flipping and scrolling techniques are also discussed.

The only requirements for this book are an inquisitive mind, perseverance, and a good assembler. Although prior assembly language programming experience is not necessary, you won't be able to write code without an assembler. The Apple's mini-assembler is totally inadequate for such a task.

I will attempt to explain the ideas in this book through a combination of text, drawings, and flow charts. The concepts in this book may seem easy at times, and somewhat difficult at other times. The Apple with its many idiosyncrasies is a strange beast to master. My advice is to read the book in stages and try the examples. Learn how they work.

While my goal for presenting this material was to educate a new generation of arcade game designers, I dread the proliferation of copy cat games. The world doesn't need an eighth Asteroids game, or a tenth PacMan game. They have been done. I do hope that programmers both young and old will use their imaginations to create something novel and exciting.

Jeffrey Stanton

JEFFREY STANTON
VENICE, CALIFORNIA
APRIL 16, 1982

PROGRAM LISTINGS AVAILABLE ON DISK

The majority of the code listed in this book is available on diskette to readers who disdain typing long computer programs. The disk is unprotected. The cost of this disk is a nominal $15.00 plus $1.50 postage to U.S. residents (foreign orders please add $5.00 for air mail). California residents add 6% state sales tax (Los Angeles County residents add 6½% sales tax). Available from The Book Co., 11223 S. Hindry Avenue, Suite 6, Los Angeles, CA 90045. (See order card at back of this book.)

A bit-mapping utility program, which was mentioned briefly in Chapter 4, is available to readers who purchase the above disk for an additional $10.00 plus tax. It enables the user to design any multi-colored bit-mapped shape on a grid 49 pixels wide by 32 lines deep. The program calculates the subsequent shape table in hexadecimal for both even and odd starting offsets, plus six additional shifted tables if that option is selected. Shapes can be displayed in their actual size and color as well as saved to disk. The program supports a line printer but it is not required.

The Applesoft and machine language object files provided will run on any standard Apple II Computer, but the assembly language source code requires one of three assemblers to interpret them. Big Mac and TED II + assemblers are available from Call A.P.P.L.E. Additionally, Merlin is available from Southwestern Data Systems. These binary source files can also be reformated for use in other assemblers like Lisa 2.5 or Tool Kit by using a text editor such as Apple Pie.

CHAPTER 1

APPLESOFT HI-RES

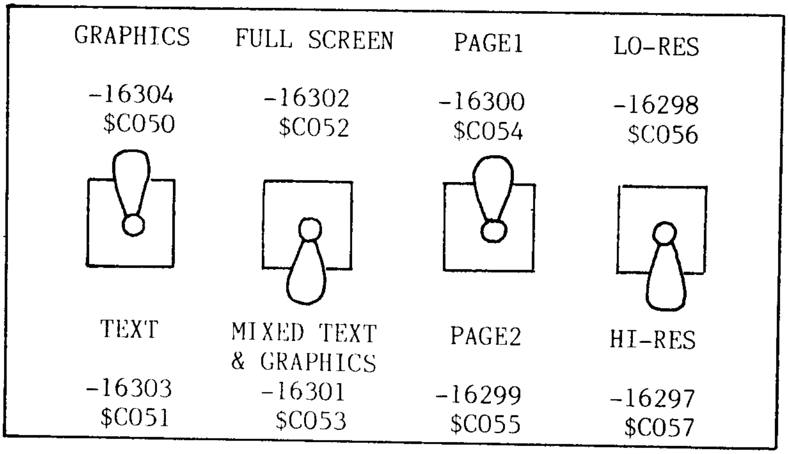
The Apple II computer has the ability to display color graphic images on a video monitor or television screen. It displays these images through a process known as Memory Mapped Output. Various circuits scan specific areas of Random Access Memory (RAM) to determine what should be displayed on the screen. These circuits convert memory information into images containing pixels or dots that are either turned on or off at particular screen positions. Each memory location contains a coded series of instructions for a particular segment of the Hi-Res screen. Thus the hardware maps the image coded in memory to the video screen.

The Apple II computer has two distinct graphics modes. Lo-Res graphics, which occupies the memory space reserved for the text page ($400 - $800), has a resolution of 40 dots horizontally by 48 dots vertically. Each dot is very coarse (7 X 8) pixels. Any one of sixteen colors can fill each of the 1920 positions on the screen. Hi-Res graphics, on the other hand, is much more detailed or dense. The resolution is 280 horizontal dots by 192 vertical dots. This gives 53,760 points on the screen. However, only six different distinct colors are available in this graphics mode. (There are actually eight colors including two whites and two blacks.)

Both graphics modes can either be full screen or they can be a mix of graphics and four lines of text at the bottom of the screen. This format reduces the Lo-Res screen to 40 lines and the Hi-Res screen to 160 lines.

Each of the graphics modes has two distinct pages or screens. They reside in specific areas of memory which are hardware set. Each screen can be viewed separately by setting a series of software switches that are located in Read Only Memory (ROM). These are not real physical switches but switches that can be toggled by POKEing values to their ROM reserved memory locations. These switches tell the video hardware to display either text or graphics, Lo-Res or Hi-Res, full screen graphics or mixed text and graphics, and either page 1 or page 2.

When you execute the GR statement in BASIC, the computer turns on the Lo-Res graphics mode, clears display memory so that the screen is black, and defaults to four lines of text at the bottom of the screen. The text window can be eliminated by typing the statement POKE −16302,0, thus giving full screen Lo-Res graphics. Similarly, the HGR statement turns on page one Hi-Res graphics, clears Hi-Res memory so that the screen is black, and defaults to the mixed text and graphics mode. Full screen graphics can be achieved by the statement, POKE −16302,0. And if you wish to view page 2 of Hi-Res



memory, the command HGR2 turns it on. The statement POKE −16301,0 sets full screen graphics for page 2.

The principal disadvantage of using HGR or HGR2 is that executing either of these commands clears the Hi-Res page selected, regardless of your wishes. There are times when you have produced a display and want to switch to a full page of text. If you return from text mode through the above commands, your display will be erased.

It is possible to enter the Hi-Res graphics mode without erasing the display screen. If you set the following soft switches which reside in reserved memory locations −16304 through −16297 ($C050 through $C057), you can display Hi-Res graphics page 1 without erasing its previous contents.

```
POKE -16304,0     SETS GRAPHICS MODE
POKE -16297,0     SETS HI-RES MODE
POKE -16300,0     SELECTS HI-RES PAGE 1
```

Hi-Res page 2 can be displayed with the following commands:

```
POKE -16304,0     SETS GRAPHICS MODE
POKE -16297,0     SETS HI-RES MODE
POKE -16299,0     SELECTS HI-RES PAGE 2
```

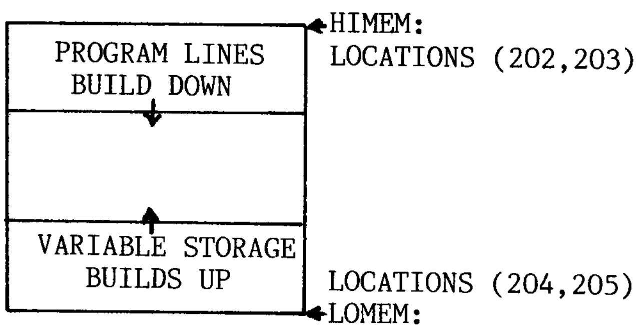
If you wished only to switch displays from Hi-Res page 1 to Hi-Res page 2, only the last command is necessary because the first two commands were previously set.

I should point out that the command "TEXT" will normally return you to page one of the text mode in Applesoft, but may not do so in Integer BASIC. If page two graphics were previously being displayed, the computer would return to page 2 of the text mode. Since this isn't the screen where the commands that you are typing are being displayed, the keyboard would consequently appear to be dead. Page one text can be selected with the statement, POKE −16300,0.

MEMORY CONSIDERATIONS

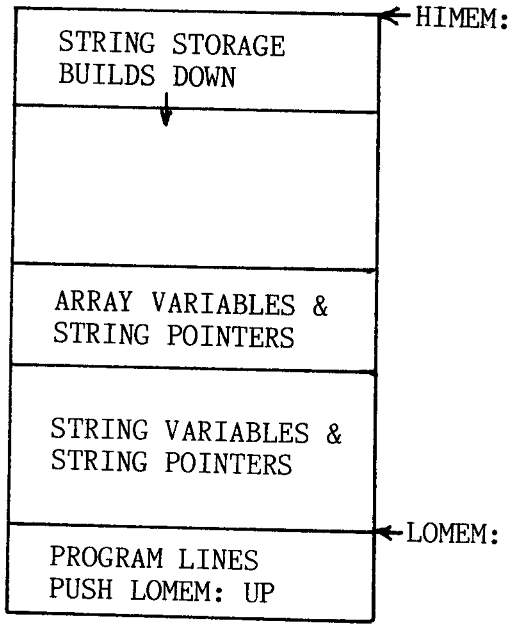
The two Hi-Res screens reside at memory locations 8192 – 16383 ($2000 – $3FFF) for page 1, and at 16384 – 24575 ($4000 – $5FFF) for page 2. These locations are permanently set. When programming in either BASIC, some considerations must be made as to where you should put your programs so that they don't conflict with the Hi-Res graphics screens.

If we examine an Integer BASIC program memory map below, we see that the program begins at HIMEM:, which is set by the computer to be just below DOS. Variables are stored beginning at LOMEM:, which is normally set just above the text page at location 2048 ($800). Unless you have some huge storage arrays or a very long program, neither the program nor its variables will cross the Hi-Res screen memory boundary. For safety's sake, it is often better to set LOMEM:16384 ($4000) so that no conflict could arise. This is especially true if both Hi-Res screens are being used. In that case, set LOMEM:24576 ($6000).



INTEGER BASIC PROGRAM MEMORY MAP

Applesoft, on the other hand, stores its program just above the text page at 2048 ($800). Program lines build upwards towards the top of memory. As the program gets longer, LOMEM:, which is the end of the Applesoft program, is pushed upwards. Simple variables and array variables begin just above LOMEM:, and string storage beginning at HIMEM:, builds downward. Thus, setting LOMEM: to a value above the Hi-Res screen would not relocate the Applesoft program nor prevent a long program from occupying the same memory space as the Hi-Res screens.



APPLESOFT BASIC PROGRAM MEMORY MAP

The solution is to set the pointers to the beginning of program text to a value above the Hi-Res screen(s) which you are using. These pointers must be set prior to loading or running the Applesoft program.

The easiest method for accomplishing this is to write an EXEC file which will automatically set these pointers and load or run your program in the proper position. The two pointers that must be set are at locations 103 and 104 decimal, lo byte and hi byte respectively. These are the pointers to the beginning of program text. A reset of the pointers and linkage to either firmware Applesoft ROM or Applesoft in the language card can be assured with a call to the subroutine at 54514 ($D452). One of the idiosyncrasies of this method requires that a zero byte precede the main program. Therefore the pointers are set one byte higher than requested, and the zero byte is poked into the first position. The following short program will create an EXEC file that will put your Applesoft program in the proper place, free of interference from your graphics.

```
10 D$ =  CHR$ (4): PRINT D$;"NOMON C,I,O
20  HOME
25  PRINT "THIS PROGRAM CREATES AN EXEC FILE THAT"
26  PRINT "RELOCATES AN APPLESOFT PROGRAM TO SOME"
27  PRINT "ADDRESS OTHER THA $800 (2048 DECIMAL)"
30  VTAB 6: INPUT "NAME OF APPLESOFT PROGRAM? ";FILE$: IF FI
LE$ = "" THEN 30
40  PRINT : PRINT "ENTER THE DECIMAL ADDRESS FOR THE START":
 INPUT "OF THE PROGRAM:";START
45  IF START < 2047 THEN  PRINT : PRINT "VALUE MUST BE GREAT
ER THAN 2047": PRINT : GOTO 40
50  PRINT : INPUT "NAME OF EXEC FILE: ";EFILE$
55 S = START + 1:HB =  INT (S / 256):LB = S - HB * 256
60  PRINT D$;"OPEN ";EF$: PRINT D$;"DELETE";EF$
65  PRINT D$;"OPEN ";EF$: PRINT D$;"WRITE ";EF$
70  PRINT "FP": PRINT "HOME: POKE 50,128"
80  PRINT "POKE103,";LB;"
85  PRINT "POKE104,";HB;"
87  PRINT "POKE ";START;",0"
90  PRINT "LOAD ";FILE$
95  PRINT "CALL54514": PRINT "POKE50,255"
100  PRINT "RUN": PRINT D$;"CLOSE"
105  END
```

COLOR & BACKGROUND FILL

There are eight color choices (0-7) on the Hi-Res screen. These are selected by the HCOLOR statement. Since the screen is arranged in alternating columns of either violet-green or blue-orange colors, depending on whether the hi bit is set in a screen memory byte, the absence of color produces two different blacks, and the presence of two adjacent lit pixels produces two different whites. (See chapter 5 for a more detailed explanation.) Thus, only six distinct colors are available. These are listed in the following chart.

COLOR	NUMBER
BLACK	0
GREEN	1
VIOLET	2
WHITE	3
BLACK	4
ORANGE	5
BLUE	6
WHITE	7

Sometimes it is desirable to clear the screen to a background color other than black. This can be accomplished by calling an Applesoft ROM subroutine located at decimal 62454. This clears the screen you used last, regardless of switch settings, to the color most recently HPLOTed. Of course, a call to this subroutine must be preceded by a HPLOT statement. For example, to clear the background to green, try the following:

```
100 HCOLOR = 1:HPLOT 0,0 :CALL 62454
```

PAGE FLIPPING

Using both Hi-Res screens is an effective way of smoothing animation, or creating an image on one screen while viewing the alternate screen. When a group of objects or lines are drawn successively to the screen during an animation frame, the last object drawn is on screen only a fraction of the time that the first object is on the screen. And if there are many large objects, the continuous drawing becomes noticeable.

Page flipping is an effective method to reduce flicker between animation frames. However, one assumes a reasonable animation frame rate of at least 10 frames per second, or the animation appears slow and jerky. The trick to this method is controlling the screen that is drawn to, regardless of the screen switch positions. There is a pointer in zero page, decimal location 230 ($E6), that sets which screen is plotted to. A POKE 230,32 indicates screen *#1*, and POKE 230,64 indicates screen #2.

The following example demonstrates the technique. The program HPLOTs thirty random line segments on one screen while the other screen is viewed. It then changes viewing screens to the screen where the image had just been drawn, and erases the opposite screen before randomly drawing thirty new line segments. The result is a series of completed line drawings that change from one image to the next without anyone being aware that they are being drawn elsewhere.

When screen #1 is viewed by toggling the switch with POKE -16299,0 , the statement, POKE 230,64 , tells the computer to draw to screen #2. Since $E6 points to screen #2 when the clear screen is called at line 52, it clears screen #2 before plotting our thirty random line segments. When we switch viewing screens to the completed picture with a POKE -16300,0 ,we reset $E6 to the opposite screen with a POKE 230,32. Now we are viewing screen #2, and drawing on screen #1.

```
5 X1 = 0:Y1 = 0
10  REM  CLEAR BOTH SCREENS
20  HOME : HGR : HGR2 : HCOLOR= 3
30  REM  NOW LOOKING AT PAGE #2
40  REM  SET DRAWING MODE POINTER (E6) TO SCREEN #1
50  POKE 230,32
51  REM  LEAR SCREEN #1
52  CALL 62450
60  FOR I = 1 TO 35
70 X2 =  INT ( RND (1) * 280)
80 Y2 =  INT ( RND (1) * 192)
90  HPLOT X1,Y1 TO X2,Y2
100 X1 = X2:Y1 = Y2
110  NEXT I
120  REM  LOOK AT SCREEN #1 FULL SCREEN
125  POKE  - 16300,0: POKE  - 16302,0
130  REM  SET DRAWING MODE POINTER (E6) TO SCREEN #2
135  POKE 230,64
136  REM  CLEAR SCREEN #2
137  CALL 62450
145  FOR I = 1 TO 35
150 X2 =  INT ( RND (1) * 280)
160 Y2 =  INT ( RND (1) * 192)
170  HPLOT X1,Y1 TO X2,Y2
180 X1 = X2:Y1 = Y2
190  NEXT I
200  REM  LOOK AT SCREEN #2
210  POKE  - 16299,0
230  GOTO 50
```

As you view the different supposedly random screens, you will notice that the screens appear to repeat every few frames. The repetition, although not perfect, is due to a faulty random number generator in Applesoft. This program graphically illustrates the fault.

A demonstration of the same program without page flipping can be shown. If you take the previous listing and make the following changes, the images can be seen as they are drawn.

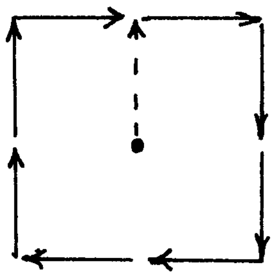
```
DELETE LINES 50 & 135
52 HGR2 : POKE-16302,0
125 POKE -16299,0
137 HGR : POKE-16302,0
210 POKE -16300,0
230 GOTO 52
```

APPLE SHAPE TABLES

The Apple II offers a very powerful feature in Applesoft BASIC called shape tables. They are essentially figures or shapes that use tiny vectors to quickly generate their form. They are very flexible in that they can be plotted anywhere on the Hi-Res screen without destroying the background, and they can be scaled (expanded) and rotated. These shapes are often used in animation and game design.

A shape table can consist of up to 255 different shapes. Each shape in the table is generated by outlining it with tiny unit vectors which are all the same length, but may take any of four directions (up,down,left,right). The vectors are placed head to tail until the entire shape is outlined. These vectors can also be of two types: plot vectors or move-without-plotting vectors. Then, using a key, these direction vectors are encoded into a string of hexadecimal bytes which are stored in memory as part of a shape table.

The procedure for creating a shape table isn't difficult, but it is time-consuming and quite prone to error if you aren't careful. The method, due to the nature of its encoding, has several peculiarities that the programmer should be aware of. The most important point, one that is rarely explained, is that the first vector is the position that the shape is drawn when X,Y coordinates are specified. For example, if you wish to draw a square shape to the screen that is two vector units per side, you will prefer to have the shape drawn so that it is centered at the coordinates specified. But if you start your string of vectors at the upper left corner instead of at the center, the shape's center will be at the corner. If the shape is rotated, it will pivot about that point instead of neatly rotating about the square's center. The solution to this misconception is to start at the shape's center and make a move upwards without plotting to the outline of the square's shape.



DESIGNING AND FORMING SHAPES

The first step in this procedureis to define your shape or shapes on a piece of graph paper. Direction vectors are drawn to indicate the sequence of coded instructions that will become our shape table. You can start your vectors around your shape in either a clockwise or counterclockwise direction; it doesn't matter. Next, we unwrap these vectors, starting with vector one at the left. This sequence forms a graphic list of our plotting vectors. Solid vectors indicate moves while plotting, and dotted vectors indicate moves without plotting. These vector codes range in value from 0-7 and are summarized in the table below.

SYMBOL	ACTION	BINARY CODE	DECIMAL CODE
↑ (dotted)	MOVE UP WITHOUT PLOTTING	000	0
--->	MOVE RIGHT WITHOUT PLOTTING	001	1
↓ (dotted)	MOVE DOWN WITHOUT PLOTTING	010	2
<---	MOVE LEFT WITHOUT PLOTTING	011	3
↑	MOVE UP WITH PLOTTING	100	4
→	MOVE RIGHT WITH PLOTTING	101	5
↓	MOVE DOWN WITH PLOTTING	110	6
←	MOVE LEFT WITH PLOTTING	111	7

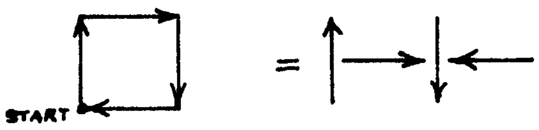
Each shape table byte (8 bits) is divided into three sections. Sections one and two are three bits each and contain any plotting vector. But section three, which contains only two bits, can only hold certain plotting vectors. The three vectors allowed are down, left and right without plotting. Most of the time this section remains unused. This is acceptable, because if section three of the shape definition byte is zero, Applesoft ignores the section and advances to the next byte of the shape.

	SECTION 3		SECTION 2			SECTION 1		
BIT M = MOVEMENT BIT P = PLOT /NO PLOT BIT	7 M	6 M	5 P	4 M	3 M	2 P	1 M	0 M

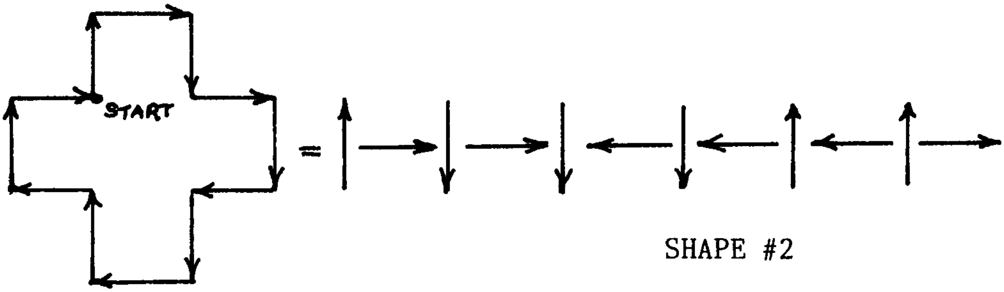
There is some ambiguity with plotting vectors that are equal to zero. In sections one or two, a zero specifies that you can "move up without plotting", but in section three it means "no movement and no plotting". This also means that you can't have a "move up without plotting" in the third section or it will be misinterpreted.

When all three sections are set to zero, Applesoft interprets it as an end of the shape. This limits the number of "move up without plotting" vectors that can be present in a row. If, for example, sections one and two both contained "move up without plotting" vectors and the next instruction was a plot, section three would be zero also. The value for the byte would be zero, or an end of shape. You can use the "move without plotting" vector in a byte as long as a different plotting vector comes after it. So how do you move upwards several vector units without plotting? By not moving in a straight line. You can move up one, left one, right one, then up one again. This can be repeated a number of times.

All these details may have left your head in a spin, but an example will show that shape tables can be constructed by mere mortals. I should point out that the final table is in hexadecimal, and that once the binary coded plotting vectors for each segment are arranged in groups of two or three within a byte, it becomes easier to divide that byte into two nibbles (4 bits each) for easier encoding.



SHAPE #1



SHAPE #2

DRAWINGS OF BOTH SHAPES

SHAPE #1	00	101	100		0010	1100		2C
	00	111	110	=	0011	1110	=	3E
	00	000	000		0000	0000		00
	00	101	100		0010	1100		2C
	00	101	110		0010	1110		2E
	00	111	110		0011	1110		3E
SHAPE #2	00	111	110		0011	1110		3E
	00	111	100		0011	1100		3C
	00	101	100		0010	1100		2C
	00	000	000		0000	0000		00

ASSEMBLING A SHAPE TABLE DIRECTORY

Shape tables are preceded by a shape table directory which contains information concerning the number of shapes in the table, and pointers to the beginning of each shape. The first byte contains the number of shapes (0-255), the second byte is unused, and the remaining pairs of bytes contain the offsets to each shape in the table. The actual number of pairs depends on the number of shapes in the table's first byte.

Although space may be defined for a certain number of shapes when the directory is constructed, there is no rule that says all these shapes need be in the table. Most programmers leave extra space because it is somewhat difficult to expand the table later if extra shapes are needed. A summary of the directory is shown below.

DISPLACEMENT	
0	NUMBER OF SHAPES IN TABLE ($0 -FF)
1	UNUSED
2	OFFSET TO SHAPE 1 LO ORDER BYTE
3	OFFSET TO SHAPE 1 HI ORDER BYTE
	. . .
2N+2	OFFSET TO SHAPE N LO ORDER BYTE
2N+3	OFFSET TO SHAPE N HI ORDER BYTE
2N+4	. . PLOTTING VECTORS SHAPE 1
	. . .
	PLOTTING VECTORS SHAPE N

LENGTH DEPENDS ON NUMBER OF SHAPES IN TABLE (2 BYTES/SHAPE)

If we construct a directory for our previous two shape examples, it takes the following form.

BYTE		
0	02	NUMBER OF SHAPES
1	00	UNUSED
2	06	LO BYTE OF OFFSET TO SHAPE #1
3	00	HI BYTE
4	09	LO BYTE OF OFFSET TO SHAPE #2
5	00	HI BYTE
6	2C	
7	3E	SHAPE #1
8	00	
9	2C	
A	2E	
B	3E	
C	3E	SHAPE #2
D	3C	
E	2C	
F	00	

This procedure is very time-consuming and, if the shape is complex, prone to error. Fortunately, there are a number of commercial programs that can perform this chore automatically. Most of these, in addition to the standard shape creator, incorporate an editor for merging shapes from several different tables.

Several products that I would recommend are Higher Graphics (Synergistics Software), The Complete Graphics System (CO-Op Software), and Shape Builder and Editor (Telephone Transfer Connection). These packages range in price from $35 to $60.

The shape table creator which I've included below lacks an editor for merging, inserting, or deleting shapes. It is also limited to shapes with a maximum size of 25 X 15 pixels. This is inherent in the design, which allows you to define shapes precisely on an oversized grid.

The program is menu-driven and somewhat user-proofed to prevent "bombing" the program in the midst of a hundred-shape-long table, which the user in this case, might have neglected saving periodically to the disk. Once a shape table is initialized, shapes are created one at a time with the command, (C)reate. A starting point is chosen for the shape's center. These values have no relationship to the coordinates where the shape is plotted later, but is the center of the shape and the point about which the shape is rotated with the ROT command. Your shape doesn't have to start there, but can be offset from it or completely surround it.

The current cursor position can be moved by the I,J,K,M keys. If you want to plot a point, press the P key after a move. If you make a mistake, the E key will erase the last plotted point; however,this must be done before the cursor is moved again. Sorry, but it doesn't step back through your keystrokes. When you are finished with the shape, you simply (Q)uit.

When you are returned to the main menu, you have a choice of (V)iewing the shape or (A)dding the shape to the table. Look at the shape first, because if it is incorrect, you can try again with the (C)reate command rather than add it to the table. You can also save the table or load a new table at any time.

This Applesoft program must be relocated above Hi-Res screen page 1. Use the program discussed earlier to create an EXEC file which will reset the pointers. Set the loading address at 16385 decimal. The Shape Creator stores its shape tables at $800, or 2048 decimal. If you choose to put your tables elsewhere, you must give the program a specific starting location address (e.g., LOAD SHAPE, A$7000).

Some of the readers who attempt to decipher my code will notice that I stored a value in the second position of the shape table directory. This location is normally unused. I chose to use the location to keep track of the number of shapes currently in the table. The first location contains the maximum number of shapes that the table can hold. This notation is entirely compatible with Applesoft.

```
1 D$ =  CHR$ (4):B$ =  CHR$ (7)
3 AFLAG = 1:N = 0
5  POKE 232,0: POKE 233,3
14  FOR I = 0 TO 9
16  READ A: POKE 768 + I,A: NEXT I
18  DATA  1,0,4,0,62,36,45,54,4,0
20  TEXT : HOME
24  HTAB 13: PRINT "C O M M A N D S": PRINT
26  HTAB 9: PRINT "(I)NITILIZE SHAPE TABLE": PRINT
27  HTAB 9: PRINT "(C)REATE NEW SHAPE": PRINT
28  HTAB 9: PRINT "(A)DD SHAPE TO TABLE": PRINT
29  HTAB 9: PRINT "(V)IEW SHAPES": PRINT
30  HTAB 9: PRINT "(L)OAD SHAPE TABLE": PRINT
31  HTAB 9: PRINT "(S)AVE SHAPE TABLE": PRINT
32  HTAB 9: PRINT "(Q)UIT": PRINT
33  PRINT "----------------------------------": POKE 34,1
7: HOME
34  REM  MENU COMMANDS
39  VTAB 19: HTAB 4: PRINT "COMMAND? ";: GET Q$:PK =  PEEK (
 - 16384): POKE  - 16368,0
41  IF PK = 73 THEN 50
```

```
42  IF PK = 67 THEN 100
43  IF PK = 65 THEN 500
44  IF PK = 86 THEN 600
45  IF PK = 76 THEN 65
46  IF PK = 83 THEN 700
47  IF PK = 81 THEN 2000
48  GOTO 39
49  REM  INITILIZE TABLE
50  HOME : PRINT : INPUT "  NO. OF SHAPES IN TABLE? ";MAX
52  POKE 2048,MAX
54  FOR I = 1 TO 2 * MAX + 1: POKE 2048 + I,0: NEXT I
56 ADDR = 2050 +  PEEK (2048) * 2
58 M = 2 + MAX * 2: POKE 2050,M - 256 *  INT (M / 256)
59  POKE 2051, INT (M / 256)
60  HOME : GOTO 39
64  REM  LOAD SHAPE TABLE
65  HOME : PRINT : INPUT "  SHAPE TABLE NAME ? ";NAME$
67  PRINT D$;"BLOAD";NAME$;",A$800"
70 N =  PEEK (2049):MAX =  PEEK (2048)
76  HOME : IF MAX > N THEN 39
78  PRINT "SHAPE TABLE FULL!": GOTO 2000
99  REM  CREATE NEW SHAPE
100  IF N = MAX THEN 450
101 ADDR = 2048 +  PEEK (2050 + 2 * N) + 256 *  PEEK (2051 +
 2 * N)
102  IF N = 0 THEN ADDR = 2050 + MAX * 2
103  IF AFLAG = 1 THEN N = N + 1
104  POKE 2049,N
106  HGR : HCOLOR= 3: SCALE= 1: ROT= 0:CYCLE = 0
108  FOR X = 0 TO 250 STEP 10: HPLOT X,0 TO X,150: NEXT X
110  FOR Y = 0 TO 150 STEP 10: HPLOT 0,Y TO 250,Y: NEXT Y
112  HOME : VTAB 22
114  INPUT "ENTER STARTING COORDINATES X,Y? ";X,Y
115  IF X < 1 OR X > 25 THEN 112
116  IF Y < 1 OR Y > 15 THEN 112
117 X = 10 * X - 5:Y = 10 * Y - 5
118  DRAW 1 AT X,Y:XS = X:YS = Y
120  HOME : VTAB 22: PRINT "MOVE PLOT CURSOR WITH KEYS"
122  PRINT "J -LEFT, K -RIGHT , I -UP, M - DOWN"
124  PRINT "P -PLOT ,E -ERASE LAST PLT , Q -QUIT": POKE 36,
41
126 KY$ = "":KSVE$ = "": GOTO 145
128  IF FLAG = 1 THEN 132
130  XDRAW 1 AT X1,Y1
132 X1 = X:Y1 = Y:FLAG = 0
```

```
135  XDRAW 1 AT X,Y
140 KI$ = KSVE$:KSVE$ = KY$
145  GET KY$
150  IF KY$ <  > "I" THEN 160
155 SYMBOL = 0:Y = Y - 10: IF Y =  > 0 THEN 225
157 Y = Y + 10: CALL  - 1052: GOTO 145
160  IF KY$ <  > "K" THEN 170
165 SYMBOL = 1:X = X + 10: IF X <  = 250 THEN 225
167 X = X - 10: CALL  - 1052: GOTO 145
170  IF KY$ <  > "M" THEN 180
175 SYMBOL = 2:Y = Y + 10: IF Y <  = 150 THEN 225
177 Y = Y - 10: CALL  - 1052: GOTO 145
180  IF KY$ <  > "J" THEN 190
185 SYMBOL = 3:X = X - 10: IF Y =  > 0 THEN 225
187 X = X + 10: CALL  - 1052: GOTO 145
190  IF KY$ <  > "P" THEN 200
195 FLAG = 1: GOSUB 300: GOTO 135
200  IF KY$ = "Q" THEN 400
205  IF KY$ <  > "E" THEN 145
210  HCOLOR= 0:FLAG = 0: GOSUB 300
220 KSVE$ = KI$: HCOLOR= 3: GOTO 130
225  IF KSVE$ = "P" THEN SYMBOL = SYMBOL + 4
230 CYCLE = CYCLE + 1
235  IF CYCLE <  > 1 THEN 245
240 BYTE = SYMBOL: GOTO 128
245  IF CYCLE <  > 2 THEN 270
250 BYTE = BYTE + 8 * SYMBOL
255  IF BYTE > 7 THEN 128
260 BYTE = BYTE + 8: POKE ADDR,BYTE:ADDR = ADDR + 1
265 BYTE = 24:CYCLE = 2: GOTO 128
270  IF SYMBOL > 3 THEN 280
275 BYTE = BYTE + 64 * SYMBOL
280  POKE ADDR,BYTE:ADDR = ADDR + 1
285  IF SYMBOL = 0 OR SYMBOL > 3 THEN 295
290 CYCLE = 0: GOTO 128
295 CYCLE = 1:BYTE = SYMBOL: GOTO 128
300  FOR Y2 = Y - 3 TO Y + 3 STEP 6: HPLOT X - 1,Y2 TO X + 1
,Y2: NEXT Y2
305  FOR Y2 = Y - 2 TO Y + 2 STEP 4: HPLOT X - 2,Y2 TO X + 2
,Y2: NEXT Y2
310  FOR Y2 = Y - 1 TO Y + 1: HPLOT X - 3,Y2 TO X + 3,Y2: NE
XT Y2
315  IF X = XS AND Y = YS THEN  RETURN
320  XDRAW 1 AT X,Y: RETURN
400  IF KSVE$ <  > "P" THEN 430
```

```
405  IF CYCLE <  > 2 THEN 415
410  POKE ADDR,BYTE:ADDR = ADDR + 1
415  IF CYCLE <  > 1 THEN 425
420 BYTE = BYTE + 32: GOTO 430
425 BYTE = 4
430  POKE ADDR,BYTE:ADDR = ADDR + 1
435  POKE ADDR,0:ADDR = ADDR + 1
440  POKE  - 16303,0: HOME : VTAB 22: PRINT " (A)DD SHAPE TO
 TABLE IF CORRECT":AFLAG = 0: GOTO 39
450  HOM : VTAB 22: PRINT " SHAPE TABLE FULL!!!": GOTO 39
499  REM  ADD SHAPE TO TABLE
500  HOME : IF AFLAG = 1 THEN 540
502 OFF = ADDR - 2048:AFLAG = 1
505  IF N <  > MAX THEN 515
510  HOME : VTAB 22: PRINT "TABLE FULL WITH THIS SHAPE!!!"
515  IF N > MAX THEN 550
520  POKE 2050 + 2 * N,OFF - 256 *  INT (OFF / 256)
525  POKE 2050 + 2 * N + 1, INT (OFF / 256)
530  GOTO 39
540  VTAB 22: PRINT "NO SHAPE TO ADD!": GOTO 39
550  VTAB 22: PRINT "TABLE FULL CAN'T ADD SHAPE!!!": GOTO 39

599  REM  VIEW SHAPES
600  HOME : VTAB 20: INPUT "VIEW LAST SHAPE Y/N? ";Q$
605  IF Q$ = "Y" THEN 627
610  VTAB 20: INPUT "WHICH SHAPE NUMBER TO VIEW? ";K
615  IF K =  < N THEN 625
620  PRINT "SHAPE #";K;" DOESN'T EXIST!": GOTO 39
625 M = K: GOTO 630
627 M = N
630  HGR : POKE 233,8: SCALE= 1: DRAW M AT 50,75
635  SCALE= 3: DRAW M AT 165,75
638  VTAB 21: PRINT "   SCALE=1         SCALE=3    SHAPE# ";M

640  SCALE= 1: POKE 233,3: VTAB 23: PRINT "        PRESS ANY
KEY!": POKE 36,41
645  GET Q$: POKE  - 16368,0: POKE  - 16303,0
650  HOME : VTAB 22: IF AFLAG = 0 THEN  PRINT " (A)DD SHAPE
TO TABLE IF CORRECT"
655  GOTO 39
699  REM  SAVE
700  HOME : PRINT : INPUT "SHAPE TABLE NAME? ";NAME$
705  PRINT D$;"BSAVE";NAME$;",A2048,L";ADDR
710  HOME : GOTO 39
2000  TEXT : END
```

SIMPLE GRAPHIC ANIMATION USING APPLE SHAPE TABLES

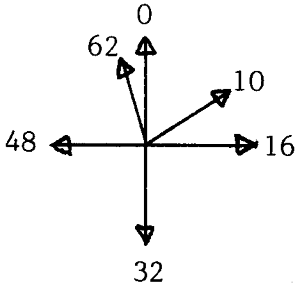
Apple shape tables can be incorporated very easily into games to produce animation. The principle is elementary. A shape is drawn to the screen in one position, then erased before moving it to the next position. If the move is in small increments, and if the animation frame rate is fast enough, the object will appear to have fluid motion. This is exactly how cartoons are animated.

Applesoft has a number of commands which work with shape tables. Any shape in a table can be drawn to the screen with the command, DRAW N AT X,Y , where N is the shape number in the table, and X and Y are the screen coordinates to plot the shape. The DRAW command plots over the background, thus erasing whatever was there previously. There is an alternate command: XDRAW, which exclusive-or's the screen where the shape is plotted. This means if the background is black, the pixels are lit (white) when the shape is XDRAWn to the screen, and they revert back to black when XDRAWn again. But if the background is white and a white shape is XDRAWn to the screen, the pixels are reversed, so that the shape becomes black. Similar complementary effects occur if the background color is green, blue, orange or violet.

Shapes can be rotated with the ROT command or scaled with the SCALE command. Values can range from 0-255. Values for both SCALE and ROT must be set to some value before drawing a shape for the first time.

When a shape is drawn at a scale larger than one (SCALE = 0 is equivalent to 256) , the computer will draw more than one point for each unit vector. If the scale is four, four points will be drawn for each single plotting vector.

Although rotation angles can range from 0-63, the actual number of rotation angles depends on the shape's scale. When the scale is set to 1, rotations can only occur in 90 degree increments (0 = 0 degrees, 16 = 90 degrees, 32 = 180 degrees, and 48 = 270 degrees). Shape rotations at SCALE = 2 can be incremented by 45 degrees, and by specifying SCALE 5 or greater, all 64 rotational angles are possible.



ROTATION ANGLES

When a shape is plotted to the screen, Applesoft needs to know the location of the stored shape table. Locations 232 and 233 decimal contain the starting address of the table, lo byte first. Thus, if the table were stored in memory at $300 or 768 decimal, Applesoft would be informed with POKE 232,0 : POKE 233,3 (00 being the lo order byte and 03 being the hi order byte).

It is important to find a safe spot in memory for your table, a place where it won't be overwritten by either the Applesoft program or its variable storage space. Short shape tables can be placed in page three of memory (locations $300 - $3CF) as long as you aren't using those locations for any other machine language routine, such as sound. An alternate location would be above the string storage space at HIMEM:. This involves resetting the pointers to a lower value. Addresses 115 and 116 ($73 and $74) contain the latest HIMEM: values, stored as lo byte first. The new address can be computed by the following statements.

```
PRINT PEEK(116)*256 +PEEK(115) -X
```

where X is the length of the shape table.

```
HI = INT ( HIMEM/256 )

LO = HIMEM - 256*HI
```

Then use the statements POKE 116,HI : POKE 115,LO to reset HIMEM:.

The shape table is then BLOADed at this address and locations 232 and 233 are set to point to the table.

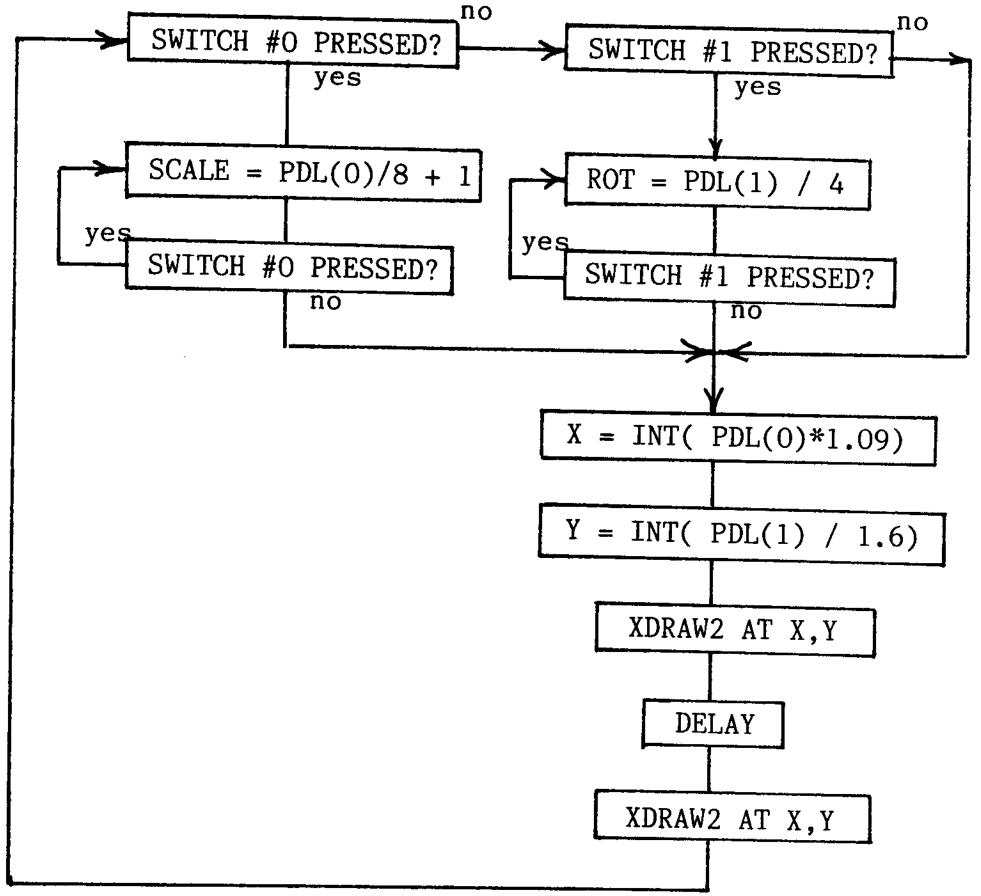
Sometimes it is best to illustrate a concept with an example. Many animated shapes like gun crosshairs are moved around the screen by paddle or joystick control. We can take shape #2, which is shaped like a cross, from our previous shape table example, and XDRAW it to the screen at a position determined by the settings of the two paddles. Remember that if you XDRAW a shape to the screen the first time, the shape appears. But if you XDRAW a shape that is on the screen, it will disappear.

The paddles in this example do more than just position the crosshair. If button #0 is depressed, the paddle setting changes the SCALE, and if paddle #1 is depressed, that paddle setting varies the ROT (rotation). Thus, you are able to observe the various effects that occur when varying the drawing parameters. Wrap-a-round is the most observable effect. This occurs when part of a shape crosses the screen's borders. This feature, which is performed automatically, can be either a help or a hindrance depending on the desired effect. There are times when you would like your shape to exit cleanly off one side of the screen without appearing at the opposite side. In those cases, you will have to test the screen coordinates so that wrap-a-round doesn't occur. Others who have, for example, a freely-floating spaceship, will be pleased by the convenience.

For convenience sake, I poked the shape table into memory at location 768

($300) with a FOR-NEXT loop that reads the values in a DATA statement. The hexadecimal shape table values have been converted to decimal values for the data. The alternate method is to enter the monitor and put the values into memory directly at $300, then BSAVE the table (BSAVE SHAPE, A$300,L$10 or BSAVE SHAPE, A768,L16).

Several of the paddle-controlled variables are scaled in the program. Paddle values range from 0 - 255. To obtain X coordinate values, which range from 0-279, the paddle values are multiplied by 1.09, and Y values are divided by 1.6 to keep them within the screen boundaries of 0-191. The SCALE was also trimmed to values 0 to 32 by dividing by 8. I think you will find the code and the accompanying flow chart clear.



```
1  POKE 232,0: POKE 233,3
5  FOR I = 0 TO 15: READ V: POKE 768 + I,V: NEXT I
10  HGR : POKE  - 16302,0: HCOLOR= 3
15  SCALE= 4: ROT= 0
20 BUT =  PEEK ( - 16287): IF BUT < 128 THEN 60
30  SALE=  INT ( PDL (0) / 8 + 1)
32  XDRAW 2 AT X,Y
34  FOR DE = 1 TO 50: NEXT DE
36  XDRAW 2 AT X,Y
40 BUT =  PEEK ( - 16287): IF BUT > 127 THEN 30
50  GOTO 90
60 BUT =  PEEK ( - 16286): IF BUT < 128 THEN 90
70  ROT=  INT ( PDL (1) / 4)
72  XDRAW 2 AT X,Y
74  FOR DE = 1 TO 50: NEXT DE
76  XDRAW 2 AT X,Y
80 BUT =  PEEK ( - 16286): IF BUT > 127 THEN 70
90 X =  INT ( PDL (0) * 1.09)
100 Y =  INT ( PDL (1) / 1.60)
110  XDRAW 2 AT X,Y
120  FOR DE = 1 TO 50: NEXT DE
130  XDRAW 2 AT X,Y
140  GOTO 20
200  DATA   2,0,6,0,9,0,44,62,0,44,46,62,62,60,44,0
```

Drawing shapes to the screen with XDRAW commands isn't the only method of drawing if erasing background is not a concern. The DRAW command works just as well for putting an object on the screen. The XDRAW command is still used for erasing the object. However, the DRAW command doesn't work properly at certain combined rotation angles and scale factors. This can be demonstrated in the last program by changing the XDRAWs in lines 32, 72 and 110 to DRAW commands. Now if the program is run, pixels from the shape sometimes aren't erased at some rotation angles with large scale factors. Thus, it is safer to always use the XDRAW command.

CHARACTER GENERATORS

Character generators are designed to assist the programmer in placing text on the Hi-Res screen. Their ability to mirror the print functions on the text screen makes them extremely easy to use from BASIC programs. Once the character generator is engaged (usually by a CALL to its starting address) any print statements within the BASIC program are printed on the Hi-Res screen instead of the text page. The HTAB and VTAB functions are fully supported, so that Hi-Res text can be accurately positioned.

Since the character set is in memory rather than in a ROM chip on the keyboard, character sets can be changed at will. An Old English or Gothic character set could easily be substituted for the standard ASCII character set used in the ROM.

This versatility in character set design has led to users creating character sets consisting of playing cards, alien monsters for games, or electrical symbols used in schematics. While each character is only 7 X 8 pixels, groups of characters can be arranged in a block to form larger shapes. A playing card could easily consist of nine different characters, forming a three by three block. If the Q W E A S D Z X C letters were used to define the queen of hearts, printing them to the screen in the following form would produce the playing card:

QWE
ASD
ZXC

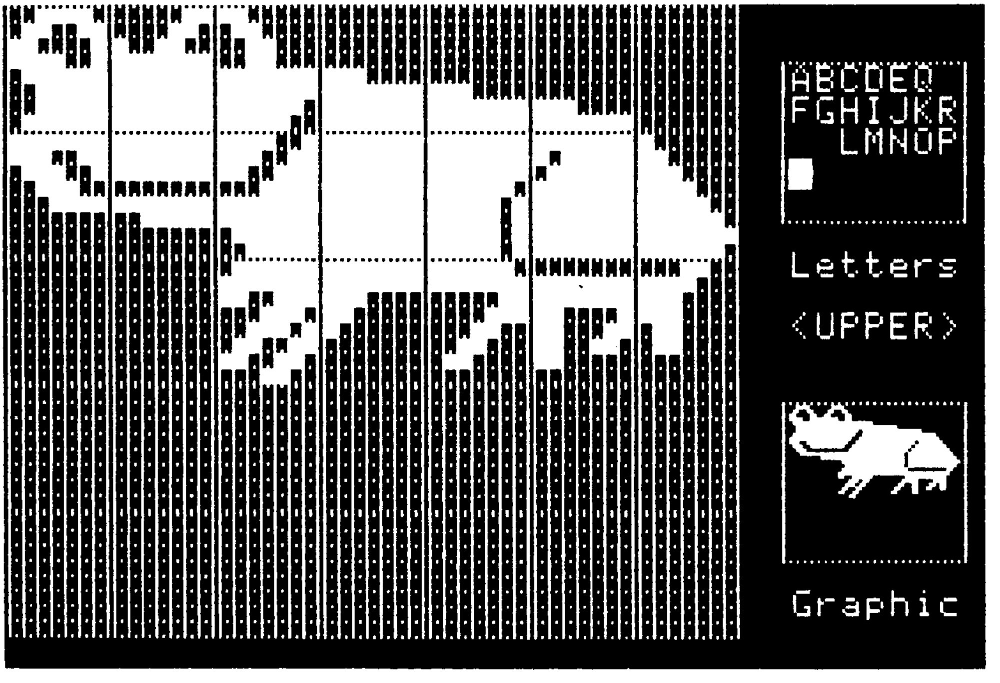
With 96 different characters available in one character set, you could easily represent the 13 card values, if two of the diagonal character elements defined the suit.

Many programmers have taken advantage of the high speed drawing ability of these machine language character generators to do animated graphics. Since sequences of characters representing shapes can be rapidly "printed" on the Hi-Res screen, each animated frame consists of characters "printed" at a new position.

Animating with character generators is relatively easy; however, it does have several disadvantages. First, the speed advantage gained by the machine language routine is badly offset by interfacing it with Applesoft. BASIC programs need to be compiled into machine code in order to produce marginal frame rates. Second, animation appears to be jerky due to the nature of the character position boundaries. There are only 40 horizontal positions and 24 vertical positions for placing a character on the Hi-Res screen. Since characters can't be drawn in-between positions, they tend to jump 8 pixel positions vertically and 7 pixel positions horizontally. Lastly, as a rule, character generator animation lacks color. Most limit color because of the peculiarities of the Hi-Res screen. If, for example, a green character were "printed" in column one, it would appear violet in column two. This would require two character sets to

compensate for this annoying effect between even and odd columns. It is easier to buffer the color to white.

The need to design new character sets has spawned a number of commercial character set editors and character set generators. One versatile package is included in the DOS TOOL KIT that is available from Apple Computer Incorporated. It has a program called "Animatrix" that enables you to construct shapes consisting of a number of user-defined characters. The illustration below shows a shape drawn on the enlarged grid, while the display in the upper right shows which characters these represent. When the character set is attached to their character generator (also in this package), animated drawings or games can be produced. They include an example of an animated game in which a joystick-controlled frog leaps in the air to catch passing butterflies.



ANIMATRIX DRAWING

Other available character generators are HIGHER TEXT from Synergistics Software and SCREEN MACHINE from Softape. Neither is suited for large character animation, but HIGHER TEXT can produce very nice color text displays.

HOW CHARACTER GENERATORS WORK

Character generators incorporate high speed machine language routines that calculate the character's position, then draws it on the screen one byte at a time. Characters consist of eight bytes in memory, where each byte represents the on/off positions of seven adjacent pixels. Each character is 7 pixels wide by 8 pixels deep. There are 96 characters in a set, each eight bytes in length, for a total of 768 bytes of memory.

The program has an index to the character set. Each character fits in a particular position within the set depending on its ASCII assigned value. The character numeric values range from decimal 160 to 255, including both upper and lower case characters. When the character generator begins processing the PRINT statement within the BASIC program, it reads a character, determines its ASCII value, then indexes to the proper eight bytes in its table to obtain the character shape bytes to be drawn to the screen. For example, the program says to print an H, which is interpreted as the ASCII character 200. That character is 40 characters past the tables first character value. Therefore, the H shape begins 40 X 8 bytes into the character set storage table. Now those eight bytes which will be plotted on the screen don't have to represent an H. They may have been redefined with a character editor to be a section of a much larger shape.

\$800	00	00	00	00	00	00	00	00	ASCII 160 (blank)
	.	.	.	.	.	.	.	.	
	.	.	.	.	.	.	.	.	
	.	.	.	.	.	.	.	.	
\$900	1C	22	2A	3A	1A	02	3C	00	ASCII 192 (@)
\$908	08	8C	14	92	3E	22	22	00	ASCII 193 (A)
\$910	1E	22	22	1E	22	22	1E	00	ASCII 194 (B)
	.	.	.	.	.	.	.	.	
	.	.	.	.	.	.	.	.	

Char A = 2048 + (193-160)*8 = 2312 (\$908)

Most character generators use control characters to set various modes. The Apple II lacks a true lower/upper case shift key; control characters are used for this function. Sometimes, control characters are used to put the user in "Block Mode". This saves inserting numerous VTABs and HTABs when printing a multi-character shape such as playing cards. Other control characters are often used to clear to the end of a line or even an entire page. This facilitates erasing the old characters before drawing new ones on the screen.

Screen animation is obtained by drawing the characters at one position, then moving them to the next position. Unlike Apple shape tables, you don't need to XDRAW to erase characters. Instead, leading or trailing blanks are added to help erase characters from the old string that may not be erased when drawing the new string. It is equivalent to using a DRAW command, with spaces inserted on either side of the shape. The other alternative is to erase the character shape entirely using blanks. This method is more likely to increase screen flicker since an extra step is involved.

The TOOL KIT character generator has one feature not found in other packages. It has the ability to preserve background while drawing characters. A good example of this is the demo game, RIB ✱ BIT. The character generator stores the background picture on Hi-Res page two, and ORs the characters against it while drawing on Hi-Res page one. This technique also facilitates erasing the characters in their previous position. One is relieved of the task of printing blanks to the Hi-Res screen before repositioning the character shape.

In summation, although a character generator is capable of animating simple games from BASIC for beginners, it doesn't offer the speed, flexibility, color, and smoothness that is required for quality arcade games. Although character generators have their place, there are better methods presented later in this book.

CHAPTER 2

LO-RES GRAPHICS

The words, machine language and/or assembly language, evoke visions of indecipherable code to the novice BASIC language programmer. The code looks unfamiliar. But so was BASIC when it was first learned. While BASIC has its roots in the English Language and algebraic expressions, assembly language appears to consist of unfamiliar op codes or mnemonics that are used in conjunction with an unfamiliar base 16 number system called hexadecimal.

It is my intent in this chapter to teach you the fundamentals of assembly language programming by comparing it to similar code written in BASIC. Rather than try to teach all aspects of the language, I'll concentrate only on the operations needed to do simple Lo-Res plotting and, later, additional operations to enable you to write a Lo-Res Breakout game.

A good assembler is needed to write assembly language programs. Although owners of Apple II Integer BASIC machines have mini-assemblers built-in, they don't offer the flexibility needed to write anything other than short programs. A good assembler allows you to enter assembly language code by line number and later edit, insert or delete particular lines. Since any line of code can have a label in its first field, the assembler will automatically calculate the branches or "GOTOs" to lines referenced with these labels. Also, if you wish to store a value in a variable called "ZAP", the assembler which assigns a memory storage location for the variable, and will automatically furnish the correct memory address for any subsequent store or load operations using that variable.

Readers who already own assemblers may use the one they have. For those of you who are new programmers, I would recommend one of two types of assemblers. One type of assembler evolved out of the Apple Computer organization and the Apple Puget Sound Programming Library (CALL - A.P.P.L.E.). These are mostly co-resident assemblers, wherein both the assembler and text editor reside in memory simultaneously. They are marketed under names like TED II + , BIG MAC , MERLIN, and TOOL KIT. Only the TOOL KIT is the exception. It is disk-based and loads either the assembler or text editor to memory. Its prime advantage lies in writing larger programs; however, its disadvantage is that it is time-consuming to shift files back and forth to the disk when testing short programs. I chose and used BIG MAC for writing the programs for this book. The other popular assembler that I would recommend is the LISA series by Randall Hyde. It is a co-resident assembler with a mediocre text editor and fast assembler, but its mnemonics are not completely compatible with the other assemblers. It also complements Randy's "Using 6502 Assembly Language" book, which I would recommend

reading for a more comprehensive introduction to assembly language programming. However, it does not cover graphics.

BASIC ASSEMBLY LANGUAGE

The Apple II contains a central processing unit (CPU), a 6502 microprocessor. It accepts instructions to perform various operations, like taking a value and storing it somewhere in memory, adding a number to another number located in one of its internal registers, or comparing two values. What makes programming in assembly language rather difficult (or at least tedious) is that it can only execute one tiny instruction at a time, and only perform its operations in three internal registers. These three addressable registers are known as the X register, Y register and Accumulator. Each can hold eight binary digits called bits, which are individually valued at 0 or 1. The eight bits, collectively called a byte, have values ranging from 0 to 255 decimal or ($00 to $FF in hexadecimal notation).

Essentially, the computer, which is an eight bit microprocessor, can manipulate data whose values range from all eight bits off (00000000) to all eight bits on (11111111). The average person has great difficulty in thinking of values represented by 0's and 1's. Fortunately, someone invented a number system called hexadecimal, which is base 16 instead of binary or base 2.

Since 16 is 2 x 2 x 2 x 2, we can divide our eight bits into two four bit groups. If you determine each of the decimal equivalents of all the combinations of base two representations, you obtain the following table. These values range from 0 to 15 decimal. In the hexadecimal numbering system, values above 9 are represented by the letters A - F. In order to prevent confusion between decimal and hexadecimal numbers, hexadecimal numbers are preceded by a "$".

BINARY	DECIMAL	HEXADECIMAL
0000	0	$0
0001	1	$1
0010	2	$2
0011	3	$3
0100	4	$4
0101	5	$5
0110	6	$6
0111	7	$7
1000	8	$8
1001	9	$9
1010	10	$A
1011	11	$B
1100	12	$C
1101	13	$D
1110	14	$E
1111	15	$F

Hexadecimal numbers are very much like decimal numbers. They can be added and subtracted in like manner. The only difference is that instead of having units, tens and hundreds, etc, the hexadecimal numbers have units, sixteens and 256's, and so forth. Each successive digit is 16 times the position to the right instead of ten times as in our decimal system.

```
        DECIMAL                          HEXADECIMAL

        1  6  5                          $ 1  3  A

    1 HUNDRED                        1- 256
          6 TENS                             3 SIXTEENS
             5 ONES                             A - ONES

        1 x (100) = 100                     1 x (256) = 256
    +   6 x ( 10) =  60                 +   3 x ( 16) =  48
    +   5 x (  1) =   5                 +   A x (  1) =  10
                 --------                             --------
                    165 DECIMAL              $ 13A  = 314 DECIMAL
```

Hexadecimal numbers are used to address the Apple II's 48000 + memory locations. Each group of 256 bytes ($00 - $FF) is called a page, starting with page zero. In 48K Apples, memory is directly addressable from locations $0000 to $BFFF (0 – 49050). Locations above $BFFF are also addressable, but these locations don't contain RAM. These locations, from $C000 – $FFFF, either address physical connections like the speaker and game switches at locations $C000 – $CFFF, or address the ROM (Read Only Memory) beginning at $D000 and extending to $FFFF. The latter area contains machine language monitor routines and either Integer or Applesoft BASIC, depending on whether you have an Apple II or Apple II Plus.

MEMORY MAP

PAGE	HEX RANGE	USEAGE
192–255 (192)	$C000 - $FFFF	HARDWARE & ROM
191 – 150	$9600 - $BFFF	DOS
149 – 96	$6000 - $95FF	FREE RAM
95 – 64	$4000 - $5FFF	HI-RES PAGE #2 OR FREE RAM
63 – 32	$2000 - $3FFF	HI-RES PAGE #1 OR FREE RAM
31 – 12	$C00 - $1FFF	FREE RAM
11 – 8	$800 - $BFF	FREE MEMORY OR PAGE #2 TEXT & LO RES
7 – 4	$400 - $7FF	PAGE #1 TEXT & LO RES
3	$300 - $3FF	MONITOR VECTOR LOCATIONS
2	$200 - $2FF	GETLN INPUT BUFFER
1	$100 - $1FF	SYSTEM STACK
0	$00 - $FF	ZERO PAGE - SYSTEM VARIABLES

The lowest eight pages of memory, locations $0000 to $07FF, are very important; programs should not be stored there. The upper four pages of this section of memory, $0400 to $07FF, are the memory locations of the text screen page. Storing values in these locations directly affects the text display. Page two, $200 to $2FF, is the keyboard buffer. Inputting data from the keyboard tends to wipe out stored data here. Page one, $100 to $1FF, is called the stack. It is used by a special purpose register in the 6502 microprocessor for keeping track of return addresses when calling subroutines. This scratch area for the Stack Pointer is sometimes used for temporary register storage. Page zero, $00 to $FF, is a very special area. There are a number of zero page addressing instructions. These instructions are two bytes long instead of the usual three, because they address a memory location from $00 to $FF instead of $0000 to $BFFF. The latter takes an extra byte to address the larger addresses. Also, these instructions execute faster. Page zero is used extensively for variable storage by the monitor, BASIC interpreters, and DOS. Only some of these memory locations are free for your use. You should consult the chart in the Apple Reference manual for usable locations.

When a microprocessor processes a machine language program, it keeps track of which instruction it is executing with an internal 16 bit register called the program counter. The program counter contains the current address of the instruction that is being processed. When the computer finishes with an instruction, it sets a flag or condition in a seven bit, Program Status Word, which is a register. For example, if you want to test if a value in the Accumulator is equal to zero, you can compare the Accumulator to zero. If true, the zero flag will be set and the instruction Branch Equal to Zero (BEQ) will be executed. Other flags that can be set are the carry flag, overflow flag, and the negative flag. A diagram of the Program Status Word is shown below.

7	6	5	4	3	2	1	0
N	V		B	D	I	Z	C
SIGN	OVERFLOW		BREAK	DECIMAL	INTERRUPT	ZERO	CARRY

PROGRAM STATUS WORD

The 6502 microprocessor accepts only machine language instructions. These are called op-codes. When the computer encounters a $4C, it performs a equivalent to a GOTO in BASIC. The machine language instruction $4C 00 08 tells the computer to jump to memory location $800. (Remember, addresses require two bytes with the low order byte containing $00 and the high order byte, $08 — in effect, the reverse order of the actual values. Unfortunately,

machine language is difficult to remember, so programmers invented a substitute called Assembly language, wherein each op-code is assigned a mnemonic such as JMP, BRK, and LDA. The above example looks like this: JMP $0800.

If you were to type the following machine code into the monitor, you would see how the monitor disassembler interprets the code, as in the following example:

```
>CALL-151
*800:A9 05 8D 00 09 CE 00 09 AD 00
     09 C9 00 D0 F6 60 < CR >
```

If you enter a 800L from the monitor you will see the following:

```
0800 A9 05       LDA #$05
0802 8D 00 09    STA $0900
0805 CE 00 09    DEC $0900
0808 AD 00 09    LDA $0900
080B C9 00       CMP #$00
080D D0 F6       BNE $0805
080F 60          RTS
```

The disassembler translates the machine code to easier understood mnemonics. In the first line of code, LDA is the mnemonic for Load Accumulator. It is the instruction for the 6502 to load the Accumulator with an immediate value -in this case, $05. The # sign signifies that it is an "immediate" instruction; the ($05) is the data portion of the instruction. The STA in line two is an "absolute" instruction. It specifies the address in memory for storing the byte of data that is in the Accumulator.

The difference between "immediate" and "absolute" instructions is an important point. Let us take the example LDA #$05. In this "immediate" instruction, the computer takes the operand ($05) as a value and places it in the Accumulator. However, with LDA $05, which is an "absolute" instruction, the computer takes the operand as an address from which to load data in the computer. In both cases, we get a value in the Accumulator. You can tell the modes apart because "immediate" instructions have a # sign before the operand.

You might wonder, what does this code do? It puts the value of 5 in memory location $900. Line two stores it there, then the value of that memory location is decremented by one in line three. It is then reloaded into the Accumulator to be compared against the value zero. If it is zero it falls through to a return-from-subroutine and ends; but if it isn't zero it branches back to memory location $805. That location tells the computer to decrement the value in $900 once

again. The code will perform this small loop until the value in $900 becomes zero. At that time, the test for a zero becomes true and the program returns to whatever called it. In our case, we called the code from the monitor - thus it returns to the monitor. If we had called it from within a program, it would have returned to the appropriate place in the code to continue the program.

Does it work? First, type 900:AA <CR> to place something in that memory location, then type 800G <CR> from the monitor. The code will return you back to the monitor when it finishes. Type 900 <CR> and a 00 is returned. This is the value in memory location $900. If you have an Integer machine that has STEP and TRACE, you can do a 800S <CR> instead, followed by a S <CR> each time and watch the code single step. The value in the Accumulator is the first value displayed. When it finally reaches zero the program will reach the RTS and finish.

This program has a direct analogy to the following BASIC program:

```
10 X = 5
20 X = X - 1
30 IF X <> 0 THEN 20
40 RETURN
```

The major differences between the two programs is that in assembly language there are no line numbers, and you have to take care of every detail. BASIC automatically assigns the storage locations of all variables and the location of each instruction in memory. In assembly language programming, we have to assign the X variable to memory location $900 and have to calculate the relative branch or GOTO so that it references the memory location $805. This is done by branching back $F6 bytes, or -8 bytes, to the proper address. Yet, many of these details can be greatly simplified if we use an assembler to do our programming.

The same program using an assembler looks like the following:

```
                LINE LABEL  INSTRUCTION  COMMENT
                  #  FIELD     FIELD      FIELD

                  1         ORG $800    ;ASSEMBLE CODE AT $800
                  2         OBJ $6000
                  3  X      EQU $900    ;X IS STORED AT $900
0800: A9 05       4         LDA #$05
0802: 8D 00 19    5         STA  X
0805: CE 00 09    6  LOOP   DEC  X      ;X = X - 1
0808: AD 00 09    7         LDA  X
080B: C9 00       8         CMP #$00
080D: D0 F6       9         BNE LOOP
080E: 60         10         RTS
```

The assembler generates identical machine code, but many of the tedious details are simplified. Once X is equated to the memory location in line 3, references to that variable in lines 5 through 7 are handled automatically. If X were assigned to a different memory location because our program was lengthened, you would only have to change line 3. Also, labels are allowed. They act like line numbers in BASIC. Since the assembler assigns the line of code labeled LOOP to a particular memory location, it can calculate the correct relative branch automatically when it encounters line 9 during assembly. The ORG and OBJ in lines one and two are pseudo-opcodes, understood only by the assembler. These do not generate machine code, but tell the assembler where the code is to be run and stored, respectively.

Although the ORG can be specified anywhere in memory, the OBJ is peculiar to older assemblers. The OBJ, or the place in memory where the code that is built is stored, must not overwrite either the assembler or the text file containing your source program.

Older assemblers, like TED II +, need to be told where the location is. Default values are recommended. Newer assemblers like BIG MAC, MERLIN, and TOOL KIT don't use OBJ pseudo-opcodes since they default to those values automatically.

When an assembler builds its code for an ORG different from its OBJ (as in the above example), the code has addresses and relative branches that will only execute at the proper ORG runtime address. The assembler, however, saves the code that is physically stored, beginning at address $6000. It will not execute if run at that address, so that you need to load or run it at $800 using a ",A$800" after the name of the program.

Now that you have had a taste of assembly language programming and have seen that it isn't as bad as you thought, there are a number of fundamental operations that must be learned. The most important operation is to move numbers from one memory location to another. This can be accomplished by loading a value into any one of the three internal 6502 registers, the Accumulator, X or Y registers, and storing that number somewhere in memory. A LDA (Load Accumulator) instruction can be carried out in several different ways depending on its addressing mode. First, we can load the Accumulator with a real hexadecimal value (LDA #$05). This is called Immediate Mode Addressing. Sometimes, we need to be able to load the Accumulator with a variable stored in a memory location (LDA $900). This is called Absolute Addressing. The only other addressing mode which we will discuss for the time being is the indexed addressing mode. It takes the form of LDA $900,X or LDA $900,Y depending on whether the X or Y register is used as an index. If, for example, the X register contains #$05, then the instruction above loads the value from location $900 + $5 or $905. This addressing mode is used primarily for indexing into tables stored at particular memory locations.

Store operations are similar to load operations. You can store a value into an "absolute" memory location, or you can store indirectly into a memory location, offset by the value contained in either the X or Y register.

In summary, the table below shows the various load and store operations.

	ACCUMULATOR	X REGISTER	Y REGISTER
LOAD	LDA #$05	LDX #$05	LDY #$05
	LDA $900	LDX $900	LDY $900
	LDA $900,X	LDX $900,Y	
	LDA $900,Y		LDY $900,X
STORE	STA $900	STX $900	STY $900
	STA $900,X		STY $900,X
	STA $900,Y	STX $900,Y	

Sometimes it is necessary when counting cycles or looping through code to increment or decrement a value directly - similar to a FOR-NEXT loop in BASIC. In assembly language, either the X and Y registers or any memory location can be incremented or decremented. If the X register contained $FE, then it would contain $FF when incremented. But if it contained $FF, it would wrap around to become $00. The computer informs you by setting a zero flag in its Program Status Register.

	ACCUMULATOR	X -REG	Y -REG	MEMORY LOCATION
INC BY 1	NOT AVAILABLE	INX	INY	INC $900
DEC BY 1	NOT AVAILABLE	DEX	DEY	DEC $900

Program flow can be altered, as in BASIC, with equivalent instructions that resemble GOTO, GOSUB, and IF-THEN statements. The JMP instruction is equivalent to a GOTO statement in that it can go to any location in the machine to continue executing code. JMP $AD6C instructs the computer to continue executing code beginning at address $AD6C. The GOSUB statement is identical to a JSR (Jump Subroutine) in machine language. When the computer executes the instruction JSR $FCA8, it pushes the two-byte memory address of the instruction onto the stack, so that when it returns from the subroutine at $FCA8 via an RTS (ReTurn from Subroutine), it will know the address of where to continue the program. When it returns, it pulls that return address off the stack and increments it by one, so that it points to the next executable instruction. The stack is like a dish dispenser. Bytes are pushed on the stack in order and pulled off in reverse order. New bytes are added to the top, while the rest of the bytes on the stack are pushed deeper.

The IF-THEN statement is simulated by a number of branch instructions which test the Program Status Register for which flags are set. Flags are usually set by compare operations. You can compare a value against the value stored in either the Accumulator or X and Y Registers. The mnemonics are CMP, CPX and CPY, respectively. For example,

```
LDA  $900  ;LOAD ACCUMULATOR WITH VALUE AT $900
CMP  #$05  ;COMPARE $5 WITH ACCUMULATOR
```

Different flags are set depending on the result.

Branch instructions are very similar to a JMP instruction (which is an unconditional branch), except that only under certain circumstances will it cause program flow to continue at a different location. For example, if we were to test for that wrap-a-round case when we incremented the X- register that contained $FF, we would want to test the Zero Flag with a Branch Equal Zero (BEQ) instruction, and go to some label if the condition is true.

```
       LDX   $900   ;LOAD X REGISTER WITH VALUE IN MEMORY
       INX          ;INCREMENT X- REGISTER
       BEQ   SKIP   ;TEST IF 0, AND IF TRUE GO TO SKIP
       RTS          ;RETURN TO MAIN PROGRAM
SKIP   LDA   #$05
        .      .
        .      .
```

This short example loads a value from the memory location into the X register, then increments it. If wrap-a-round occurs, the test for a zero flag causes the program to jump to a label called SKIP, and the code does not return to the program that called it via the RTS. There are numerous tests on each of the flags in the Program Status Register. A summary is shown below.

BCC -	Branch if the carry flag is clear.	C = 0
BCS -	Branch if the carry flag is set.	C = 1
BEQ -	Branch if the zero flag is set	Z = 1
BNE -	Branch if the zero flag is clear	Z = 0
BMI -	Branch if minus	N = 1
BPL -	Branch if plus	N = 0
BVS -	Branch if overflow is set	V = 1
BVC -	Branch if overflow is clear	V = 0

Most assemblers offer alternative mnenomics for BCC and BCS. Since, during comparisons, the carry flag is set when the value is equal or greater than the value compared, BCS might be called BGE (Branch Greater or Equal). Likewise, BCC is equivalent to BLT (Branch Less Than). Why use these alternatives? Because they are easier to remember and visualize, and they make it clear that you are doing logical comparisons rather than testing the results of an addition or subtraction.

There is one other important concept that should be understood when doing comparisions. I implied that the subsequent branch was like a GOTO in BASIC or like a JMP instruction in machine language. This is not entirely true, since the range of the branch can not exceed −126 to +129 bytes. This is because the branch instruction is only two bytes long. The first byte is the instruction code and the second the relative address. It takes a two byte address to branch to any place in memory (Except Page Zero). The JMP instruction has the advantage that it is three bytes long. In most cases, this limitation will not cause problems. But if a branch out of range error occurs, you must reverse the test so that it will reach the required destination via a JMP instruction.

EXAMPLE: If BEQ SKIP is out of range then substitute the following:

```
BNE *+$5      or        BNE  A
JMP SKIP                JMP  SKIP
 .                    A NOP
 .                        .
```

This change causes the program to drop through to the JMP instruction if the zero flag was set, and then jump to location SKIP. However, if the zero flag is not set, it will advance ahead five bytes to the instruction following the JMP. All of the other branch instructions work in a similar manner. This gives the equivalent of a Long Branch.

Simple addition and subtraction of unsigned numbers is easily accomplished in machine language. All addition and subtraction must be performed one byte at a time. Thus, large numbers or multi-byte numbers (those that exceed $FF), must be added or subtracted one byte at a time, and the carry flag must be accounted for. It's actually not much different than addition of two multi-digit long decimal numbers. Those numbers have a digit in the one's column, another in the ten's, etc. If you add 65 to 78, you add the one's column first. Five plus eight equals 13. The value in the one's column is 3; you then carry the one into the tens digit before you add the two numbers in the ten's column. Hexadecimal addition is similar. You clear the carry before you add. If the sum of the two values exceeds $FF, the carry is set. Since you don't clear the carry when adding the next higher byte, the resultant answer will be the sum plus the previously computed carry, as in the following example:

```
EXAMPLE :     +CARRY
                63     F4
              + 02   + 16
               ---    ---
                66     0A   ; SETS CARRY
```

The code for additions and subtractions is as follows:

ADDITIONS

```
CLC         ; CLEAR CARRY
LDA  #$F4 ; LOAD LO ORDER BYTE
ADC  #$16 ; ADD WITH CARRY
STA  LOW  ; STORE LO BYTE
LDA  #$63 ; LOAD HI ORDER BYTE
ADC  #$02 ; ADD WITH CARRY (NOTE DON'T CLEAR CARRY)
STA  HIGH ; STORE HI BYTE
```

SUBTRACTIONS

```
SEC         ; SET CARRY FLAG
LDA  #$F4 ; LOAD VALUE
SBC  #$16 ; SUBTRACT WITH CARRY
STA  VALUE; STORE ANSWER
```

You should be aware that the rules for subtraction are different than for addition. The carry must be set first. This is equivalent to a borrow in subtraction. After the subtraction operation, the carry will be clear if an underflow (borrow) occurred. The carry will be set otherwise. Setting the carry is very important, a step that many beginners forget. The results are invariably incorrect if this step is skipped - and possibly even ''random'', since the status of the carry flag can be on or off when the subtraction operation is performed. This can make debugging difficult.

LO-RES SCREEN

The Lo-Res screen occupies the same memory locations as the text page: $400 to $7FF for page one and $800 to $BFF for page two. When the Lo-Res graphics mode is toggled, the 1024 memory locations are presented as colored blocks rather than ASCII characters. Each ASCII character becomes two colored blocks, stacked one upon the other. Since the text page contains 24 lines of forty characters, the Lo-Res screen shows 48 rows of blocks, 40 blocks wide. Each block can be any one of 16 colors.

LOW - RESOLUTION GRAPHICS COLORS

DECIMAL	HEX	COLOR	DECIMAL	HEX	COLOR
0	$0	BLACK	8	$8	BROWN
1	$1	MAGENTA	9	$9	ORANGE
2	$2	DARK BLUE	10	$A	GREY II
3	$3	PURPLE	11	$B	PINK
4	$4	DARK GREEN	12	$C	LIGHT GREEN
5	$5	GREY I	13	$D	YELLOW
6	$6	MEDIUM BLUE	14	$E	AQUAMARINE
7	$7	LIGHT BLUE	15	$F	WHITE

Since each screen memory location represents two colored blocks in Lo-Res, each byte is divided into two equal halves called nibbles (4 bits). The value which is in the lower nibble of the byte determines the color for the upper block, and the higher order nibble determines the color for the lower block. Thus, if memory location $400, which is the first position in the first row, contains $D1, then the upper block is magenta and the lower block is yellow.

LOCATION $400	MAGENTA	VALUE
	YELLOW	$D1

I would like to point out that the map of the text screen is not sequential in memory. Like its big brother, the Hi-Res screen, the first 40 bytes map across the first row, but the second 40 bytes represent a row which is a third of the way down the screen. The third 40 bytes consitute a row in the bottom third of the screen. The exact order is not important at this time, because monitor subroutines calculate the base address for any Lo-Res color plotting automatically. To plot any Lo-Res point you need only give the monitor subroutine located at $F800 the row and column to plot and the proper color. The column is loaded into the Y register, the color into memory location $30, and the row into the Accumulator. A call to $F800 will plot a Lo-Res dot to the

screen, and will be seen if the Lo-Res graphics display is activated first. The dot's value is always placed into Lo-Res memory by this subroutine, even if you are viewing Hi-Res screen memory.

I would like to interject a word of caution when inputting color values for Lo-Res plotting subroutines. Because setting the proper color nibble depends on whether you are plotting on an odd or even row, it is safer to put the color desired in both low and high nibbles. To illustrate the point, let's assume we placed a $01 in the color register and we wanted to plot the point on row 0, column 0. The plotting subroutine would use the lower order nibble $1 to plot the magenta dot, then it would ignore the higher order nibble. However, if we choose instead to plot at row 1, column 0 , the subroutine will use $0 for the color and ignore the lo order nibble. Thus, the screen would remain black. The solution is to put the color in both nibbles. Placing $11 in the color register will always plot the proper color in the above example anywhere on the Lo-Res screen.

	FUNCTION	Y REG	ACC.	$0030	$002C	$002D
$FC58	CLEAR SCREEN	--	--	--	--	--
$FB40	SET GRAPHICS	--	--	--	--	--
$F800	PLOT A POINT	COLUMN	ROW	COLOR	--	--
$F819	HORIZ. LINE	START COLUMN	ROW COLUMN	COLOR	END	--
$F828	VERT. LINE		START	COLOR	--	END
			ROW			ROW
$F871	SCRN (X,Y)	COLUMN	ROW *	--	--	--

*(NOTE: COLOR RETURNED IN ACC.)

It is time to get your feet wet; we're going to plot your first few dots and lines on the Lo-Res screen. The code that I'll present is written on the TED II + assembler. However, the code is simple enough to type in on the mini-assembler if you haven't purchased an assembler as yet.

```
ORG $6000 ;ASSEMBLE CODE AT $6000
OBJ $6000
JSR $FB40 ;SET LO-RES GRAPHICS MODE
JSR $FC58 ;CLEAR SCREEN
LDA #$66  ;SET COLOR BLUE
STA $30   ;STORE IN COLOR LOCATION
LDY #$05  ;COLUMN
LDA #$03  ;ROW
JSR $F800 ;PLOT POINT
LDA #$99  ;SET COLOR ORANGE
STA $30   ;STORE IN COLOR LOCATION
LDA #$08  ;END COLUMN
STA $2C   ;STORE END COLUMN
LDY #$02  ;START COLUMN
LDA #$06  ;ROW
JSR $F819 ;PLOT HORIZ ROW
RTS       ;RETURN TO MONITOR
```

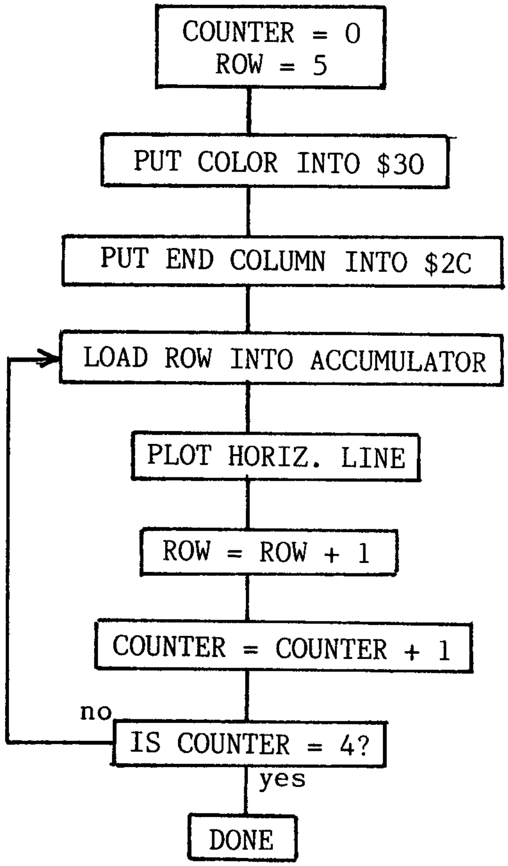
The above program plots a blue dot at location X = 5, Y = 3. It then draws a horizontal orange line from X = 2 ,Y = 6 to X = 8 ,Y = 6. The program can be run by typing a 6000G <CR> from the monitor. If the ORG is assembled elsewhere with another assembler type, the appropriate start. For example, if LISA assembles your code at $800, then type 800G <CR>.

As you can see, plotting with Lo-Res graphics is relatively easy but involves tedious details. The same code in BASIC, as listed below, would have taken a mere five statements. Yet the machine language program will run at least twenty times faster.

```
10 GR: COLOR =6:PLOT 5,3
20 COLOR =9:HLIN 2,8 at 6
30 END
```

The ability to plot several horizontal lines having the same color is useful in setting up our "Breakout" game. The code is also instructive in that it simulates the FOR-NEXT loop in BASIC. We will need a counter which we will appropriately call COUNTER. We will first initialize COUNTER to zero. Since we aren't going to begin plotting our horizontal lines at row zero but instead at row five, we will use a variable called ROW to keep track of our vertical row position. The object is to plot four horizontal red lines beginning at row 5 and extending through row 8. The beginning column for each row is $5 and the ending column is $22.

As we plot each row successively, we increment our variables, COUNTER and ROW. The variable COUNTER is then tested to see if it has reached the value #$04. If it has, the code exits the loop. Otherwise, it branches back to LOOPA so that it plots the next row. When it has plotted all four red lines, it exits. The code and flow chart are shown below.




```
        LDA   #$00
        STA   COUNTER
        LDA   #$05      ;START FIFTH ROW
        STA   ROW
        LDA   #$11      ;RED COLOR FIRST 4 ROWS
        STA   $30       ;COLOR STORAGE
        LDA   #$22      ;END COLUMN
        STA   $2C
LOOPA   LDA   ROW
        LDY   #$05      ;START COLUMN
        JSR   $F819     ;PLOT HORIZ LINE
        INC   ROW       ;NEXT ROW
        INC   COUNTER   ;COUNTER = COUNTER + 1
        LDA   COUNTER
        CMP   #$04      ;HAVE WE DONE ALL FOUR ROWS
        BNE   LOOPA     ;NO! GOTO LOOPA
        RTS             ;DONE!
```

The "Breakout" game involves the simplest animation technique available on the Apple. We have a ball or, in Lo-Res graphics, a dot, that bounces around the screen. It will ricochet off a moveable paddle, the walls, or any of the two-by-two sized color bricks. Movement is accomplished by erasing the ball at its old position and redrawing it at its new position. The ball is very predictable. It changes direction only upon collision, and in all cases (except contact with the paddle), simply reverses its direction. The position of contact with the paddle determines the ball's direction. Balls striking the left end travel upwards and to the left at a 45 degree angle, while balls striking the inside left travel in the same direction but at a 60 degree angle. Balls striking the paddle's right side travel at similar angles but to the right.

Determining where the ball struck the paddle is easy. The four block-wide paddle is always drawn at row 35 decimal or $23, and the first block begins at PADX, a variable controlled by the paddle. The ball's position is always at BX,BY , and it has a velocity VX,VY. By comparing the ball's vertical position to PADX first, and then PADX + 1, etc, when a collision is detected, the ball's velocity components VX and VY are reset. VY is always reset to -1 so that the ball travels upwards. However, VX varies with which block was hit. As we mentioned earlier, the two outside blocks would cause the ball to travel at 45 degree angles. This would mean a VX of +1 or −1. The inside blocks would cause the ball to bounce at 60 degree angles or VX at +1/2 or −1/2.

Incrementing the ball's position by 1/2 is not possible in machine code. But if the incremented value was first doubled before calculating the ball's new position, and the result divided by two, the same result would be obtained with the loss of the fractional part. This doesn't matter since the ball can only be placed at whole number positions.

For example: BX = 6 and VY = 1/2

BX = BX + VY = 6 + 1/2 = 6 (ROUNDED).

If the numbers were doubled and the result divided by two,then

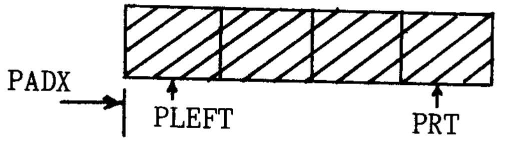
BX = 12 + 1 = 13/2 = 6 (ROUNDED).

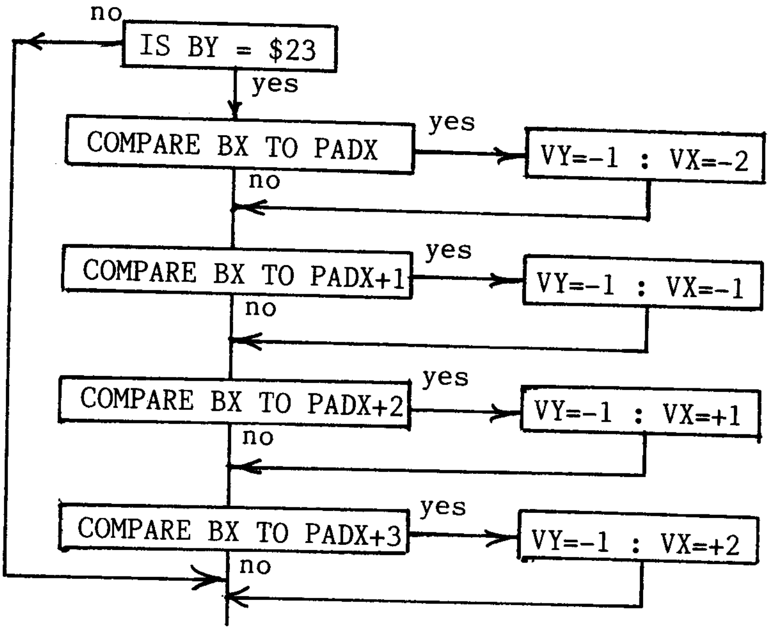
If the doubled position is kept rather than discarded and we wished to move the ball another 1/2 position, then

BX = 13 + 1 = 14/2 = 7.

This would result in the ball moving in the X direction every other cycle. With VY = −1, it would travel at a 60 degree angle upwards and towards the right.

PADDLE DEFLECTOR

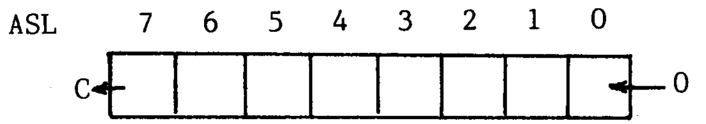


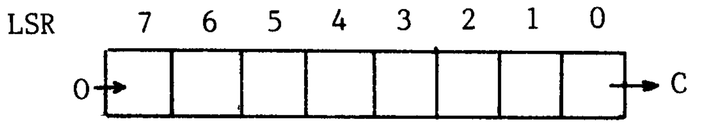


*Note all VX values doubled.

Multiplication and division by powers of two is easy in machine language. The mnemonic ASL is used for multiplication by two. The Arithmetic Shift Left (ASL) instruction shifts all of the bits in the Accumulator one position to the left. Thus, bit 0 is shifted into bit 1, bit 1 into bit 2, etc. Bit seven is shifted into the carry bit so that you can use the BCC and BCS instructions to test for overflows. For example, if only bit two was on (4 decimal) and we did an ASL, the bit would be shifted to bit three (8 decimal). Thus, it is easy to multiply by powers of two by doing repeated ASL instructions.

Conversely, division is performed by the Logical Shift Right (LSR) instruction. Bits are shifted to the right and the bit 0 is shifted into the carry. This is equivalent to dividing by two with loss of the fractional part.






```
LDA  #$05  ;LOAD ACCUMULATOR WITH 5
LSR        ;DIVIDE NUMBER BY TWO
STA  $900  ;VALUE STORED IN $900 IS 2
```

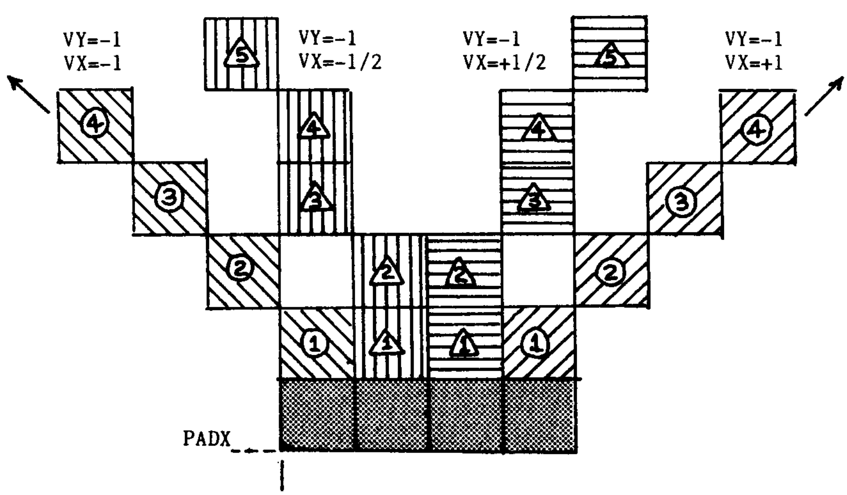
In order to update the ball's position, we take the ball's old BX,BY position in each direction and add the change in position or its directional velocity. Negative values are converted to their two's complement equivalent so that all operations are simple additions. A negative one becomes a $FF, so that $FF plus $02 = $01.

NEW POSITION = OLD POSITION + CHANGE IN POSITION

BX = BX + VX		X DIRECTION
BY = BY + VY		Y DIRECTION

The ball's X position is calculated using doubled position values DBX and doubled velocities values VX to avoid 1/2 values

Thus, DBX = DBX + VX and BX = DBX/2.



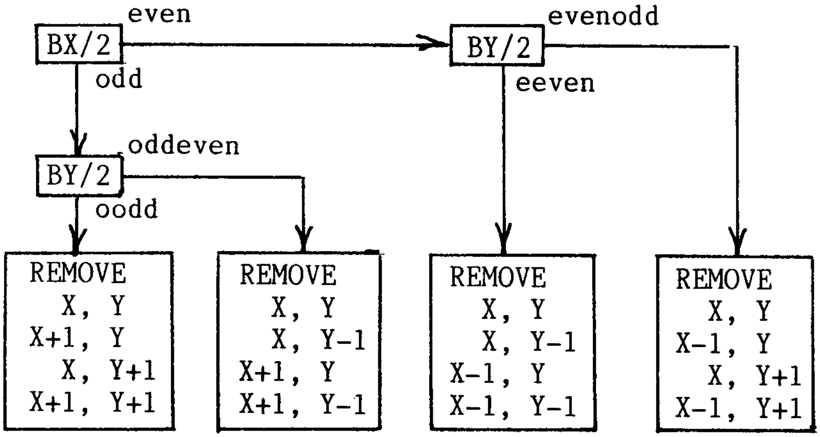
```
LDA  DBX   ;OLD DOUBLED X POSITION
CLC
ADC  VX    ;X DIRECTION VALUE
STA  DBX   ;THIS DOUBLED VALUE WILL RETAIN FRACTION
LSR        ;DIVIDE BY 2 , WILL LOSE FRACTION
STA  BX    ;NEW BALL X POSITION
LDA  BY    ;OLD Y POSITION OF BALL
CLC
ADC  VY    ;ADD Y DIRECTION VELOCITY
STA  BY    ;NEW BALL Y POSITION
```

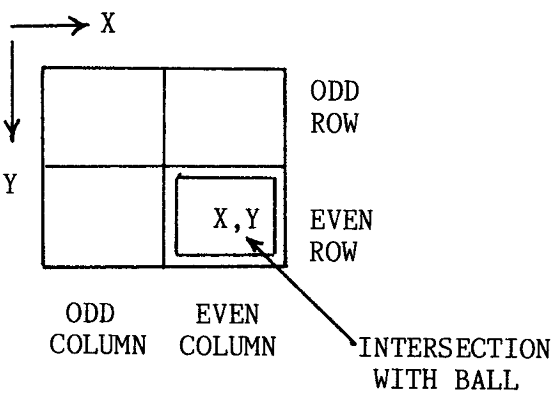
As the ball bounces around the screen, it will soon collide with one of the colored 2 by 2 bricks at the top of the screen. Since these are colored blocks, collisions can be detected between the ball and these blocks with the SCRN function. This monitor subroutine will return the value of the color at any position. This test is performed before the ball is drawn to the screen, or the test becomes meaningless at the ball's position since the ball will plot over the background color blocks.

We will want to delete the block if a non-black (background) color is returned during the test. The brick is four times larger than our ball, so we must delete all four blocks at once. This is a troublesome operation, since we might have collided with any of the four color blocks that comprise the brick. The block that we hit is BX,BY. If we hit the top left block of the brick we will want to delete block BX,BY ,BX + 1,BY , BX + 1,BY + 1 , and BX,BY + 1. The other three possible collisions with the brick have completely different sequences of blocks to be removed.

Bricks always begin in an odd row, at an odd column. A test can be made to see if our ball is in an odd or even row, or an odd or even column. That will determine which of four sequences of blocks to remove. An odd even test can be done on BX using a division by two or LSR instruction. Odd values always have a one in the bit zero position. An LSR operation shifts them to the carry bit. Therefore, odd values set the carry. A BCC (Branch Carry Clear) test will determine if the value is odd or even.

```
      LDA  BX
      LSR       ;DIVIDE BY TWO
      BCC  EVEN ;BX IS EVEN IF CARRY IS CLEAR
ODD   JMP  SKIP
EVEN  NOP       ;CONTINUE WIH EVEN CODE
```





Once the block is removed, the score must be incremented by the point value for each block. In this game, yellow is worth one point, blue two points, and red three points. The score is kept in a memory location called SUM. There has been no attempt in this example to convert the hexadecimal value of SUM to a decimal value. That type of scorekeeping routine is outlined in Chapter 6.

The scorekeeping routine first checks the color of the block hit for yellow. If it is equal to #$0D (Yellow) it will add #$01 to SUM. Otherwise, it will branch to the label NEXT. There it encounters a test for the color blue. If the block isn't blue it branches to the label NEXT1. If it is blue, #$02 is added to SUM, otherwise #$03 is added to SUM because it must be red.

```
SCORE     LDA  COLOR
          CMP  #$0D          ;HIT YELLOW?
          BNE  NEXT
          LDA  SUM
          CLC
          ADC  #$01
          STA  SUM
          JMP  SCORE1
NEXT      LDA  COLOR
          CMP  #$06          ;HIT BLUE?
          BNE  NEXT1
          LDA  SUM
          CLC
          ADC  #$02
          STA  SUM
          JMP  SCORE1
NEXT1     LDA  COLOR
          CMP  #$01          ;HIT RED?
          BNE  SCORE1
          LDA  SUM
          CLC
          ADC  #$03
          STA  SUM
SCORE1    JSR  PRINT
          CMP  #$F0          ;SUM=240 FOR ALL BLOCKS
          BGE  END
```

This score will be printed in the text window below the Lo-Res graphics. We want to print the letters SCORE followed by the value in SUM. There is a monitor subroutine called COUT that outputs a single character to the screen. If the cursor position has been previously set, any ASCII character placed into the Accumulator will be outputted to the screen. Since strings are usually more than one character, the code must be looped so that each character is retrieved in its turn, then placed on the screen by COUT. The string can be stored as a hexadecimal table in memory beginning at a location labeled STRING. Each time we load the Accumulator, we index into the table X bytes where X is the value in the X-Register. They call the operation LDA STRING, X ,Indirect Addressing. The X-Register begins at #$00 and is incremented after each byte is outputted to the screen.

A test is needed to detect the end of the string. Since a general purpose print output routine is desired for any length string up to 255 characters , it is best not to restrict the test to detecting the length of the string, but to detect a character that is never sent to the screen. The hexadecimal 00 (the reverse @ sign) is rarely used and is a good choice for a test byte. When the code detects

this byte, it knows it has completed the string and exits the print loop. The value of SUM is then outputted by the monitor subroutine PRBYTE, which prints a single hexadecimal byte. The print subroutine is shown below.

```
PRINT   LDX  #$00        ;INDEX INTO STRING BEGINS AT 0
        LDA  #$05
        STA  $24         ;HTAB5
        LDA  #$17
        JSR  TABV        ;VTAB23
PRINT1  LDA  STRING,X    ;GET Xth ELEMENT OF STRING
        BEQ  DONE        ;FINISHED?
        JSR  COUT        ;PRINT LETTER
        INX              ;NEXT ELEMENT
        JMP  PRINT1      ;LOOP
DONE    LDA  SUM
        JSR  PRBYTE      ;OUTPUT BYTE SUM
        RTS
STRING  ASC  "SCORE = "
        HEX  00
```

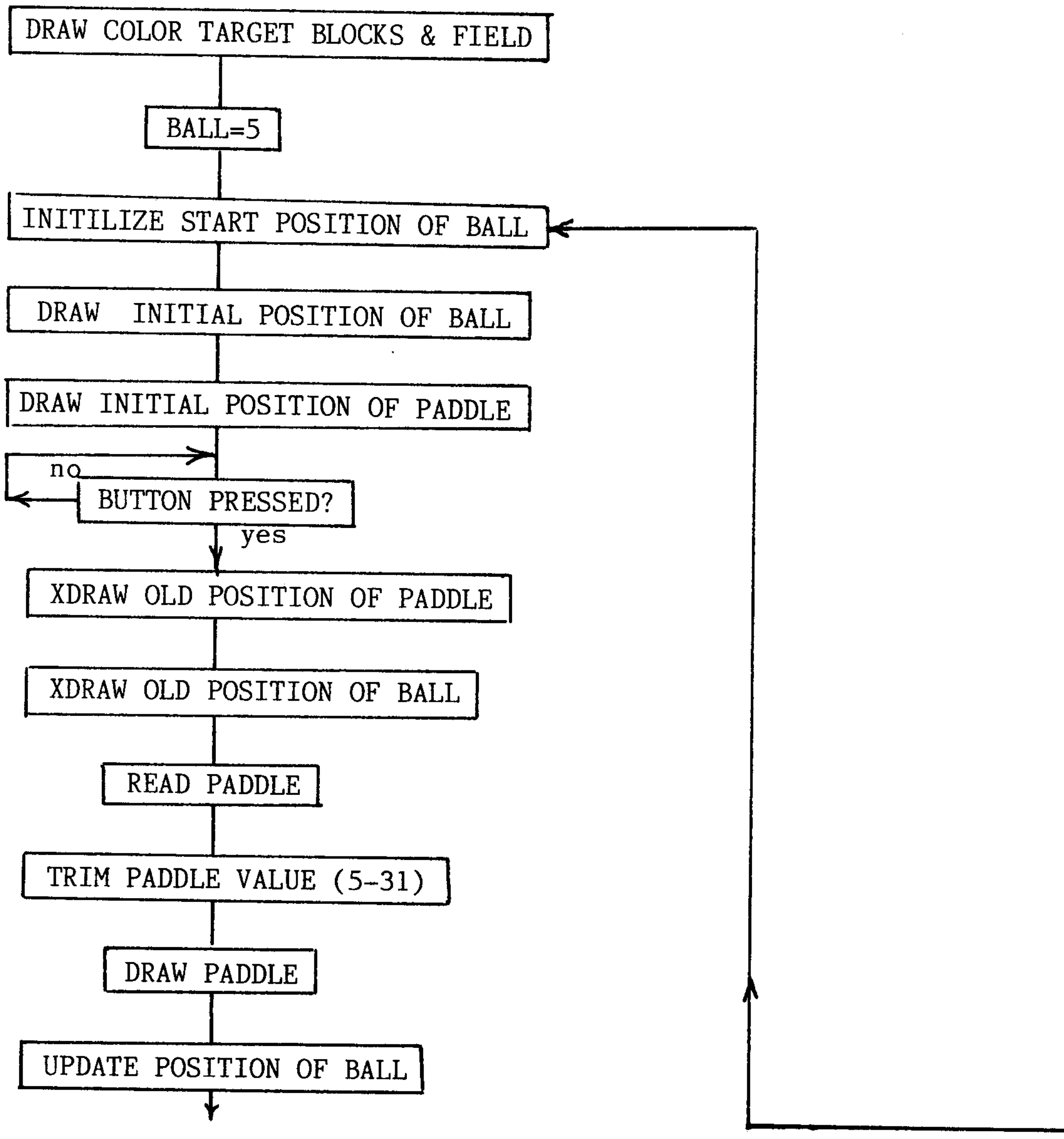
The "Breakout" game needs paddle control. The paddle is used both to initially start the game by a button press, and to move the deflector back and forth at the bottom of the screen. Button presses are the easiest to detect. There are three paddle switches that are located at \$C061 – \$C063. The lowest hardware location is for paddle #0. If the button is pushed, the value loaded into the Accumulator is negative. The program can be put into an endless loop waiting for a button press with the following code:

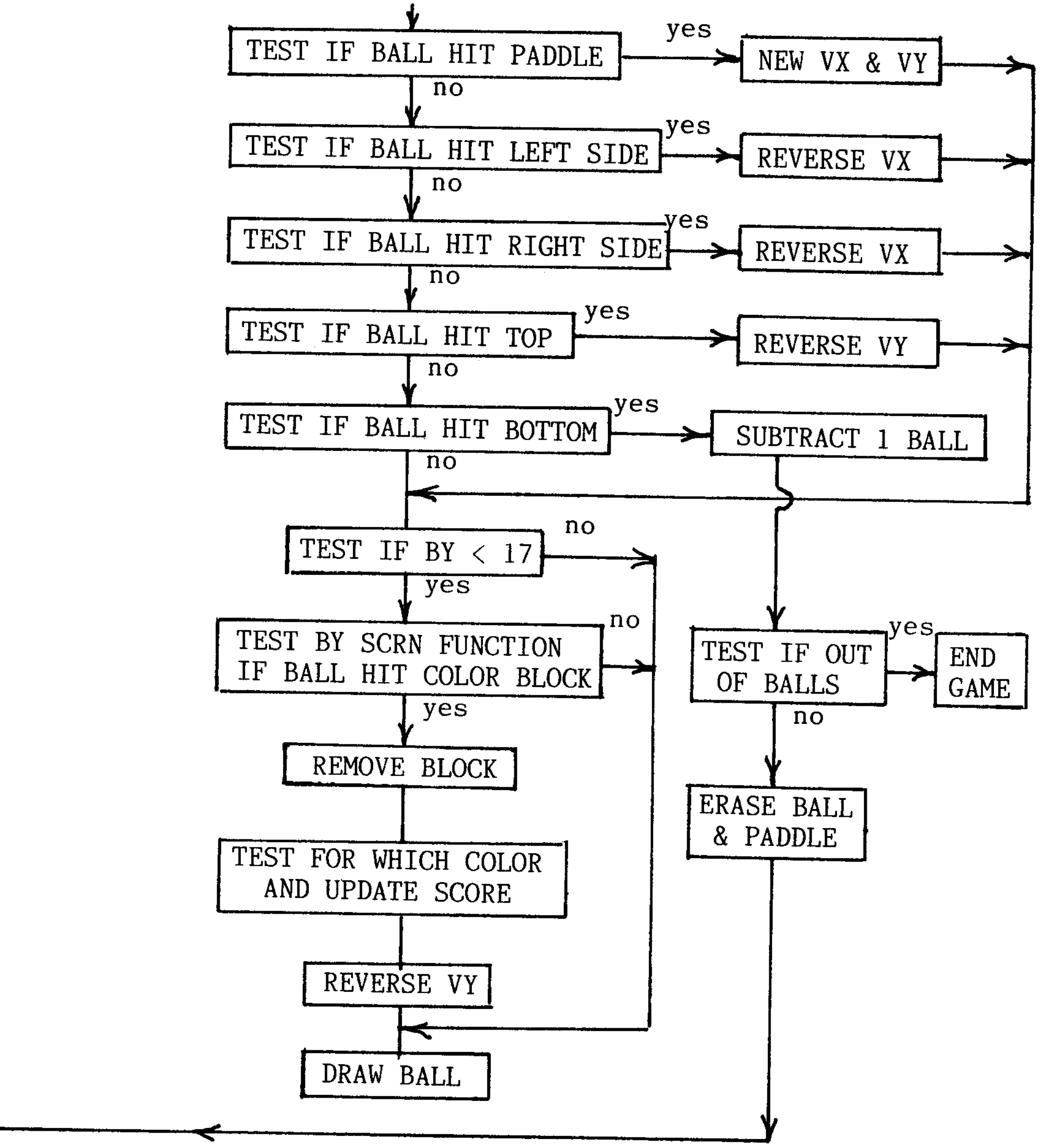
```
BUTTON  LDA  $C061
        BPL  BUTTON
```

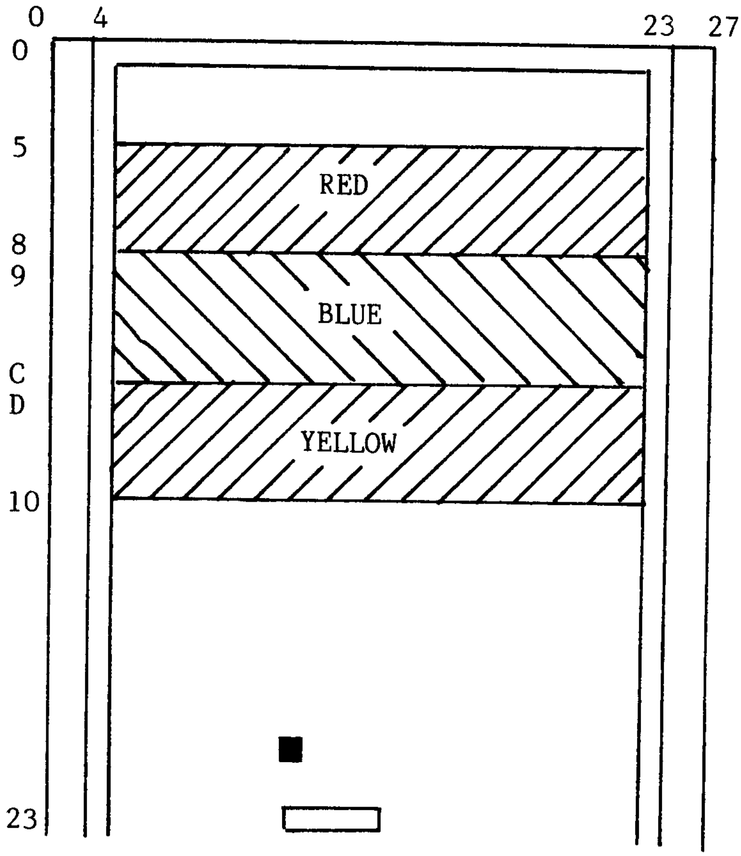
The code will only exit the loop if the button is pressed.

The paddle's output value (0-255) can be read by accessing a monitor subroutine called PREAD, located at \$FB1E. The paddle number is placed into the X-Register and the value of the paddle is outputted to the Y-Register. It is directly equivalent to the BASIC command PDL(0). In our case, we need the output clipped to a value (0-31). It is first necessary to divide the value by four. This gives a value between 0-64. This range was chosen rather than 0-32, so that the player has better control with half the amount of paddle turning. The value is then tested to be within that range. If it is less than \$05 it is set to \$05, and if greater than \$1F (decimal 31), it is set equal to \$1F. This is called clipping.

We have covered all of the pertinent code that is necessary to write a "Breakout" game. The only thing left is the flowchart, and that is shown below. The complete assembled code follows.


DRAW COLOR TARGET BLOCKS & FIELD
BALL=5
INITILIZE START POSITION OF BALL
DRAW INITIAL POSITION OF BALL
DRAW INITIAL POSITION OF PADDLE
no
BUTTON PRESSED?
yes
XDRAW OLD POSITION OF PADDLE
XDRAW OLD POSITION OF BALL
READ PADDLE
TRIM PADDLE VALUE (5-31)
DRAW PADDLE
UPDATE POSITION OF BALL


TEST IF BALL HIT PADDLE
yes
NEW VX & VY
no
TEST IF BALL HIT LEFT SIDE
yes
REVERSE VX
no
TEST IF BALL HIT RIGHT SIDE
yes
REVERSE VX
no
TEST IF BALL HIT TOP
yes
REVERSE VY
no
TEST IF BALL HIT BOTTOM
yes
SUBTRACT 1 BALL
no
TEST IF BY < 17
no
yes
TEST BY SCRN FUNCTION IF BALL HIT COLOR BLOCK
no
yes
REMOVE BLOCK
TEST FOR WHICH COLOR AND UPDATE SCORE
REVERSE VY
DRAW BALL
TEST IF OUT OF BALLS
yes
END GAME
no
ERASE BALL & PADDLE



BREAKOUT SCREEN

```
                **  B R E A K O U T   G A M E **
                         ORG    $6000
6000: 4C 17 60           JMP    PROG          ;JMP TO MAIN PROGRAM
                ROW      DS     1
                COUNTER  DS     1
                BX       DS     1
                BY       DS     1
                BBX      DS     1
                BBY      DS     1
                VX       DS     1
                VY       DS     1
                DBX      DS     1
                PDX      DS     1
```

```
                PADX     DS   1
                PRT      DS   1
                PLEFT    DS   1
                SUM      DS   1
                BALL     DS   1
                COLOR    DS   1
                CBALL    DS   1
                CPDL     DS   1
                PITCH    DS   1
                TIME     DS   1
                PREAD    EQU  $FB1E
                COUT     EQU  $FDF0
                TABV     EQU  $FB5B
                PRBYTE   EQU  $FDDA
6017: 20 40 FB  PROG     JSR  $FB40      ;SET LORES GRAPHICS MODE
601A: 20 58 FC           JSR  $FC58      ;CLEAR SCREEN
                *DRAW SCREEN & BLOCKS
601D: A9 88              LDA  #$88       ;SET COLOR BROWN
601F: 85 30              STA  $30
6021: A9 23              LDA  #$23       ;END COLUMN
6023: 85 2C              STA  $2C
6025: A9 00              LDA  #$00       ;TOP ROW
6027: A0 04              LDY  #$04       ;START COLUMN
6029: 20 19 F8           JSR  $F819      ;PLOT HORIZ LINE
602C: A9 27              LDA  #$27       ;END ROW
602E: 85 2D              STA  $2D
6030: A9 01              LDA  #$01       ;START ROW
6032: A0 04              LDY  #$04       ;COLUMN
6034: 20 28 F8           JSR  $F828      ;PLOT VERT LINE
6037: A9 01              LDA  #$01       ;START ROW
6039: A0 23              LDY  #$23       ;COLUMN
603B: 20 28 F8           JSR  $F828      ;PLOT VERT LINE
603E: A9 00              LDA  #$00
6040: 8D 04 60           STA  COUNTER
6043: A9 05              LDA  #$05       ;START 5TH ROW
6045: 8D 03 60           STA  ROW
6048: A9 11              LDA  #$11       ;RED COLOR FIRST 4 ROWS
604A: 85 30              STA  $30
604C: A9 22              LDA  #$22       ;END COLUMN
604E: 85 2C              STA  $2C
6050: AD 03 60  LOOPA    LDA  ROW
6053: A0 05              LDY  #$05       ;START COLUMN
6055: 20 19 F8           JSR  $F819      ;PLOT HORIZ LINE
6058: EE 03 60           INC  ROW        ;NEXT ROW
605B: EE 04 60           INC  COUNTER
605E: AD 04 60           LDA  COUNTER
6061: C9 04              CMP  #$04
6063: D0 EB              BNE  LOOPA
6065: A9 66              LDA  #$66       ;BLUE COLOR NEXT 4 ROWS
6067: 85 30              STA  $30
6069: AD 03 60  LOOPB    LDA  ROW
606C: A0 05              LDY  #$05       ;START COLUMN
606E: 20 19 F8           JSR  $F819      ;PLOT HORIZ LINE
6071: EE 03 60           INC  ROW
6074: EE 04 60           INC  COUNTER
6077: AD 04 60           LDA  COUNTER
607A: C9 08              CMP  #$08
607C: D0 EB              BNE  LOOPB
607E: A9 DD              LDA  #$DD       ;YELLOW COLOR
6080: 85 30              STA  $30
```

```
6082: AD 03 60  LOOPC   LDA  ROW
6085: A0 05             LDY  #$05      ;START COLUMN
6087: 20 19 F8          JSR  $F819
608A: EE 03 60          INC  ROW
608D: EE 04 60          INC  COUNTER
6090: AD 04 60          LDA  COUNTER
6093: C9 0C             CMP  #$0C
6095: D0 EB             BNE  LOOPC
6097: A9 05             LDA  #$05
6099: 8D 11 60          STA  BALL
609C: A9 00             LDA  #$00
609E: 8D 10 60          STA  SUM
                *INITIALIZE VARIABLES
60A1: A9 14     START   LDA  #$14      ;INITIAL POSITION BALL
60A3: 8D 05 60          STA  BX
60A6: 8D 06 60          STA  BY
60A9: A9 28             LDA  #$28
60AB: 8D 0B 60          STA  DBX
60AE: A9 00             LDA  #$00      ;INITIAL VELOCITY BALL
60B0: 8D 09 60          STA  VX
60B3: A9 01             LDA  #$01
60B5: 8D 0A 60          STA  VY
60B8: A9 11             LDA  #$11      ;INITIAL PADDLE POSITION
60BA: 8D 0D 60          STA  PADX
60BD: A9 14             LDA  #$14
60BF: 8D 0E 60          STA  PRT
60C2: A9 FF             LDA  #$FF      ;WHITE BALL
60C4: 8D 13 60          STA  CBALL
60C7: A9 CC             LDA  #$CC      ;GREEN PADDLE
60C9: 8D 14 60          STA  CPDL
                *PRINT INITIAL SCORE
60CC: 20 C2 63          JSR  PRINT
                *DRAW INITIAL POSITIONS BALL& PADDLE
60CF: AD 13 60          LDA  CBALL
60D2: 85 30             STA  $30
60D4: AC 05 60          LDY  BX        ;COLUMN
60D7: AD 06 60          LDA  BY        ;ROW
60DA: 20 00 F8          JSR  $F800     ;PLOT BALL
60DD: AD 14 60          LDA  CPDL
60E0: 85 30             STA  $30
60E2: AD 0E 60          LDA  PRT
60E5: 85 2C             STA  $2C
60E7: AC 0D 60          LDY  PADX      ;START COLUMN
60EA: A9 23             LDA  #$23      ;PADDLE ROW
60EC: 20 19 F8          JSR  $F819     ;PLOT PADDLE
                *START GAME WITH BUTTON
60EF: AD 61 C0  BUTTON  LDA  $C061     ;NEG IF BUTTON PRESSED
60F2: 10 FB             BPL  BUTTON
                *
                ** M A I N   P R O G R A M   L O O P **
                *
                *XDRAW OLD POSITIONS BALL& PADDLE
60F4: A9 00     MAIN    LDA  #$00
60F6: 85 30             STA  $30
60F8: AC 05 60          LDY  BX
60FB: AD 06 60          LDA  BY
60FE: 20 00 F8          JSR  $F800     ;XPLOT BALL
6101: AD 0E 60          LDA  PRT
6104: 85 2C             STA  $2C
6106: AC 0D 60          LDY  PADX
```

```
6109: A9 23             LDA  #$23
610B: 20 19 F8          JSR  $F819      ;XPLOT PADDLE
                 *READ PADDLE
610E: A2 00             LDX  #$00       ;PADDLE 0
6110: 20 1E FB          JSR  PREAD
6113: 98                TYA             ;PADDLE VALUE(0-255) IN Y REG
6114: 4A                LSR             ;DIVIDE BY 4
6115: 4A                LSR
6116: C9 20             CMP  #$20       ;CLIP TO (5-31)
6118: 90 05             BLT  SKIPP
611A: A9 1F             LDA  #$1F
611C: 8D 0D 60          STA  PADX
611F: C9 05      SKIPP  CMP  #$05
6121: B0 02             BGE  SKIPP1
6123: A9 05             LDA  #$05
6125: 8D 0D 60   SKIPP1 STA  PADX
6128: 18                CLC
6129: 69 03             ADC  #$03
612B: 8D 0E 60          STA  PRT
                 *DRAW NEW POSITION PADDLE
612E: AD 14 60          LDA  CPDL
6131: 85 30             STA  $30
6133: AD 0E 60          LDA  PRT
6136: 85 2C             STA  $2C
6138: AC 0D 60          LDY  PADX
613B: A9 23             LDA  #$23       ;ROW
613D: 20 19 F8          JSR  $F819      ; PLOT HORIZ PADDLE
                 *UPDATE POSITION BALL
                 *NOTE ALL VX VALUES DOUBLED TO AVOID 1/2 VALUES
6140: AD 0B 60          LDA  DBX        ;OLD DOUBLED X POS VALUE
6143: 18                CLC
6144: 6D 09 60          ADC  VX         ;X DIRECTION VELOCITY
6147: 8D 0B 60          STA  DBX        ;THIS DOUBLED VALUE WILL KEEP FRACT-
                 *_                    ;TIONAL PART OF NEW POSITION
614A: 4A                LSR             ;HALF VALUE WILL LOSE FRACTION
614B: 8D 05 60          STA  BX         ;NEW BALL X POS
614E: AD 06 60          LDA  BY         ;OLD Y POS
6151: 18                CLC
6152: 6D 0A 60          ADC  VY         ;ADD Y DIRECTION VELOCITY
6155: 8D 06 60          STA  BY         ;NEW BALL Y POSITION
                 *TEST IF BALL HIT SIDES OR PADDLE
6158: AD 06 60   PADDLE LDA  BY
615B: C9 23             CMP  #$23       ;AT PADDLE ROW?
615D: F0 03             BEQ  PAD1       ;YES!
615F: 4C B7 61          JMP  LEFT
6162: AD 0D 60   PAD1   LDA  PADX
6165: 8D 0F 60          STA  PLEFT
6168: AD 05 60   FIRST  LDA  BX
616B: CD 0F 60          CMP  PLEFT
616E: D0 0A             BNE  SECOND
6170: A9 FF             LDA  #$FF
6172: 8D 0A 60          STA  VY         ;VY=-1
6175: A9 FE             LDA  #$FE
6177: 8D 09 60          STA  VX         ;VX=-2
617A: EE 0F 60   SECOND INC  PLEFT
617D: AD 05 60          LDA  BX
6180: CD 0F 60          CMP  PLEFT
6183: D0 08             BNE  THIRD
6185: A9 FF             LDA  #$FF
6187: 8D 0A 60          STA  VY         ;VY=-1
```

```
618A: 8D 09 60 194          STA  VX         ;VX=-1
618D: EE 0F 60 195  THIRD   INC  PLEFT
6190: AD 05 60 196          LDA  BX
6193: CD 0F 60 197          CMP  PLEFT
6196: D0 0A    198          BNE  FOURTH
6198: A9 FF    199          LDA  #$FF
619A: 8D 0A 60 200          STA  VY         ;VY=-1
619D: A9 01    201          LDA  #$01
619F: 8D 09 60 202          STA  VX         ;VX=1
61A2: EE 0F 60 203  FOURTH  INC  PLEFT
61A5: AD 05 60 204          LDA  BX
61A8: CD 0F 60 205          CMP  PLEFT
61AB: D0 0A    206          BNE  LEFT
61AD: A9 FF    207          LDA  #$FF
61AF: 8D 0A 60 208          STA  VY         ;VY=-1
61B2: A9 02    209          LDA  #$02
61B4: 8D 09 60 210          STA  VX         ;VX=2
61B7: AD 05 60 211  LEFT    LDA  BX
61BA: C9 06    212          CMP  #$06       ;HIT LEFT SIDE?
61BC: B0 0B    213          BGE  RIGHT      ;NO!
61BE: AD 09 60 214          LDA  VX         ;REVERSE VX
61C1: 49 FF    215          EOR  #$FF       ;COMPLEMENT
61C3: 8D 09 60 216          STA  VX
61C6: EE 09 60 217          INC  VX         ;VALUE CORRECTED
61C9: AD 05 60 218  RIGHT   LDA  BX
61CC: C9 22    219          CMP  #$22       ;HIT RIGHT SIDE?
61CE: 90 0B    220          BLT  TOP        ;NO!
61D0: AD 09 60 221          LDA  VX         ;REVERSE VX
61D3: 49 FF    222          EOR  #$FF       ;COMPLEMENT
61D5: 8D 09 60 223          STA  VX
618: EE 09 60 224           INC  VX         ;VALUE CORRECTED
61DB: AD 06 60 225  TOP     LDA  BY
61DE: C9 01    226          CMP  #$01       ;HIT TOP?
61E0: D0 0B    227          BNE  BOTTOM     ;NO!
61E2: AD 0A 60 228          LDA  VY         ;REVERSE VY
61E5: 49 FF    229          EOR  #$FF       ;COMPLEMENT
61E7: 8D 0A 60 230          STA  VY
61EA: EE 0A 60 231          INC  VY         ;VALUE CORRECTED
61ED: AD 06 60 232  BOTTOM  LDA  BY
61F0: C9 27    233          CMP  #$27
61F2: D0 3A    234          BNE  BLOCKS
61F4: CE 11 60 235          DEC  BALL
61F7: A9 FF    236          LDA  #$FF       ;BAD SOUND FOR MISSING
61F9: 8D 15 60 237          STA  PITCH
61FC: 8D 16 60 238          STA  TIME
61FF: 20 E9 63 239          JSR  SOUND
6202: A9 FF    240          LDA  #$FF       ;SHORT DELAY
6204: 20 A8 FC 241          JSR  $FCA8
6207: AD 11 60 242          LDA  BALL
620A: C9 00    243          CMP  #$00       ;ALL BALLS GONE?
620C: D0 03    244          BNE  CONT
620E: 4C DD 62 245          JMP  END
               246  *ERASE BALL & PADDLE
6211: A9 00    247  CONT    LDA  #$00
6213: 85 30    248          STA  $30
6215: AC 05 60 249          LDY  BX
6218: AD 06 60 250          LDA  BY
621B: 20 00 F8 251          JSR  $F800      ;XPLOT BALL
621E: AD 0E 60 252          LDA  PRT
```

```
6221: 85 2C              STA  $2C
6223: AC 0D 60           LDY  PADX
6226: A9 23              LDA  #$23
6228: 20 19 F8           JSR  $F819     ;XPLOT PADDLE
622B: 4C A1 60           JMP  START
622E: AD 06 60  BLOCKS   LDA  BY
6231: C9 11              CMP  #$11      ;IN AREA OF BLOCKS?
6233: 90 03              BLT  SK2       ;YES!
6235: 4C C7 62           JMP  DRAW
                *TEST COLLISION WITH BLOCK VIA SCRN FUNCTION
6238: AC 05 60  SK2      LDY  BX        ;COLUMN
623B: AD 06 60           LDA  BY        ;ROW
623E: 20 71 F8           JSR  $F871     ;SCRN(X,Y)
6241: 8D 12 60           STA  COLOR     ;RETURNS OLOR IN ACC.
6244: C9 00              CMP  #$00      ;IS BLACK?
6246: D0 03              BNE  NBLACK
6248: 4C C7 62           JMP  DRAW      ;YES!
                *FIND WHICH OF FOUR SUBBLOCKS HIT
624B: AD 05 60  NBLACK   LDA  BX
624E: 4A                 LSR            ;BX/2
624F: 90 12              BCC  EVEN
6251: AD 06 60  ODD      LDA  BY
6254: 4A                 LSR            ;BY/2
6255: 90 06              BCC  ODDEVEN
6257: 20 DE 62  OODD     JSR  OODDS
625A: 4C 72 62           JMP  REV
625D: 20 17 63  ODDEVEN  JSR  ODDEVENS
6260: 4C 72 62           JMP  REV
6263: AD 06 60  EVEN     LDA  BY
6266: 4A                 LSR            ;BY/2
6267: 90 06              BCC  EEVEN
6269: 20 89 63  EVENODD  JSR  EVENODDS
626C: 4C 72 62           JMP  REV
626F: 20 50 63  EEVEN    JSR  EEVENS
                *REVERSE VY
6272: AD 0A 60  REV      LDA  VY
6275: 49 FF              EOR  #$FF
6277: 8D 0A 60           STA  VY
627A: EE 0A 60           INC  VY
                *CHECK COLOR & UPDATE SCORE
627D: AD 12 60  SCORE    LDA  COLOR
6280: C9 0D              CMP  #$0D      ;HIT YELLOW?
6282: D0 0C              BNE  NEXT
6284: AD 10 60           LDA  SUM
6287: 18                 CLC
6288: 69 01              ADC  #$01
628A: 8D 10 60           STA  SUM
628D: 4C B3 62           JMP  SCORE1
6290: AD 12 60  NEXT     LDA  COLOR
6293: C9 06              CMP  #$06      ;HIT BLUE?
6295: D0 0C              BNE  NEXT1
6297: AD 10 60           LDA  SUM
629A: 18                 CLC
629B: 69 02              ADC  #$02
629D: 8D 10 60           STA  SUM
62A0: 4C B3 62           JMP  SCORE1
62A3: AD 12 60  NEXT1    LDA  COLOR
62A6: C9 01              CMP  #$01      ;HIT RED?
62A8: D0 09              BNE  SCORE1
```

```
62AA: AD 10 60               LDA   SUM
62AD: 18                     CLC
62AE: 69 03                  ADC   #$03
62B0: 8D 10 60               STA   SUM
62B3: 20 C2 63    SCORE1     JSR   PRINT
62B6: C9 F0                  CMP   #$F0          ;SUM=240 FOR ALL BLOCKS
62B8: B0 23                  BGE   END
                  *SOUND FOR HITTING BLOCK
62BA: A9 50                  LDA   #$50
62BC: 8D 15 60               STA   PITCH
62BF: A9 25                  LDA   #$25
62C1: 8D 16 60               STA   TIME
62C4: 20 E9 63               JSR   SOUND
                  *DRAW BALL
62C7: AD 13 60    DRAW       LDA   CBALL
62CA: 85 30                  STA   $30
62CC: AC 05 60               LDY   BX            ;COLUMN
62CF: AD 06 60               LDA   BY            ;ROW
62D2: 20 00 F8               JSR   $F800         ;PLOT BALL
                  *DELAY
62D5: A9 80                  LDA   #$80
62D7: 20 A8 FC               JSR   $FCA8         ;SHORT DELAY
62DA: 4C F4 60               JMP   MAIN
62DD: 60          END        RTS                 ;RETURN TO MONITOR AT END OF GAME
                  *
                  ** S U B R O U T I N E S **
                  *
                  *ERASE BLOCK SUBROUTINES
                  *
62DE: A9 00       OODDS      LDA   #$00
62E0: 85 30                  STA   $30           ;BLACK
62E2: AD 05 60               LDA   BX
62E5: 8D 07 60               STA   BBX           ;TEMP VALUE
62E8: A8                     TAY                 ;COLUMN
62E9: AD 06 60               LDA   BY            ;ROW
62EC: 8D 08 60               STA   BBY           ;TEMP VALUE
62EF: 20 00 F8               JSR   $F800         ;ERASE PT X,Y
62F2: EE 07 60               INC   BBX
62F5: AC 07 60               LDY   BBX           ;COLUMN
62F8: AD 08 60               LDA   BBY           ;ROW
62FB: 20 00 F8               JSR   $F800         ;ERASE PT X+1,Y
62FE: EE 08 60               INC   BBY
6301: AC 07 60               LDY   BBX           ;COLUMN
6304: AD 08 60               LDA   BBY           ;ROW
6307: 20 00 F8               JSR   $F800         ;ERASE PT X+1,Y+1
630A: CE 07 60               DEC   BBX
630D: AC 07 60               LDY   BBX           ;COLUMN
6310: AD 08 60               LDA   BBY           ;ROW
6313: 20 00 F8               JSR   $F800         ;ERASE PT X,Y+1
6316: 60                     RTS
6317: A9 00       ODDEVENS   LDA   #$00
6319: 85 30                  STA   $30           ;BLACK
631B: AD 05 60               LDA   BX
631E: 8D 07 60               STA   BBX
6321: A8                     TAY                 ;COLUMN
6322: AD 06 60               LDA   BY            ;ROW
6325: 8D 08 60               STA   BBY
6328: 20 00 F8               JSR   $F800         ;ERASE PT X,Y
632B: CE 08 60               DEC   BBY
632E: AC 07 60               LDY   BBX           ;COLUMN
```

```
6331: AD 08 60              LDA  BBY        ;ROW
6334: 20 00 F8              JSR  $F800      ;ERASE PT X,Y-1
6337: EE 07 60              INC  BBX
633A: AC 07 60              LDY  BBX        ;COLUMN
633D: AD 08 60              LDA  BBY        ;ROW
6340: 20 00 F8              JSR  $F800      ;ERASE PT X+1,Y-1
6343: EE 08 60              INC  BBY
6346: AC 07 60              LDY  BBX        ;COLUMN
6349: AD 08 60              LDA  BBY        ;ROW
634C: 20 00 F8              JSR  $F800      ;ERASE PT X+1,Y
634F: 60                    RTS
6350: A9 00        EEVENS   LDA  #$00
6352: 85 30                 STA  $30
6354: AD 05 60              LDA  BX
6357: 8D 07 60              STA  BBX
635A: A8                    TAY             ;COLUMN
635B: AD 06 60              LDA  BY         ;ROW
635E: 8D 08 60              STA  BBY
6361: 20 00 F8              JSR  $F800      ;ERASE PT X,Y
6364: CE 08 60              DEC  BBY
6367: AC 07 60              LDY  BBX        ;COLUMN
636A: AD 08 60              LDA  BBY        ;ROW
636D: 20 00 F8              JSR  $F800      ;ERASE PT X,Y-1
6370: CE 07 60              DEC  BBX
6373: AC 07 60              LDY  BBX        ;COLUMN
6376: AD 08 60              LDA  BBY        ;ROW
6379: 20 00 F8              JSR  $F800      ;ERASE PT X-1,Y-1
637C: EE 08 60              INC  BBY
637F: AC 07 60              LDY  BBX        ;CLUMN
6382: AD 08 60              LDA  BBY        ;ROW
6385: 20 00 F8              JSR  $F800      ;ERASE PT X-1,Y
6388: 60                    RTS
6389: A9 00        EVENODDS LDA  #$00
638B: 85 30                 STA  $30
638D: AD 05 60              LDA  BX
6390: 8D 07 60              STA  BBX
6393: A8                    TAY             ;COLUMN
6394: AD 06 60              LDA  BY         ;ROW
6397: 8D 08 60              STA  BBY
639A: 20 00 F8              JSR  $F800      ;ERASE PT X,Y
639D: CE 07 60              DEC  BBX
63A0: AC 07 60              LDY  BBX        ;COLUMN
63A3: AD 08 60              LDA  BBY        ;ROW
63A6: 20 00 F8              JSR  $F800      ;ERASE PT X-1,Y
63A9: EE 08 60              INC  BBY
63AC: AC 07 60              LDY  BBX        ;COLUMN
63AF: AD 08 60              LDA  BBY        ;ROW
63B2: 20 00 F8              JSR  $F800      ;ERASE PT X-1,Y+1
63B5: EE 07 60              INC  BBX
63B8: AC 07 60              LDY  BBX        ;COLUMN
63BB: AD 08 60              LDA  BBY        ;ROW
63BE: 20 00 F8              JSR  $F800      ;ERASE PT X,Y+1
63C1: 60                    RTS
                   *
                   *PRINT SUBROUTINE
                   *
63C2: A2 00        PRINT    LDX  #$00
63C4: A9 05                 LDA  #$05
63C6: 85 24                 STA  $24        ;HTAB5
63C8: A9 17                 LDA  #$17
```

```
63CA: 20 5B FB 432             JSR  TABV       ;VTAB23
63CD: BD E0 63 433  PRINT1     LDA  STRING,X
63D0: F0 07    434             BEQ  DONE
63D2: 20 F0 FD 435             JSR  COUT
63D5: E8       436             INX
63D6: 4C CD 63 437             JMP  PRINT1
63D9: AD 10 60 438  DONE       LDA  SUM
63DC: 20 DA FD 439             JSR  PRBYTE
63DF: 60       440             RTS
63E0: D3 C3 CF
63E3: D2 C5 A0
63E6: BD A0    441  STRING     ASC  "SCORE = "
63E8: 00       442             HEX  00
               443  *
               444  *SOUND SUBROUTINE
               445  *
63E9: AD 30 C0 446  SOUND      LDA  $C030
63EC: 88       447  S1         DEY
63ED: D0 05    448             BNE  S2
63EF: CE 16 60 449             DEC  TIME
63F2: F0 09    450             BEQ  SEND
63F4: CA       451  S2         DEX
63F5: D0 F5    452             BNE  S1
63F7: AE 15 60 453             LDX  PITCH
63FA: 4C E9 63 454             JMP  SOUND
63FD: 60       455  SEND       RTS

--END ASSEMBLY--    1022 BYTES
```

CHAPTER 3

MACHINE LANGUAGE ACCESS TO APPLESOFT HI-RES ROUTINES

The Applesoft ROM contains a full set of Hi-Res graphics routines. But Applesoft, being an interpretive language rather than a compiled language, accesses these routines rather inefficiently as far as speed is concerned. This is because the interpreter has to determine where to go and what to do with each tokenized BASIC instruction as it encounters it. The speed penalty for this added overhead is considerable. The interpreter runs these routines from four to six times slower than if they were called directly from machine language.

At first glance, it appears to be rather simple to call to graphics subroutines located in the ROM. In retrospect, it is, provided that you understand how the interpreter handles the data structure both internally and externally as it executes these graphics subroutines. Since the information has never been fully documented, it is some help if you have the Programmer's Aid Manual, where a source listing of that ROM chip is quite similar to the ROM Applesoft Hi-Res subroutines.

I'm quite reluctant at this stage to attempt an explanation of how these routines actually work. A solid grounding both in machine language and in the Hi-res screen's peculiarities won't come until much later in the book. I will, however, discuss the data structure in regards to what you need to input, and how you input these parameters when calling the subroutines.

There are a series of memory locations stored in zero page that specify a point on the Hi-Res screen. Some people call these locations External Cursor Data. They are as follows:

$E0: Lo order byte of the horizontal screen coordinate
$E1: Hi order byte of the horizontal screen coordinate
$E2: Vertical screen coordinate
$E4: Color masking word from the color table ($F6F6-$F6FD)
$E6: Page indicator ($20 page 1, $40 for page 2).

In addition, three other memory locations hold information regarding shape table data for the drawing subroutines:

$E7: Scale factor for drawing shapes
$E8: Lo byte pointer to beginning of shape table
$E9: Hi byte pointer to beginning of shape table.

There are also a number of zero page page locations that the Hi-Res subroutines use internally when doing the actual screen plotting of points, or strings of points called lines. Some of these contain the memory address of the byte to plot on the screen, while others contain the color and masking information, so that only the correct pixel within that seven-pixel byte is turned on or off.

$1C: The color masking byte, which is shifted for odd addresses but other wise remains unchanged.
$26: Lo address for the leftmost byte in a particular vertical row.
$27: Hi address for the leftmost byte in a particular vertical row.
$E5: The integer part of the horizontal screen coordinate divided by 7, or the horizontal offset into row.
$30: The bit position taken from the Bit Position table.

This corresponds to remainder from horizontal coordinate divided by 7 or which bit in the byte is to be lit.

What I should point out is that after a series of other subroutines set up the position to plot on the screen, the actual plotting of the point is done with a five line subroutine called PLOT located at $F45A, as in the following:

```
LDA    $1C
EOR    ($26),Y
AND    $30
EOR    ($26),Y
STA    ($26),Y
RTS
```

The internal cursor data is more important than the external cursor data if speed is the consideration. There are internal subroutines within the ROM that set the external cursor data to correspond with the internal data, and several more that can manipulate the screen cursor directly. However, for plotting points and drawing shapes from Apple shape tables, you need not concern yourself with any internal workings of these subroutines. Instead, I've summarized all of the necessary subroutines in the table below, and will demonstrate examples using them.

NAME	ADDRESS	ACC.	XREG	YREG	NOTES
HGR	$F3E2	----------	-----		
HGR2	$F3D8	-----	-----	-----	
BKGND	$F3F4	COLOR FROM COLOR MASK TABLE	-----	-----	
HCOLOR	$F6F0	-----	COLOR 0-7	-----	
HPLOT	$F457	VERT	HORIZ LO	HORIZ HI	THIS CALLS HPOSN
HLINE	$F53A	HORIZ LO	HORIZ HI	VERT	DRAWS FROM INT CURSOR POS. TO PT. IN INPUT
HPOSN	$F411	VERT	HORIZ LO	HORIZ HI	ALWAYS CALL BEFORE DRAW
SHPTR	$F730	-----	SHAPE #	-----	SETS $1A, $1B SHAPE POINTERS
DRAW	$F601	ROTATION	$1A	$1B	
XDRAW	$F65D	ROTATION	$1A	$1B	

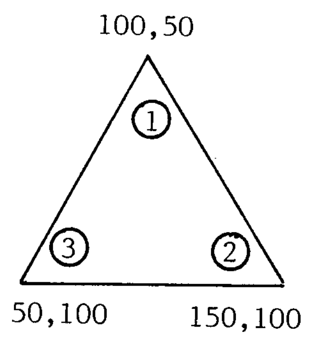
Simple shapes can be plotted to the Hi-Res screen in BASIC by HPLOTting from point to point. Their speed, in comparison to Apple shapes (vector shapes), is rather slow. However, in machine code, HPLOTed shapes become a viable alternative if the shape is rather large and complex. Their disadvantage is that they can't be scaled or rotated, but they are easier to plot if you choose to place the coordinate pairs into a table.

Our first example will plot a simple triangle by accessing the Applesoft Hi-Res ROM routines directly. It is equivalent to the following BASIC program.

```
10  HGR
20  HCOLOR = 3
30  HPLOT 100,50 TO 150,100 TO 50,100 TO 100,50
40  END
```

The program sets the mode to Hi-Res graphics page one, mixed text and graphics, by calling HGR at $F3E2. The plotting color is set to white (3) by a call to HCOLOR at $F6F0. Then, by loading the Accumulator and the X & Y registers with the correct screen coordinates, the point at 100,50 is plotted to the screen with a call to HPLOT at $F457. Each of the triangle's lines are drawn by calling HLINE at $F53A. This subroutine draws a line from the internal cursor position (last point) to the point defined by the input to HLINE. Since the last point was at 100,50 and we are inputting the coordinates 150,100 , the line is drawn between these two points. After drawing the next two lines, the triangle is completed and the program ends. The complete code follows.

IMPORTANT NOTE: The programs in this chapter access the Applesoft ROM. While this is no problem to Apple II Plus owners, those of us that have an Integer machine with an Applesoft ROM card, or Applesoft in RAM on a 16K memory board, should understand that if they enter the monitor by hitting reset, they have lost Applesoft. The machine reverts to the Integer ROM on the motherboard. If you try to restart the programs they won't run unless the ROMs are reconnected by a 9DBFG and you return to the monitor by a CALL -151.



```
                   *PLOT TRIANGLE
                            ORG  $6000
6000: 20 E2 F3              JSR  $F3E2       ;HGR
6003: A2 03                 LDX  #$03        ;COLOR=WHITE
6005: 20 F0 F6              JSR  $F6F0       ;HCOLOR
                   *PLOT FIRST PT
6008: A0 00                 LDY  #$00        ;HORIZ POS HI BYTE
600A: A2 64                 LDX  #$64        ;HORIZ POS LO BYTE
600C: A9 32                 LDA  #$32        ;VERT POS
600E: 20 57 F4              JSR  $F457       ;HPLOT
                   *DRAW TO SECOND POINT
6011: A2 00                 LDX  #$00        ;HORIZ POS HI BYTE
6013: A9 96                 LDA  #$96        ;HORIZ POS LO BYTE
6015: A0 64                 LDY  #$64        ;VERT POS
6017: 20 3A F5              JSR  $F53A       ;HLINE
                   *DRAW TO THIRD POINT
601A: A2 00                 LDX  #$00        ;HORIZ POS HI BYTE
601C: A9 32                 LDA  #$32        ;HORIZ POS LO BYTE
601E: A0 64                 LDY  #$64        ;VERT POS
6020: 20 3A F5              JSR  $F53A       ;HLINE
                   *DRAW TO FIRST POINT
6023: A2 00                 LDX  #$00        ;HORIZ POS HI BYTE
6025: A9 64                 LDA  #$64        ;HORIZ POS LO BYTE
6027: A0 32                 LDY  #$32        ;VERT POS
6029: 20 3A F5              JSR  $F53A       ;HLINE
602C: 60                    RTS

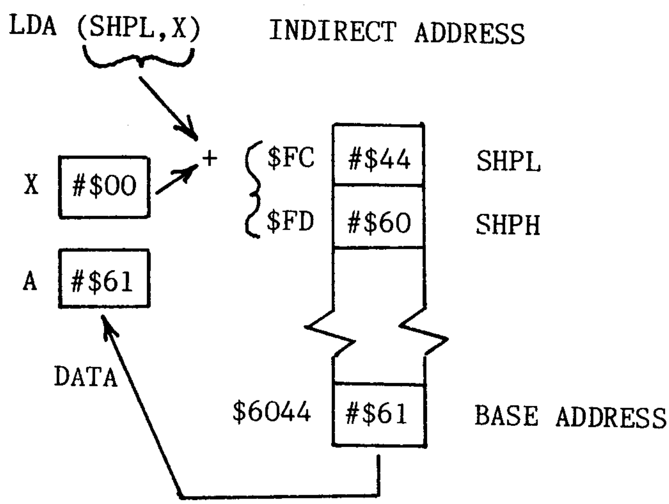
--END ASSEMBLY--
```

The HPLOT technique can be used to draw shapes of greater complexity. Since these shapes require numerous calls to HLINE for each line segment of the completed shape, it is best to design the code to access the coordinate pairs from a stored table and put the drawing routine into a loop.

For the sake of simplicity, I decided to store the X-Y coordinates as two byte pairs. This limits the range along the horizontal axis, since values greater than 255 would require using the hi byte, too. If you wanted to use the entire screen, you would have to use three byte coordinate pairs and modify the code accordingly. A test was needed to determine when all the shape's points had been plotted. I used an $FF as a flag for the last point. The test is on the vertical coordinate, since Y coordinate values don't exceed $BF. Actually, the pair's first byte can be anything, since it is the last byte of the pair that is the flag. When the loop detects this flag, it skips plotting the last line segment and exits the loop.

The technique for accessing elements of a shape table involves loading the first of a pair of bytes into the Accumulator, and the second byte into the X register before calling HLINE to draw the line segment. Each element of the table is stored at a particular two-byte address. In our example, the very first element is called the 0th element of the table and is located at $6044. Elements of a table can be accessed by using a zero page indexing system called Indexed Indirect Addressing. It takes the form LDA (SHPL,X). If the X-register were zero,it would load a byte from an address indicated by a pair of bytes, SHPL and SHPH stored in zero page. For example, if location $FC and $FD, which are equivalent to SHPL and SHPH respectively, contain a #$44 and #$60 in that order, then LDA (SHPL,X) will load a #$61 from location $6044 into the Accumulator.

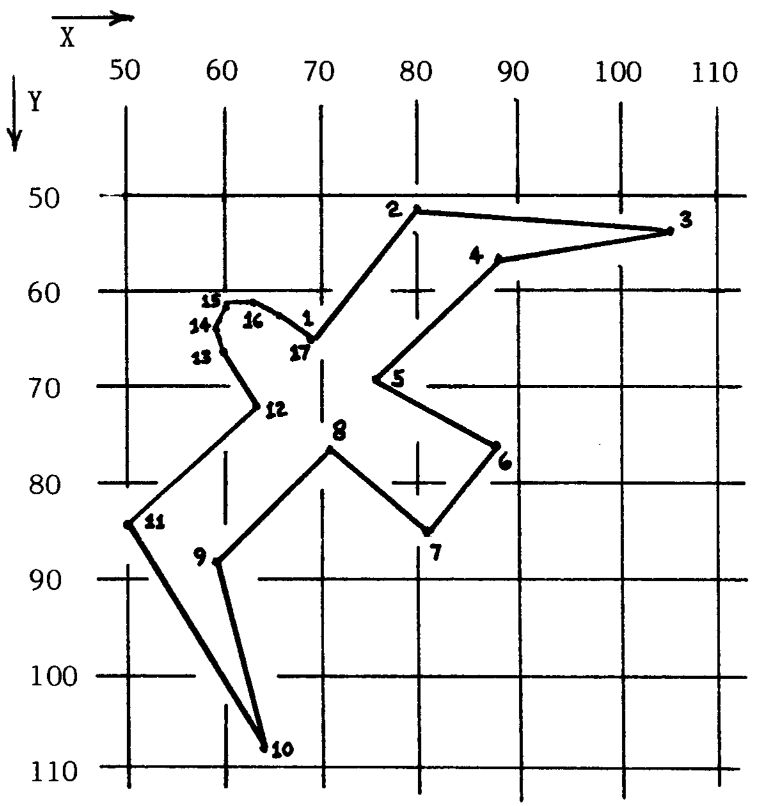
INDEXED INDIRECT ADDRESSING



As you will soon discover, there are never enough registers in the 6502. Certainly, the Accumulator and X and Y registers are not enough when all three need to be loaded to call a subroutine, and you also need to use two of them simultaneously for retrieving data from a table. The solution is to temporarily store your data in a memory location. When you're done with the table and your registers are free, the data can be moved to the proper registers just before calling the subroutine. The important thing is to be careful that you do not clobber your working registers.

In the example below, the X-register must be set to zero each time the indexed indirect load is used to retrieve a value from the table. This is no problem the first time through the loop, but this value for the horizontal position lo byte eventually needs to reside in the X-register before calling HLINE. Since we

need to do another indirect indexed load using both the Accumulator and X-register for the next byte, we temporarily store our data in XLOW. If we increment SHPL, the lo byte pointer to our shape data, it will point to the next byte in our shape table. At this point, since we haven't disturbed the X-register, we don't need to put zero into it to perform our next indirect indexed load. This second value retrieved — the vertical coordinate is transferred to the Y-register. The horizontal hi byte is placed into the X-register and the horizontal lo byte, which was temporarily stored at XLOW, is moved into the Accumulator before calling the subroutine HLINE.



	DECIMAL		HEX	
PT	X	Y	X	Y
1	69	65	45	41
2	80	52	50	34
3	106	57	6A	39
4	87	57	57	39
5	76	71	4C	47
6	88	77	58	4D
7	81	85	51	55
8	72	77	48	40
9	59	88	38	58
10	64	108	40	6C
11	50	84	32	54
12	63	72	3F	48
13	59	67	3B	43
14	58	64	3A	40
15	60	62	3C	3E
16	64	62	40	3E
17	69	65	44	41
			FF	FF

```
                *HPLOTS A BIRD SHAPE ON SCREEN ONCE
                         ORG   $6000
                XLOW     DS    1
                HPLOT    EQU   $F457
                HLINE    EQU   $F53A
                HCOLOR   EQU   $F6F0
                HGR      EQU   $F3E2
                SHPL     EQU   $FC
                SHPH     EQU   SHPL+$1
                *PROGRAM
6001: 20 E2 F3           JSR   HGR
6004: A2 03              LDX   #$03       ;WHITE COLOR
6006: 20 F0 F6           JSR   HCOLOR     ;SET WHITE COLOR
6009: A9 44              LDA   #<SHAPE
600B: 85 FC              STA   SHPL
600D: A9 60              LDA   #>SHAPE
600F: 85 FD              STA   SHPH
                *PLOT FIRST POINT
6011: A2 00     PLOT     LDX   #$00
6013: A1 FC              LDA   (SHPL,X)   ;THIS IS HOR POS LO BYTE
6015: 8D 00 60           STA   XLOW
6018: E6 FC              INC   SHPL       ;NEXT BYTE IN SHAPE TABLE
601A: A1 FC              LDA   (SHPL,X)   ;THIS IS VERT VALUE FOR PT
601C: AE 00 60           LDX   XLOW       ;HORIZ POS LO BYTE
601F: A0 00              LDY   #$00       ;HORIZ POS HI BYTE
6021: 20 57 F4           JSR   HPLOT
6024: E6 FC              INC   SHPL       ;NEXT BYTE IN TABLE
                *DRAW NEXT POINT
```

```
6026: A2 00      LOOP   LDX  #$00
6028: A1 FC             LDA  (SHPL,X)   ;HORIZ POS LO BYTE
602A: 8D 00 60          STA  XLOW
602D: E6 FC             INC  SHPL       ;NEXT BYTE IN TABLE
602F: A1 FC             LDA  (SHPL,X)   ;THIS IS VERT VALUE FOR PT
6031: C9 FF             CMP  #$FF
6033: F0 0E             BEQ  DONE       ;IF BYTE CONTAINS 255, DONE
6035: A8                TAY             ;VERT IN Y REG
6036: A2 00             LDX  #$00       ;HORIZ POS IN HI BYTE
6038: AD 00 60          LDA  XLOW       ;HORIZ POS IN LO BYTE
603B: 20 3A F5          JSR  HLINE
603E: E6 FC             INC  SHPL       ;NEXT BYTE
6040: 4C 26 60          JMP  LOOP
6043: 60         DONE   RTS
                 *
6044: 45 41 50
6047: 34 6A 39
604A: 57 39      SHAPE  HEX  454150346A395739
604C: 4C 47 58
604F: 4D 51 55
6052: 48 4D             HEX  4C47584D5155484D
6054: 3B 58 40
6057: 6C 32 54
605A: 3F 48             HEX  3B58406C32543F48
605C: 3B 43 3A
605F: 40 3C 3E
6062: 40 3E             HEX  3B433A403C3E403E
6064: 44 41 FF
6067: FF                HEX  4441FFFF
```

Shape tables that cross page boundaries (256 byte sections of memory where the hi byte is constant) can cause problems. If, for example, our table began at $60FC instead of $6044, after incrementing four times, the lo byte would be #$00. The program would attempt to load the byte at location $6000 instead of the byte at location $6100. This can be prevented if a test is performed after you increment SHPL. If SHPL were equal to zero, it would increment SHPH; otherwise, it would skip this step.

```
        INC  SHPL       ;INCREMENT LO BYTE
        LDA  SHPL
        CMP  #$00       ;IS IT 0 ?
        BNE  SKIP       ;NO
        INC  SHPH       ;YES INCREMENT HI POINTER
SKIP    LDA  (SHPL,X)   ;NEXT BYTE IN TABLE
         .     .
         .     .
```

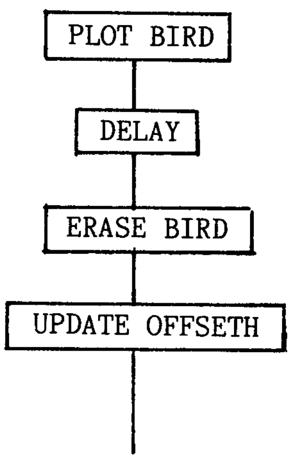
The object of this fast machine language algorithm is to enable you to animate your shapes smoothly and quickly. While one would never attempt to animate HPLOTed shapes in Applesoft BASIC, it is completely feasible in machine language. Speed increases on the order of 6 to 8 times are the rule.

The code to animate our HPLOTed bird in Applesoft follows. Try it, then try the same algorithm written in machine language. I should point out that the speed differences can not be directly correlated, since to keep the object on the screen longer than off, a delay loop of 7 milliseconds per frame was used. If you remove the delay or set the value in the Accumulator to #$01 before calling the delay subroutine at $FCA8, the speed increases to 8 times that of the Applesoft version. However, screen flicker becomes more noticeable.

```
10  DIM X(20),Y(20)
30  FOR I = 1 TO 50
40  READ X(I),Y(I)
50  IF Y(I) = 255 THEN 65
60  NEXT I
65  HGR :OFF =  - 50:I = 1
70  HCOLOR= 3
80  HPLOT X(I) + OFF,Y(I) TO X(I + 1) + OFF,Y(I + 1) TO X(I
+ 2) + OFF,Y(I + 2) TO X(I + 3) + OFF,Y(I + 3) TO X(I + 4) +
 OFF,Y(I + 4) TO X(I + 5) + OFF,Y(I + 5) TO X(I + 6) + OFF,Y
(I + 6) TO X(I + 7) + OFF,Y(I + 7) TO X(I + 8) + OFF,Y(I + 8
) TO X(I + 9) + OFF,Y(I + 9)
90  HPLOT X(I + 9) + OFF,Y(I + 9) TO X(I + 10) + OFF,Y(I + 1
0) TO X(I + 11) + OFF,Y(I + 11) TO X(I + 12) + OFF,Y(I + 12)
 TO X(I + 13) + OFF,Y(I + 13) TO X(I + 14) + OFF,Y(I + 14) T
O X(I + 15) + OFF,Y(I + 15) TO X(I + 16) + OFF,Y(I + 16)
100  HCOLOR= 4
110  HPLOT X(I) + OFF,Y(I) TO X(I + 1) + OFF,Y(I + 1) TO X(I
 + 2) + OFF,Y(I + 2) TO X(I + 3) + OFF,Y(I + 3) TO X(I + 4)
+ OFF,Y(I + 4) TO X(I + 5) + OFF,Y(I + 5) TO X(I + 6) + OFF,
Y(I + 6) TO X(I + 7) + OFF,Y(I + 7) TO X(I + 8) + OFF,Y(I +
8) TO X(I + 9) + OFF,Y(I + 9)
120  HPLOT X(I + 9) + OFF,Y(I + 9) TO X(I + 10) + OFF,Y(I +
10) TO X(I + 11) + OFF,Y(I + 11) TO X(I + 12) + OFF,Y(I + 12
) TO X(I + 13) + OFF,Y(I + 13) TO X(I + 14) + OFF,Y(I + 14)
TO X(I + 15) + OFF,Y(I + 15) TO X(I + 16) + OFF,Y(I + 16)
130 OFF = OFF + 5
140  IF OFF = 155 THEN OFF =  - 50
150  GOTO 70
160  DATA   69,65,80,52,106,57,87,57,76,71,88,77,81,85,72,77
,59,88,64,108,50,84,63,72,59,67,58,64,60,62,64,62,69,65,255,
255
```

The code for the moving bird is quite similar to the stationary bird, except that once we plot the bird, it must be erased before replotting it at a different position. It becomes rather convenient to place the entire plotting program in a subroutine. An offset is added to each horizontal point of the bird to position it properly on the screen. This offset starts at −50 or #$CE in order to position the bird's left-most point at X = 0. The offset is incremented by five for each additional frame and tested each time so that it doesn't exceed 150 or #$96. If it does, the bird's right-most point will exceed 255 decimal. The test must be exactly at 150 rather than equal or greater, because our negative numbers #$CE and larger would also meet the test. Be careful in this kind of test. If your hexadecimal addition isn't correct when choosing the test position, the number will never meet the test conditions and therefore never reset the offset back to the beginning position after traversing the screen's width. One hint is to use the monitor when adding two hexadecimal single byte numbers. For example, the monitor command 03 + FE <CR> will return the hexadecimal value $02.

When alternating between drawing and erasing, the color shifts between white and black, respectively. The pointers to the shape table must also be reset for each plot/erase cycle because these pointers are incremented when retrieving bytes within the table. The flow chart and machine code for the moving bird follows.



```
                  *MOVING HPLOTTED BIRD ACROSS SCREEN
                           ORG   $6000
                  XLOW     DS    1
                  HPLOT    EQU   $F457
                  HLINE    EQU   $F53A
                  HCOLOR   EQU   $F6F0
                  HGR      EQU   $F3E2
                  SHPL     EQU   $FC
                  SHPH     EQU   SHPL+$1
                  OFFSETH  DS    1
                  *PROGRAM
6002: 20 E2 F3             JSR   HGR
6005: A9 CE                LDA   #$CE         ;-50 DECIMAL
6007: 8D 01 60             STA   OFFSETH
600A: A9 7C       MAIN     LDA   #<SHAPE
600C: 85 FC                STA   SHPL
600E: A9 60                LDA   #>SHAPE
6010: 85 FD                STA   SHPH
6012: A2 03                LDX   #$03         ;WHITE COLOR
6014: 20 F0 F6             JSR   HCOLOR       ;SET TO WHITE
6017: 20 41 60             JSR   PLOT
601A: A9 50                LDA   #$50
601C: 20 A8 FC             JSR   $FCA8        ;DELAY
601F: A9 7C                LDA   #<SHAPE
6021: 85 FC                STA   SHPL
6023: A9 60                LDA   #>SHAPE
6025: 85 FD                STA   SHPH
6027: A2 04                LDX   #$04         ;BLACK COLOR
6029: 20 F0 F6             JSR   HCOLOR       ;SET TO BLACK
602C: 20 41 60             JSR   PLOT
                  *UPDATE HORIZ OFFSET
602F: AD 01 60             LDA   OFFSETH
6032: 18                   CLC
6033: 69 05                ADC   #$05
6035: C9 96                CMP   #$96         ;150 DECIMAL
6037: D0 02                BNE   SKIP
6039: A9 CE                LDA   #$CE         ;OFF RT SIDE OF SCREEN
603B: 8D 01 60    SKIP     STA   OFFSETH
603E: 4C 0A 60             JMP   MAIN
                  *PLOT FIRST POINT
6041: A2 00       PLOT     LDX   #$00
6043: A1 FC                LDA   (SHPL,X)     ;THIS IS HOR POS LO BYTE
6045: 18                   CLC
6046: 6D 01 60             ADC   OFFSETH
6049: 8D 00 60             STA   XLOW         ;NEW HORIZ POS LO BYTE
604C: E6 FC                INC   SHPL         ;NEXT BYTE IN SHAPE TABLE
604E: A1 FC                LDA   (SHPL,X)     ;THIS IS VERT VALUE FOR PT
6050: AE 00 60             LDX   XLOW         ;HORIZ POS LO BYTE
6053: A0 00                LDY   #$00         ;HORIZ POS HI BYTE
6055: 20 57 F4             JSR   HPLOT
6058: E6 FC                INC   SHPL         ;NEXT BYTE IN TABLE
                  *DRAW NEXT POINT
605A: A2 00       LOOP     LDX   #$00
605C: A1 FC                LDA   (SHPL,X)     ;HORIZ POS LO BYTE
605E: 18                   CLC
605F: 6D 01 60             ADC   OFFSETH
6062: 8D 00 60             STA   XLOW         ;NEW HORIZ POS LO BYTE
6065: E6 FC                INC   SHPL         ;NEXT BYTE IN TABLE
6067: A1 FC                LDA   (SHPL,X)     ;THIS IS VERT VALUE FOR PT
6069: C9 FF                CMP   #$FF
```

```
606B: F0 0E              BEQ  DONE           ;IF BYTE CONTAINS 255, DONE
606D: A8                 TAY                 ;VERT IN Y REG
606E: A2 00              LDX  #$00           ;HORIZ POS IN HI BYTE
6070: AD 00 60           LDA  XLOW           ;HORIZ POS IN LO BYTE
6073: 20 3A F5           JSR  HLINE
6076: E6 FC              INC  SHPL           ;NEXT BYTE
6078: 4C 5A 60           JMP  LOOP
607B: 60        DONE     RTS
                *
607C: 45 41 50
607F: 34 6A 39
6082: 57 39     SHAPE    HEX  454150346A395739
6084: 4C 47 58
6087: 4D 51 55
608A: 48 4D              HEX  4C47584D5155484D
608C: 3B 58 40
608F: 6C 32 54
6092: 3F 48              HEX  3B58406C32543F48
6094: 3B 43 3A
6097: 40 3C 3E
609A: 40 3E              HEX  3B433A403C3E403E
609C: 44 41 FF
609F: FF                 HEX  4441FFFF

--END ASSEMBLY--    160 BYTES
```

APPLE SHAPE TABLES IN ANIMATION

The advantage of accessing Apple shape tables (vector shape tables) directly from machine language results in a sixfold increase in animation speed. For many applications and simple games, this speed increase may be sufficient. If it isn't, you should use raster or block shape animation.

I think that beginning machine language programmers, whose prior experience is with Apple shapes in BASIC, should attempt the techniques in this section before learning more complicated methods shown later in this book.

If you were to DRAW or XDRAW a shape in BASIC, you would set the color, scale, and rotation before doing a DRAW 1 at 10,10. The location of the shape table would have been indicated by poking the address to locations decimal 232 and 233. These two locations are $E8 and $E9, respectively.

However, before calling the DRAW subroutine at $F601 or XDRAW at $F65D, the pointers to the correct shape number must be set through a subroutine that I call SHPTR (short for shape pointer). This subroutine located at $F730 takes the shape number, which is inputted via the X-register, and sets the pointers to the shape in locations $1A (lo byte) and $1B (hi byte).

This subroutine is deeply linked into the Applesoft interpreter. It calls subroutines that increment the Applesoft "Get Next Character" Routine. Although I don't believe that this subroutine located at $B7 will cause any pro-

blems, before you clobber anything, I would pay attention to the chart of available zero page locations in the Apple Reference Manual. Don't touch the locations used by Applesoft. You can also disconnect that routine by placing a #$60 (RTS) in location $B7 (its first location), but be sure to put the original value, #$AD, back when you're done, or you will hang the computer when it returns the Applesoft prompt, and doesn't understand anything that you type. In short, don't make the change unless you think it is causing you grief.

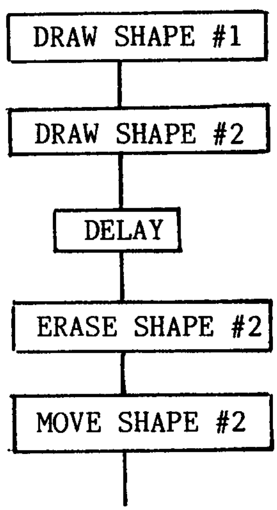
The second thing that must be set before calling the DRAW subroutine is the internal cursor position, or where you want to plot your shape. This is easily accomplished with the HPOSN subroutine at $F411. Once the horizontal and vertical locations are inputted, the subroutine sets locations $26, $27, $30, and $E5 to begin plotting. When you finally call the DRAW or XDRAW subroutine, the only inputs that are required are the rotation value in the Accumulator and the pointers to the correct shape that are stored at $1A and $1B in the X and Y registers. It may sound complicated but if you examine the following code, you will see that it is relatively straight-forward. The following routine XDRAWs two shapes. The first, a square, is plotted at X = 64, Y = 64, and the second shape, a cross, is plotted at X = 128, Y = 50. The scale is 4.

```
            *PLOTS TWO APPLE SHAPE TABLE SHAPES
                     ORG  $6000
            HGR      EQU  $F3E2
            HCOLOR   EQU  $F6F0
            HPOSN    EQU  $F411
            XDRAW    EQU  $F65D
            SHPTR    EQU  $F730
6000: 20 E2 F3       JSR  HGR
6003: A9 00          LDA  #$00
6005: 85 E8          STA  $E8         ;LO BYTE OF SHAPE TABLE
6007: A9 08          LDA  #$08
6009: 85 E9          STA  $E9         ;HI BYTE OF SHAPE TABLE
600B: A2 03          LDX  #$03        ;WHITE
600D: 20 F0 F6       JSR  HCOLOR
6010: A9 02          LDA  #$02
6012: 85 E7          STA  $E7         ;SCALE
6014: A2 01          LDX  #$01        ;SHAPE #1
6016: 20 30 F7       JSR  SHPTR       ;SET UP POINTER TO 1ST SHAPE
6019: A2 40          LDX  #$40        ;HOR LO
601B: A0 00          LDY  #$00        ;HOR HI
601D: A9 40          LDA  #$40        ;VERT
601F: 20 11 F4       JSR  HPOSN
6022: A6 1A          LDX  $1A         ;LO BYTE SHAPE ADDRESS
6024: A4 1B          LDY  $1B         ;HI BYTE SHAPE ADDRESS
6026: A9 00          LDA  #$00        ;ROT
6028: 20 5D F6       JSR  XDRAW
            *PLOT SECOND SHAPE
602B: A2 02          LDX  #$02        ;SHAPE #2
602D: 20 30 F7       JSR  SHPTR       ;SET UP POINTER TO 2ND SHAPE
6030: A2 80          LDX  #$80        ;HOR LO
6032: A0 00          LDY  #$00        ;HOR HI
6034: A9 32          LDA  #$32        ;VERT
```

```
6036: 20 11 F4          JSR  HPOSN
6039: A6 1A             LDX  $1A        ;LO BYTE SHAPE ADDRESS
603B: A4 1B             LDY  $1B        ;HI BYTE SHAPE ADDRESS
603D: A9 00             LDA  #$00       ;ROT
603F: 20 5D F6          JSR  XDRAW
6042: 60                RTS

--END ASSEMBLY--    67 BYTES
```

Animating a shape is simple. You plot it once, erase it, move it to a new position, and then replot it at its new position. The procedure is accomplished via a loop. There is very little to say about the method. It is the same in Applesoft. I think the only thing you should be aware of is that HPOSN doesn't need to be called twice, since the erase is done at the same screen position as the XDRAW. In the example, shape #2 moves horizontally to the right, while shape #1 is stationary. The move routine checks for wrap-a-round at X = #$FF as it moves the shape across the screen. The flow chart and code follows.



SHAPE #1   SHAPE #2

SHAPE @ $800

SHAPE TABLE: $\underbrace{\texttt{02}}_{\text{TWO SHAPES}}$ 00 $\underbrace{\texttt{06 00}}_{\text{OFFSET TO SHAPE \#1}}$ $\underbrace{\texttt{09 00}}_{\text{OFFSET TO SHAPE \#2}}$ $\underbrace{\texttt{2C 3E 00}}_{\text{SHAPE \#1}}$ $\underbrace{\texttt{2C 2E 3E 3E 3C 2C 00}}_{\text{SHAPE \#2}}$

```
                 *MOVES APPLE SHAPE TABLE SHAPE ACROSS SCREEN
                          ORG   $6000
                 HGR      EQU   $F3E2
                 HCOLOR   EQU   $F6F0
                 HPOSN    EQU   $F411
                 XDRAW    EQU   $F65D
                 SHPTR    EQU   $F730
                 XLOW     DS    1
6001: A9 05               LDA   #$05
6003: 8D 00 60            STA   XLOW
6006: 20 E2 F3            JSR   HGR
6009: A9 00               LDA   #$00
600B: 85 E8               STA   $E8         ;LO BYTE OF SHAPE TABLE
600D: A9 08               LDA   #$08
600F: 85 E9               STA   $E9         ;HI BYTE OF SHAPE TABLE
6011: A2 03               LDX   #$03        ;WHITE
6013: 20 F0 F6            JSR   HCOLOR
6016: A9 04               LDA   #$04
6018: 85 E7               STA   $E7         ;SCALE
601A: A2 01               LDX   #$01        ;SHAPE #1
601C: 20 30 F7            JSR   SHPTR       ;SET UP POINTER TO 1ST SHAPE
601F: A2 40               LDX   #$40        ;HORIZ POS LO BYTE
6021: A0 00               LDY   #$00        ;HORIZ POS HI BYTE
6023: A9 50               LDA   #$50        ;VERT POS
6025: 20 11 F4            JSR   HPOSN
6028: A6 1A               LDX   $1A         ;LO BYTE SHAPE ADDRESS
602A: A4 1B               LDY   $1B         ;HI BYTE SHAPE ADDRESS
602C: A9 00               LDA   #$00        ;ROT
602E: 20 5D F6            JSR   XDRAW
                 *PLOT SECOND SHAPE
6031: A2 02      LOOP     LDX   #$02        ;SHAPE #2
6033: 20 30 F7            JSR   SHPTR       ;SET UP POINTER TO 2ND SHAPE
6036: AE 00 60            LDX   XLOW        ;HOR POS LO BYTE
6039: A0 00               LDY   #$00        ;HOR POS HI BYTE
603B: A9 32               LDA   #$32        ;VERT POS
603D: 20 11 F4            JSR   HPOSN
6040: A6 1A               LDX   $1A         ;LO BYTE SHAPE ADDRESS
6042: A4 1B               LDY   $1B         ;HI BYTE SHAPE ADDRESS
6044: A9 00               LDA   #$00        ;ROT
6046: 20 5D F6            JSR   XDRAW       ;DRAW SHAPE #2
6049: A9 50               LDA   #$50
604B: 20 A8 FC            JSR   $FCA8       ;DELAY
604E: A2 02               LDX   #$02        ;SHAPE #2
6050: 20 30 F7            JSR   SHPTR
                 *DON'T HAVE TO DO HPOSN BEFORE ERASE
                 *BECAUSE POSITION HASN'T CHANGED
6053: A6 1A               LDX   $1A         ;LO BYTE SHAPE ADDRESS
6055: A4 1B               LDY   $1B         ;HI BYTE SHAPE ADDRESS
```

```
6057: A9 00            LDA  #$00       ;ROT
6059: 20 5D F6         JSR  XDRAW      ;ERASE SHAPE #2
              *MOVE SHAPE TO NEW POSITION
605C: AD 00 60         LDA  XLOW
605F: 18               CLC
6060: 69 05            ADC  #$05
6062: C9 FF            CMP  #$FF
6064: D0 02            BNE  SKIP
6066: A9 0A            LDA  #$0A
6068: 8D 00 60   SKIP  STA  XLOW
606B: 4C 31 60         JMP  LOOP
```

CHAPTER 4

HI-RES SCREEN ARCHITECTURE

The Apple II has two Hi-Res graphics screens, a primary and a secondary, each with a resolution of 280 dots horizontally (columns) and 192 dots or lines vertically. This gives an effective screen resolution of 53,760 picture elements or pixels per screen.

The large number of pixels presented a dilemma to the Apple II designers. Using one memory location for each dot would far outstrip the Apple's 48K memory; besides, they wanted to have two screens. Their solution was to divide the screen horizontally into 40 groups of 7 pixels. Each memory location would represent information for seven adjacent pixels. This lowered the memory requirement to 7680 bytes per screen. Since it was easier to work in 8K blocks of memory, this left an unused 512 bytes of memory per page.

In 1977, when memory chips were expensive, most Apple II computers were sold with only 16K of memory. With various monitor areas, zero page, the stack, and the text page using the first 2K (2048) bytes of memory, it seemed logical to place Hi-Res graphics screen # one at the upper end of memory, locations 8192 to 16383 ($2000- $3FFF). Screen # two of Hi-Res graphics was placed in the 8K block of memory just beyond locations 16384 to 24575 ($4000 -$5FFF). It was usable by owners who purchased extra memory. Both of these screen's locations are hardwired into the machine and, unfortunately, are not relocatable. In those days, before DOS and Applesoft made their debut, Integer BASIC programmers whose machines contained 48K of memory could start their program at the top of memory and write 32K of code.

Today, Applesoft programmers face the dilemma of where to place their programs without overwriting the information stored in the Hi-Res screen areas. Since Applesoft loads a program immediately above the text screen which begins at $800 or 2048 decimal, only small programs fit, if they are using Hi-Res graphics commands. The solution is to set the Applesoft pointers so that the program loads above the Hi-Res screen. Unfortunately, you waste the 6K of usable memory between the operating system and the beginning of Hi-Res screen one. In retrospect, what seemed to be a logical choice in 1977 is cumbersome today.

The Apple's Hi-Res screen is considered memory-mapped. If you were to change the values of the first 40 bytes of screen memory so that each turned on all 7 pixels, then the screen would display a solid white line at the top. Changing any particular byte in Hi-Res memory directly affects the resultant picture.

Any byte in screen memory consists of a sequence of eight individual bits. If a bit is on, it has a value of 1; if it is off, it has a value of 0. This on-off system of numbers is called ''Binary''. Binary numbers, represented by strings of 0's and 1's, have their least significant numbers starting at the right, as shown:

128	64	32	16	8	4	2	1	
0	0	0	0	0	0	0	1	= $01

Each successive move of a bit to the left results in the value of the byte being multiplied by two.

128	64	32	16	8	4	2	1	
0	0	0	0	0	0	1	0	= $02

Eventually, the on bit would be shifted to the far left with a value of $80 or 128 decimal.

The Hi-Res screen's convention is in reverse. Pixel values increase from left to right. This can be verified by poking values into the primary screen's first memory location, $2000. To do this it, is best to enter the monitor with a CALL -151 from BASIC. Hi-Res graphics with mixed text can be invoked with the following commands:

```
*C050    <CR>    SET GRAPHICS MODE
*C053    <CR>    SET MIXED TEXT AND GRAPHICS
*C057    <CR>    SET HI-RES GRAPHICS
```

Most likely, the screen is not clear. Although an HGR from Applesoft would clear it before entering the monitor, you should learn to perform this operation from the monitor. Typing a 2000:00 <CR> will place a zero or no lit pixels in the first screen location. Doing the following memory move shifts the 0 to all other locations in a cascade effect on Hi-Res screen page one:

```
*2001<2000.3FFFM <CR>
```

If you enter 2000:01 <CR>, a single dot appears at the top left. If you enter 2000:02 <CR>, the dot moves one position to the right. A 2000:04 <CR> moves it right once again. Since seven dots are controlled by one byte, you can do this seven times. The value $40 shifts it to the seventh position. If you shift the dot one extra time with the value $80, nothing happens. This eighth bit position doesn't activate any pixels.

PIXEL POSITIONS								BINARY							
								128	64	32	16	8	4	2	1
●							$01	0	0	0	0	0	0	0	1
	●						$02	0	0	0	0	0	0	1	0
		●					$04	0	0	0	0	0	1	0	0
●	●	●					$07	0	0	0	0	0	1	1	1
			●				$08	0	0	0	0	1	0	0	0
●	●	●	●				$0F	0	0	0	0	1	1	1	1
●	●	●	●	●			$1F	0	0	0	1	1	1	1	1
●	●	●	●	●	●	●	$7F	0	1	1	1	1	1	1	1
							$80	1	0	0	0	0	0	0	0
●	●	●	●	●	●	●	$FF	1	1	1	1	1	1	1	1

You can see from the diagram that 2000:07 turns on the first three pixels and either 2000:7F (127) or 2000:FF (255) turns on all seven dots. As you shall see shortly, the eight bit, the high bit or most significant bit, is used for color control. While it is not important to use the hi bit in black and white graphics, it does explain why there is a WHITE1 and WHITE2, as well as a BLACK1 and BLACK2. The difference between WHITE1 and WHITE2 is whether or not the hi bit is set.

Those using a color TV as a monitor will notice that some of the lit pixels are a violet like color (magenta) while others are green. The Apple II's designers

alternated the colors every other column. The leftmost column in any row always starts with violet if the high bit is off, followed by green in the next column. Thus, there are 140 violet-green pairs in any row. Since the leftmost column is column 0, violet pixels are always in even columns, (i.e., 0,2,4 ... 278). Conversely, green pixels are always in odd columns (i.e. 1,3,5 ... 279).

There is a logical reason for alternating the Apple's colors from column to column. The pairs of colors are related to the square wave pulses in respect to the colorburst reference signal in television receivers. If the Apple sends a pulse that corresponds with the peak of the color signal, you get one color; if the pulse corresponds to the low point of the color signal, you get the complementary color. The Apple can send a pulse shifted 1/4 cycle (in between). That generates two other complementary colors, also in adjacent pairs. I should note that this arrangement is completely independent of the physical locations of the colored phosphors on the television picture tube.

HI- BIT OFF (0)

V	G	V	G	V	G	V	G	V	G	V	G	V	G

$2000 — 0TH BYTE (EVEN) $2001 — 1ST BYTE (ODD)

When the hi-bit is set in any byte, the pixel colors shift to blue (cyan) and orange.

HI- BIT ON (1)

B	O	B	O	B	O	B	O	B	O	B	O	B	O

$2000 — 0TH BYTE (EVEN) $2001 — 1ST BYTE (ODD)

When color is considered, there are three primary colors; green, blue and red. Each primary color has a complement. These are magenta (violet), yellow, and cyan (blue) respectively. If a primary color plus its complement are projected on a screen, the result is white, as shown:

PRIMARY COLOR		SECONDARY COLOR	
GREEN	+	MAGENTA (VIOLET)	= WHITE
BLUE	+	YELLOW	= WHITE
RED	+	CYAN (LIGHT BLUE)	= WHITE

What happens on a color monitor is quite similar. If only the first pixel is lit, you get a violet dot. If only the second pixel is lit, you get a green dot. If the first and second pixels are lit, the colors cancel each other and you get an elongated white dot, which is actually two dots wide. The same is true with the blue-orange pairs, except the hi bit is set.

If you want to draw a solid line of one color over the length of the byte, you must turn on the correct sequence of bits.

V/B	G/O	V/B	G/O	V/B	G/O	V/B	HI-BIT		
							OPT	$00 or $80	BLACK
●		●		●		●		$55	VIOLET
	●		●		●			$2A	GREEN
●		●		●		●	●	$D5	BLUE
	●		●		●		●	$AA	ORANGE
●	●	●	●	●	●	●	OPT	$7F or $FF	WHITE
1	2	4	8	16	32	64	128	VALUE (DECIMAL)	

EVEN BYTE

One of the first things you notice, is that although violet and green pixels can be mixed in the same byte, violet and orange pixels can't. The hi-bit is either on or off. You must settle for combinations of violet and green, or blue and orange.

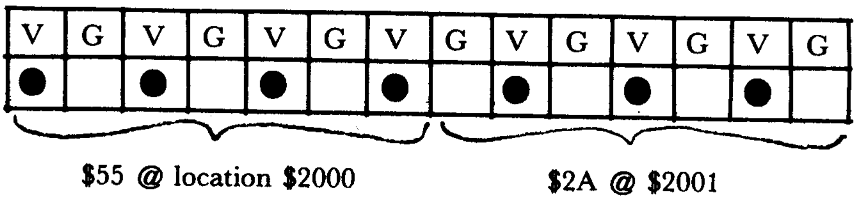
Applesoft users might recall some of the color problems they have encountered in the past. If you were plotting an orange horizontal line starting at column 0 that extended some 20 pixels across the screen and then attempted to plot a white line vertically in column 0 that crossed that orange line, the first few pixels would suddenly turn green. This is because the white color chosen, WHITE1, turned the hi bit off.

The unfortunate result in choosing seven pixels per byte is that the starting color of every other byte alternates. The even bytes start with violet, while the odd bytes start with green. If you were to poke a $55 into location $2000, you would get a violet line. But if you poked $55 into location $2001, you would get a green line, as indicated below:

V	G	V	G	V	G	V	G	V	G	V	G	V	G
●		●		●		●	●		●		●		●

$55 @ location $2000 — $55 @ location $2001

In order to correct this effect, the pixels in the second byte would have to be shifted over one position so that the value of $2A would produce violet, as shown below. We will continue this discussion later, when we discuss shape tables.



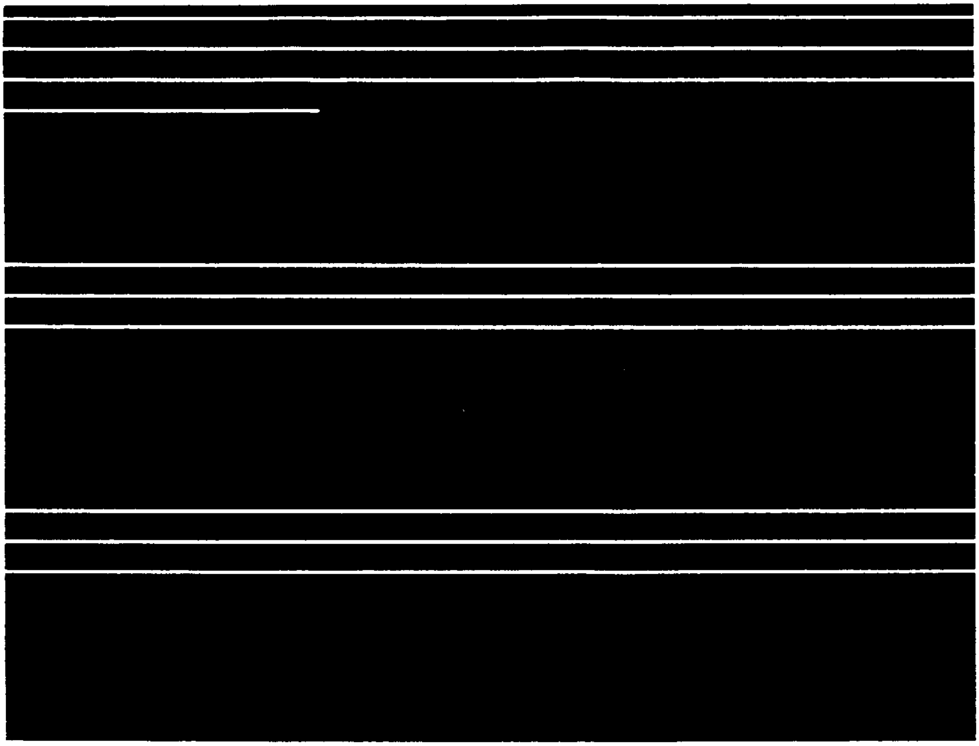
The following table lists the values needed to display solid colored lines:

COLOR	EVEN OFFSET	ODD OFFSET
VIOLET	$55	$2A
GREEN	$2A	$55
BLUE	$D5	$AA
ORANGE	$AA	$D5
WHITE	$7F $FF	$7F $FF
BLACK	$00 $80	$00 $80

It is an understatement to say that if you were to map the sequential memory locations of the Hi-Res display, they would not map row by row down the screen as you would expect the television's raster scan to plot these pixels. To illustrate this point, let's plot white line segments on a screen by poking a $FF or decimal 255 into each sequential byte of the Hi-Res page one screen memory.

```
10 HGR : POKE -16302,0
20 FOR I = 8092 TO 16384
30 POKE I,255
40 NEXT I
50 END
```

As you would expect, the computer plotted the first 40 bytes across row 0, but the next 40 bytes appeared 1/3 of the screen below on line 64. The third group of 40 bytes appeared 64 rows below that in the bottom third of the



screen. You would then expect the 4th line to plot directly below line 0 but no, it appears as line eight. Soon the whole display fills up first by thirds, then in groups eight lines apart. If the plotting is stopped with a control C when the screen is half filled, you will notice that there are 24 groups of eight lines.

Perhaps the most frequently asked question about the Hi-Res screen is: Why would the designers make programming the screen so difficult? In 1977, computer components were much more expensive. In an effort to produce a computer for a mere $1200, several short cuts were taken in the video circuits. Two OR gates were saved by incorporating this strange interlacing with the television's raster scan.

If you look at the memory addresses for the beginning of each of the 192 screen lines, you begin to detect a pattern. The difference in base addresses between any two lines in one of the 24 subgroups is +1024 bytes, or $400. The differences between each subgroup in each third of the screen is +128 bytes. And finally, the difference between lines between each third section is +40 bytes.

	LINE	ADDRESS				
1ST SUBGROUP	0	$2000	8192	+ 1024 BYTES		
	1	$2400	9216			
	2	$2800	10240			
	3	$2C00	11264			
	4	$3000	12288		+ 128 BYTES	
	5	$3400	13312			
	6	$3800	14336			
	7	$3C00	15360			
	8	$2080	8320			
	9	$2480	9344			
	.	.	.			
	.	.	.			+ 40 BYTES (THIRDS)
	.	.	.			
7TH SUBGROUP	48	$2300	8960	+ 1024 BYTES		
	49	$2700	9984			
	50	$2B00	11008			
	51	$2F00	12032		+ 128 BYTES	
	52	$3300	13056			
	53	$3700	14080			
	54	$3B00	15104			
	55	$3F00	16128			
8TH SUBGROUP	56	$2380	9088	+ 1024 BYTES		
	57	$2780	10112			
	58	$2B80	11136			
	59	$2F80	12160			
	60	$3380	13184			
	61	$3780	14208			
	62	$3B80	15232			
	63	$3F80	16256			
	64	$2028	8232			
	.	.	.			
	.	.	.			
		ETC				

A formula can be derived from the preceding such that, given any line number, the starting memory address for that line can be found. If Y is the line number from 0 to 191, then the section of the screen that the line is in is A = INT(Y/64). To find which subsection the line is in, use B = INT(D/8), where D = Y − 64 * A. And to find which line Y is on within the subsection, use C = D − 8 * B.

Memory Location = 8192 ✱SN + 1024 ✱C + 128 ✱B + 40 ✱A

where SN = HI-RES PAGE # (1-2).

Thus, if Y = 93 then A = INT (93/64) = 1
D = 93-64 = 29
B = INT (29/8) = 3
C = 29 − 8 ✱3 = 5

If SN = 1 then
memory Location = 8192 + 1024 ✱5 + 128 ✱3 + 40 ✱5 = 13796.
An assembly language implementation of this algorithm is shown below.

```
             *MEMORY ADDRESS FOR START OF SCREEN LINE
                       ORG  $6000
             Y         DS   1
             A         DS   1
             D         DS   1
             B         DS   1
             C         DS   1
             TEMP      DS   1
             SN        DS   1
             WORKL     DS   1
             WORKH     DS   1
             HIRESL    EQU  $01
             HIRESH    EQU  HIRESH+$01
6009: AD 00 60  START  LDA  Y           ;Y=LINE #
600C: 4A               LSR              ;DIVIDE BY 32
600D: 4A               LSR
600E: 4A               LSR
600F: 4A               LSR
6010: 4A               LSR
6011: 8D 01 60         STA  A
6014: 0A               ASL              ;MULTIPLY BY 64
6015: 0A               ASL
6016: 0A               ASL
6017: 0A               ASL
6018: 0A               ASL
6019: 8D 05 60         STA  TEMP        ; TEMP=64*A
601C: AD 00 60         LDA  Y
601F: 38               SEC              ;SET CARRY TO SUBTRACT
6020: ED 05 60         SBC  TEMP
6023: 8D 02 60         STA  D           ; D=Y-(64*A)
6026: 4A               LSR              ; COMPUTE D/8
6027: 4A               LSR
6028: 4A               LSR
6029: 8D 03 60         STA  B           ; B=INT(D/8)
602C: 0A               ASL              ; COMPUTE 8*B
602D: 0A               ASL
602E: 0A               ASL
602F: 8D 05 60         STA  TEMP        ; TEMP=8*B
6032: AD 02 60         LDA  D
6035: 38               SEC              ;SET CARRY
6036: ED 05 60         SBC  TEMP        ;SUBTRACT TEMP
6039: 8D 04 60         STA  C           ; C=D-(8*B)
```

```
603C: A9 00           LDA  #$00      ;CLEAR WORKING REGISTER
603E: 8D 07 60        STA  WORKL
6041: 8D 08 60        STA  WORKH
6044: AD 06 60        LDA  SN         ;LOAD SCREEN #
6047: 0A              ASL            ;MULT BY 32
6048: 0A              ASL
6049: 0A              ASL
604A: 0A              ASL
604B: 0A              ASL
604C: 8D 08 60        STA  WORKH      ;STORE IN HIGH ORDER
604F: AD 04 60        LDA  C         ; LOAD C
6052: 0A              ASL            ; MULTIPLY BY 4
6053: 0A              ASL
6054: 6D 08 60        ADC  WORKH     ; ADD TO PREVIOUS HI ORDER
6057: 8D 08 60        STA  WORKH     ; STORE BACK IN HI ORDER
605A: AE 03 60        LDX  B         ; RECALL B
605D: E8        CONT  INX
605E: CA              DEX
605F: F0 14           BEQ  SKIP0     ; CHECK FOR B=0
6061: CA              DEX
6062: F0 0C           BEQ  SKIP1     ; CHECK FOR B=1
6064: CA              DEX
6065: A9 01           LDA  #$01       ; ADD 1 TO HIGH ORDER
6067: 6D 08 60        ADC  WORKH
606A: 8D 08 60        STA  WORKH
606D: 4C 5D 60        JMP  CONT      ; CONTINUE COUNTING
6070: A9 80     SKIP1 LDA  #$80      ;LOAD ACC WITH 128
6072: 8D 07 60        STA  WORKL     ; ADD TO LOW ORDER
6075: AD 01 60  SKIP0 LDA  A         ; RECALL A
6078: 0A              ASL            ; MULTIPLY BY 32
6079: 0A              ASL
607A: 0A              ASL
607B: 0A              ASL
607C: 0A              ASL
607D: 6D 07 60        ADC  WORKL     ; ADD TO LOW ORDER
6080: 8D 07 60        STA  WORKL     ; STORE BACK IN LOW ORDER
6083: AD 01 60        LDA  A         ; RECALL A
6086: 0A              ASL            ; MULTIPLY BY 8
6087: 0A              ASL
6088: 0A              ASL
6089: 6D 07 60        ADC  WORKL     ; ADD TO LO ORDER
608C: 8D 07 60        STA  WORKL
608F: AD 08 60        LDA  WORKH     ; MOVE RESULTS TO ZERO PAGE
6092: 8D 0A 60        STA  HIRESH
6095: AD 07 60        LDA  WORKL
6098: 85 01           STA  HIRESL
609A: 60              RTS

--END ASSEMBLY--
```

This implementation is rather lengthy in that it takes 79 instructions. It was chosen more for its clarity rather than for its speed. Notice that the multiplications are tricky, and that 40∗A is split into two easier multiplications, (8 + 32)∗A. A much faster algorithm, taking only 24 instructions to calculate the screen position for the Yth line, and an additional 18 instructions for the X

offset, is listed in the Programmer's Aid Chip at $D02E under the label HPOSN. It is also listed under HPOSN in the Applesoft ROM at $F411. The Y coordinate is placed in the Accumulator, the lo byte of the X coordinate in the X- register, and the hi byte in the Y- register. The screen position is returned in HBASL and HBASH in zero page locations $26 and $27, respectively. HMASK is stored in $30.

I would like to make the point that even 24 instructions is far too many if you are doing fast screen animation. Consider the problem of simply plotting a moving star background for your space game. Twenty stars are scattered about the screen. It takes 480 instructions just to locate the starting memory locations for each line where the star is to be plotted. This doesn't even consider the algorithm needed to decide which pixel in which of 40 bytes on the line needs to be activated. Clearly, a much faster method must be devised. That method is called Table Lookup, and it will be thoroughly discussed in the next chapter.

The X coordinate calculation is much clearer, since the 40 bytes in each line are stored sequentially in memory. Recalling that there are 7 bits per byte times 40 bytes per line gives us 280 bits per line.

Given X, the byte offset is

E = INT (X/7).

and the position within the byte is

F = X - 7*E

For example, if the X coordinate is 152

E = INT (152/7) = 21 and F = 152 - 7*21 = 5.

So, for the screen coordinate (152,93), the memory location is 13896 + 21 = 13917, the 5th bit activated.

While the formulas for finding the proper byte and bit positions for the X direction are rather simple; dividing by seven normally requires a complicated divide subroutine. Again, speed is a problem. Although I'll present a complex subroutine below to accomplish the job, it is much faster and simpler to resort to Table Lookup algorithms. Still, it is a matter of trade-offs, using speed versus memory. The tables require 384 bytes plus some code; the subroutine requires only the code.

The subroutine below accepts the X coordinate as a hexadecimal value in the A and X registers. The X register contains the hi byte value. It returns the horizontal byte offset in the Y register and the bit position within that byte in the Accumulator. The theory behind the algorithm is rather simple, but the implementation is complicated because to divide the X position (0-279) by 7 to obtain the horizontal offset is tedious in machine language, in addition to being

complicated by the use of a double precision X value (X values >255 require two bytes).

The division is accomplished by successive subtraction. The idea is subtract 140 to find which half of the screen the point lies, then narrow it to which quarter of the screen. When we have located the position within four bytes, seven is subtracted successively until a zero is crossed. The remainder is the bit position within that screen byte. The hexadecimal plotting value is returned from a table.

```
XCOR  LDY  #$00
      DEX        ;TEST IF X COORDINATE >255. X COORDINATE
                 ;WOULD CONTAIN A ONE IF TRUE
      BNZ  XCOR2 ;TEST FOR SPECIAL CASE
      SUB  #$FC  ;SUBTRACTS LARGEST MULTIPLE OF 7 IN 255
      LDY  #$24  ;SET PROVISIONAL QUOTIENT
      BNZ  XCOR8
XCOR2 SEC
      SBC  #$8C  ;LEFT OR RIGHT HALF SCREEN?
      BCC  XCOR3
      LDY  #$14  ;RIGHT HALF, SET QUOTIENT
      BNZ  XCOR4
XCOR3 ADC  #$8C
XCOR4 SEC
      SBC  #$46  ;WHICH QUARTER OF SCREEN
      BCS  XCOR5
      ADC  #$46
      JMP  XCOR6 ;SKIP TO 8THS STAGE
XCOR5 PHA        ;SAVE ACC
      TYA        ;GET QUOTIENT
      CLC
      ADC  #$0A  ;INCREMENT FOR QUARTER
      TAY
      PLA
XCOR6 SEC
      SBC  #$23  ;WHICH 8TH OF SCREEN?
      BCS  XCOR7
      CLC
      ADC  #$23  ;RESTORE DIVIDEND
      JMP  XCOR8
XCOR7 PHA
      TYA
      CLC
      ADC  #$05  ;INCREMENT FOR EIGHTS
      TAY        ;RESTORE QUOTIENT
```

```
        PLA
XCOR8   SEC
        SBC   #$07   ;NOW KEEP SUBTRACTING 7
        BCC   XCOR9  ;UNTIL ZERO IS CROSSED
        INY
        BNZ   XCOR8
XCOR9   CLC
        ADC   #$07   ;RESTORE TO GET REMAINDER
        TAX
        LDA   BITS,X;GET BIT FROM TABLE
        RTS
BITS    HEX   01 02 04 08 10 20 40   ;BIT POSITION TABLE
```

To complete the discussion of the Hi-Res screen's architecture, I'd like to mention what happened to the 512 unused bytes in Hi-Res screen memory. Sequential memory is plotted in lines separated into thirds on the screen. The top line of the bottom third (line #128) uses memory locations 8272 through 8311. It then jumps to the top of the screen, but eight lines down, or line #8. These forty memory locations are 8320 through 8359. Notice there is a gap of eight unused bytes. These unused bytes are at the end of every line in the bottom third of the screen. These 64 lines times 8 bytes accounts for the missing 512 memory locations.

RASTER GRAPHICS

Programmers talk about Raster Graphics and Vector Graphics on the Apple II. In reality, due to the nature of the hardware, vector graphics is a misnomer. Television sets and monitors are raster scanners. Starting at the top of the screen, they scan one line at a time and turn pixels on or off as needed. True vector graphics generators have an electron gun that can move in any direction, so that the beam draws directly between end points.

What is meant by Vector Graphics on the Apple is that a line consisting of a string of pixels is drawn by the television's raster scan. However, raster graphics differs in that entire bytes representing parts of the shape or line are placed into Hi-Res memory locations to obtain a Hi-Res picture. You don't deal in individual pixels per se, but in manipulating Hi-Res shapes a byte at a time. The entire shape is plotted as a block. In some literature, it is referred to as the block shape method.

RASTER SHAPE TABLES (PROS AND CONS)

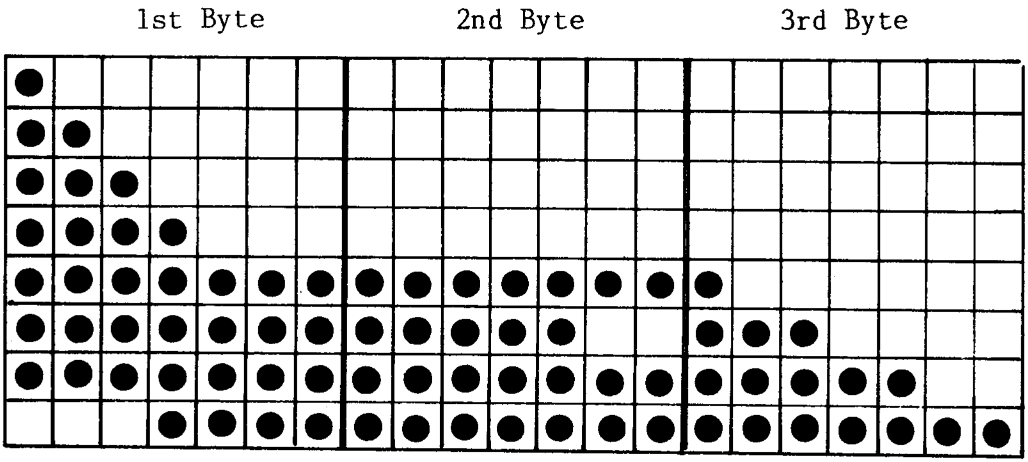
Raster Graphics shape tables, which are bit-mapped shape tables, differ substantially from Apple's Hi-Res shape table routines. Apple's shape table routines, as described in Chapter 1, are plotting vectors that control direction of either plot or no-plot commands. These shape tables can be scaled, rotated, or colored entirely to one of six Hi-Res colors. Bit-mapped shapes, however, are precise instructions used to determine which pixels to activate in a particular section of the screen. Although the shape's detail and color control are superior, they can't be easily scaled or rotated.

At first glance, the pros and cons of using one versus the other appear to be a toss up, but the real advantage in using bit-mapped shape tables is the speed of implementation. Placing a bit-mapped shape table on the screen involves only moving bytes of that table stored in memory to the specific screen memory locations where you want that shape to be drawn. Apple shape tables, on the other hand, require time-consuming machine language routines to translate these plotting vectors into a shape on the screen.

FORMING A BIT MAPPED SHAPE TABLE

The shape's size must be decided before forming a bit-mapped shape table. A shape can be as large as the entire screen, or as small as one byte wide by one line deep. But in each case, the shape's width is N bytes wide, or a multiple of seven pixels wide. A shape doesn't have to be 7,14,21... pixels wide, but if a shape were, say, 16 pixels wide, it would require a width of 3 bytes. The remaining five pixels would be zeroed.

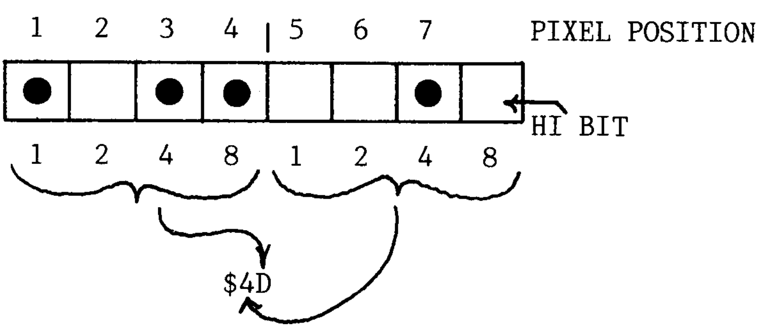
The second step is to plot the shape's pixels on a sheet of graph paper. A rocket whose shape table can be used later for an arcade game is shown below.



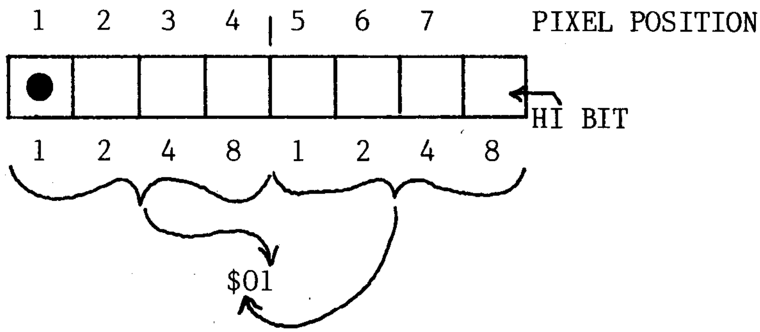
WHITE SHIP

As a first example, we shall plot this shape in white, thus ignoring color problems for the time being. Recall that the color white is produced when adjacent violet and green pixels, or blue and orange pixels, are activated simultaneously. To produce a white ship, all of the pixels will be used to form the table. Some of the readers will question whether the ship is entirely white where bytes have an odd number of pixels, such as in the first and third lines. If you took a magnifying glass to the ship's shape on the TV screen, you would see fringes of violet or green at the edges of an otherwise white ship. This, of course, would not matter on a black and white monitor.

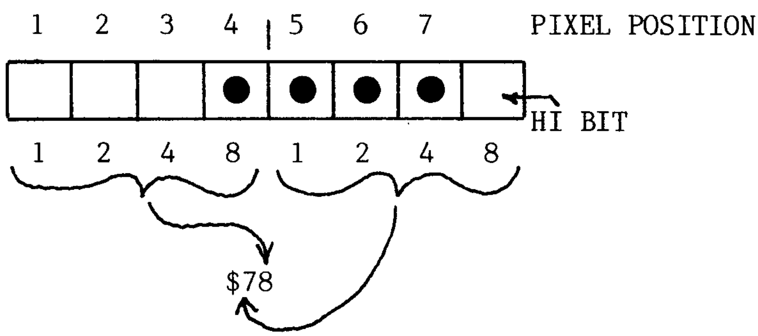
For those that have difficulty converting pixel patterns into hexadecimal values, it is easier if you split the byte's seven bits into a 4-3 pattern. Remember that the right most three dots plus its hi bit is the first part of the byte, or "hi nibble", as four bit halves of a byte are called.



Encoding the rocket's first byte, the first row is as follows:



and the first byte in the last row is:

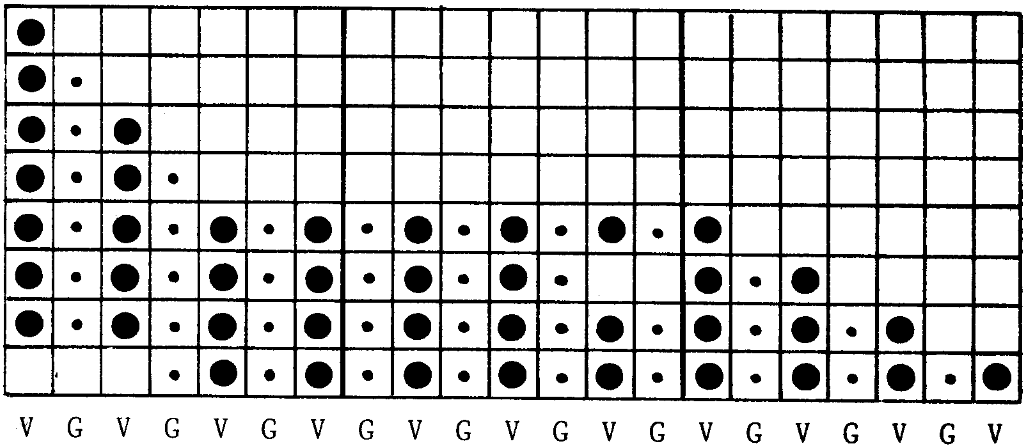


The rocket ship's shape table becomes:

01	00	00
03	00	00
07	00	00
0F	00	00
7F	7F	00
7F	1F	07
7F	7F	1F
78	7F	7F

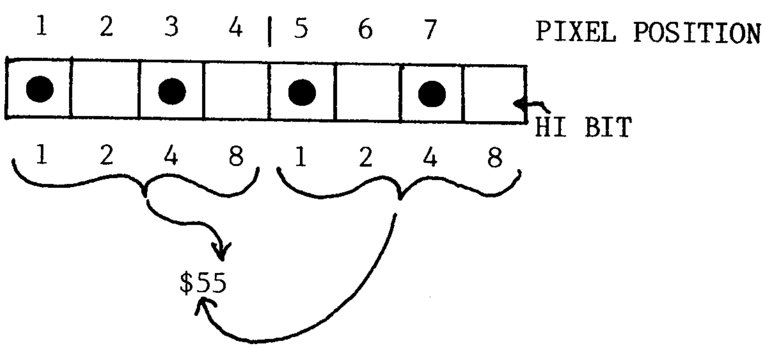
Producing a shape table for the same ship in a particular color presents a more difficult problem. To produce a violet color, all of the green pixels (or those dots in odd columns) must be suppressed. The revised drawing of the ship's shape table is shown below.

VIOLET SHIP
(EVEN OFFSET)



where ● — indicates pixel on
— indicates suppressed dots of original shape

Taking the 5th row, 1st byte as an example:



The complete shape table for the violet colored space ship is:

01	00	00
01	00	00
05	00	00
05	00	00
55	2A	01
55	0A	05
55	2A	15
50	2A	55

At this time it would be instructive to actually plot both white and violet space ships on the Hi-Res screen. This can be done by poking the appropriate bytes into Hi-Res memory.

When we talked about how the screen was mapped, we showed the starting addresses for the first eight lines of the screen. The starting addresses of each line are 1024 bytes or $0400 apart. Enter the monitor with a CALL -151, then turn on the Hi-Res graphics page 1 and clear the screen as follows:

```
*C050              <CR> ;SET GRAPHICS MODE
*C053              <CR> ;SET MIXED TEXT & GRAPHICS
*C057              <CR> ;SET HI-RES GRAPHICS
*2000:00           <CR>
*2001<2000.3FFFM   <CR> ;CLEAR PAGE 1 GRAPHICS
```

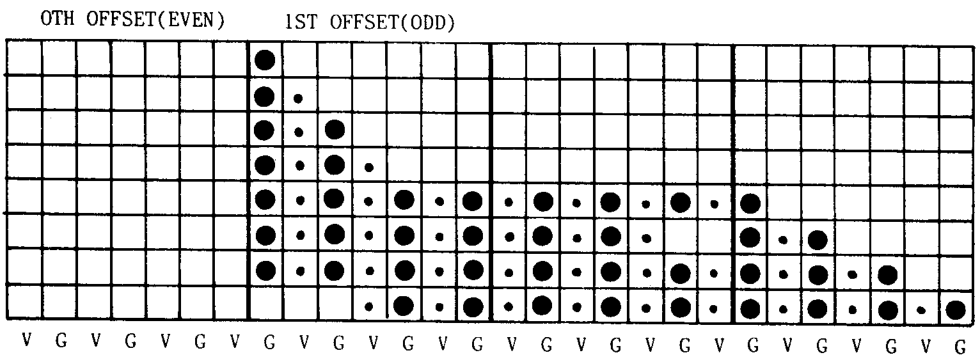
Now poke in the shape table for the white ship. It will appear at the upper left corner of the Hi-Res screen.

```
*2000:01  0000
*2400:03  0000
*2800:07  0000
*2C00:0F  0000
*3000:7F  7F00
*3400:7F  1F07
*3800:7F  7F1F
*3C00:78  7F7F
```

A white ship appears. Now clear the screen and poke in the shape table of the violet ship. The violet ship's table starts at the screen's far left, which is the 0th byte or offset into a particular 40 byte row. Since 0,2,4 are considered even numbers, this is an even offset. As an experiment, poke the violet ship's values into an odd offset, one byte over. First, clear the screen, then type the following:

```
*2001:01  0000
*2400:01  0000
*2800:05  0000
*2C00:........
                etc.
```

Instead of a violet ship, you get a green space ship. This is because the even offsets start with violet as the first pixel, and the odd offsets start with green. Turning the first pixel on in the odd byte no longer turns on a violet dot, but a green dot. The solution is to use two sets of shape tables; one for even offsets and one for odd offsets. Another solution would be to shift the shape's bit pattern one bit when going from even to odd offsets; however, this is too time consuming for fast animation.



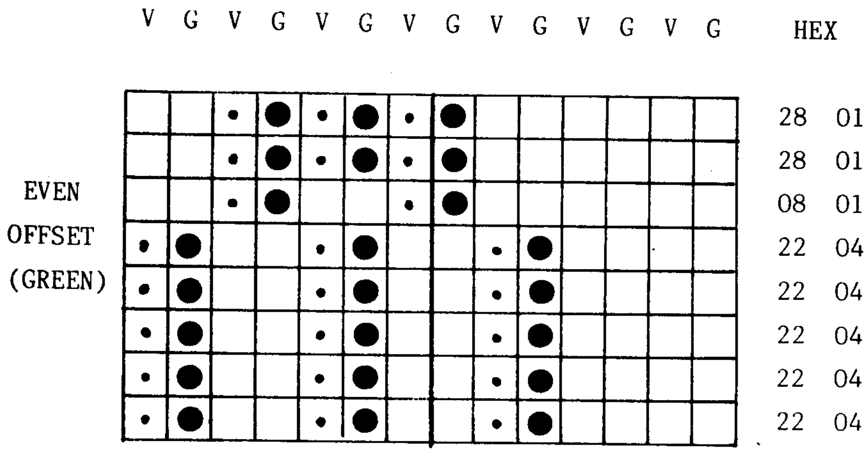
If the original (white) ship's shape is placed so that it begins in an odd offset (above diagram), and the green-columned pixels (the odd columns) are suppressed, the shape becomes:

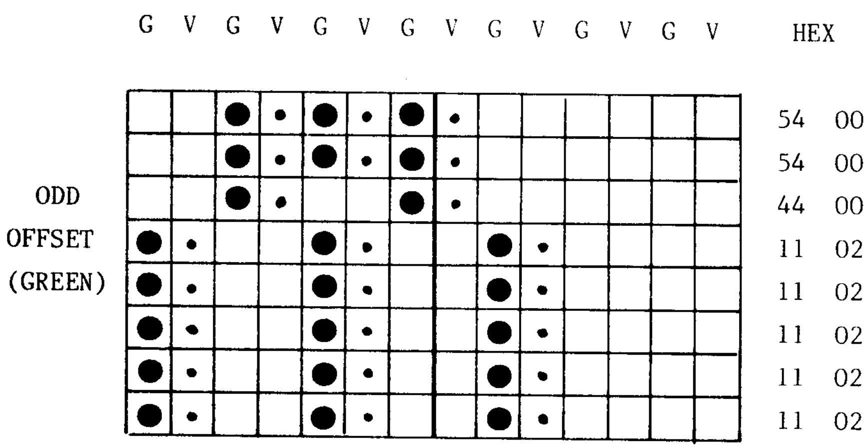
00	00	00
02	00	00
02	00	00
0A	00	00
2A	55	00
2A	15	02
2A	55	0A
28	55	2A

The first thing that you notice is that the two plotted shapes (even and odd) aren't identical. This can be observed by plotting the even offset table beginning at $2000, and the odd offset table beginning at $2005. You will see that the odd offset ship is slightly shorter and the peak of the tail lacks a pixel in row one. This is caused by a lack of symmetry.

This problem can be partially remedied by planning the shape so that the violet column and its adjacent green column are identical in form. For example, if an extra pixel were placed in row 1, column 2 of the orginal white shape of the ship, the peak of the tail would look identical for both the even and odd offsets.

To reinforce the concept of keeping a shape symmetrical and identical while moving it a byte at a time to the right or left, we will consider the following shape, a green alien:



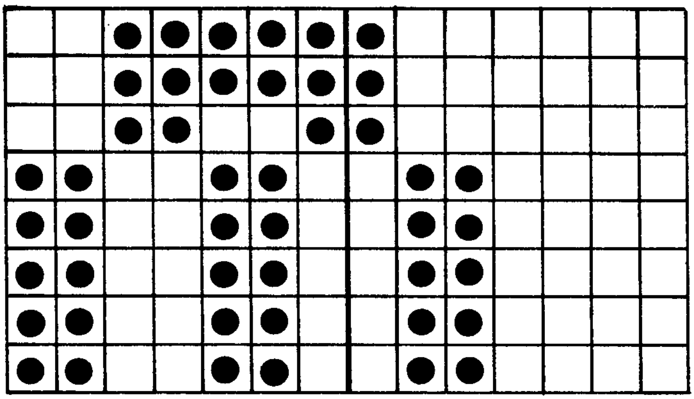


The even and odd offset shapes have been plotted directly below each other to show that the shapes are indeed identical, but the lower shape has been shifted one dot to the left. This effect is inherent in the hardware, because the colors alternate from column to column. Black and white shapes, however, don't require any shifts and, therefore, do not need both odd and even shape tables.

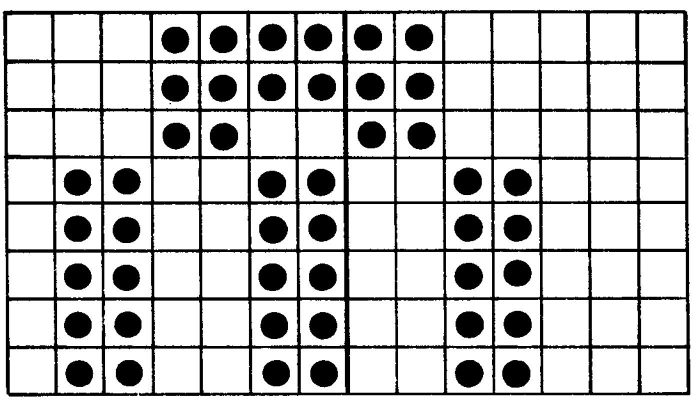
It is important to design your shape with pixels of double width. Otherwise, when you block out the columns of the non-needed color, part of the shape may be absent in the designated color. While this isn't likely to happen if you form shape tables by hand, those ambitious programmers who write a utility to do this automatically might be surprised when plotting their utility generated shape tables.

What we have discussed so far is fine for simply plotting a shape on the screen, or even moving a shape left or right one byte or seven pixels at a time. But what would happen if you wanted to move a shape only one pixel or one horizontal position to the right? If the shape is moved to the right, it no longer has the same bit patterns in each byte.

Consider the alien shape plotted entirely in white. Each time it is shifted right it forms a new bit pattern. By the sixth rightward shift, only the first column of the shape remains in the first byte. Shift it right once more, and we are back to the beginning pattern, but one entire byte to the right.

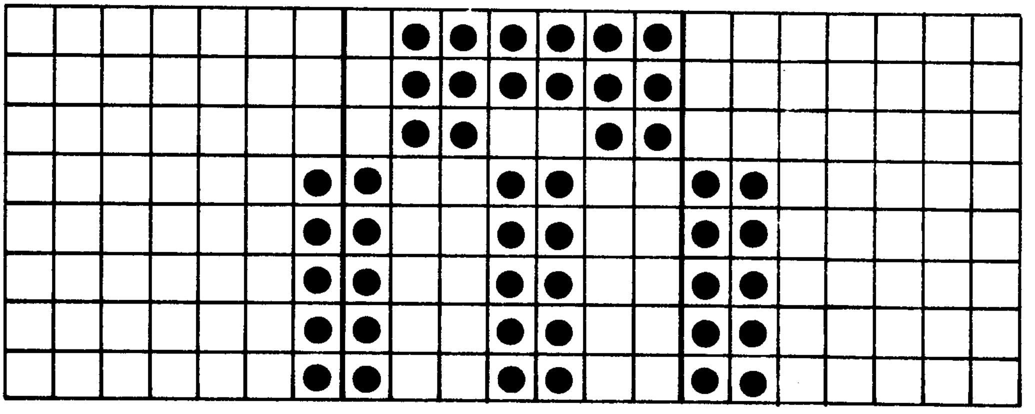


White - 0th Shift



White - 1st Shift

Since the width of a byte is seven pixels, there are seven shifted tables (0-6) for each of the seven positions. When the shape is shifted the fifth time, the pixels extend into a third byte. This requires each of the seven shifted tables to be three bytes wide.



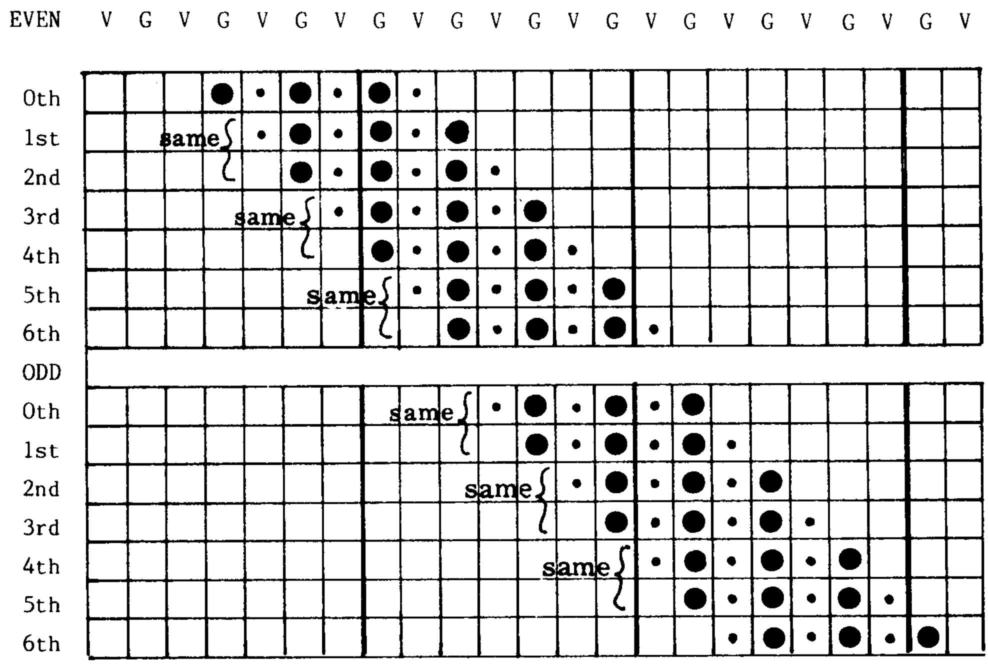
White - 6th Shift

Color shape tables, as you might have guessed, have a similar logic for odd and even offsets. But, as we shall demonstrate, only seven offset tables are needed rather than the expected fourteen.

If you take a simple horizontal line, six pixels wide, as a shape and form a shape table for its green color, you would always have three green pixels lit. As you shift this line over the seven positions, starting first with the even offset, then continuing over the odd offset, you will notice a pattern. Every other time that you shift, the pixel pattern remains the same.

If you were to shift this shape to the right one column for each screen cycle using 14 shape tables, the shape would remain static for two cycles, then move, then stay put for two, then move once again. This produces a very jerky motion. Since the shape tables duplicate themselves in pairs, it would be easier to use the 0th even, 2nd even, 4th even, 6th even, 1st odd, 3rd odd, and 5th odd for a total of 7 shifted tables. The 6th odd shape in the above figure, which appears to be the eighth shape, isn't. It is actually a duplicate of the 0th even shape, but beginning at the next even-odd pair.

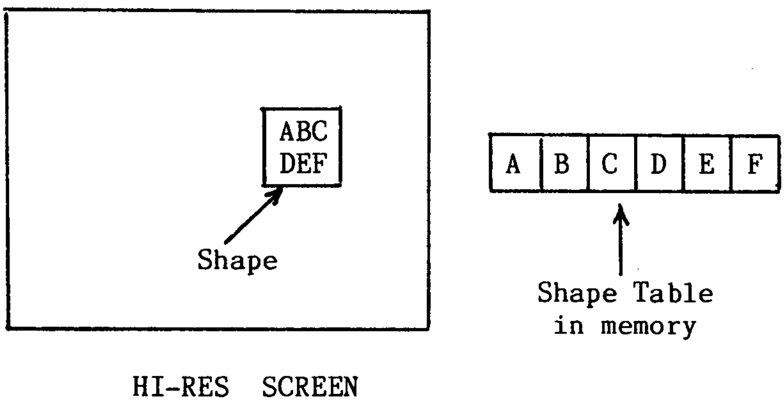
In summary you have learned how bit-mapped shape tables are formed. In the next chapter, we shall learn how to draw and animate these shape tables.


EVEN
V G V G V G V G V G V G V G V G V G V G V G V
0th
1st
2nd
3rd
4th
5th
6th
ODD
0th
1st
2nd
3rd
4th
5th
6th
same

CHAPTER 5

BIT MAPPED GRAPHICS

Drawing a bit-mapped shape table anywhere on the Hi-Res screen is a simple procedure once the basic concept is understood. The shape table is stored sequentially in memory, either by rows or by columns. The technique, therefore, is to load each of the bytes, one at a time, into the Accumulator, find the position in memory for the screen location where you want to plot that byte, then store it in that memory location.



The difficulty, as shown in the previous chapter, lies in finding a particular memory location, given an X,Y screen coordinate. Speed is the critical factor in doing arcade animation; therefore, a technique known as Table Lookup is used to locate the starting address of any single line on the Hi-Res screen.

Each of the 192 screen lines has a starting address for the first position (left most) or the 0th offset. The first line or line #0 is located in memory at location $2000. The second line is at $2400, etc. Each address takes two bytes. The first part is the hi-byte, which in the later case is $24. The second byte, $00 ,is the lo-byte. These can be separated into two tables, one containing the lower order address of each line (call it YVERTL) and the other containing the higher order address of each line, YVERTH. Each table is 192 bytes long (0-191).

You can access any element in either table by absolute indexed addressing. The effective address of the operand is computed by adding the contents of the Y register to the address in the instruction. That is:

EFFECTIVE ADDRESS = ABSOLUTE ADDRESS + Y REGISTER.

If our YVERTH table were stored at $6800 and we wanted to find the starting address of line 1 (remember lines are numbered 0-191), we would index into the table one position and load that value into the Accumulator,

6800 :20 24 28 2C 30 34 ....YVERTH TABLE

so LDA YVERTH,Y where Y = $01 will fetch the value $24 from memory location $6800 + $01 = $6801, and place it in the Accumulator.

Similarly, if YVERTL were stored immediately after the first table, then:

68C0:00 00 00 00 ....Y VERTL TABLE
Y Register = $01

LDA YVERTL,Y will take the value $00 stored in memory location $68C0 + $01 = $68C1, then place it in the Accumulator.

Eventually, we will want to store the first byte from the shape table into memory location $2400. This can be done efficiently if the two byte address is stored sequentially in zero page. Let's store the lo byte half of the address, HIRESL, at location $26, and the hi byte half, HIRESH, at location $27 in zero page:

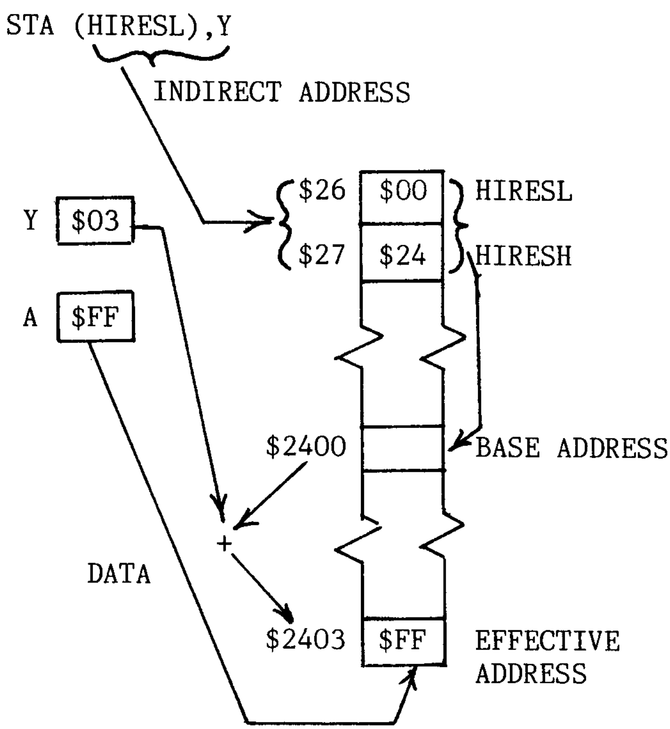
```
LDY  #$01        ;Y REGISTER CONTAINS LINE
LDA  YVERTH,Y    ;LOOKUP HI BYTE OF START
                 ;OF ROW IN MEMORY
STA  HIRESH      ;STORE ZERO PAGE
LDA  YVERTL,Y    ;LOOKUP LO BYTE OF ROW IN
                 ;MEMORY
STA  HIRESL      ;STORE ZERO PAGE
```

We can change a particular Hi-Res screen memory location using zero page by indirect indexed addressing in the form:

STA (HIRESL),Y Y Reg = $03

If the computer finds a $00 in location $26 (HIRESL) and a $24 in location $27 (HIRESH), then the base address is $2400. The Accumulator stores a value into memory location $2400 + $03, or location $2403, as shown:

INDIRECT INDEXED ADDRESSING

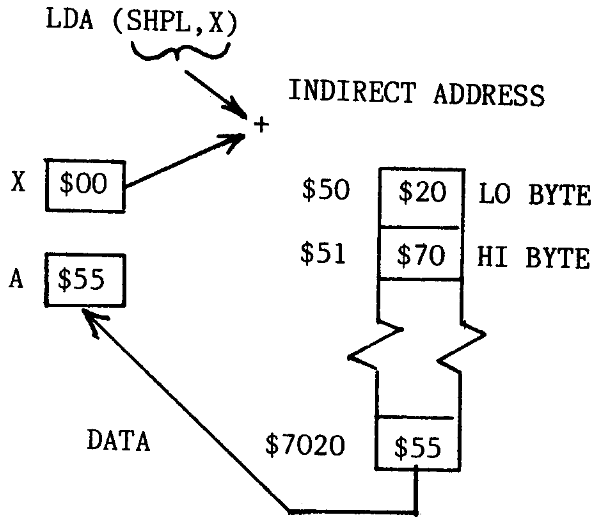


The final addressing mode that we must consider is Indexed Indirect Addressing. It is of the form:

LDA (SHPL,X)

It is very similar to the the Indirect Indexed addressing mode except the index is added to the zero page base address before it retrieves the effective address. It is primarily used for indexing a table of effective addresses stored in zero page. But in the form we are going to use it, the X register is set to 0; thus, it simply finds a base address:

INDEXED INDIRECT ADDRESSING



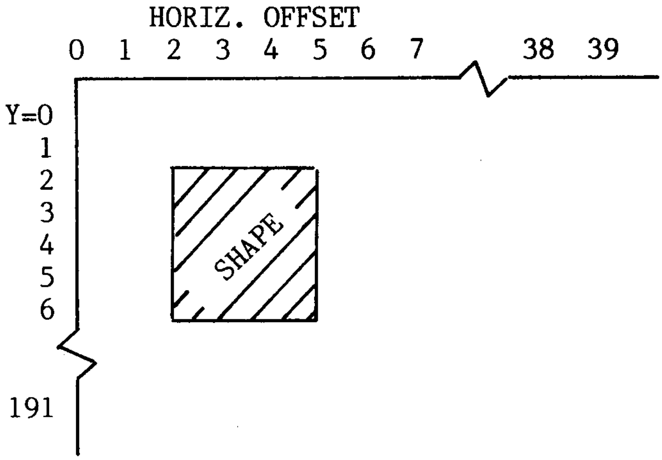
The reason we must use this second form of indirect addressing is a shortage of registers in the 6502 microprocessor. We are already using the Y register in the store operation and there isn't an indirect indexed addressing mode of the form LDA (SHPL),X. Thus, we must go to the alternative addressing mode LDA(SHPL,X).

What this all boils down to is that we want to load a byte from a shape table into the Accumulator and store it on the screen with the following instructions:

```
LDA  (SHPL,X)     ;STORE BYTE FROM SHAPE TABLE
STA  (HIRESL),Y   ;STORE BYTE ON HI-RES SCREEN
```

We can index into the shape table by incrementing the low byte SHPL by one each time, then store that byte into the next screen position on a particular line by incrementing the Y register. This zero page method is faster than doing the equivalent code with absolute index addressing, because two byte addresses can be handled with fewer instructions, less memory space, and with fewer machine cycles.

Obviously, a generalized subroutine must be developed to find the screen memory address (HIRESL & HIRESH), given a line number and a horizontal displacement. We will call this subroutine GETADR, short for Get Address:



Each time a row of shape table bytes is transferred to successive memory locations on the Hi-Res screen, the program will call the subroutine GETADR. The line's starting memory address is then offset by the horizontal location of the shape on the screen.

Memory address = Line # starting address + horizontal offset

```
GETADR  LDA  YVERTL,Y   ;LOOK UP LO BYTE OF LINE
        CLC
        ADC  HORIZ      ;ADD DISPLACEMENT INTO LINE
        STA  HIRESL     ;STORE ZERO PAGE
        LDA  YVERTH,Y   ;LOOK UP HI BYTE OF LINE
        STA  HIRESH
        RTS
```

where the Y register has the vertical screen value (0-191).

If you are designing an arcade game, you will probably have several different shapes on the screen at the same time. Perhaps your defending space ship is paddle-controlled to move vertically but always remains at one particular horizontal offset; while the aliens, attacking in zig-zag fashion, always move horizontally from one side of the screen to the other. Keeping track of each shape's variables, which are inputted into a generalized drawing routine, is more easily done if a setup subroutine is incorporated into your program. This assures that you haven't forgotten to initialize anything before entering the drawing subroutine.

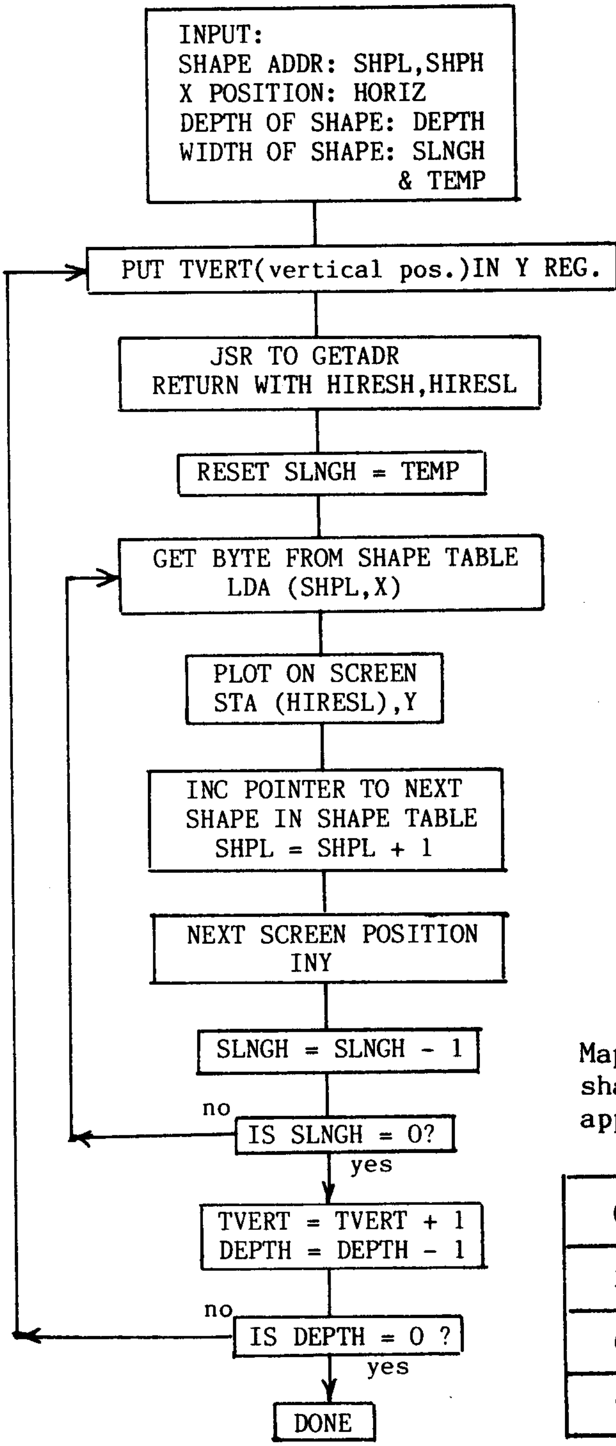
Only a few variables need to be defined in the setup routine: the location of the shape table, the horizontal displacement on the screen, and the width and depth of the shape.

The following example is for the space ship that we designed a shape table for in the last chapter. A word on the notation used for determining the lo and hi addresses for the shape called SHIP is suitable here. In the TED II + and BIG MAC assemblers from CALL APPLE, MERLIN from Southwestern Data Systems, and TOOL KIT from Apple, LDA #<SHIP obtains the lower order address of the table called SHIP. LDA #>SHIP returns the higher order byte of the address. In the LISA assembler from ON-LINE Systems, LDA #SHIP loads the lower order byte and LDA /SHIP loads the higher order byte, as shown:

```
*SHIP SETUP
SSETUP  LDA  #<SHIP   ;LOAD LOWER ORDER BYTE OF SHAPE TABLE
        STA  SHPL
        LDA  #>SHIP   ;LOAD HIGHER ORDER BYTE OF SHAPE TABLE
        STA  SHPH
        LDA  #$08
        STA  DEPTH    ;SHAPE IS 8 LINES DEEP
        LDA  #$09
        STA  HORIZ    ;SHAPE STARTS IN 10TH COLUMN
        LDA  #$03
        STA  SLNGH    ;SHAPE IS 3 BYTES WIDE
        STA  TEMP     ;STORED HERE ALSO BECAUSE DRAWING
                      ;ROUTINE DECREMENTS SLNGH ON EACH
                      ;LINE AND VARIABLE MUST BE RESTORED
                      ;AT START OF NEXT ROW
        RTS
```

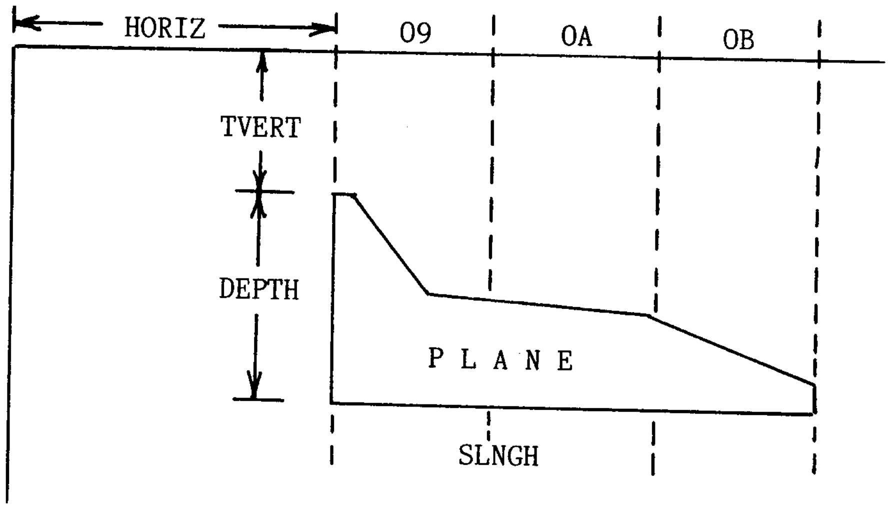
The drawing routine is more efficient the fewer times it accesses the GETADR subroutine. Therefore, it is much faster to load and store on the same screen line until the end of the shape's width is reached. Drawing our spaceship a byte at a time across its width will only require calling GETADR Eight times. But if we plotted down instead, GETADR would be called for each byte, or 24 times, an unnecessary waste of time.

As we load and store across a particular screen line, we decrement SLNGH, the ship's width until SLNGH equals zero. When we are finished with a row, we increment TVERT to the next screen line down and decrement the DEPTH. When DEPTH reaches zero, we have plotted all rows of the shape and we are finished.



Map of elements in shape table as they appear on the screen

0	1	2
3	4	5
6	7	8
9	...	




```
DRAW   LDY TVERT        ;VERTICAL POSITION
       JSR GETADR       ;FIND BEGINNING HI-RES SCREEN ADDRESS
                        ;OF ROW
       LDX #$00
       LDA TEMP
       STA SLNGH        ;RESTORE VALUE OF WIDTH FOR NEXT ROW
DRAW2  LDA (SHPL,X)     ;GET BYTE OF SHAPE TABLE
       STA (HIRESL),Y   ;PLOT ON SCREEN
       INC SHPL         ;NEXT BYTE OF SHAPE TABLE
       INY              ;NEXT POSITION ON SCREEN
       DEC SLNGH        ;DECREMENT WIDTH
       BNE DRAW2        ;FINISHED WITH ROW YET?
       INC TVERT        ;IF SO, INCREMENT TO NEXT LINE
       DEC DEPTH        ;DECREMENT DEPTH
       BNE DRAW         ;FINISHED ALL ROWS?
       RTS              ;YES, END
```

Although the first row of the shape can be plotted at any TVERT (0-191) position, if TVERT began at 190, the computer would attempt to plot the third line at TVERT, which would equal 192. Indexing into the table that far would most likely produce garbage, as you would index beyond the end of the table. You should be always careful that:

TVERT < = 192 − DEPTH

A simple test somewhere before the draw subroutine would suffice. Normally, this should be incorporated into a paddle read-routine. This will be discussed further in the next chapter.

XDRAWING SHAPES

Objects that move on the screen are shifted in position by erasing the object's first position before drawing it at its new position. The simplest method to accomplish this is to draw the shape by exclusive-oring it before shifting it.

The exclusive-or instruction (EOR) is primarily used to determine which bits differ between two operands, but it can also be used to complement selected Accumulator bits. The way it works is elementary. If neither a particular memory bit or Accumulator bit is set or their values are zero, the result is zero. If either one is set, then the result is on. But if both are set, they cancel and the result is zero.

	MEMORY BIT	ACCUMULATOR BIT	RESULT BIT IN ACCUMULATOR
	0	0	0
EOR	0	1	1
	1	0	1
	1	1	0

If we take a byte on the screen and EOR it with the same byte

```
        0 1 1 0 0 1 1      SHAPE ON SCREEN
EOR     0 1 1 0 0 1 1          SHAPE
        -------------
        0 0 0 0 0 0 0          RESULT
```

from the shape table, the result is zero or a screen erase. A similar effect would happen if a blank screen were EORed with a shape then EORed once again.

```
        0 0 0 0 0 0 0          BLANK SCREEN
EOR     0 1 1 0 0 1 1           WITH SHAPE
        -------------
        0 1 1 0 0 1 1      RESULT IS SHAPE ON SCREEN
EOR     0 1 1 0 0 1 1
        -------------
        0 0 0 0 0 0 0      RESULT IS BLANK SCREEN
```

Another use for EORing is that it doesn't damage the background if a shape is EORed on the screen, and then off again. However, it does distort the shape slightly.

	0 0 0 0 0 0 1	BACKGROUND
EOR	0 1 0 1 1 0 0	WITH SHAPE
	0 1 0 1 1 0 1	RESULT ON SCREEN (SHAPE DISTORTED LAST BIT)
EOR	0 1 0 1 1 0 0	WITH SHAPE
	0 0 0 0 0 0 1	GET BACKGROUND BACK

In the above example, an extra pixel in the shape's last bit position distorts the shape drawn on the screen. In the example below, the fourth bit position becomes a hole in the shape.

	0 0 0 1 0 0 0	BACKGROUND
EOR	0 1 0 1 1 0 0	WITH SHAPE
	0 1 0 0 1 0 0	RESULT ON SCREEN
	← hole here	
EOR	0 1 0 1 1 0 0	WITH SHAPE
	0 0 0 1 0 0 0	GET BACKGROUND BACK

There are techniques to avoid distorting the shape wherein the background is likely to interfere during the drawing process. This involves a combination of EORing and ORing the Hi-Res screen, with the background stored on a second Hi-Res screen. An alternate method is to store the screen memory bytes in a temporary table equal in size to your shape, while you draw your shape. When erasing, you replace the shape with the background stored in your temporary table. This is a little complicated, but it works. An example using this method is presented at the end of this chapter.

The OR memory with Accumulator (ORA) instruction differs from the EOR instruction in that if both memory and Accumulator bits are on, then the result is one, or on.

	MEMORY BIT	ACCUMULATOR BIT	RESULT BIT IN ACCUMULATOR
	0	0	0
ORA	0	1	1
	1	0	1
	1	1	1

If the background were as follows, and you ORed it with the shape, the shape is correct.

```
        0 1 0 1 0 1 0        BACKGROUND PAGE 1
ORA     1 1 1 1 0 0 0           WITH SHAPE
        -------------
        1 1 1 1 0 1 0   GET SHAPE + BACKGROUND WITH
                             NO HOLE IN SHAPE
```

Unfortunately, if you EOR this result with the shape again, the background is flawed.

```
        1 1 1 1 0 1 0       SHAPE + BACKGROUND
XOR     1 1 1 1 0 0 0           WITH SHAPE
        -------------
        0 0 0 0 0 1 0       FLAWED BACKGROUND
```

Another solution is to take the shape with the background above and EOR it with itself, then EOR it with the background stored on page 2. However, it is probably quicker and easier to just copy the background stored on page 2 directly to screen 1.

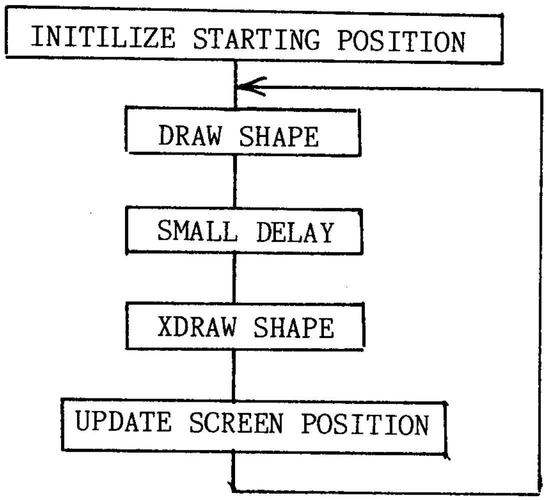
```
        1 1 1 1 0 1 0       SHAPE + BACKGROUND
XOR     1 1 1 1 0 1 0          WITH ITSELF
        -------------
        0 0 0 0 0 0 0        LOSE EVERYTHING
XOR     0 1 0 1 0 1 0   WITH BACKGROUND STORED
                                PAGE 2
        -------------
        0 1 0 1 0 1 0     GET BACKGROUND BACK
```

We can incorporate the exclusive-or instruction in our XDRAW routine. If we EOR the shape we had previously drawn on the screen, nothing remains.

```
XDRAW   LDY  TVERT        ;VERTICAL POSITION
        JSR  GETADR
        LDA  TEMP
        STA  SLNGH        ;RESTORE VALUE OF WIDTH FOR NEXT ROW
        LDX  #$00
XDRAW2  LDA  (SHPL,X)     ;GET BYTE FROM SHAPE TABLE
        EOR  (HIRESL),Y   ;XOR WITH BYTE ALREADY ON THE SCREEN
        STA  (HIRESL),Y   ;DRAW ON SCREEN
        INC  SHPL         ;NEXT BYTE OF SHAPE TABLE
```

```
INY                 ;NEXT POSITION ON SCREEN
DEC   SLNGH         ;DECREMENT WIDTH
BNE   DRAW2         ;FINISHED WITH ROW?
INC   TVERT         ;IF SO, INCREMENT TO NEXT LINE
DEC   DEPTH         ;DECREMENT DEPTH
BNE   DRAW          ;FINISHED ALL ROWS?
RTS                 ;YES, END ROUTINE
```

Now that we know how to DRAW and XDRAW a bit-mapped shape anywhere on the Hi-Res screen, the principle for animating these shapes is the same as for Apple shapes discussed previously in Chapter 1. A shape is erased from the screen, its new position is calculated, then it is redrawn at this new position. The procedure is outlined below:



A delay has been inserted between the DRAW and the XDRAW to allow the object to be on the screen longer than it is off. Without the delay, the object is erased immediately after it is drawn. This does not give the shape's image sufficient time to remain on screen during one animation frame. The result is a badly flickering image. The necessary delay can be a accomplished by a call to the monitor WAIT subroutine. A hundredth of a second delay is sufficient, but it could be doubled by changing the value in the Accumulator to $56.

```
LDA   #$3C
JSR   $FCA8 ;CALL TO WAIT SUBROUTINE
```

COLOR PROBLEMS WITH HORIZONTAL MOVEMENT

When colored shapes are moved vertically, as with our paddle driven space ship, they remain in either the same even or odd offset in which they started. However, when an object moves horizontally a byte at a time, colors shift, or alternate, as the shape moves from an even to an odd offset. As we saw in the last chapter, two different shape tables are needed, one for the even offsets and another for the odd offsets.

An algorithm must be devised to determine whether the HORIZ offset is odd or even. You can ascertain if a value is odd or even by right-shifting the value in the Accumulator so that the low bit enters the carry bit. Since only odd

128	64	32	16	8	4	2	1 →	C

numbers contain a one in the first bit position, only odd numbers will set the carry. Of course, the carry must be cleared first or this operation will be meaningless.

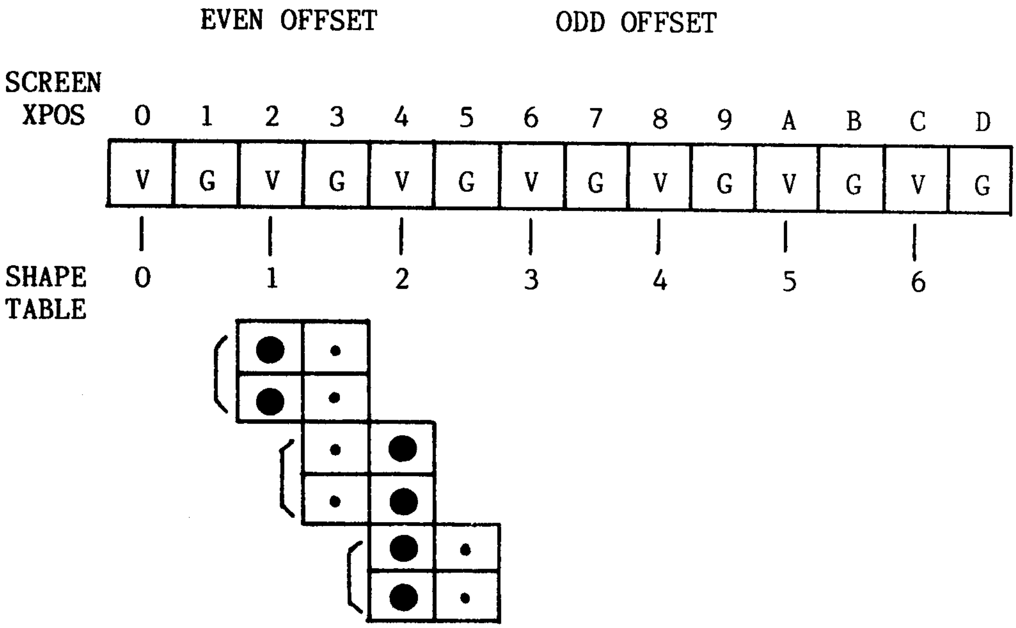
In order to make the example more meaningful, we will assume we have an even and an odd shape stored in a table called SHAPES. Each shape is one byte wide by eight bytes deep. The even offset shape occupies the first eight bytes, and the odd offset shape follows in the next eight bytes. Let us also assume that the shape table doesn't cross a page boundary (the hi byte is constant).

```
                   *EXAMPLE:COLOR OFFSET PROBLEM & SOLUTION
                            ORG  $6000
                   HORIZ    DS   1
                   SHPL     EQU  $50
                   SHPH     EQU  SHPL+$1
6001: 18                    CLC               ;CLEAR CARRY
6002: AD 00 60              LDA  HORIZ        ;LOAD HORIZ VALUE STORED AT $6000
6005: 4A                    LSR               ;LOGICAL SHIFT RIGHT INTO CARRY
6006: B0 07                 BCS  ODD          ;IF CARRY SET, GOTO ODD CODE
6008: A9 18        EVEN     LDA  #<SHAPES     ;LO BYTE OF EVEN SHAPE TABLE
600A: 85 50                 STA  SHPL
600C: 4C 13 60              JMP  CONT
600F: A9 20        ODD      LDA  #<SHAPES+8   ;LO BYTE OF ODD SHAPE TABLE
6011: 85 50                 STA  SHPL
6013: A9 60        CONT     LDA  #>SHAPES     ;HI BYTE OF TABLE
6015: 85 51                 STA  SHPH
6017: 60                    RTS
                   *
6018: 00 01 02
601B: 03 04 05
601E: 06 07        SHAPES   HEX  0001020304050607 ;ODD OFFSET SHAPE
6020: 08 09 0A                                     even
6023: 0B 0C 0D
6026: 0E 0F                 HEX  08090A0B0C0D0E0F ;ODD OFFSET SHAPE

--END ASSEMBLY--
```

You can easily see in the above example that the pointers to the proper shape table will be used correctly by our drawing subroutine. You can put a HORIZ value in location $6000 and single step the code in the monitor. If you don't have the single step and trace feature because you have an APPLE II PLUS, type a 6001G, then check locations $50 and $51 for the values of SHPL, and SHPH, respectively. Thus, if both the even and odd offset tables are generated for a violet colored object, the object will always remain violet at any horizontal screen position 0 – 39 if the correct table is used.

Color shifting problems become more intricate if you intend to do very fine movement or single pixel moves to the left or right, versus coarse movements of a byte or seven pixels at a time. As we discovered in the last chapter, single pixel movements in color aren't effective due to the alternating columns of complementary colors. The shape tends to lag a cycle, then jumps two pixels.



You can see from the above illustration that our shape stays in the same position for two cycles, then moves. It would be easier to move a shape two pixels horizontally at a time and use only seven shape tables for a shape instead of fourteen.

The simplest method for keeping track of which offset table is to be used at a particular horizontal position is through tables. One table (XBASE) is needed for the horizontal byte for any horizontal screen position, and another (XOFF) is needed to determine which of the seven offsetted shape table is to be plotted. The tables take the following form:

```
XBASE  HEX 00000000000000
       HEX 00010101010101
       HEX 02020202020202
       HEX 02030303030303
           .      .
           .      .

       HEX 26262626262626
       HEX 26272727272727


XOFF   HEX 00000101020203
       HEX 03040405050606
       HEX 00000101020203
       HEX 03040405050606
             ETC
```

	0th SHAPE		1st SHAPE		2nd SHAPE		3rd SHAPE		4th SHAPE		5th SHAPE		6th SHAPE		7th SHAPE	
XOFF	00	00	01	01	02	02	03	03	04	04	05	05	06	06	00	00
XBASE	00	00	00	00	00	00	00	00	01	01	01	01	01	01	02	02
	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F

Oth Horiz. Offset (X = 0–6)   1st Horiz. Offset (X = 7–D)

X COORDINATE VALUE

While the XOFF table is straight-forward in that two adjacent X positions reference the same shape in the table, the XBASE table, which references the horizontal byte offset, requires some explanation. You would assume that all shapes plotted in the first seven horizontal screen positions (X = 0 to 6) would be plotted in the 0th, or even offset, and all shapes plotted in the second seven positions (X = 7 to 13) would be plotted in the first or odd offset. The problem occurs at the boundary of even-odd offset pairs. The third shape table is plotted for both X = 6 and X = 7. But, if the 3rd shape is plotted first in the 0th (even) offset for X = 6, then plotted in the 1st (odd) offset at X = 7, you would get a red shape in the first case, and a blue shape in the second case. The shape would also be shifted over one whole byte, because the shape at X = 7, which is equivalent to that at X = 6 in the odd offset, would instead have an offset of 2; thus it would appear to be at the end of the byte instead of at the beginning.

Therefore, the shape at X = 7 must also be plotted in the 0th (even) offset. I'll be frank and say that the first time I encountered the problem, I spent some time looking for the error by stepping through my code. The solution was that the XBASE tables had to be modified to account for the inconsistency.

The following example will make this clearer. To determine the proper offset and which shape to plot at X = 2, you would calculate as follows:
Look up the third position of XBASE for the offset

or XBASE,2 = $00

Look up the third position of XOFF for the shape number

or XOFF,2 = $01

So plot the first shape in 0th offset.
For X = 7
Look up the eighth position of XBASE for the offset

or XBASE,7 = $00

Look up the eighth position of XOFF for the shape number

or XOFF,7 = $03

So plot third shape in 0th offset.

This can be formalized into code as part of a setup routine prior to accessing our drawing routine.

```
SETUP LDY  XVALUE
      LDA  XBASE,Y    ;GET BYTE OFFSET FROM TABLE
      STA  HORIZ      ;STORE OFFSET
      LDX  XOFF,Y     ;TABLE TO FIND SHAPE NUMBER
      LDA  SHPLO,X    ;INDEX TO GET LO BYTE OF SHAPE TABLE
      STA  SHPL       ;STORE LO BYTE IN ZERO PAGE
      LDA  #>SHAPES   ;GET HI BYTE OF SHAPE TABLE
      STA  SHPH       ;STORE HI BYTE IN ZERO PAGE
```

SHPLO is a table seven bytes long that contains the lo order byte address of our shapes. Assuming that there are seven shapes, each containing 24 bytes, which are stored at $800 in a table called SHAPES, then the table takes the following form. The HEX pseudo-op in most assemblers informs the assembler to place hexadecimal data bytes beginning at the location SHPLO. It is equivalent to directly assigning storage space and filling in the values, as follows:

```
SHPLO  HEX  00 18 30 48 60 78 90

                OTH    1ST
               SHAPE SHAPE  ETC.
```

The obvious intent of the previous method was to save shape table space. If a shape were three bytes wide by eight rows deep, seven tables would require 168 bytes of storage. Requiring the use of all fourteen shapes would double that. While 336 bytes isn't much memory, ten shapes use nearly 3.5K and if any of these were to be rotating shapes, much of memory would be wasted with shape tables.

For those readers who would feel more comfortable calculating and using all fourteen shapes in their table, the code is the same but the tables differ slightly. The tables are more straight-forward because there are no boundary problems.

```
XBASE  HEX  00000000000000
       HEX  01010101010101
       HEX  02020202020202
        .          .
        .          .

       HEX  26262626262626
       HEX  27272727272727


XOFF   HEX  00010203040506
       HEX  0708090A0B0C0D
       HEX  00010203040506
       HEX  0708090A0B0C0D


SHPLO  HEX  00183048607890
       HEX  A8C0D8F0082038
```

In this case the shape table extends beyond a page boundary, so a table to reference the Hi byte as well must be included.

```
SHPHI  HEX  08080808080808
       HEX  08080808090909
```

Replace the last two instructions for the hi byte in our setup routine with the following:

```
        LDA   SHPHI,X ;INDEX TO GET HI BYTE OF SHAPE TABLE
        STA   SHPH    ;STORE HI BYTE IN ZERO PAGE
```

There is an alternate way to avoid modifying the XBASE table. You could test for the combination of drawing the third shape while at an odd offset.

At first it seemed plausible that using fourteen shape tables might be the better method if,say, the gun were in color and its bullets were in B&W. But since the gun shifted two dots per move, the bullet should do likewise. Besides, the same drawing routines could be accessed.

THE SCREEN ERASE

Erasing an entire Hi-Res screen quickly without the viewer being aware is very important in some games. One well known Asteroid game resorted to a partial (160 line) screen erase instead of XDRAWing the shapes. No one noticed because the frame rate was fast enough, and the animation was page-flipping between graphics screens.

The process is simple and can be used for setting an entire screen to a background color. The Accumulator is loaded with a value (#$00 for black) and stored successively in all 8192 screen memory locations. If we had a sixteen-bit machine and could index all 8192 locations in one gigantic loop, things would be easy. But it has to be done in 256 byte blocks, or in what is called pages of memory. The flow chart is shown below.

Remember that the instruction STA (HIRESL),Y uses a two byte address in zero page

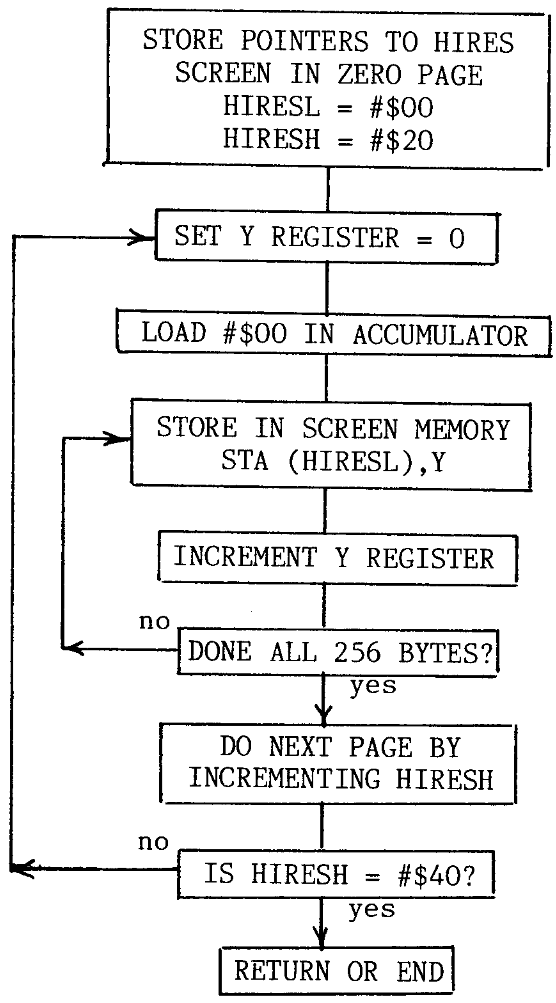
```
$26 = HIRESL = #$00
$27 = HIRESH = #$20
```

then increments it by Y. If Y = $07, then STA (HIRESL),Y stores what is in the Accumulator in location $2000 + $03 = $2003.

```
HIRESL EQU  $26
HIRESH EQU  HIRESL +$01

CLRSCR LDA  #$00         ;SETUP POINTERS TO CLEAR SCREEN
       STA  HIRESL       ;BEGINNING A $2000 (PAGE1)
       LDA  #$20
       STA  HIRESH
  CLR1 LDY  #$00         ;PAGE BEGINS AT 0
       LDA  #$00         ;LOAD ZERO TO ERASE TO BLACK
  CLR2 STA  (HIRESL),Y;STORE IN SCREEN MEMORY
       INY               ;NEXT BYTE
```

```
BNE  CLR2     ;DO ALL 256 BYTES; AT 256TH BYTE WRAPS
              ;BACK TO 0 IN Y REGISTER,FALLS THROUGH
INC  HIRESH   ;DO NEXT PAGE
LDA  HIRESH
CMP  #$40     ;FINISHED WITH SCREEN?
BLT  CLR1     ;NO, START NEXT 256 BYTE PAGE
RTS           ;YES, ALL DONE
```



This routine takes 35 milliseconds. Note: Screen #2 could be cleared just as easily by storing #$40 in HIRESH and comparing it to #$60 to test for the finish.

The screen can be cleared somewhat faster if inline code is used. This is sometimes desirable if part of a screen must be cleared quickly, but becomes a very long and tedious routine if every line is to be cleared. A zero is stored in each screen memory location indicated for a particular column or offset. When it is finished with that column, it increments to the next and clears that, also. Since the code contains the addresses for each line sequentially, precise control can be achieved over what portion of the screen is to be cleared. Of course, other colors can be used too. For instance:

```
        LDA #00       ;BLACK
        LDY #$00      ;START WITH OTH COLUMN
LOOP    STA $2000,Y   ;ADDRESS OF OTH LINE
        STA $2400,Y   ;ADDRESS OF 1ST LINE
        STA $2800,Y   ;ADDRESS OF 2ND LINE
         .    .   .
         .    .   .   ;Other lines
        INY
        CPY #$28      ;RIGHT SIDE SCREEN?
        BEQ END
        JMP LOOP      ;NEXT COLUMN
 END    RTS
```

Sometimes it is desirable to set a Hi-Res screen to a particular color. But color has its inherent odd-even offset problems. For example, to set a screen to blue, a #$D5 would be stored in all even offset memory locations, while a #$AA would be required in all odd offset memory locations. Therefore, we have to load and store in pairs as we completely fill the screen memory with bytes that cause only the blue pixels to be activated.

Fortunately, this routine only changes our clear screen routine slightly. You load a #$D5 for the even offset in the Accumulator, store it at the appropriate screen location referenced by HIRESL & HIRESH, then increment the index or pointer in the Y register. Then #$AA is loaded and stored for the odd offset in the next screen location. The Y register pointer is then incremented again. Because the BNE test only falls through when the Y register reaches 0 (or actually 256), this can only happen on an even increment. Therefore, the test isn't needed after the first INY, as it can't happen when Y is an odd value.

```
                *CLEAR SCREEN COLOR TO BLUE
                        ORG  $6000
                HIRESL  EQU  $26
                HIRESH  EQU  HIRESL+$1
6000: A9 00     CLRSCR  LDA  #$00
6002: 85 26             STA  HIRESL
6004: A9 20             LDA  #$20
6006: 85 27             STA  HIRESH
```

```
6008: A0 00    CLR1   LDY  #$00
600A: A9 D5    CLR2   LDA  #$D5         ;BLUE (EVEN)
600C: 91 26           STA  (HIRESL),Y
600E: C8              INY
600F: A9 AA           LDA  #$AA         ;BLUE (ODD)
6011: 91 26           STA  (HIRESL),Y
6013: C8              INY
6014: D0 F4           BNE  CLR2
6016: E6 27           INC  HIRESH       ;DO NEXT PAGE
6018: A5 27           LDA  HIRESH
601A: C9 40           CMP  #$40         ;FINISHED WITH SCREEN?
601C: 90 EA           BCC  CLR1         ;NO,START NEXT 256 BYTE PAGE
601E: 60              RTS               ;YES! DONE

--END ASSEMBLY--
```

SELECTIVE DRAWING CONTROL & DRAWING MOVEMENT ADVANTAGES

We have seen how background is preserved by EORing shapes on and then off the Hi-Res screen. However, there are times when this is not effective. For instance, complex backgrounds make a mess of a shape, often making it unrecognizable. In these cases, it is best to draw the shape on the screen normally. Naturally, background is lost, but it can be redrawn from memory.

There is another function that is quite important in selective drawing control. That is the And Memory with Accumulator (AND) instruction. It is primarily used to filter or mask out certain bits in the Accumulator or, in the case of the Hi-Res screen, mask out certain pixels. Both the memory bit and the Accumulator bit must be set (on) for the result to be one. If either memory bit or Accumulator bit is off, or both bits are off, the result is zero.

Example:

```
                       Hi bit
1 0 1 0 1 0 1 1            LDA  #$D5
0 0 0 0 1 1 1 1            AND  #$F0
---------------
0 0 0 0 1 0 1 1         RESULT  #$D0
```

The above example effectively stripped off the first four pixels of the byte. While it is difficult to design a simple case for using the AND instruction in selective drawing, it is used for "making a hole" in a background before ORing a colored shape into the hole. It is a tricky procedure for beginners, because the complement of an equivalent white shape is used during the AND operation.

We have the following background and colored shape:

1	1	1	1	0	0	0	1	1	0	1	1	1	1	BACKGROUND
1	0	1	0	1	0	1	0	1	0	0	0	0	0	SHAPE

First we need the complement of the white shape.

1	1	1	1	1	1	1	1	1	0	0	0	0	0	WHITE SHAPE CONTAINS VIOLET & GREEN
1	1	1	1	1	1	1	1	1	1	1	1	1	1	EOR #$FF
0	0	0	0	0	0	0	0	0	1	1	1	1	1	
1	1	1	1	0	0	0	1	1	0	1	1	1	1	AND WITH BACKGROUND
0	0	0	0	0	0	0	0	0	0	1	1	1	1	RESULTANT HOLE

Now OR the shape into the hole.

0	0	0	0	0	0	0	0	0	0	1	1	1	1	BACKGROUND HOLE
1	0	1	0	1	0	1	0	1	0	0	0	0	0	ORA COLORED SHAPE INTO HOLE
1	0	1	0	1	0	1	0	1	0	1	1	1	1	RESULTANT COLORED SHAPE & BACKGROUND

Notice that the background doesn't interfere with the colored shape but surrounds it.

The AND instruction is also quite useful in detecting collisions. The procedure will be discussed in detail in the next chapter.

The goal of any programmer is to write fast and efficient code. You can do this by taking advantage of the way the screen is mapped and manipulated in memory. Because it is faster to change a byte, or group of seven pixels rather than each of the pixels separately, it is easier to have separate shapes for each movement to the right or left within a byte. It is also easier to move a shape or object one byte, or seven pixels at a time, horizontally.

Likewise, it is easier during horizontal movement to keep a shape within one of the 24 – eight row subgroups on the Hi-Res screen. If you adhere to that restriction, only the memory address of the first line of the shape need be accessed by tables. Each succeeding line is +$400 in memory at any given horizontal offset. This method saves many machine cycles by not accessing the GETADR routine for each and every horizontal line in the shape. If your shape is three bytes wide by eight lines deep, the drawing algorithm only has to call the GETADR routine once. Each successive byte in that offset or column is plotted at a location incremented by +$400 bytes in screen memory. After all

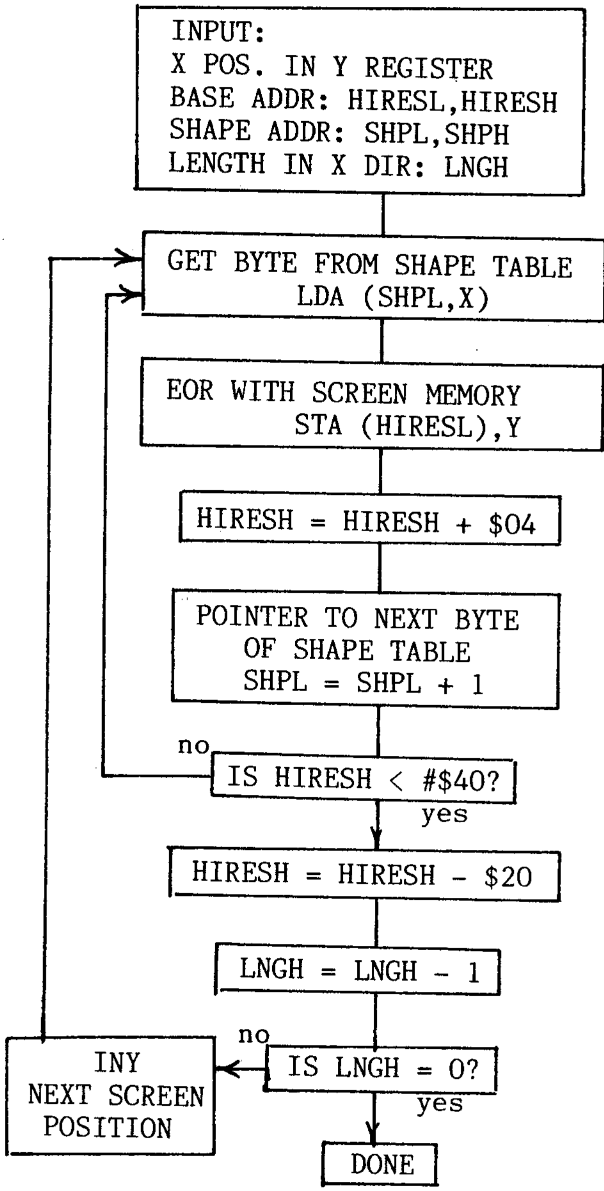
eight bytes have been plotted in that column, screen memory is decremented by $2000 bytes to return to the top of the subgroup in order to plot in the next column. It is a very fast method, one that many games, like Apple Invaders, uses. If you examine that game, the aliens move slowly across the screen, each character being eight lines deep. When they advance closer to landing, they jump a full eight lines, to be plotted within the next lower eight line subgroup. Although moving 40 aliens may appear slow in the game, there is a very long delay loop. Perhaps some readers have seen the modified version with the hyperspeed option. The game is quite capable of running ten times faster.

The subroutine shown below has the following inputs which can be set in another subroutine called SETUP.

```
*       X POSITION IN Y REGISTER
*       BASE ADDR: HIRESL , HIRESH
*       SHAPE ADDR: SHPL, SHPH
*       LENGTH IN X DIRECTION: LNGH

DRAW   LDX  #$00         ;X-REG MUST BE 0
DRAW2  LDA  (SHPL,X)     ;GET BYTE FROM SHAPE TABLE
       EOR  (HIRESL),Y   ;EXCLUSIVE OR IT WITH WHAT IS ON SCREEN
       STA  (HIRESL),Y   ;PUT IT ON HI-RES SCREEN
       LDA  HIRESH       ;WANT TO REACH NEXT LINE BY ADDING $400
       CLC               ;BY ADDING 4 TO HI BYTE OF BASE ADDR.
       ADC  #$04         ;ADD AFTER CLEARING CARRY
       STA  HIRESH       ;SAVE IT
       INC  SHPL         ;NEXT BYTE OF SHAPE ADDR.
       CMP  #$40         ;ARE WE FINISHED WITH THAT COLUMN
       BCC  DRAW2        ;NO, DO NEXT BYTE
       SBC  #$20         ;YES,BACK TO BASE ADDR (OR TOP)
       STA  HIRESH       ;SAVE IT
       DEC  LNGH         ;NEXT COLUMN SO DECREMENT LENGTH
       BEQ  DRAW3        ;ARE WE FINISHED
       INY               ;DRAW AT NEXT X POSITION
       BNE  DRAW2        ;THIS BRANCH IS ALWAYS TAKEN
DRAW3  RTS               ;DONE!
```

Another way of keeping the code simple is to use only the first 256 horizontal screen positions. This simplifies horizontal paddle routines and eliminates the problem of multi-byte additions to reach screen positions between X = 256 and X = 279. A large number of games like GAMMA GOBLINS and ASTEROID FIELD have resorted to this technique. The 256 position field need not be left justified, but could be centered using a fixed left margin displacement.



Map of elements in shape table as they appear on the screen

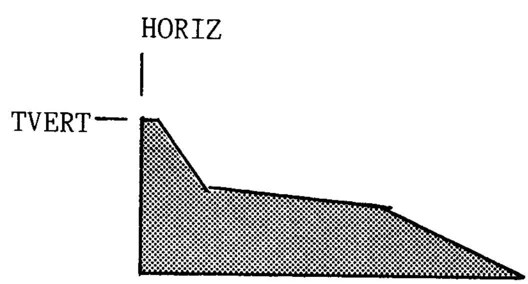
0	8
1	9
2	10
3	.
. .	. .
. 7	. 15

INTERFACING THE DRAWING ROUTINES TO AN APPLESOFT PROGRAM

Bit-mapped shape tables, as we have seen, are much more detailed and more colorful than APPLE shape tables. There are many programmers not writing a high speed animated game who would like to use these shape drawing routines in an Applesoft program.

If you wanted to control the vertical movement of our space ship by paddle control from an Applesoft program, it can be accomplished in the following manner:

The machine language drawing routine and the setup routine require only the inputs of where to start drawing the ship on the screen. The ship's horizontal location is called HORIZ in the machine language subroutine. The ship can be positioned horizontally from the far left (0) to nearly the right hand side of the screen (37). At 37, the ship's nose touches the right screen boundary. Larger values would produce a very strange wrap-a-round, especially at 38 and 39. HORIZ is located at $6001 or 24577 decimal. A value has only to be poked in at this location to change the ship's horizontal location. The ship's vertical position is set by TVERT. Its value is trimmed to 0-183 to prevent vertical wrap-a-round. It is located at $6000 or 24576 decimal. TVERT can be directly driven by a paddle routine in the Applesoft program.



The machine language subroutine with code, lookup and shape tables is only 502 bytes long. It starts a $6006 or 24582 decimal. It sets up the drawing routine before calling it. The drawing routine EOR's the ship's shape to the screen, one byte at a time.

This routine is quite versatile and could handle multiple shapes from Applesoft with little modification to the code. The variables for each shape in the setup routine; lo and hi bytes of the shape, as well as its depth and length, would have to be poked in from Applesoft. The JSR to SSETUP would be removed and the new shapes would be added to the end or in a table elsewhere in memory, in a location where it wouldn't be overwritten by your Applesoft program.

You must be careful with zero page pointers when interfacing BASIC programs to machine language programs. Although I've been lax in choosing locations $52 through $58, these conflict with both BASICS. There is a chart in the Apple II Reference manual which shows which zero page locations are free. Safe locations for either BASIC are $6 to $9 , $1A to $1F , $EB to $EF, and $F9 to $FF. There are others, but I would consult the manual.

Our small Applesoft interface routine is listed below and the machine language code follows.

```
10 HGR: POKE-16302,0                   ;SET GRAPHICS
15 H=10 : POKE 24577,H                 ;SET HORIZONTAL POSITION
20 TVERT = PDL(1) :IF TVERT >183       ;SET VERTICAL POSITION
   THEN TVERT = 183                            WITH PADDLE
25 POKE 24576, TVERT                   ;
30 CALL 24582                          ;CALL DRAWING ROUTINE
40 FOR DE = 1 TO 5: NEXT DE            ;SHORT DELAY
45 POKE 24576, TVERT                   ;REFRESH VERTICAL POSITION
50 CALL 24582                          ;XDRAW SHIP
60 GOTO 20                             ;LOOP AGAIN
```

```
               *CODE FOR APPLESOFT PADDLE INTERFACE
                         ORG   $6000
               TVERT     DS    1
               HORIZ     DS    1
               DEPTH     DS    1
               LNGH      DS    1
               SLNGH     DS    1
               TEMP      DS    1
               HIRESL    EQU   $1A
               HIRESH    EQU   HIRESL+$1
               SSHPL     EQU   $1C
               SSHPH     EQU   SSHPL+$1
               *MAIN CODE
6006: 20 43 60 START     JSR   SSETUP
6009: 20 0D 60           JSR   SXDRAW
600C: 60                 RTS
               *SUBROUTINES
               *SHIP DRAWING SUBROUTINE
600D: AC 00 60 SXDRAW    LDY   TVERT        ;PADDLE VALUE
6010: 20 2C 60           JSR   GETADR
6013: A2 00              LDX   #$00         ;NEED 0 IN X REG. FOR INDEX
6015: A1 1C    SXDRAW2   LDA   (SSHPL,X)    ;LOAD BYTE FROM SHAPE TABLE
6017: 51 1A              EOR   (HIRESL),Y   ;EOR IT AGAINST SCREEN
6019: 91 1A              STA   (HIRESL),Y   ;STORE RESULT ON SCREEN
601B: E6 1C              INC   SSHPL        ;NEXT BYTE IN SHAPE TABLE
601D: C8                 INY                ;NEXT SCREEN POSITION IN ROW
601E: CE 04 60           DEC   SLNGH        ;DECREMENT WIDTH
6021: D0 F2              BNE   SXDRAW2      ;FINISHED WITH ROW?
6023: EE 00 60           INC   TVERT        ;IF SO, INCREMENT TO NEXT LINE
6026: CE 02 60           DEC   DEPTH        ;DECREMENT ROW
6029: D0 E2              BNE   SXDRAW       ;FINISHED ALL ROWS?
602B: 60                 RTS
```

```
                 *GETADR SUBROUTINE
602C: B9 5E 60   GETADR   LDA   YVERTL,Y    ;LOOK UP LO BYTE OF LINE
602F: 18                  CLC
6030: 6D 01 60            ADC   HORIZ       ;ADD DISPLACEMENT INTO LINE
6033: 85 1A               STA   HIRESL
6035: B9 1E 61            LDA   YVERTH,Y    ;LOOK UP HI BYTE OF LINE
6038: 85 1B               STA   HIRESH
603A: AD 05 60            LDA   TEMP
603D: 8D 04 60            STA   SLNGH       ;RESTORE VARIABLE
6040: A0 00               LDY   #$00
6042: 60                  RTS
                 *SHIP SET UP SUBROUTINE
6043: A9 DE      SSETUP   LDA   #<SHIP      ;OCATION OF SHIP SHAPE TABLE
6045: 85 1C               STA   SSHPL
6047: A9 61               LDA   #>SHIP
6049: 85 1D               STA   SSHPH
604B: A9 08               LDA   #$08        ;DEPTH 8 LINES
604D: 8D 02 60            STA   DEPTH
6050: A9 09               LDA   #$09        ;STARTING HORIZ POSITION
6052: 8D 01 60            STA   HORIZ
6055: A9 03               LDA   #$03        ;SHIP 3 BYTES WIDE
6057: 8D 04 60            STA   SLNGH
605A: 8D 05 60            STA   TEMP
605D: 60                  RTS
605E: 00 00 00
6061: 00 00 00
6064: 00 00      YVERTL   HEX   0000000000000000
6066: 80 80 80
6069: 80 80 80
606C: 80 80               HEX   8080808080808080
606E: 00 00 00
6071: 00 00 00
6074: 00 00               HEX   0000000000000000
6076: 80 80 80
6079: 80 80 80
607C: 80 80               HEX   8080808080808080
607E: 00 00 00
6081: 00 00 00
6084: 00 00               HEX   0000000000000000
6086: 80 80 80
6089: 80 80 80
608C: 80 80               HEX   8080808080808080
608E: 00 00 00
6091: 00 00 00
6094: 00 00               HEX   0000000000000000
6096: 80 80 80
6099: 80 80 80
609C: 80 80               HEX   8080808080808080
609E: 28 28 28
60A1: 28 28 28
60A4: 28 28               HEX   2828282828282828
60A6: A8 A8 A8
60A9: A8 A8 A8
60AC: A8 A8               HEX   A8A8A8A8A8A8A8A8
60AE: 28 28 28
60B1: 28 28 28
60B4: 28 28               HEX   2828282828282828
60B6: A8 A8 A8
60B9: A8 A8 A8
60BC: A8 A8               HEX   A8A8A8A8A8A8A8A8
```

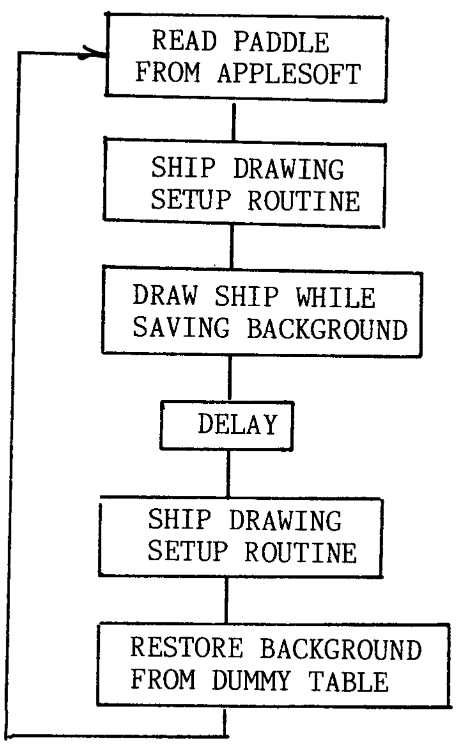
```
60BE: 28 28 28
60C1: 28 28 28
60C4: 28 28      69          HEX  2828282828282828
60C6: A8 A8 A8
60C9: A8 A8 A8
60CC: A8 A8      70          HEX  A8A8A8A8A8A8A8A8
60CE: 28 28 28
60D1: 28 28 28
60D4: 28 28      71          HEX  2828282828282828
60D6: A8 A8 A8
60D9: A8 A8 A8
60DC: A8 A8      72          HEX  A8A8A8A8A8A8A8A8
60DE: 50 50 50
60E1: 50 50 50
60E4: 50 50      73          HEX  5050505050505050
60E6: DO DO DO
60E9: DO DO DO
60C: DO DO     74          HEX  DODODODODODODODO
60EE: 50 50 50
60F1: 50 50 50
60F4: 50 50      75          HEX  5050505050505050
60F6: DO DO DO
60F9: DO DO DO
60FC: DO DO      76          HEX  DODODODODODODODO
60FE: 50 50 50
6101: 50 50 50
6104: 50 50      77          HEX  5050505050505050
6106: DO DO DO
6109: DO DO DO
610C: DO DO      78          HEX  DODODODODODODODO
610E: 50 50 50
6111: 50 50 50
6114: 50 50      79          HEX  5050505050505050
6116: DO DO DO
6119: DO DO DO
611C: DO DO      80          HEX  DODODODODODODODO
                 81   *
611E: 20 24 28
6121: 2C 30 34
6124: 38 3C      82   YVERTH HEX  2024282C3034383C
6126: 20 24 28
6129: 2C 30 34
612C: 38 3C      83          HEX  2024282C3034383C
612E: 21 25 29
6131: 2D 31 35
6134: 39 3D      84          HEX  2125292D3135393D
6136: 21 25 29
6139: 2D 31 35
613C: 39 3D      85          HEX  2125292D3135393D
613E: 22 26 2A
6141: 2E 32 36
6144: 3A 3E      86          HEX  22262A2E32363A3E
6146: 22 26 2A
6149: 2E 32 36
614C: 3A 3E      87          HEX  22262A2E32363A3E
614E: 23 27 2B
6151: 2F 33 37
6154: 3B 3F      88          HEX  23272B2F33373B3F
6156: 23 27 2B
6159: 2F 33 37
```

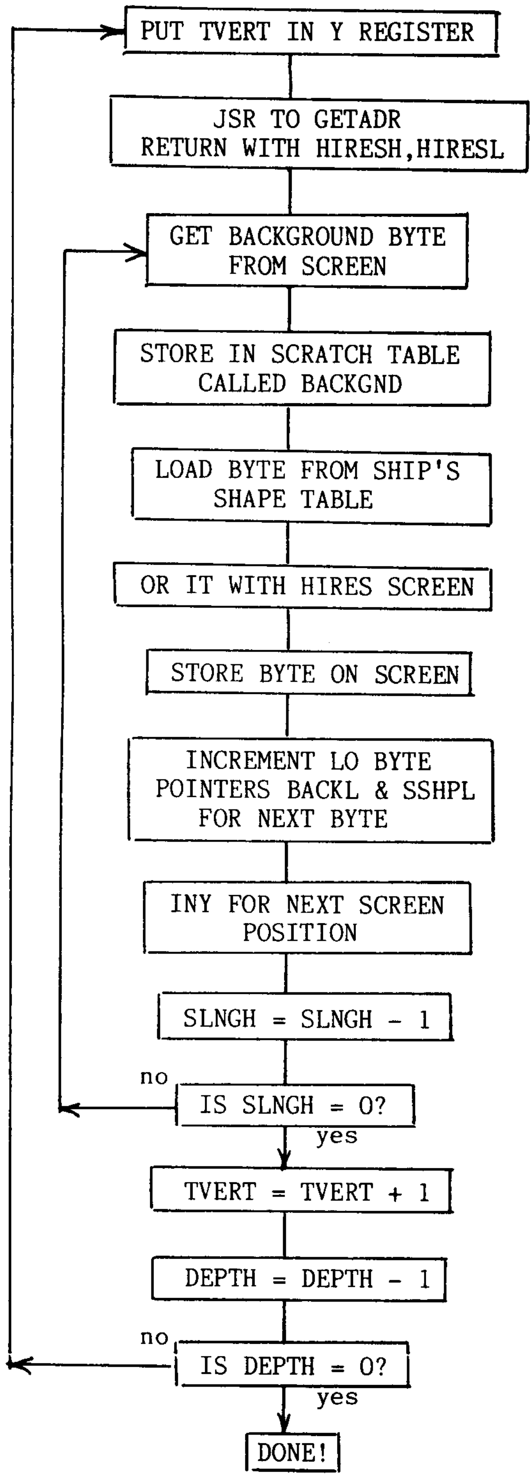
```
615C: 3B 3F    89          HEX  23272B2F33373B3F
615E: 20 24 28
6161: 2C 30 34
6164: 38 3C    90          HEX  2024282C3034383C
6166: 20 24 28
6169: 2C 30 34
616C: 38 3C    91          HEX  2024282C3034383C
616E: 21 25 29
6171: 2D 31 35
6174: 39 3D    92          HEX  2125292D3135393D
6176: 21 25 29
6179: 2D 31 35
617C: 39 3D    93          HEX  2125292D3135393D
617E: 22 26 2A
6181: 2E 32 36
6184: 3A 3E    94          HEX  22262A2E32363A3E
6186: 22 26 2A
6189: 2E 32 36
618C: 3A 3E    95          HEX  22262A2E32363A3E
618E: 23 27 2B
6191: 2F 33 37
6194: 3B 3F    96          HEX  23272B2F33373B3F
6196: 23 27 2B
6199: 2F 33 37
619C: 3B 3F    97          HEX  23272B2F33373B3F
619E: 20 24 28
61A1: 2C 30 34
61A4: 38 3C    98          HEX  2024282C3034383
61A6: 20 24 28
61A9: 2C 30 34
61AC: 38 3C    99          HEX  2024282C3034383C
61AE: 21 25 29
61B1: 2D 31 35
61B4: 39 3D    100         HEX  2125292D3135393D
61B6: 21 25 29
61B9: 2D 31 35
61BC: 39 3D    101         HEX  2125292D3135393D
61BE: 22 26 2A
61C1: 2E 32 36
61C4: 3A 3E    102         HEX  22262A2E32363A3E
61C6: 22 26 2A
61C9: 2E 32 36
61CC: 3A 3E    103         HEX  22262A2E32363A3E
61CE: 23 27 2B
61D1: 2F 33 37
61D4: 3B 3F    104         HEX  23272B2F33373B3F
61D6: 23 27 2B
61D9: 2F 33 37
61DC: 3B 3F    105         HEX  23272B2F33373B3F
61DE: 80 00 00
61E1: 82 00 00
61E4: 82 00    106  SHIP   HEX  8000008200008200
61E6: 00 8A 00
61E9: 00 AA D5
61EC: 80 AA    107         HEX  008A0000AAD580AA
61EE: 95 82 AA
61F1: D5 8A A8
61F4: D5 AA    108         HEX  9582AAD58AA8D5AA

--END ASSEMBLY--  502 BYTES
```

When raster or block shapes are plotted against a complex background by EORing them to the screen, the shape is often difficult to discern. As we mentioned in our discussion of the OR function, if a shape is ORed to the screen instead, the shape would be intact. However, this isn't entirely true. The background will affect the shape if either the shape has a window in it, or if true color is always to be preserved. If we had a red locomotive with a black window in the cab and we ORed it against a blue background, the window would not remain black, but would become blue. The color of the train is likely to shift to white because pixels in both the even and odd columns will be activated. A more effective solution would be to AND the complement of a white locomotive shape with the background and then OR the red locomotive to the screen. (See similar example, page 132.

Background can be saved when ORing a shape to the screen by saving the bytes to a scratch table just before plotting our shape. This is done a byte at a time in sequence with the shape plotting operation rather than as a seperate subroutine. Then, when the shape is to be removed from the screen, it isn't XDRAWn; instead, the original background is replotted from this scratch table. I modified the last example to perform this technique and set the background to a color in the Applesoft program so that you could observe the effect. It might be more interesting to load a Hi-Res picture as a very busy background. The code and flow chart are shown below.




PUT TVERT IN Y REGISTER
JSR TO GETADR
RETURN WITH HIRESH,HIRESL
GET BACKGROUND BYTE
FROM SCREEN
STORE IN SCRATCH TABLE
CALLED BACKGND
LOAD BYTE FROM SHIP'S
SHAPE TABLE
OR IT WITH HIRES SCREEN
STORE BYTE ON SCREEN
INCREMENT LO BYTE
POINTERS BACKL & SSHPL
FOR NEXT BYTE
INY FOR NEXT SCREEN
POSITION
SLNGH = SLNGH - 1
no
IS SLNGH = 0?
yes
TVERT = TVERT + 1
DEPTH = DEPTH - 1
no
IS DEPTH = 0?
yes
DONE!

```
10  HGR : POKE  - 16302,0
12  HCOLOR= 1
13  HPLOT 100,100: CALL 62454
15 H = 10: POKE 24577,H
20 TVERT =  PDL (1): IF TVERT > 183 THEN TVERT = 183
25  POKE 24576,TVERT
30  CALL 24582
40  FOR DE = 1 TO 5: NEXT DE
45  POKE 24576,TVERT
50  CALL 24589
60  GOTO 20
```

```
                *CODE FOR APPLESOFT PADDLE INTERFACE
                *WHILE SAVING BACKGROUND
                         ORG  $6000
                TVERT    DS   1
                HORIZ    DS   1
                DEPTH    DS   1
                LNGH     DS   1
                SLNGH    DS   1
                TEMP     DS   1
                HIRESL   EQU  $1A
                HIRESH   EQU  HIRESL+$1
                SSHPL    EQU  $1C
                SSHPH    EQU  SSHPL+$1
                BACKL    EQU  $1E
                BACKH    EQU  BACKL+$1
                *MAIN CODE
6006: 20 6D 60  START    JSR  SSETUP
6009: 20 14 60           JSR  SDRAW       ;DRAW SHIP WHILE SAVING BACKGROUND
600C: 60                 RTS
600D: 20 6D 60           JSR  SSETUP
6010: 20 39 60           JSR  BKDRAW      ;REPLACE BACKGROUND
6013: 60                 RTS
                *SUBROUTINES
6014: AC 00 60  SDRAW    LDY  TVERT       ;PADDLE VALUE
6017: 20 56 60           JSR  GETADR
601A: A2 00              LDX  #$00        ;NEED 0 IN X REG. FOR INDEX
601C: B1 1A     SDRAW2   LDA  (HIRESL),Y ;LOAD BYTE ON SCREEN
601E: 81 1E              STA  (BACKL,X)  ;STORE BACKGROUND TABLE
6020: A1 1C              LDA  (SSHPL,X)  ;LOAD BYTE FROM SHIP SHAPE TABLE
6022: 11 1A              ORA  (HIRESL),Y ;ORA WITH SCREEN
6024: 91 1A              STA  (HIRESL),Y ;STOR RESULT ON SCREEN
6026: E6 1E              INC  BACKL       ;NEXT BYTE IN BACKGROUND TABLE
6028: E6 1C              INC  SSHPL       ;NEXT BYTE IN SHIP TABLE
602A: C8                 INY              ;NEXT SCREEN POS. IN ROW
602B: CE 04 60           DEC  SLNGH       ;DECREMENT WIDTH
602E: D0 EC              BNE  SDRAW2      ;FINISHED WITH ROW?
6030: EE 00 60           INC  TVERT       ;IF SO, INCREMENT TO NEXT LINE
6033: CE 02 60           DEC  DEPTH       ;DECREMENT DEPTH
6036: D0 DC              BNE  SDRAW       ;FINISHED ALL ROWS?
6038: 60                 RTS              ;YES, END ROUTINE
```

```
6039: AC 00 60    BKDRAW   LDY  TVERT        ;PADDLE VALUE
603C: 20 56 60             JSR  GETADR
603F: A2 00                LDX  #$00
6041: A1 1E       BKDRAW2  LDA  (BACKL,X)    ;LOAD BYTE FROM BACKGROUND TABLE
6043: 91 1A                STA  (HIRESL),Y   ;STORE ON HIRES SCREEN
6045: E6 1E                INC  BACKL        ;NEXT BYTE IN TABLE
6047: C8                   INY               ;NEXT SCREEN POSITION IN ROW
6048: CE 04 60             DEC  SLNGH
604B: D0 F4                BNE  BKDRAW2
604D: EE 00 60             INC  TVERT
6050: CE 02 60             DEC  DEPTH
6053: D0 E4                BNE  BKDRAW
6055: 60                   RTS
6056: B9 90 60    GETADR   LDA  YVERTL,Y     ;LOOK UP LO BYTE OF LINE
6059: 18                   CLC
605A: 6D 01 60             ADC  HORIZ        ;ADD DISPLACEMENT INTO LINE
605D: 85 1A                STA  HIRESL
605F: B9 50 61             LDA  YVERTH,Y     ;LOOK UP HI BYTE OF LINE
6062: 85 1B                STA  HIRESH
6064: AD 05 60             LDA  TEMP
6067: 8D 04 60             STA  SLNGH        ;RESTORE VARIABLE
606A: A0 00                LDY  #$00
606C: 60                   RTS
                  *SHIP SET UP
606D: A9 10       SSETUP   LDA  #<SHIP       ;LOCATION OF SHIP SHAPE TABLE
606F: 85 1C                STA  SSHPL
6071: A9 62                LDA  #>SHIP
6073: 85 1D                STA  SSHPH
6075: A9 28                LDA  #<BACKGRD    ;LOCATION OF BACKGROUND TABLE
6077: 85 1E                STA  BACKL
6079: A9 62                LDA  #>BACKGRD
607B: 85 1F                STA  BACKH
607D: A9 08                LDA  #$08         ;DEPTH OF SHAPE
607F: 8D 02 60             STA  DEPTH
6082: A9 09                LDA  #$09         ;STARTING HORIZ. POSITION
6084: 8D 01 60             STA  HORIZ
6087: A9 03                LDA  #$03         ;SHIP 3 BYTES WIDE
6089: 8D 04 60             STA  SLNGH
608C: 8D 05 60             STA  TEMP
608F: 60                   RTS
6090: 00 00 00
6093: 00 00 00
6096: 00 00       YVERTL   HEX  0000000000000000
6098: 80 80 80
609B: 80 80 80
609E: 80 80                HEX  8080808080808080
60A0: 00 00 00
60A3: 00 00 00
60A6: 00 00                HEX  0000000000000000
60A8: 80 80 80
60AB: 80 80 80
60AE: 80 80                HEX  8080808080808080
60B0: 00 00 00
60B3: 00 00 00
60B6: 00 00                HEX  0000000000000000
60B8: 80 80 80
60BB: 80 80 80
60BE: 80 80                HEX  8080808080808080
60C0: 00 00 00
60C3: 00 00 00
```

```
60C6: 00 00     87          HEX  0000000000000000
60C8: 80 80 80
60CB: 80 80 80
60CE: 80 80     88          HEX  8080808080808080
60D0: 28 28 28
60D3: 28 28 28
60D6: 28 28     89          HEX  2828282828282828
60D8: A8 A8 A8
60DB: A8 A8 A8
60DE: A8 A8     90          HEX  A8A8A8A8A8A8A8A8
60E0: 28 28 28
60E3: 28 28 28
60E6: 28 28     91          HEX  2828282828282828
60E8: A8 A8 A8
60EB: A8 A8 A8
60EE: A8 A8     92          HEX  A8A8A8A8A8A8A8A8
60F0: 28 28 28
60F3: 28 28 28
60F6: 28 28     93          HEX  2828282828282828
60F8: A8 A8 A8
60FB: A8 A8 A8
60FE: A8 A8     94          HEX  A8A8A8A8A8A8A8A8
6100: 28 28 28
6103: 28 28 28
6106: 28 28     95          HEX  2828282828282828
6108: A8 A8 A8
610B: A8 A8 A8
610E: A8 A8     96          HEX  A8A8A8A8A8A8A8A8
6110: 50 50 50
6113: 50 50 50
6116: 50 50     97          HEX  5050505050505050
6118: D0 D0 D0
611B: D0 D0 D0
611E: D0 D0     98          HEX  D0D0D0D0D0D0D0D0
6120: 50 50 50
6123: 50 50 50
6126: 50 50     99          HEX  5050505050505050
6128: D0 D0 D0
612B: D0 D0 D0
612E: D0 D0     100         HEX  D0D0D0D0D0D0D0D0
6130: 50 50 50
6133: 50 50 50
6136: 50 50     101         HEX  5050505050505050
6138: D0 D0 D0
613B: D0 D0 D0
613E: D0 D0     102         HEX  D0D0D0D0D0D0D0D0
6140: 50 50 50
6143: 50 50 50
6146: 50 50     103         HEX  5050505050505050
6148: D0 D0 D0
614B: D0 D0 D0
614E: D0 D0     104         HEX  D0D0D0D0D0D0D0D0
                105  *
6150: 20 24 28
6153: 2C 30 34
6156: 38 3C     106  YVERTH HEX  2024282C3034383C
6158: 20 24 28
615B: 2C 30 34
615E: 38 3C     107         HEX  2024282C3034383C
6160: 21 25 29
```

```
6163: 2D 31 35
6166: 39 3D     108          HEX  2125292D3135393D
6168: 21 25 29
616B: 2D 31 35
616E: 39 3D     109          HEX  2125292D3135393D
6170: 22 26 2A
6173: 2E 32 36
6176: 3A 3E     110          HEX  22262A2E32363A3E
6178: 22 26 2A
617B: 2E 32 36
617E: 3A 3E     111          HEX  22262A2E32363A3E
6180: 23 27 2B
6183: 2F 33 37
6186: 3B 3F     112          HEX  23272B2F33373B3F
6188: 23 27 2B
618B: 2F 33 37
618E: 3B 3F     113          HEX  23272B2F33373B3F
6190: 20 24 28
6193: 2C 30 34
6196: 38 3C     114          HEX  2024282C3034383C
6198: 20 24 28
619B: 2C 30 34
619E: 38 3C     115          HEX  2024282C3034383C
61A0: 21 25 29
61A3: 2D 31 35
61A6: 39 3D     116          HEX  2125292D3135393D
61A8: 21 25 29
61AB: 2D 31 35
61AE: 39 3D     117          HEX  2125292D3135393D
61B0: 22 26 2A
61B3: 2E 32 36
61B6: 3A 3E     118          HEX  22262A2E32363A3E
61B8: 22 26 2A
61BB: 2E 32 36
61BE: 3A 3E     119          HEX  22262A2E32363A3E
61C0: 23 27 2B
61C3: 2F 33 37
61C6: 3B 3F     120          HEX  23272B2F33373B3F
61C8: 23 27 2B
61CB: 2F 33 37
61CE: 3B 3F     121          HEX  23272B2F33373B3F
61D0: 20 24 28
61D3: 2C 30 34
61D6: 38 3C     122          HEX  2024282C3034383C
61D8: 20 24 28
61DB: 2C 30 34
61DE: 38 3C     123          HEX  2024282C3034383C
61E0: 21 25 29
61E3: 2D 31 35
61E6: 39 3D     124          HEX  2125292D3135393D
61E8: 21 25 29
61EB: 2D 31 35
61EE: 39 3D     125          HEX  2125292D3135393D
61F0: 22 26 2A
61F3: 2E 32 36
61F6: 3A 3E     126          HEX  22262A2E32363A3E
61F8: 22 26 2A
61FB: 2E 32 36
61FE: 3A 3E     127          HEX  22262A2E32363A3E
6200: 23 27 2B
```

```
6203: 2F 33 37
6206: 3B 3F      128              HEX  23272B2F33373B3F
6208: 23 27 2B
620B: 2F 33 37
620E: 3B 3F      129              HEX  23272B2F33373B3F
6210: 80 00 00
6213: 82 00 00
6216: 82 00      130  SHIP        HEX  8000008200008200
6218: 00 8A 00
621B: 00 A D5
621E: 80 AA      131              HEX  008A0000AAD580AA
6220: 95 82 AA
6223: D5 8A A8
6226: D5 AA      132              HEX  9582AAD58AA8D5AA
                 133  BACKGRD     DS   24

--END ASSEMBLY--

ERRORS: 0

576 BYTES
```

CHAPTER 6

ARCADE GRAPHICS

INTRODUCTION

Arcade game animation uses many of the graphics techniques introduced in the previous chapter. Their requirement for high frame rates, coupled with smooth yet detailed animation, necessitates raster shape tables using their inherent high speed drawing routines. Yet, to produce quality games requires game designers to pay particular attention to the smallest programming details.

The fundamentals of any arcade game, in the broad sense, are easy to grasp. It is the details that elude the average programmer. While it is obvious that any object that can be moved must also be controlled, it isn't obvious how that motion is programmed in machine language.

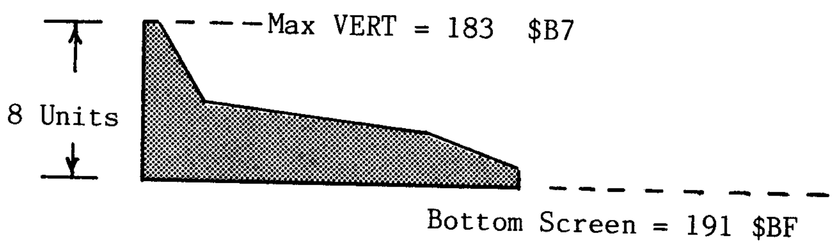
This chapter and the next will discuss the three major types of arcade games and the algorithms that make them work. First, there is the Invaders-type game, wherein a movable gun in the horizontal plane defends against attackers from above. Second, there is the fully maneuverable spaceship from the Space War and Asteroid-type games. These ships fly or float freely in both the X and Y axis. Finally, there are the games that simulate horizontal or vertical motion by scrolling the background. These games have ships that are usually maneuverable in the non-scrolling axis only. Apple games like Pegasus II and Phantoms Five fall into this category.

There are numerous details to consider in game design, such as paddle control, bullets firing and bombs dropping. A game must also include a scorekeeping device for determining a winner, and an explosion subroutine for ridding the screen of losers. And, sometimes, page-flipping techniques are needed to smooth the flickering effects of complex animation. It is hoped that by my first flow charting these routines, then presenting and explaining commented machine language subroutines, you will be able to use these techniques in your own games. And for those who need an example of a working game, many of these routines are combined in a functioning yet unfinished arcade game.

PADDLE ROUTINE

We previously controlled our moveable plane through an Applesoft interface. While it is easy to access the paddle routine directly from machine language, a more realistic subroutine that would prevent almost instantaneous jumps in position needs to be developed. It is the purpose of this section to develop a useable paddle subroutine.

The Hi-Res screen's vertical axis ranges only from 0-191. Paddle values, on the other hand, range from 0-255. An attempt to plot a shape on any horizontal line exceeding 191 would result in unpredictable consequences, because the YVERT tables for the screen address of any line contains only 192 values. Your program might store the shape anywhere in memory, depending on what values might be stored in the locations following our YVERT tables. Therefore, the maximum paddle value can be 191 minus the shape's depth. In the case of our ship, which is eight lines deep, you must clip the paddle value to 183 or $B7.



A paddle value is read by accessing a monitor subroutine called PREAD, located at $FB1E. The monitor reads the paddles by writing a strobe to start the selected paddle timer, then increments the Y register until the timer goes off. The paddle value is returned in the Y register. You access PREAD by placing the selected paddle number (0-3) in the X-register. You should be aware that what was previously stored in the Accumulator is destroyed when calling PREAD.

The following paddle subroutine prevents instantaneous jumps of the plane's position by rapid paddle movement. It accomplishes this by adjusting VERT, the ship's vertical position, rather than storing the paddle position (PDL) directly as VERT. This adjustment is based on the relationship of PDL to VERT.

There is a certain maximum paddle-driven movement that is desirable in any game. If the movement, in this case, is set to ten units per frame and the animation was twenty frames per second, then the plane will require approximately one second to move from top to bottom. Slower movement factors will take more time. The speed constant is subjective, and is determined by what you think is a suitable and a controllable speed.

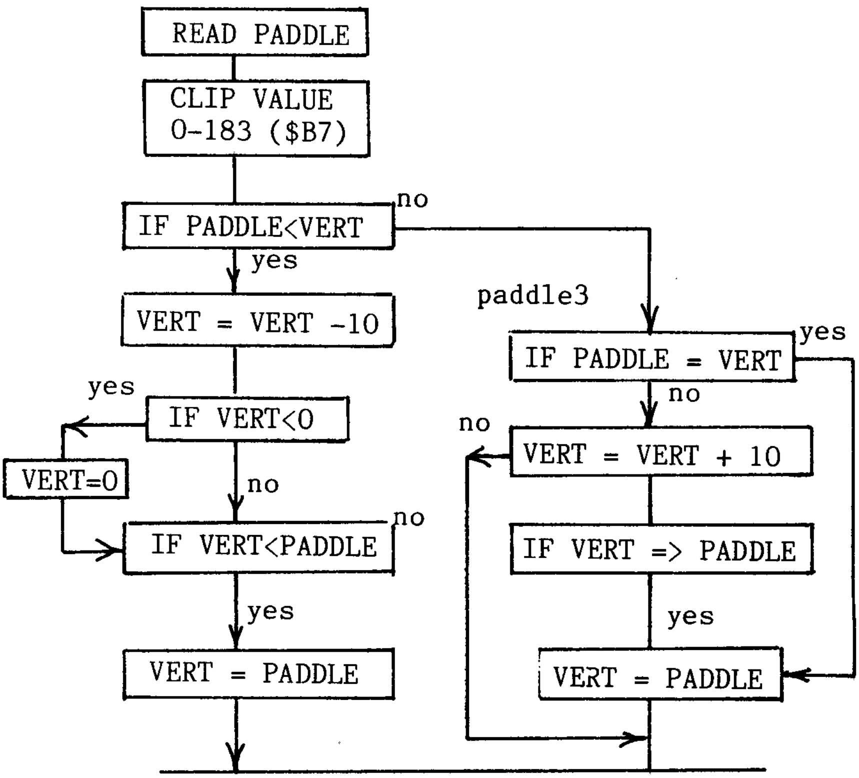
VERT is initialized at 90 decimal to position the ship initially at the center of the screen. If the paddle value is less than VERT, it subtracts ten from VERT and, if greater, adds ten. There are other safeguards to make sure VERT is greater than zero and less than the maximum paddle value, 183 decimal.

There is another test to make sure that VERT actually homes in on the PDL value. Let us assume that VERT was at 70 and the paddle (PDL) is set to 63. Since PDL is less than VERT, ten is subtracted from VERT. VERT is now 60, which is beyond, or less than PDL. But if VERT is less than PDL, it sets

VERT = PDL so that the resulting VERT position is exactly that of the paddle value. The same type of test is performed if PDL is greater than VERT, and VERT is homing in on the paddle value from a higher value.

CYCLE	PDL	VERT		CYCLE	PDL	VERT
0		90		0		90
1	63	80	OR	1	112	100
2	63	70		2	112	100
3	63	63		3	112	112

The flow chart is shown below.

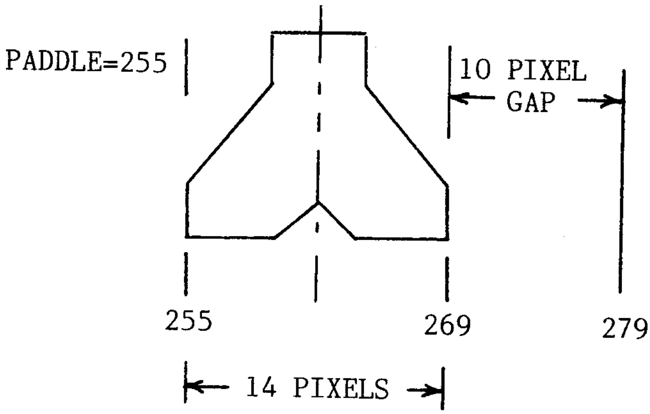


Rather than proceed with the development of what is to become a very complex game using our ship, I would like to digress to another paddle routine. This one controls a moveable gun turret in the horizontal plane. It is used quite frequently in most Invaders-type games.

The screen range on the horizontal axis is 0-279. Our paddle range is, as usual, limited to 0-255. In Applesoft, it was easy to multiply by 1.1 to obtain

the proper range. However, in machine language the multiplication and division routines are too complex, and require numerous machine cycles to execute. Besides, they return the result as two byte values, which means that all of our adding and subtracting would require two byte operations.

It is much easier to accept the fact that the right 10% of the screen is unusable or can't be reached by paddles, unless we center the screen by adjusting the horizontal offsets. Actually, if our gun is large, we can use part of this space without adjustment. Take the gun turret illustrated below. It is 14 pixels, or two bytes wide.



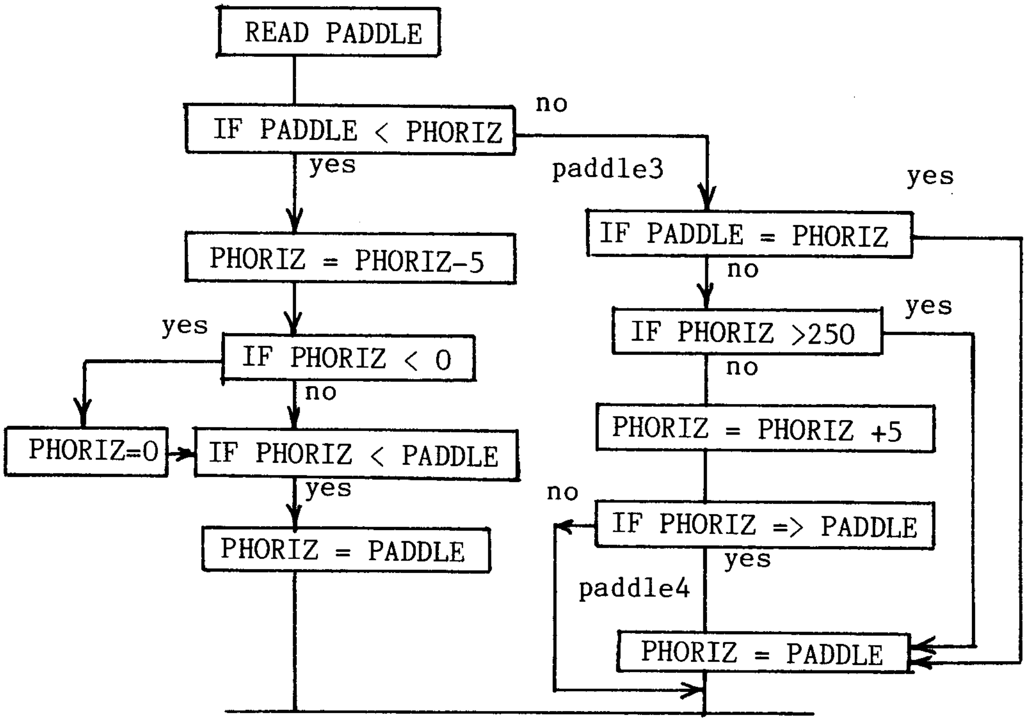
When the paddle value is at zero, the gun plots between 0-13 on the horizontal axis, and when the paddle is at 255, the gun plots between 255 and 269. That leaves only a ten pixel gap, which is hardly noticeable.

In order to use the paddle routine already developed for the vertical axis, it must be modified. The paddle's full range is needed, so clipping is removed just after the paddle is read. Instead, we must place a test in the code to prevent it from incrementing past $FF (255 decimal) as it homes in on the actual paddle value. In this case, we have slowed the turret's movement to five units per animation cycle. Again, the value of five is based on the frame rate, and what appears to be a reasonable movement rate on the screen.

After testing the various possibilites of whether the paddle is set to a value greater than PHORIZ (the horizontal position) you must prevent it from adding five to PHORIZ if PHORIZ > 250. In this case, the PADDLE value is 251 to 255, and PHORIZ is set equal to the PADDLE.

CYCLE	PADDLE	PHORIZ
2	253	240
1	253	245
2	253	250
3	253	253

The following chart and corresponding code is shown below.




```
                 *READ PADDLE #1
6028: A2 01      RPDL     LDX  #$01
602A: 20 1E FB            JSR  PREAD
602D: 8C 07 60   SKIPP    STY  PDL
6030: 98                  TYA
6031: CD 0B 60            CMP  PHORIZ     ;PADDLE<HORIZ POS THEN SUBTRACT 5
6034: B0 1E               BGE  PADDLE3
6036: AD 0B 60            LDA  PHORIZ
6039: 38                  SEC
603A: E9 05               SBC  #$05
603C: B0 08               BGE  PADDLE1    ;MAKE SURE =>0
603E: A9 00               LDA  #$00
6040: 8D 0B 60            STA  PHORIZ
6043: 8D 0C 60            STA  TPHORIZ
6046: CD 07 60   PADDLE1  CMP  PDL        ;DON'T WANT TO GO PAST PADDLE POS
6049: B0 03               BGE  PADDLE2
604B: AD 07 60            LDA  PDL
604E: 8D 0B 60   PADDLE2  STA  PHORIZ
6051: 4C 71 60            JMP  PADDLE6
6054: CD 0B 60   PADDLE3  CMP  PHORIZ     ;PADDLE>PHORIZ POS THEN ADD 5
6057: F0 12               BEQ  PADDLE4
6059: AD 0B 60            LDA  PHORIZ
605C: C9 FA               CMP  #$FA       ;IS PHORIZ>250
605E: B0 0B               BGE  PADDLE4
6060: AD 0B 60            LDA  PHORIZ
6063: 18                  CLC
```

```
6064: 69 05              ADC  #$05
6066: CD 07 60           CMP  PDL          ;DON'T WANT TO GO PAST PADDLE POS
6069: 90 03              BLT  PADDLE5
606B: AD 07 60  PADDLE4  LDA  PDL
606E: 8D 0B 60  PADDLE5  STA  PHORIZ
6071: 8D 0C 60  PADDLE6  STA  TPHORIZ
```

PADDLE CROSSTALK

Many readers will attempt at some future time to combine two paddle read routines together to control a ship, or a gun crosshair with a joystick. They will be dismayed to learn that the paddle values don't read properly. This is called paddle crosstalk.

When a paddle trigger is strobed, all the timers start. If the first paddle that you read has a low value, it will return quickly from PREAD with a paddle value. But the timers are still counting. If you immediately call PREAD again, the timers aren't restarted at zero, so that you may see a value from the first paddle trigger instead of the second. The solution is to wait a sufficient time before reading the second paddle. How long is sufficient? Not more than 255 machine cycles is needed. It is best to space your paddle reads with other code in between.

An alternate solution is to read two paddles simultaneously by triggering both strobes (or timers) together. Since the code takes longer to execute while the paddle timers count down, the full paddle range can not be expected. The code shown below is suitable for joystick control, but only has a range of 40 to 127. Clever programmers will either adjust these values or offset them to suit their needs.

```
             *THIS DUAL PADDLE READ RETURNS
             *VALUES AS FOLLOWS
             *PADDLE(0),PADDLE(1)
             *
             *126,127 ---------------44,127
             * !                          !
             * !                          !
             * !                          !
             * !                          !
             * !                          !
             * !                          !
             *126,47 ---------------- 44,47
             *
                          ORG  $300
             ZERO         DS   1
             ONE          DS   1
0302: A2 00               LDX  #$00
0304: 8E 01 03            STX  ONE
0307: 8E 00 03            STX  ZERO
030A: A2 7F               LDX  #$7F
030C: AD 70 C0            LDA  $C070        ;STARTS BOTH TIMERS
```

```
030F: AD 64 C0    LOOP    LDA  $C064      ;PADDLE 0 TIMER
0312: 29 80               AND  #$80
0314: 0A                  ASL
0315: 2A                  ROL
0316: 6D 00 03            ADC  ZERO
0319: 8D 00 03            STA  ZERO
031C: AD 65 C0            LDA  $C065      ;PADDLE 1 TIMER
031F: 29 80               AND  #$80
0321: 0A                  ASL
0322: 2A                  ROL
0323: 6D 01 03            ADC  ONE
0326: 8D 01 03            STA  ONE
0329: CA                  DEX
032A: D0 E3               BNE  LOOP
032C: A9 7F               LDA  #$7F
032E: 38                  SEC
032F: ED 00 03            SBC  ZERO
0332: 8D 00 03            STA  ZERO
0335: A9 7F               LDA  #$7F
0337: 38                  SEC
0338: ED 01 03            SBC  ONE
033B: 8D 01 03            STA  ONE
033E: 60                  RTS

--END ASSEMBLY--
```

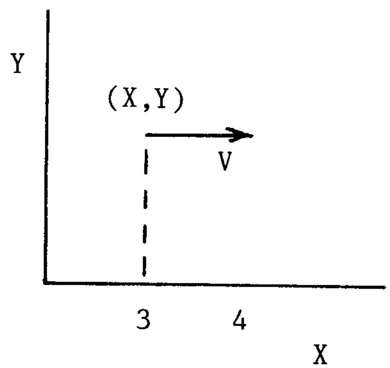
Many game designers choose keyboard controls instead of joystick controls. There are two reasons for this. The first is speed. Obviously, a test for a specific keypress only takes three instructions. A paddle, on the other hand, can take as long as 255 machine cycles. Two paddles (joystick) take nearly twice as long if you avoid crosstalk. There are many games where reading two paddles slows the program down. Several games resort to reading one paddle direction on alternate frames, and the other on the opposite frame; however, the controls seem sluggish. The only sensible solution is to write fast, efficient code, so that reading paddles does not affect the game's speed.

The second reason for keyboard control is that, until recently, few computer owners had joysticks. If the latter is the reason, the designer should offer a choice of control modes. Certainly playability is more important than monetary gain from a wider audience.

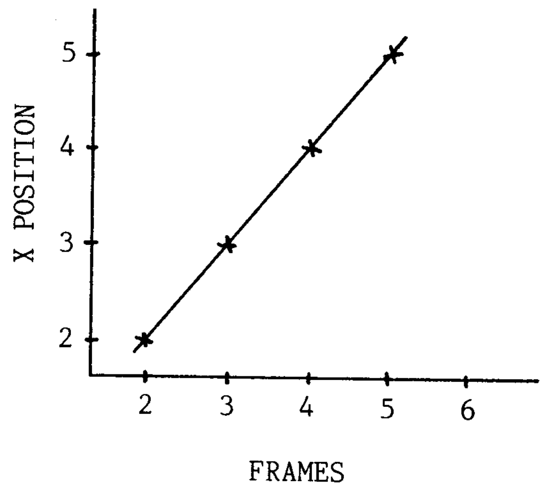
Simulating a bomb drop realistically involves some knowledge of how a body in motion reacts to a constant force; in this case, gravity. The physics of a body in motion requires advanced mathematics, mainly calculus. But calculus actually involves the summation of many bits and pieces of a body's velocity and acceleration to determine the actual distance an object travels. The computer, fortunately, automatically divides our time frame into small units, or animation frames, wherein the force vectors can be displayed as direction vectors.

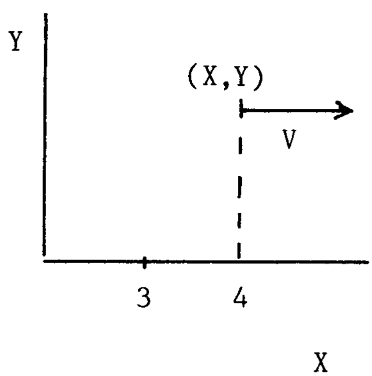
Let's examine an object in simple linear motion. The object is initially at rest. It is then given a horizontal velocity of one unit to the left. Thus, the velocity is +1 unit/time frame. During each animation frame, the object moves +1 units to the right.

An object's direction of travel and its magnitude is represented by a line segment called a vector. An object's velocity vector always points in the direction of travel. Our object shown below has a velocity of +1 units/ time frame, so that the velocity is pointing to the right. Since the velocity vector is to the right, the object moves to the right.

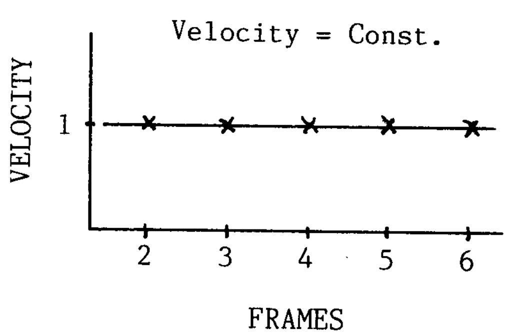


Frame #3





Frame #4



This can be formalized into equations for each of the two screen directions X and Y.

VX = +1	velocity is constant in X direction
X = X + VX	new position is the old position plus the change in position (velocity).

Likewise

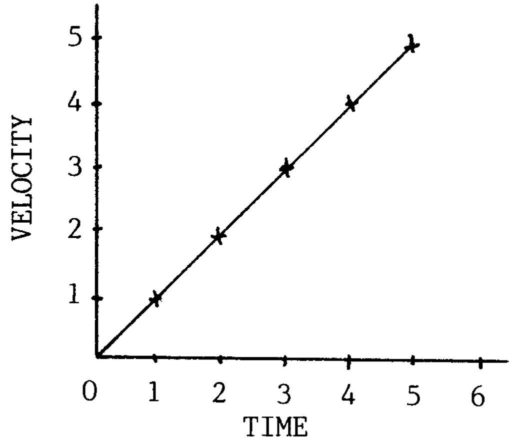
VY = 0	velocity is stationary in Y direction.
Y = Y + VY	

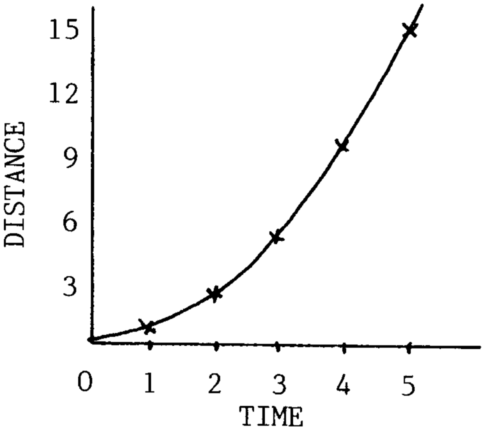
Therefore, the object remains stationary in the Y direction.

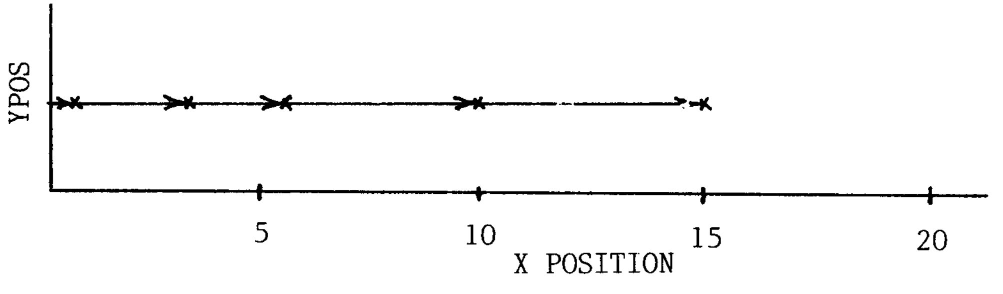
If a force were suddenly applied to our moving object so that the velocity in the X direction were to increase by one with each time frame, the distances traveled would grow substantially.

TIME	VELOCITY	POSITION (distance)
0	0	0
1	1	1
2	2	3
3	3	6
4	4	10
5	5	15
6	6	21

VX = VX + 1
X = X + VX



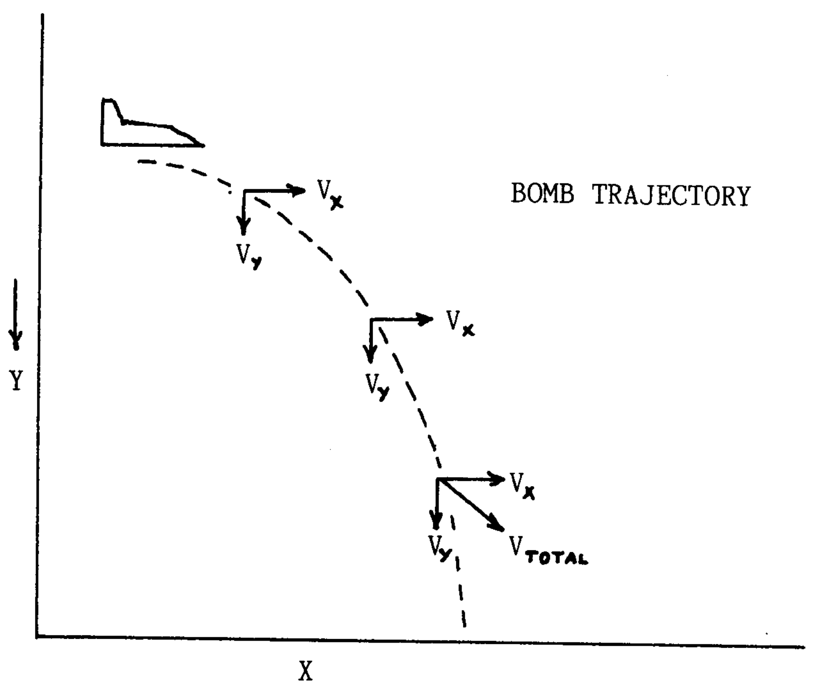




This driving force that speeds up our object is called acceleration (V = V + A) . The acceleration in the previous example was +1 units/frame. The acceleration in space games is a rocket's thrust and, for falling bombs, it is gravity. To simplify things, when working with a falling bomb, we will neglect variables like wind resistance, and assume that the bomb has a small forward velocity equal to that of the plane. The plot of the trajectory of a falling bomb is shown below. The trajectory forms a curve that is often called "parabolic". You should note that although the velocity in the X direction remains constant, the velocity in the Y direction (VY) grows larger with time. It grows larger because gravity accelerates the object constantly in the downward direction. This same effect can be observed by dropping a ball from the second or third story of a building. At first, the ball falls slowly, but then it begins falling faster. Observers at ground level will note an accelerated moving ball just before it bounces.

The velocity of the falling bomb has two components represented by velocity vectors - one in the X direction and the other in the Y direction. These two velocity vectors can be graphically added together to form a total velocity vector. The summation of the two vectors determines the resultant direction of an object's motion for each animation frame. Since the VY vector grows larger with each frame, the total velocity vector begins to point downward. Eventually, the bomb will be falling almost straight down. Thus:

VX = CONST
VY = VY + GRAVITY

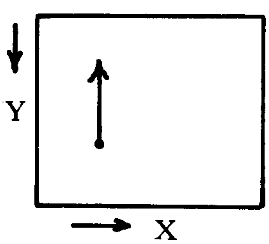


If you are programming the motion of a falling bomb, the equations or algorithm are as follows.

$$\begin{array}{llll} VX = CONST & & X = X + VX \\ VY = VY + GRAVITY & & Y = Y + VY \end{array}$$

For all practical purposes, a gravity constant of 3 to 5 will produce realistic curves on the Apple's Hi-Res screen, but this, again, like our choice of a constant for paddle movement, is dependent on factors like the animation frame rate and the scale of other objects on the screen.

The trajectories of bullets and artillery shells are another useful feature in games. Bullets in games like Apple Invaders and Galaxian travel straight upwards on the screen.

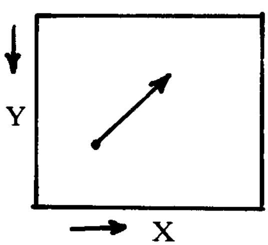


$$\begin{array}{l} X = 0 \\ VY = NEGATIVE\ CONSTANT \end{array}$$

so that

$$\begin{array}{l} X = CONST \\ Y = Y + (-VY) \end{array}$$

Bullets that travel diagonally, but at a constant velocity in the direction shown, have a VY that is negative and a VX that is positive. The velocity vector determines the direction of travel.

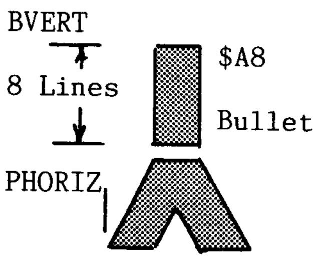


$$\begin{array}{l} VX = POSITIVE\ CONSTANT \\ VY = NEGATIVE\ CONSTANT \end{array}$$

so that

$$\begin{array}{l} X = X + VX \\ Y = Y + (-VY) \end{array}$$

Our bullet is fired from a movable gun base at the bottom of the screen. Its location, in relation to the gun barrel, is shown in the design at the right. The bullet's shape is eight units tall by four units wide and, like the gun base, uses seven different offset shape tables. Although the bullet is white, it is easier to use the same drawing routine to move it in conjunction with the gun base.

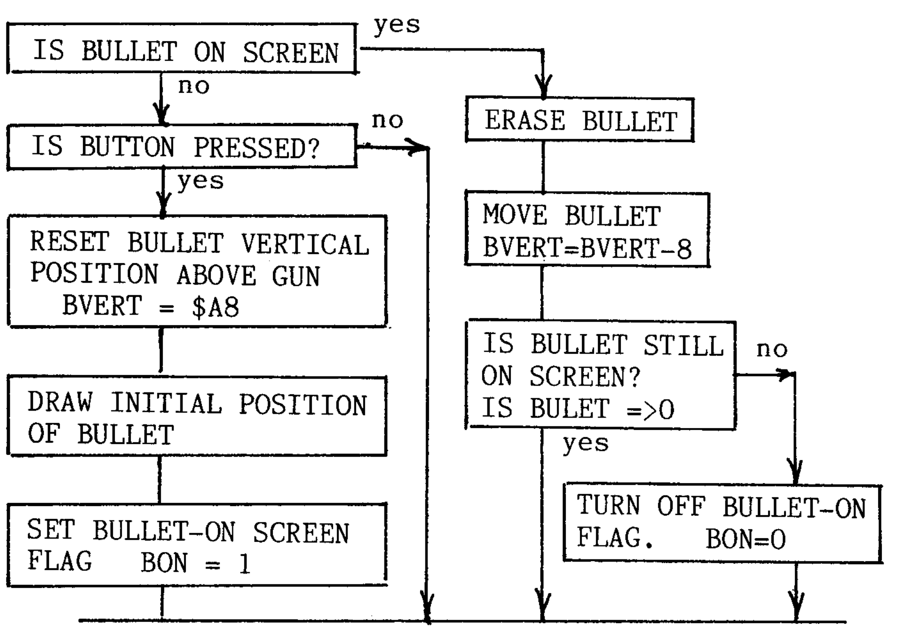


The bullet's horizontal velocity is VX = 0 and its vertical velocity is VY = −8. Thus, X = X + VX, or X = const , and Y = Y − VY. The bullet's vertical position is defined as BVERT. Therefore, BVERT = BVERT −8 for each frame. If the bullet's horizontal position is to remain constant once it is fired, it must be set free of PHORIZ (the gun's horizontal position), because its value would undoubtedly change if the gun turret moves after the bullet is fired. The bullet's horizontal position, BPHORIZ, is set equal to PHORIZ when the gun fires, and is used to determine the horizontal offset into the screen line while it plots the bullet. The value is also used to index into the XOFF table, which in turn acts as an index to the proper shape table when the bullet is plotted on the screen.

The bullet travels further toward the top of the screen during each screen frame. Notice that it travels exactly eight lines upwards per cycle. This allows us to begin drawing at the start of one of the 24 eight line subgroups.

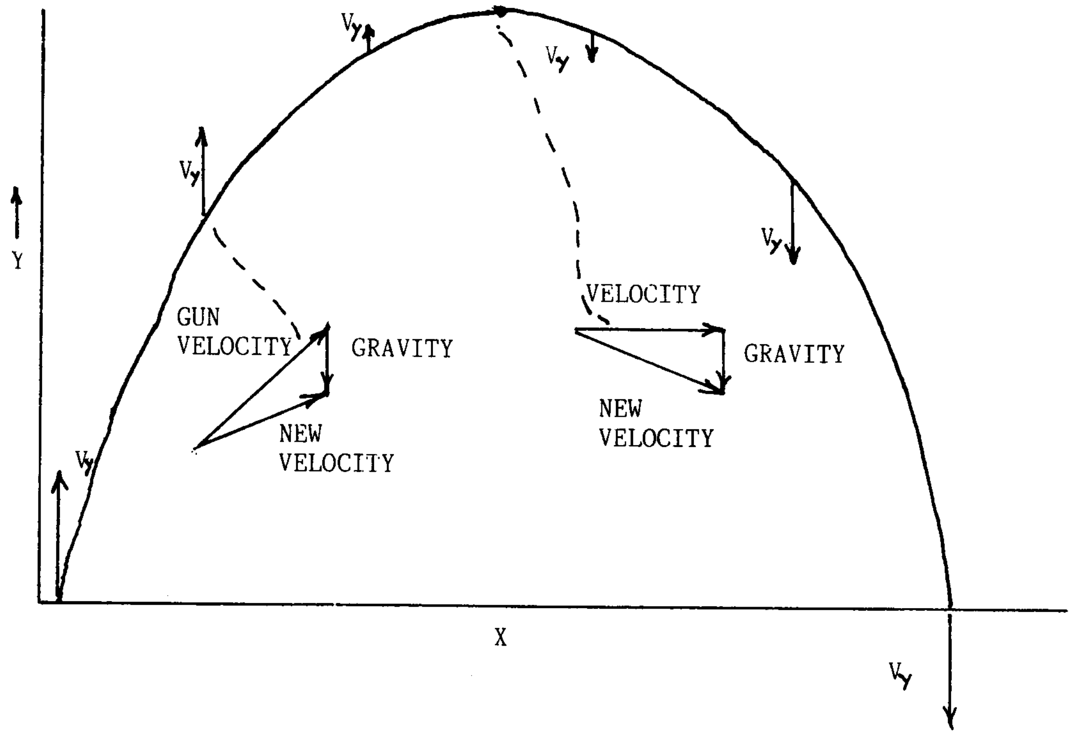
The code also prevents you from firing more than one bullet at a time. When a bullet is on the screen, a flag called BON (short for "bullet on") is set to prevent you from firing again. There is more than a casual reason for doing this. If more than one bullet were fired at one time, you would need to keep track of each bullet's position separately. While two bullets might be manageable, a large number would involve storing the position values into tables, then accessing them in sequence during the bullet setup routine.

A flow chart of the algorithm and the code is shown below.



```
                *BULLET SETUP
616D: AD 0D 60  BSETUP   LDA   BHORIZ
6170: 8D 0F 60           STA   HORIZ
6173: AC 0E 60           LDY   BPHORIZ
6176: BE 7C 64           LDX   XOFF,Y      ;INDEX TO WHICH SHAPE TABLE
6179: BD A2 65           LDA   BSHPLO,X    ;INDEX TO GET LO BYTE OF BOMB -
                *-                        ;SHAPE TABLE
617C: 85 50              STA   SHPL
617E: A9 67              LDA   #>BSHAPES   ;GET HI BYTE OF SHAPE
6180: 85 51              STA   SHPH
6182: A9 02              LDA   #$02
6184: 8D 13 60           STA   SLNGH
6187: 8D 08 60           STA   TEMP
618A: A9 07              LDA   #$07        ;SHAPE 7 LINES DEEP
618C: 8D 12 60           STA   DEPTH
618F: AD 15 60           LDA   BVERT
6192: 8D 0A 60           STA   TVERT
6195: 60                 RTS
                *BULLET SUBROUTINE
6196: AD 16 60  BULLET   LDA   BON         ;TEST BULLET ON SCREEN
6199: C9 01              CMP   #$01
619B: B0 27              BGE   BULUPD
619D: AD 62 C0           LDA   $C062       ; NEG BUTTON PRESSED
61A0: 30 03              BMI   FIRE1
61A2: 4C E3 61           JMP   NOSHOOT
61A5: A9 A8     FIRE1    LDA   #$A8
61A7: 8D 15 60           STA   BVERT
61AA: AC 0B 60           LDY   PHORIZ
61AD: 8C 0E 60           STY   BPHORIZ     ;BULLET HORIZ POS CONSTANT AT -
                *-                        ;INITIAL FIRING POSITION(0-255)
61B0: B9 64 63           LDA   XBASE,Y     ;FIND HOR BYTE OFFSET
61B3: 8D 0D 60           STA   BHORIZ      ;(CONSTANT DURING VERTICAL TRAVEL)
61B6: 20 6D 61           JSR   BSETUP
61B9: 20 A8 60           JSR   GDRAW
61BC: A9 01              LDA   #$01
61BE: 8D 16 60           STA   BON         ;SET BULLET ON SCREEN FLAG
61C1: 4C E3 61           JMP   NOSHOOT
61C4: 20 6D 61  BULUPD   JSR   BSETUP
61C7: 20 A8 60           JSR   GDRAW
61CA: 38                 SEC
61CB: AD 15 60           LDA   BVERT
61CE: E9 08              SBC   #$08
61D0: 8D 15 60           STA   BVERT       ;THE CARRY FLAG IS SET IF POS
61D3: B0 08              BCS   SKIP
61D5: A9 00              LDA   #$00        ;SET BULLET DEAD FLAG
61D7: 8D 16 60           STA   BON
61DA: 4C E3 61           JMP   NOSHOOT
61DD: 20 6D 61  SKIP     JSR   BSETUP
61E0: 20 A8 60           JSR   GDRAW
61E3: 60        NOSHOOT  RTS
```

If you consider a bullet that is traveling diagonally upwards and to the right, and allow gravity to take effect, then the trajectory resembles that of an artillery shell.

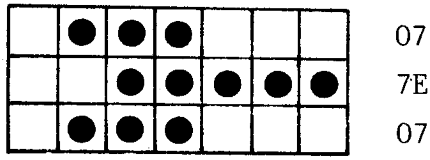


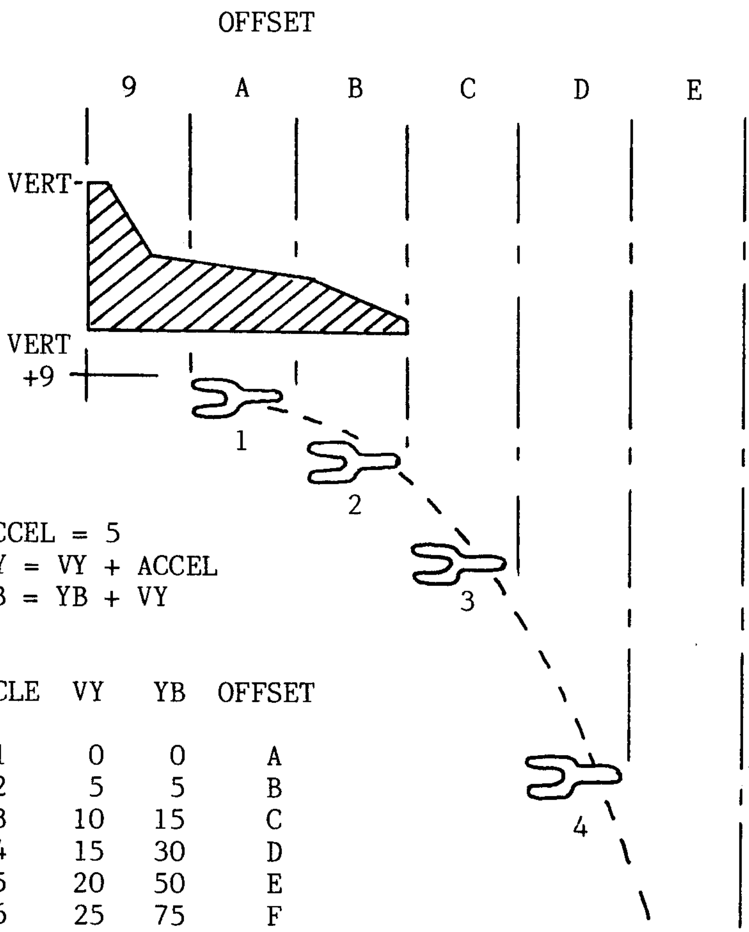
The gravity vector tends to bend our velocity vector so that it no longer travels at its initial 45 degree angle. By the time our bullet reaches the peak of its flight, the gravity vector has incrementally subtracted our vertical velocity vector to zero. At that point, there is only the horizontal velocity component. Since gravity affects our bullet at every time increment, it soon causes our velocity vector to have a negative vertical component. The bullet then begins to fall.

VY = VY + (- G)   Y = Y + VY
VX = CONST   X = X + VX

Once you understand the vector concept of how an object falls, the bomb drop routine becomes elementary. The bomb must fall from the center of our plane because, by design, bomb bays are located at the plane's center of gravity. Since the tail of our plane is the vertical paddle position (VERT) and the plane is eight lines deep, the first available plotting position beneath the plane is at (VERT + 9).

The bomb can be defined by the following shape table.

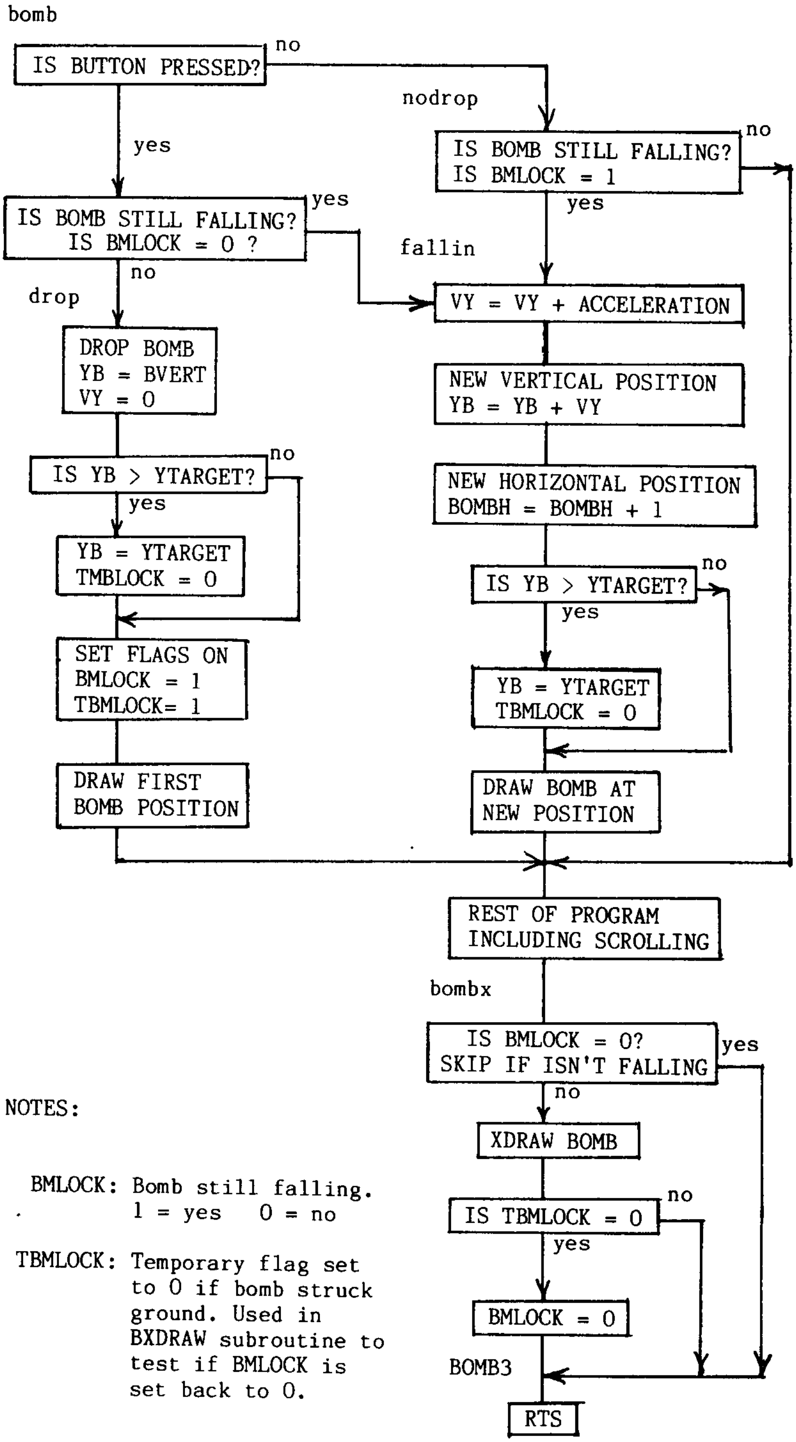




ACCEL = 5
VY = VY + ACCEL
YB = YB + VY

CYCLE	VY	YB	OFFSET
1	0	0	A
2	5	5	B
3	10	15	C
4	15	30	D
5	20	50	E
6	25	75	F

To simplify the graphics, it is easier to move the bomb horizontally one byte (or seven pixels) at a time. Consequently, with the bomb plotted in white, the even - odd offset color problems vanish. The flowchart and code follow.



NOTES:

BMLOCK: Bomb still falling.
1 = yes 0 = no

TBMLOCK: Temporary flag set to 0 if bomb struck ground. Used in BXDRAW subroutine to test if BMLOCK is set back to 0.

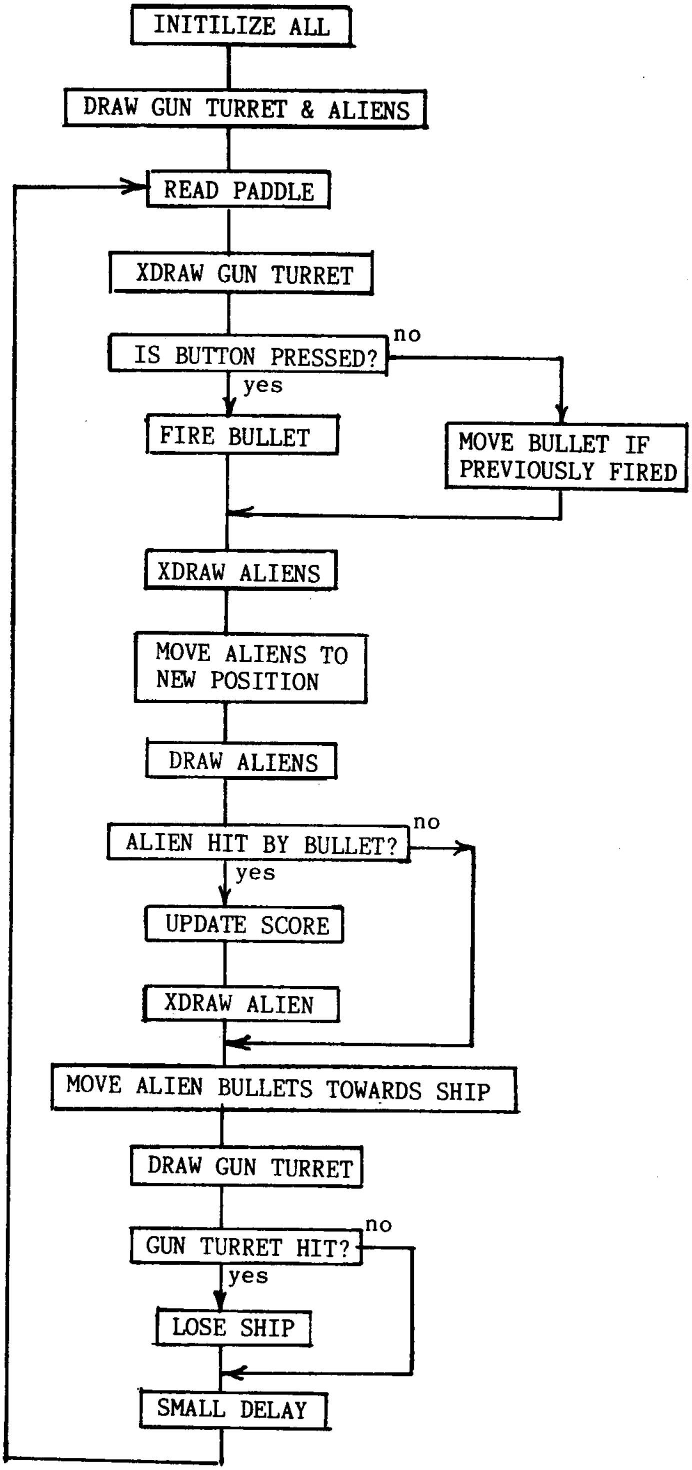
```
                *BOMB SUBROUTINE
                *
6489: AD 61 C0  BOMB     LDA  $C061      ;NEG IF BUTTON PRESSED
648C: 30 03              BMI  BOMB1
648E: 4C BD 64           JMP  NODROP
6491: AD 1A 60  BOMB1    LDA  BMLOCK
6494: C9 01              CMP  #$01       ;IS BOMB STILL FALLING?
6496: B0 2A              BGE  FALLIN     ;YES, GOTO FALLIN
6498: AD 0C 60  DROP     LDA  VERT
649B: 18                 CLC
649C: 69 09              ADC  #$09
649E: 8D 16 60           STA  BVERT      ;INITIAL POSITION OF BOMB
64A1: 8D 17 60           STA  TBVERT
64A4: A9 0A              LDA  #$0A       ;STARTING HORIZ POSITION
64A6: 8D 19 60           STA  BHORIZ
64A9: A9 00              LDA  #$00       ;INITIAL VERTICAL VELOCITY
64AB: 8D 18 60           STA  BVELY
64AE: A9 01              LDA  #$01
64B0: 8D 1A 60           STA  BMLOCK     ;RESET TO ON
64B3: 8D 1B 60           STA  TBMLOCK    ;RESET END OF FALL TO OFF
64B6: 20 45 64           JSR  BSET
64B9: 20 59 64           JSR  BDRAW      ;DRAW BOMB
64BC: 60                 RTS
64BD: AD 1A 60  NODROP   LDA  BMLOCK
64C0: F0 34              BEQ  BOMB3      ;IS BOMB STILL FALLING
64C2: AD 18 60  FALLIN   LDA  BVELY
64C5: 18                 CLC
64C6: 69 05              ADC  #$05       ;ADD ACCELERATION CONSTANT
64C8: 8D 18 60           STA  BVELY      ;NEW VERTICAL VELOCITY
64CB: 6D 16 60           ADC  BVERT
64CE: 8D 17 60           STA  TBVERT
64D1: 8D 16 60           STA  BVERT      ;BOMB'S NEW VERTICAL POSITION
64D4: AD 19 60           LDA  BHORIZ
64D7: 69 01              ADC  #$01       ;BOMB'S HORIZ. VELOCITY(CONSTANT)
64D9: 8D 19 60           STA  BHORIZ     ;BOMB'S NEW HORIZ. POSITION
                *TEMP DETECT FOR BOMB LANDING
64DC: AD 16 60           LDA  BVERT
64DF: C9 B0              CMP  #$B0       ;BOTTOM SCREEN?
64E1: 90 0D              BLT  BOMB2      ;NO! THEN BOMB2
64E3: A9 B0              LDA  #$B0
64E5: 8D 16 60           STA  BVERT
64E8: 8D 17 60           STA  TBVERT
64EB: A9 00              LDA  #$00
64ED: 8D 1B 60           STA  TBMLOCK    ;SET END OF BOMB FALL FLAG
64F0: 20 45 64  BOMB2    JSR  BSET
64F3: 20 59 64           JSR  BDRAW
64F6: 60        BOMB3    RTS
                *BOMB XDRAW
64F7: AD 1A 60  BOMBX    LDA  BMLOCK     ;IS BOMB STILL FALLING?(1=YES)
64FA: F0 16              BEQ  BOMBX1     ;SKIP IF 0
64FC: 20 45 64           JSR  BSET
64FF: AD 16 60           LDA  BVERT
6502: 8D 17 60           STA  TBVERT
6505: 20 70 64           JSR  BXDRAW     ;XDRAW BOMB
6508: AD 1B 60           LDA  TBMLOCK
650B: D0 05              BNE  BOMBX1
650D: A9 00              LDA  #$00
650F: 8D 1A 60           STA  BMLOCK     ;RESET BOMB FALLING TO OFF
6512: 60        BOMBX1   RTS
```

```
                *DRAWING ROUTINES FOR BOMB
                *
6445: A9 EF     BSET     LDA  #<SHBOMB    ;ADDRESS BOMB SHAPE
6447: 85 56              STA  BOMBL
6449: A9 68              LDA  #>SHBOMB
644B: 85 57              STA  BOMBH
644D: AD 19 60           LDA  BHORIZ      ;BOMB'S HORIZ. POSITION
6450: 8D 0E 60           STA  HORIZ
6453: A9 03              LDA  #$03
6455: 8D 11 60           STA  DEPTH
6458: 60                 RTS
6459: AC 17 60  BDRAW    LDY  TBVERT      ;BOMB VERT POS
645C: 20 1C 63           JSR  GETADR
645F: A2 00              LDX  #$00
6461: A1 56              LDA  (BOMBL,X)   ;GET ADDRESS OF BOMB SHAPE
6463: 91 26              STA  (HIRESL),Y  ;PLOT
6465: EE 17 60           INC  TBVERT
6468: E6 56              INC  BOMBL
646A: CE 11 60           DEC  DEPTH
646D: D0 EA              BNE  BDRAW
646F: 60                 RTS
6470: AC 17 60  BXDRAW   LDY  TBVERT
6473: 20 1C 63           JSR  GETADR
6476: A2 00              LDX  #$00
6478: A1 56              LDA  (BOMBL,X)
647A: 51 26              EOR  (HIRESL),Y
647C: 91 26              STA  (HIRESL),Y
647E: EE 17 60           INC  TBVERT
6481: E6 56              INC  BOMBL
6483: CE 11 60           DEC  DEPTH
6486: D0 E8              BNE  BXDRAW
6488: 60                 RTS
```

THE INVADERS TYPE GAME

Games of this type are classed as shoot-'em-up games. They generally involve a movable gun turret, or space ship, that traverses the bottom of the screen. The object is to defend against a horde of attacking aliens by firing bullets up at them. The aliens can either advance in ranks, like they do in Space Invaders, or they can swoop down singly or in groups, as they do in Apple Galaxian. Sometimes, background stars, moving from top to bottom, generate the feeling that your gun or ship is in motion. But these games still involve a static screen in the sense that all objects are manipulated within the screen space.

On the other hand, there are games that could be classed as dynamic because the entire background is scrolling in some preset direction, while the ship or other vehicle usually has controllable movement on the non-scrolling axis only. Objects which are out of view can be manipulated and scheduled to appear when your ship moves into their general vicinity. Moving your ship involves scrolling the entire background, so that terrain and objects out of the range of your display, suddenly appear. Of course, the terrain you previously

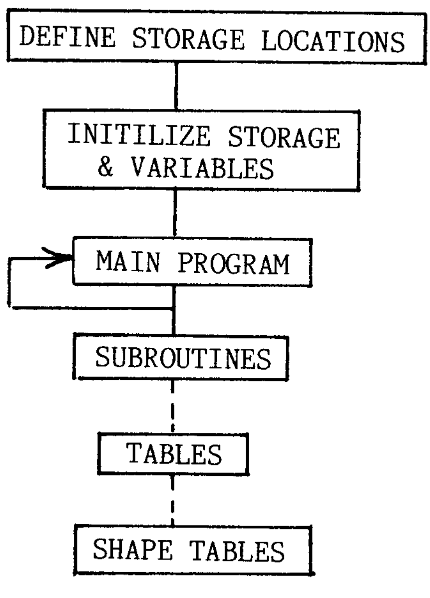


INITILIZE ALL
DRAW GUN TURRET & ALIENS
READ PADDLE
XDRAW GUN TURRET
IS BUTTON PRESSED?
no
yes
FIRE BULLET
MOVE BULLET IF PREVIOUSLY FIRED
XDRAW ALIENS
MOVE ALIENS TO NEW POSITION
DRAW ALIENS
ALIEN HIT BY BULLET?
no
yes
UPDATE SCORE
XDRAW ALIEN
MOVE ALIEN BULLETS TOWARDS SHIP
DRAW GUN TURRET
GUN TURRET HIT?
no
yes
LOSE SHIP
SMALL DELAY

occupied is now off screen. Arcade games like Pegasus II involve constant terrain scrolling from right to left as your spaceship moves further into the enemy's territory. This type of animation will be discussed in the following chapter.

The sequence of events in an Invaders game is diagrammed above. It is typical of most games. While we aren't going to develop the entire game, we will integrate the paddle and bullet firing routines previously outlined in this chapter with the color drawing routines discussed in Chapter 5.

Since this is the first time that we have actually put together developed subroutines into a workable game, I should discuss the overall structure of a machine language program. Programs begin with storage allocations for variables, and zero page equates or assignments to specific memory locations in zero page for others. These are followed by initialization routines that activate Hi-Res graphics, clear the screen, and set specific variables to their initial values. The main program loop comes next, followed by subroutines. Your tables, both shape and reference, reside at the end.



Using a good assembler makes the job of writing a program relatively easy. All the tedious mechanical problems like relative addressing for branch instructions, references to variable storage, and memory storage assignments are handled automatically. In fact, the assembler is so adept at calculating addresses that I often use it for generating internal reference tables to the locations of my shapes.

Normally, it is good programming practice to put shape tables in some specific yet safe place in memory. But while developing short programs, it is an extra step to load your shape tables into memory each time that you want to test the program. Sometimes, it is more convenient to incorporate shape tables into your program, although their memory location changes with each modification to your source code.

The assembler can be used to define a reference table to the low byte of each shape in your shape table. In the TED II + assembler, DB defines a byte - the lo byte. BIG MAC and MERLIN use DFB.

```
659B: 16    SHPLO  DB  SHAPES
659C: 2E           DB  SHAPES + $18
659D: 46           DB  SHAPES + $30

                   DB  SHAPES + $90
```

The assembler looks up the lo byte address for each of our shapes according to the address that we give to it. Each shape is 24 (or $18) bytes long. This accounts for the reason each succeeding shape address increases by $18. Notice on the left of the above listing that the actual byte value is placed into our table for each shape.(SHPLO 16 2E 46 5E ...). This corresponds exactly to the lo byte values in our floating shape table. I'll extend a word of caution about using this method. Shape tables must not cross page boundaries, because the hi byte, which is stored at SHPH in our drawing routine, must be kept constant. Sometimes, extra space needs to be allocated in the code just before the shape table for correcting this problem. The DS pseudo-op code to Define Storage can be used.

The lo and hi bytes for a particular shape are determined by the following code:

```
LDY  PHORIZ   ;PADDLE VALUE 0-255
LDX  XOFF,Y   ;INDEX TO FIND WHICH SHAPE IN TABLE
LDA  SHPLO,X  ;INDEX TO GET LO BYTE OF SHAPE IN TABLE
STA  SHPL
LDA  #>SHAPES ;GET HI BYTE OF SHAPE TABLE
STA  SHPH
```

If you were to choose, instead, to put the shape table at $7000 in memory, you would use a table called SHPADR to index to the proper shape. Each position in the table would reference the lo byte of a shape in the shape table.

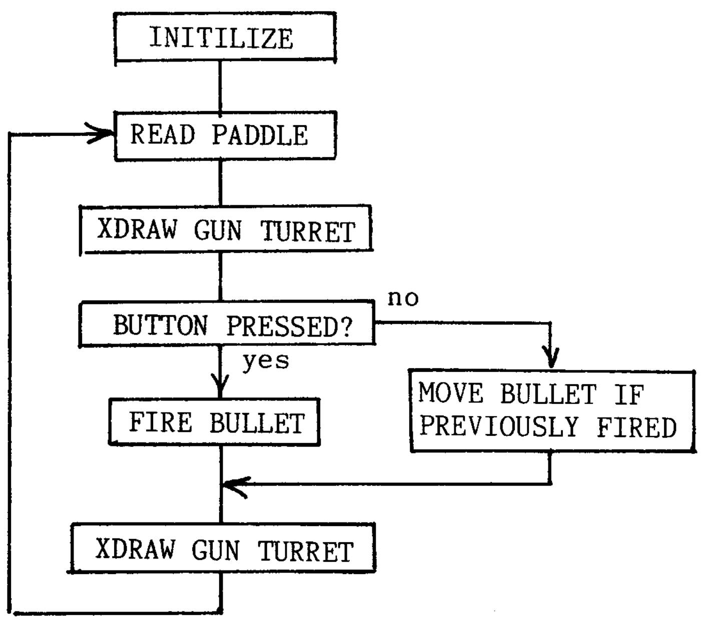
```
SHPADR  HEX  00 18 30 48 60 78 90
```

The setup routine is modified as follows:

```
LDY  PHORIZ   ;PADDLE VALUE 0-256
LDX  XOFF,Y   ;INDEX TO FIND WHICH SHAPE IN TABLE
LDA  SHPADR,X ;INDEX TO LO BYTE IN TABLE
STA  SHPL
LDA  $70      ;HI BYTE OF TABLE
STA  SHPH
```

There are no speed advantages or disadvantages gained by using either method. The former method is strictly for convenience to be used while developing small programs. To avoid mistakes, large programs should definitely have shape tables fixed in memory.

The Invaders routine which follows lacks alien targets. It does, however, have a paddle-controlled gun turret which is capable of firing one bullet at a time. It is a start, and as you will see later, putting aliens on the screen is not difficult. A simple flow chart of the program and the actual code is shown below.



```
                *CODE FOR PART OF INVADERS GAME
                         ORG  $6000
6000: 4C 17 60           JMP  PROG         ;JUMP TO START OF CODE
                COUNT    DS   1
                INDEX    DS   1
                PADDLEL  DS   1
                PADDLEH  DS   1
                PDL      DS   1
                TEMP     DS   1
                VERT     DS   1
                TVERT    DS   1
                PHORIZ   DS   1
                TPHORIZ  DS   1
                BHORIZ   DS   1
                BPHORIZ  DS   1
                HORIZ    DS   1
                OBJ      DS   1
                LNGH     DS   1
                DEPTH    DS   1
                SLNGH    DS   1
                SHOT     DS   1
                BVERT    DS   1
                BON      DS   1
                HIRESL   EQU  $26
                HIRESH   EQU  HIRESL+$1
                SHPL     EQU  $50
                SHPH     EQU  SHPL+$1
                SSHPL    EQU  $52
                SSHPH    EQU  $53
                STESTL   EQU  $54
                STESTH   EQU  STESTL+$1
                PREAD    EQU  $FB1E
6017: AD 50 C0  PROG     LDA  $C050
601A: AD 52 C0           LDA  $C052
601D: AD 57 C0           LDA  $C057
6020: 20 8E 60           JSR  CLRSCR
6023: A9 00              LDA  #$00
6025: 8D 16 60           STA  BON
                *READ PADDLE #1
6028: A2 01     RPDL     LDX  #$01
602A: 20 1E FB           JSR  PREAD
602D: 8C 07 60  SKIPP    STY  PDL
6030: 98                 TYA
6031: CD 0B 60           CMP  PHORIZ       ;PADDLE<HORIZ POS THEN SUBTRACT 5
6034: B0 1E              BGE  PADDLE3
6036: AD 0B 60           LDA  PHORIZ
6039: 38                 SEC
603A: E9 05              SBC  #$05
603C: B0 08              BGE  PADDLE1      ;MAKE SURE =>0
603E: A9 00              LDA  #$00
6040: 8D 0B 60           STA  PHORIZ
6043: 8D 0C 60           STA  TPHORIZ
6046: CD 07 60  PADDLE1  CMP  PDL          ;DON'T WANT TO GO PAST PADDLE POS
6049: B0 03              BGE  PADDLE2
604B: AD 07 60           LDA  PDL
604E: 8D 0B 60  PADDLE2  STA  PHORIZ
6051: 4C 71 60           JMP  PADDLE6
6054: CD 0B 60  PADDLE3  CMP  PHORIZ       ;PADDLE>PHORIZ POS THEN ADD 5
6057: F0 12              BEQ  PADDLE4
6059: AD 0B 60           LDA  PHORIZ
```

```
605C: C9 FA                CMP  #$FA        ;IS PHORIZ>250
605E: B0 0B                BGE  PADDLE4
6060: AD 0B 60             LDA  PHORIZ
6063: 18                   CLC
6064: 69 05                ADC  #$05
6066: CD 07 60             CMP  PDL         ;DON'T WANT TO GO PAST PADDLE POS
6069: 90 03                BLT  PADDLE5
606B: AD 07 60    PADDLE4  LDA  PDL
606E: 8D 0B 60    PADDLE5  STA  PHORIZ
6071: 8D 0C 60    PADDLE6  STA  TPHORIZ
6074: 20 3F 61             JSR  GSETUP
6077: 20 A8 60             JSR  GDRAW
607A: 20 6D 61             JSR  BSETUP
607D: 20 96 61             JSR  BULLET
6080: A9 60                LDA  #$60
6082: 20 A8 FC             JSR  $FCA8
6085: 20 3F 61             JSR  GSETUP
6088: 20 A8 60             JSR  GDRAW
608B: 4C 28 60             JMP  RPDL        ;BACK TO BEGINNING OF MAIN LOOP
                  *
                  ** S U B R O U T I N E S **
                  *
                  *CLEAR SCREEN
608E: A9 00       CLRSCR   LDA  #$00
6090: 85 26                STA  HIRESL
6092: A9 20                LDA  #$20
6094: 85 27                STA  HIRESH
6096: A0 00       CLR1     LDY  #$00
6098: A9 00                LDA  #$00
609A: 91 26       CLR2     STA  (HIRESL),Y
609C: C8                   INY
609D: D0 FB                BNE  CLR2
609F: E6 27                INC  HIRESH
60A1: A5 27                LDA  HIRESH
60A3: C9 40                CMP  #$40
60A5: 90 EF                BCC  CLR1
60A7: 60                   RTS
                  *DRAW GUN SHAPE DEPTH LINES BY LNGH
60A8: AC 0A 60    GDRAW    LDY  TVERT       ; VERTICAL POSITION
60AB: 20 E6 60             JSR  GETADR
60AE: A2 00                LDX  #$00
60B0: A1 50       GDRAW3   LDA  (SHPL,X)    ;GET BYTE OF SHIP'S SHAPE
60B2: 51 26                EOR  (HIRESL),Y
60B4: 91 26                STA  (HIRESL),Y ;PLOT
60B6: E6 50                INC  SHPL        ; NEXT BYTE OF TABLE
60B8: C8                   INY
60B9: CE 13 60             DEC  SLNGH
60BC: D0 F2                BNE  GDRAW3      ;IF LINE NOT FINISHED BRANCH
60BE: EE 0A 60             INC  TVERT       ;OTHERWISE NEXT LINE DOWN
60C1: CE 12 60             DEC  DEPTH
60C4: D0 E2                BNE  GDRAW
60C6: 60                   RTS
                  *XDRAW GUN SHAPE
60C7: AC 0A 60    GXDRAW   LDY  TVERT       ;VERTICAL POSITION
60CA: 20 E6 60             JSR  GETADR
60CD: A2 00                LDX  #$00
60CF: A1 50       GXDRAW2  LDA  (SHPL,X)
60D1: 51 26                EOR  (HIRESL),Y
60D3: 91 26                STA  (HIRESL),Y
60D5: E6 50                INC  SHPL
```

```
60D7: C8                          INY
60D8: CE 13 60                    DEC  SLNGH
60DB: D0 F2                       BNE  GXDRAW2
60DD: EE 0A 60                    INC  TVERT
60E0: CE 12 60                    DEC  DEPTH
60E3: D0 E2                       BNE  GXDRAW
60E5: 60                          RTS
                 *GETADR SUBROUTINE
60E6: B9 E4 61   GETADR           LDA  YVERTL,Y    ;LOOK UP LO BYTE OF LINE
60E9: 18                          CLC
60EA: 6D 0F 60                    ADC  HORIZ       ;ADD DISPLACEMENT INTO LINE
60ED: 85 26                       STA  HIRESL
60EF: B9 A4 62                    LDA  YVERTH,Y    ;LOOK UP HI BYTE OF LINE
60F2: 85 27                       STA  HIRESH
60F4: AD 08 60                    LDA  TEMP
60F7: 8D 13 60                    STA  SLNGH
60FA: A0 00                       LDY  #$00
60FC: 60                          RTS
                 *DRAW ALIEN SHIPS & TARGETS
60FD: A2 00      DRAW             LDX  #$00
60FF: A1 50      DRAW2            LDA  (SHPL,X)
6101: 91 26                       STA  (HIRESL),Y
6103: A5 27                       LDA  HIRESH
6105: 18                          CLC
6106: 69 04                       ADC  #$04
6108: 85 27                       STA  HIRESH
610A: E6 50                       INC  SHPL
610C: C9 40                       CMP  #$40
610E: 90 EF                       BCC  DRAW2
6110: E9 20                       SBC  #$20
6112: 85 27                       STA  HIRESH
6114: CE 11 60                    DEC  LNGH
6117: F0 03                       BEQ  DRAW3
6119: C8                          INY
611A: D0 E3                       BNE  DRAW2
611C: 60         DRAW3            RTS
                 *XDRAW ALIEN SHIPS & TARGETS
611D: A2 00      XDRAW            LDX  #$00
611F: A1 50      XDRAW2           LDA  (SHPL,X)
6121: 51 26                       EOR  (HIRESL),Y
6123: 91 26                       STA  (HIRESL),Y
6125: A5 27                       LDA  HIRESH
6127: 18                          CLC
6128: 69 04                       ADC  #$04
612A: 85 27                       STA  HIRESH
612C: E6 50                       INC  SHPL
612E: C9 40                       CMP  #$40
6130: 90 ED                       BCC  XDRAW2
6132: E9 20                       SBC  #$20
6134: 85 27                       STA  HIRESH
6136: CE 11 60                    DEC  LNGH
6139: F0 03                       BEQ  XDRAW3
613B: C8                          INY
613C: D0 E1                       BNE  XDRAW2
613E: 60         XDRAW3           RTS
                 *DRAWING ROUTINES SETUP
613F: AC 0B 60   GSETUP           LDY  PHORIZ      ;PADDLE VALUE 0-256
6142: B9 64 63                    LDA  XBASE,Y     ;GET BYTE OFFSET IN TABLE
6145: 8D 0F 60                    STA  HORIZ
6148: BE 7C 64                    LDX  XOFF,Y      ;INDEX TO FIND WHICH SHAPE TABLE
```

```
614B: BC 94 65              LDY  SHPADR,X    ;X IS 0-6
614E: B9 9B 65              LDA  SHPLO,Y     ;INDEX TO GET LO BYTE SHAPE TABLE
6151: 85 50                 STA  SHPL
6153: A9 66                 LDA  #>SHAPES    ;GET HI BYTE OF SHAPE
6155: 85 51                 STA  SHPH
6157: A9 03                 LDA  #$03
6159: 8D 13 60              STA  SLNGH
615C: 8D 08 60              STA  TEMP
615F: A9 08                 LDA  #$08
6161: 8D 12 60              STA  DEPTH
6164: A9 B0                 LDA  #$B0
6166: 8D 09 60              STA  VERT
6169: 8D 0A 60              STA  TVERT
616C: 60                    RTS
                    *BULLET SETUP
616D: AD 0D 60      BSETUP  LDA  BHORIZ
6170: 8D 0F 60              STA  HORIZ
6173: AC 0E 60              LDY  BPHORIZ
6176: BE 7C 64              LDX  XOFF,Y      ;INDEX TO WHICH SHAPE TABLE
6179: BD A2 65              LDA  BSHPLO,X    ;INDEX TO GET LO BYTE OF BOMB -
                    *-                      ;SHAPE TABLE
617C: 85 50                 STA  SHPL
617E: A9 67                 LDA  #>BSHAPES   ;GET HI BYTE OF SHAPE
6180: 85 51                 STA  SHPH
6182: A9 02                 LDA  #$02
6184: 8D 13 60              STA  SLNGH
6187: 8D 08 60              STA  TEMP
618A: A9 07                 LDA  #$07        ;SHAPE 7 LINES DEEP
618C: 8D 12 60              STA  DEPTH
618F: AD 15 60              LDA  BVERT
6192: 8D 0A 60              STA  TVERT
6195: 60                    RTS
                    *BULLET SUBROUTINE
6196: AD 16 60      BULLET  LDA  BON         ;TEST BULLET ON SCREEN
6199: C9 01                 CMP  #$01
619B: B0 27                 BGE  BULUPD
619D: AD 62 C0              LDA  $C062       ; NEG BUTTON PRESSED
61A0: 30 03                 BMI  FIRE1
61A2: 4C E3 61              JMP  NOSHOOT
61A5: A9 A8         FIRE1   LDA  #$A8
61A7: 8D 15 60              STA  BVERT
61AA: AC 0B 60              LDY  PHORIZ
61AD: 8C 0E 60              STY  BPHORIZ     ;BULLET HORIZ POS CONSTANT AT -
                    *-                      ;INITIAL FIRING POSITION(0-255)
61B0: B9 64 63              LDA  XBASE,Y     ;FIND HOR BYTE OFFSET
61B3: 8D 0D 60              STA  BHORIZ      ;(CONSTANT DURING VERTICAL TRAVEL)
61B6: 20 6D 61              JSR  BSETUP
61B9: 20 A8 60              JSR  GDRAW
61BC: A9 01                 LDA  #$01
61BE: 8D 16 60              STA  BON         ;SET BULLET ON SCREEN FLAG
61C1: 4C E3 61              JMP  NOSHOOT
61C4: 20 6D 61      BULUPD  JSR  BSETUP
61C7: 20 A8 60              JSR  GDRAW
61CA: 38                    SEC
61CB: AD 15 60              LDA  BVERT
61CE: E9 08                 SBC  #$08
61D0: 8D 15 60              STA  BVERT       ;THE CARRY FLAG IS SET IF POS
61D3: B0 08                 BCS  SKIP
61D5: A9 00                 LDA  #$00        ;SET BULLET DEAD FLAG
61D7: 8D 16 60              STA  BON
```

```
61DA: 4C E3 61                JMP  NOSHOOT
61DD: 20 6D 61      SKIP      JSR  BSETUP
61E0: 20 A8 60                JSR  GDRAW
61E3: 60            NOSHOOT   RTS
                    *
                    **T A B L E S **
                    *
61E4: 00 00 00
61E7: 00 00 00
61EA: 00 00         YVERTL    HEX  0000000000000000
61EC: 80 80 80
61EF: 80 80 80
61F2: 80 80                   HEX  8080808080808080
61F4: 00 00 00
61F7: 00 00 00
61FA: 00 00                   HEX  0000000000000000
61FC: 80 80 80
61FF: 80 80 80
6202: 80 80                   HEX  8080808080808080
6204: 00 00 00
6207: 00 00 00
620A: 00 00                   HEX  0000000000000000
620C: 80 80 80
620F: 80 80 80
6212: 80 80                   HEX  8080808080808080
6214: 00 00 00
6217: 00 00 00
621A: 00 00                   HEX  0000000000000000
621C: 80 80 80
621F: 80 80 80
6222: 80 80                   HEX  8080808080808080
6224: 28 28 28
6227: 28 28 28
622A: 28 28                   HEX  2828282828282828
622C: A8 A8 A8
622F: A8 A8 A8
6232: A8 A8                   HEX  A8A8A8A8A8A8A8A8
6234: 28 28 28
6237: 28 28 28
623A: 28 28                   HEX  2828282828282828
623C: A8 A8 A8
623F: A8 A8 A8
6242: A8 A8                   HEX  A8A8A8A8A8A8A8A8
6244: 28 28 28
6247: 28 28 28
624A: 28 28                   HEX  2828282828282828
624C: A8 A8 A8
624F: A8 A8 A8
6252: A8 A8                   HEX  A8A8A8A8A8A8A8A8
6254: 28 28 28
6257: 28 28 28
625A: 28 28                   HEX  2828282828282828
625C: A8 A8 A8
625F: A8 A8 A8
6262: A8 A8                   HEX  A8A8A8A8A8A8A8A8
6264: 50 50 50
6267: 50 50 50
626A: 50 50                   HEX  5050505050505050
626C: DO DO DO
626F: DO DO DO
6272: DO DO                   HEX  DODODODODODODODO
```

```
6274: 50 50 50
6277: 50 50 50
627A: 50 50     266           HEX  5050505050505050
627C: D0 D0 D0
627F: D0 D0 D0
6282: D0 D0     267           HEX  D0D0D0D0D0D0D0D0
6284: 50 50 50
6287: 50 50 50
628A: 50 50     268           HEX  5050505050505050
628C: D0 D0 D0
628F: D0 D0 D0
6292: D0 D0     269           HEX  D0D0D0D0D0D0D0D0
6294: 50 50 50
6297: 50 50 50
629A: 50 50     270           HEX  5050505050505050
629C: D0 D0 D0
629F: D0 D0 D0
62A2: D0 D0     271           HEX  D0D0D0D0D0D0D0D0
                272  *
62A4: 20 24 28
62A7: 2C 30 34
62AA: 38 3C     273  YVERTH   HEX  2024282C3034383C
62AC: 20 24 28
62AF: 2C 30 34
62B2: 38 3C     274           HEX  2024282C3034383C
62B4: 21 25 29
62B7: 2D 31 35
62BA: 39 3D     275           HEX  2125292D3135393D
62BC: 21 25 29
62BF: 2D 31 35
62C2: 39 3D     276           HEX  2125292D3135393D
62C4: 22 26 2A
62C7: 2E 32 36
62CA: 3A 3E     277           HEX  22262A2E32363A3E
62CC: 22 26 2A
62CF: 2E 32 36
62D2: 3A 3E     278           HEX  22262A2E32363A3E
62D4: 23 27 2B
62D7: 2F 33 37
62DA: 3B 3F     279           HEX  23272B2F33373B3F
62DC: 23 27 2B
62DF: 2F 33 37
62E2: 3B 3F     280           HEX  23272B2F33373B3F
62E4: 20 24 28
62E7: 2C 30 34
62EA: 38 3C     281           HEX  2024282C3034383C
62EC: 20 24 28
62EF: 2C 30 34
62F2: 38 3C     282           HEX  2024282C3034383C
62F4: 21 25 29
62F7: 2D 31 35
62FA: 39 3D     283           HEX  2125292D3135393D
62FC: 21 25 29
62FF: 2D 31 35
6302: 39 3D     284           HEX  2125292D3135393D
6304: 22 26 2A
6307: 2E 32 36
630A: 3A 3E     285           HEX  22262A2E32363A3E
630C: 22 26 2A
630F: 2E 32 36
```

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6312: 3A 3E     286          HEX  22262A2E32363A3E
6314: 23 27 2B
6317: 2F 33 37
631A: 3B 3F     287          HEX  23272B2F33373B3F
631C: 23 27 2B
631F: 2F 33 37
6322: 3B 3F     288          HEX  23272B2F33373B3F
6324: 20 24 28
6327: 2C 30 34
632A: 38 3C     289          HEX  2024282C3034383C
632C: 20 24 28
632F: 2C 30 34
6332: 38 3C     290          HEX  2024282C3034383C
6334: 21 25 29
6337: 2D 31 35
633A: 39 3D     291          HEX  2125292D3135393D
633C: 21 25 29
633F: 2D 31 35
6342: 39 3D     292          HEX  2125292D3135393D
6344: 22 26 2A
6347: 2E 32 36
634A: 3A 3E     293          HEX  22262A2E32363A3E
634C: 22 26 2A
634F: 2E 32 36
6352: 3A 3E     294          HEX  22262A2E32363A3E
6354: 23 27 2B
6357: 2F 33 37
635A: 3B 3F     295          HEX  23272B2F33373B3F
635C: 23 27 2B
635F: 2F 33 37
6362: 3B 3F     296          HEX  23272B2F33373B3F
6364: 00 00 00
6367: 00 00 00
636A: 00        297   XBASE  HEX  00000000000000
636B: 00 01 01
636E: 01 01 01
6371: 01        298          HEX  00010101010101
6372: 02 02 02
6375: 02 02 02
6378: 02        299          HEX  02020202020202
6379: 02 03 03
637C: 03 03 03
637F: 03        300          HEX  02030303030303
6380: 04 04 04
6383: 04 04 04
6386: 04        301          HEX  04040404040404
6387: 04 05 05
638A: 05 05 05
638D: 05        302          HEX  04050505050505
638E: 06 06 06
6391: 06 06 06
6394: 06        303          HEX  06060606060606
6395: 06 07 07
6398: 07 07 07
639B: 07        304          HEX  06070707070707
639C: 08 08 08
639F: 08 08 08
63A2: 08        305          HEX  08080808080808
63A3: 08 09 09
63A6: 09 09 09
```

```
63A9: 09        306        HEX  08090909090909
63AA: 0A 0A 0A
63AD: 0A 0A 0A
63B0: 0A        307        HEX  0A0A0A0A0A0A0A
63B1: 0A 0B 0B
63B4: 0B 0B 0B
63B7: 0B        308        HEX  0A0B0B0B0B0B0B
63B8: 0C 0C 0C
63BB: 0C 0C 0C
63BE: 0C        309        HEX  0C0C0C0C0C0C0C
63BF: 0C 0D 0D
63C2: 0D 0D 0D
63C5: 0D        310        HEX  0C0D0D0D0D0D0D
63C6: 0E 0E 0E
63C9: 0E 0E 0E
63CC: 0E        311        HEX  0E0E0E0E0E0E0E
63CD: 0E 0F 0F
63D0: 0F 0F 0F
63D3: 0F        312        HEX  0E0F0F0F0F0F0F
63D4: 10 10 10
63D7: 10 10 10
63DA: 10        313        HEX  10101010101010
63DB: 10 11 11
63DE: 11 11 11
63E1: 11        314        HEX  10111111111111
63E2: 12 12 12
63E5: 12 12 12
63E8: 12        315        HEX  12121212121212
63E9: 12 13 13
63EC: 13 13 13
63EF: 13        316        HEX  12131313131313
63F0: 14 14 14
63F3: 14 14 14
63F6: 14        317        HEX  14141414141414
63F7: 14 15 15
63FA: 15 15 15
63FD: 15        318        HEX  14151515151515
63FE: 16 16 16
6401: 16 16 16
6404: 16        319        HEX  16161616161616
6405: 16 17 17
6408: 17 17 17
640B: 17        320        HEX  16171717171717
640C: 18 18 18
640F: 18 18 18
6412: 18        321        HEX  18181818181818
6413: 18 19 19
6416: 19 19 19
6419: 19        322        HEX  18191919191919
641A: 1A 1A 1A
641D: 1A 1A 1A
6420: 1A        323        HEX  1A1A1A1A1A1A1A
6421: 1A 1B 1B
6424: 1B 1B 1B
6427: 1B        324        HEX  1A1B1B1B1B1B1B
6428: 1C 1C 1C
642B: 1C 1C 1C
642E: 1C        325        HEX  1C1C1C1C1C1C1C
642F: 1C 1D 1D
6432: 1D 1D 1D
```

```
6435: 1D        326            HEX  1C1D1D1D1D1D1D
6436: 1E 1E 1E
6439: 1E 1E 1E
643C: 1E        327            HEX  1E1E1E1E1E1E1E
643D: 1E 1F 1F
6440: 1F 1F 1F
6443: 1F        328            HEX  1E1F1F1F1F1F1F
6444: 20 20 20
6447: 20 20 20
644A: 20        329            HEX  20202020202020
644B: 20 21 21
644E: 21 21 21
6451: 21        330            HEX  20212121212121
6452: 22 22 22
6455: 22 22 22
6458: 22        331            HEX  22222222222222
6459: 22 23 23
645C: 23 23 23
645F: 23        332            HEX  22232323232323
6460: 24 24 24
6463: 24 24 24
6466: 24        333            HEX  24242424242424
6467: 24 25 25
646A: 25 25 25
646D: 25        334            HEX  24252525252525
646E: 26 26 26
6471: 26 26 26
6474: 26        335            HEX  26262626262626
6475: 26 27 27
6478: 27 27 27
647B: 27        336            HEX  26272727272727
647C: 00 00 01
647F: 01 02 02
6482: 03        337  XOFF      HEX  00000101020203
6483: 03 04 04
6486: 05 05 06
6489: 06        338            HEX  03040405050606
648A: 00 00 01
648D: 01 02 02
6490: 03        339            HEX  00000101020203
6491: 03 04 04
6494: 05 05 06
6497: 06        340            HEX  03040405050606
6498: 00 00 01
649B: 01 02 02
649E: 03        341            HEX  00000101020203
649F: 03 04 04
64A2: 05 05 06
64A5: 06        342            HEX  03040405050606
64A6: 00 00 01
64A9: 01 02 02
64AC: 03        343            HEX  00000101020203
64AD: 03 04 04
64B0: 05 05 06
64B3: 06        344            HEX  03040405050606
64B4: 00 00 01
64B7: 01 02 02
64BA: 03        345            HEX  00000101020203
64BB: 03 04 04
64BE: 05 05 06
```

```
64C1: 06         346          HEX  03040405050606
64C2: 00 00 01
64C5: 01 02 02
64C8: 03         347          HEX  00000101020203
64C9: 03 04 04
64CC: 05 05 06
64CF: 06         348          HEX  03040405050606
64D0: 00 00 01
64D3: 01 02 02
64D6: 03         349          HEX  00000101020203
64D7: 03 04 04
64DA: 05 05 06
64DD: 06         350          HEX  03040405050606
64DE: 00 00 01
64E1: 01 02 02
64E4: 03         351          HEX  00000101020203
64E5: 03 04 04
64E8: 05 05 06
64EB: 06         352          HEX  03040405050606
64EC: 00 00 01
64EF: 01 02 02
64F2: 03         353          HEX  00000101020203
64F3: 03 04 04
64F6: 05 05 06
64F9: 06         354          HEX  03040405050606
64FA: 00 00 01
64FD: 01 02 02
6500: 03         355          HEX  00000101020203
6501: 03 04 04
6504: 05 05 06
6507: 06         356          HEX  03040405050606
6508: 00 00 01
650B: 01 02 02
650E: 03         357          HEX  00000101020203
650F: 03 04 04
6512: 05 05 06
6515: 06         358          HEX  03040405050606
6516: 00 00 01
6519: 01 02 02
651C: 03         359          HEX  00000101020203
651D: 03 04 04
6520: 05 05 06
6523: 06         360          HEX  03040405050606
6524: 00 00 01
6527: 01 02 02
652A: 03         361          HEX  00000101020203
652B: 03 04 04
652E: 05 05 06
6531: 06         362          HEX  03040405050606
6532: 00 00 01
6535: 01 02 02
6538: 03         363          HEX  00000101020203
6539: 03 04 04
653C: 05 05 06
653F: 06         364          HEX  03040405050606
6540: 00 00 01
6543: 01 02 02
6546: 03         365          HEX  00000101020203
6547: 03 04 04
654A: 05 05 06
```

```
654D: 06        366              HEX  03040405050606
654E: 00 00 01
6551: 01 02 02
6554: 03        367              HEX  00000101020203
6555: 03 04 04
6558: 05 05 06
655B: 06        368              HEX  03040405050606
655C: 00 00 01
655F: 01 02 02
6562: 03        369              HEX  00000101020203
6563: 03 04 04
6566: 05 05 06
6569: 06        370              HEX  03040405050606
656A: 00 00 01
656D: 01 02 02
6570: 03        371              HEX  00000101020203
6571: 03 04 04
6574: 05 05 06
6577: 06        372              HEX  03040405050606
6578: 00 00 01
657B: 01 02 02
657E: 03        373              HEX  00000101020203
657F: 03 04 04
6582: 05 05 06
6585: 06        374              HEX  03040405050606
6586: 00 00 01
6589: 01 02 02
658C: 03        375              HEX  00000101020203
658D: 03 04 04
6590: 05 05 06
6593: 06        376              HEX  03040405050606
                377  *TABLES
6594: 00 01 02
6597: 03 04 05
659A: 06        378  SHPADR      HEX  00010203040506
                379  *
659B: 16        380  SHPLO       DFB  SHAPES
659C: 2E        381              DFB  SHAPES+$18
659D: 46        382              DFB  SHAPES+$30
659E: 5E        383              DFB  SHAPES+$48
659F: 76        384              DFB  SHAPES+$60
65A0: 8E        385              DFB  SHAPES+$78
65A1: A6        386              DFB  SHAPES+$90
                387  *
65A2: 3E        388  BSHPLO      DFB  BSHAPES
65A3: 4C        389              DFB  BSHAPES+$0E
65A4: 5A        390              DFB  BSHAPES+$1C
65A5: 68        391              DFB  BSHAPES+$2A
65A6: 76        392              DFB  BSHAPES+$38
65A7: 84        393              DFB  BSHAPES+$46
65A8: 92        394              DFB  BSHAPES+$54
65A9: A0        395              DFB  BSHAPES+$62
                396              DS   $6C
                397  *SHAPE TABLE GUN
6616: A0 81 00
6619: A0 81 00
661C: A0 81     398  SHAPES      HEX  A08100A08100A081
661E: 00 A0 81
6621: 00 A8 85
6624: 00 A8     399              HEX  00A08100A88500A8
```

```
6626: 85 00 8A
6629: 94 00 8A
662C: 94 00     400          HEX  85008A94008A9400
                401  *2ND
662E: 00 85 00
6631: 00 85 00
6634: 00 85     402          HEX  0085000085000085
6636: 00 00 85
6639: 00 A0 95
663C: 00 A0     403          HEX  00008500A09500A0
663E: 95 00 A8
6641: D0 80 A8
6644: D0 80     404          HEX  9500A8D080A8D080
                405  *3RD
6646: 00 94 00
6649: 00 94 00
664C: 00 94     406          HEX  0094000094000094
664E: 00 00 94
6651: 00 00 D5
6654: 80 00     407          HEX  0000940000D58000
6656: D5 80 A0
6659: C1 82 A0
665C: C1 82     408          HEX  D580A0C182A0C182
                409  *4TH
665E: 00 D0 80
6661: 00 D0 80
6664: 00 D0     410          HEX  00D08000D08000D0
6666: 80 00 D0
6669: 80 00 D4
666C: 82 00     411          HEX  8000D08000D48200
666E: D4 82 00
6671: 85 8A 00
6674: 85 8A     412          HEX  D48200858A00858A
                413  *5TH
6676: C0 82 00
6679: C0 82 00
667C: C0 82     414          HEX  C08200C08200C082
667E: 00 C0 82
6681: 00 D0 8A
6684: 00 D0     415          HEX  00C08200D08A00D0
6686: 8A 00 94
6689: A8 00 94
668C: A8 00     416          HEX  8A0094A80094A800
                417  *6TH
668E: 00 8A 00
6691: 00 8A 00
6694: 00 8A     418          HEX  008A00008A00008A
6696: 00 00 8A
6699: 00 C0 AA
669C: 00 C0     419          HEX  00008A00C0AA00C0
669E: AA 00 D0
66A1: A0 81 D0
66A4: A0 81     420          HEX  AA00D0A081D0A081
                421  *7TH
66A6: 00 A8 00
66A9: 00 A8 00
66AC: 00 A8     422          HEX  00A80000A80000A8
66AE: 00 00 A8
66B1: 00 00 AA
66B4: 81 00     423          HEX  0000A80000AA8100
```

```
66B6: AA 81 C0
66B9: 82 85 C0
66BC: 82 85     424          HEX  AA81C08285C08285
                425  *
                426          DS   $80
                427  *BULLET SHAPE TABLE
673E: 40 01 40
6741: 01 40 01
6744: 40        428  BSHAPES HEX  40014001400140
6745: 01 40 01
6748: 40 01 40
674B: 01        429          HEX  01400140014001
                430  *2ND
674C: 00 06 00
674F: 06 00 06
6752: 00        431          HEX  00060006000600
6753: 06 00 06
6756: 00 06 00
6759: 06        432          HEX  06000600060006
                433  *3RD
675A: 00 18 00
675D: 18 00 18
6760: 00        434          HEX  00180018001800
6761: 18 00 18
6764: 00 18 00
6767: 18        435          HEX  18001800180018
                436  *4TH
6768: 00 60 00
676B: 60 00 60
676E: 00        437          HEX  00600060006000
676F: 60 00 60
6772: 00 60 00
6775: 60        438          HEX  60006000600060
                439  *5TH
6776: 00 03 00
6779: 03 00 03
677C: 00        440          HEX  00030003000300
677D: 03 00 03
6780: 00 03 00
6783: 03        441          HEX  03000300030003
                442  *6TH
6784: 00 0C 00
6787: 0C 00 0C
678A: 00        443          HEX  000C000C000C00
678B: 0C 00 0C
678E: 00 0C 00
6791: 0C        444          HEX  0C000C000C000C
                445  *7TH
6792: 00 30 00
6795: 30 00 30
6798: 00        446          HEX  00300030003000
6799: 30 00 30
679C: 00 30 00
679F: 30        447          HEX  30003000300030

--END ASSEMBLY--

ERRORS: 0

1952 BYTES
```

I'd like to emphasize that careful attention to detail is very important when programming. Machine language is very unforgiving. Failure to initialize a single variable could cause your graphics to go haywire. One of the most common mistakes is to clobber a register in your program or subroutine when calling another subroutine. Some programmers automatically save the Accumulator and X & Y registers by pushing them onto the stack before calling a subroutine, and restore them afterwards. It requires six instructions in each direction. Yet it makes more sense to have the called subroutine save the registers that it knows will be clobbered, and restore them before returning.

The setup routine for the drawing program is often a source for error. Although the setup is basically standard for a particular drawing subroutine, accidentally omitting one variable or failure to place a variable, in say, the Y register, can be disastrous. To give you an example of unexpected results, remove the STA TVERT in line 190 by NOPing the code in memory.

```
6169: EA EA EA
```

Run the program and watch the results. Imagine how long it might take to find this mistake. Debugging machine language graphics is difficult because events happen too quickly for the eye to detect. An Integer machine or an Integer ROM card with step and trace is almost a neccessity. There have been times when I cleared the screen manually, set the graphics mode and put the machine in trace mode, so that I could watch the graphics being drawn in slow motion. Always remember to enter just after your CLRSCR or you will waste four or five minutes while the computer clears all 8K of Hi-Res memory. The commands for clearing screen #1 manually are as follows.

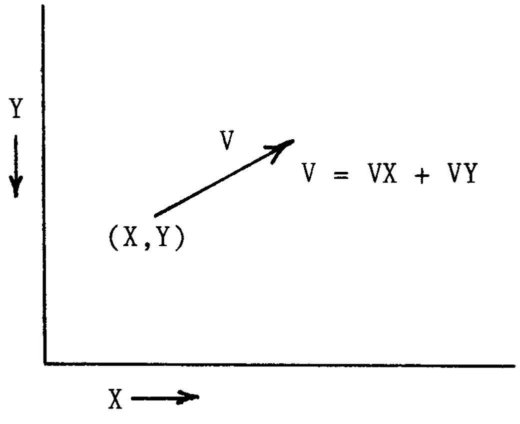
```
*2000: 00
*2001<2000.3FFFM
```

Another debugging tool that is quite helpful is the single step debug module which is discussed on page xx. It allows you to step through each animation frame using the escape key. If your drawing routines are working as expected, single stepping will allow you to verify shape movement between successive frames.

STEERABLE SPACE SHIPS

The first game with a fully steerable space ship was developed at MIT. It was called Space War. While most of the newer computer owners won't recall this game, practically everyone is familiar with Asteroids. Most versions of this game have a steerable spaceship that can be thrusted in the direction that it is headed. Although some versions invoke an automatic deceleration mode, some Asteroid games require the player to turn his ship around so that it thrusts in the opposite direction to slow down.

We previously demonstrated, with the topic of dropping bombs and shooting bullets, that objects move in the direction of their velocity vector.



An object's new position is its old position plus its change in position due to velocity, as shown:

$$X = X + VX$$
$$Y = Y + VY.$$

Using the Apple screen coordinate system for the example above, VY is negative and VX is positive. Therefore,

$$X = X + (VX)$$
$$Y = Y + (-VY)$$

While the velocity vector may remain constant for many animation cycles, resulting in a ship moving in the same direction, sooner or later a new velocity vector will be inputted to change the object's course. This new velocity is the vector sum of the old velocity vector and the new velocity vector.

Those readers who have taken Physics will recall that a body's velocity changes due to external forces on it while it is in motion. In space ships, that

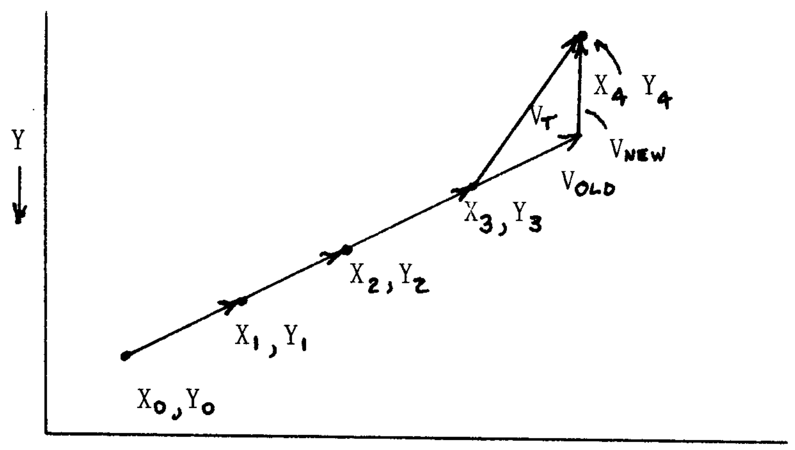
force is thrust. Thrust causes an acceleration of the object's mass as shown in the equation

$$F = m * a = m * \Delta V.$$

When thrust is applied to a space ship, it accelerates. If a ship is light and has a big engine with considerable thrust, it will accelerate quickly. But if it is heavy, it will accelerate much slower. This acceleration is essentially brought about by a change in the object's velocity if the object's mass is ignored.

Unless you are doing an actual simulation, in which values of thrust or force and an object's mass is important, only acceleration values need to be considered. Suitable values for arcade games are small and scaled, so that objects don't move too fast relative to their size, or fly off the screen in a blink of the eye.

If we consider a space ship that is in motion for two frames, then apply thrust during the third frame, it will change direction depending on the vector sum of its old and new velocity vectors. This is illustrated below. The applied thrust is straight upwards, so that VX = 0 and VY = −2. The ship's new velocity vector is calculated as follows:



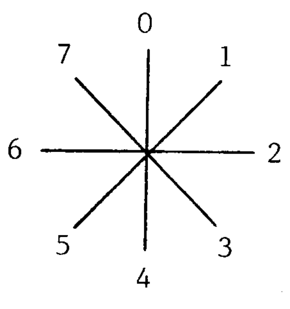
$$VX = VX + VX = 2 + 0 = 2$$
$$VY = VY + VY = -1 + (-2) = -3$$

The ship's new velocity vector causes it to move two units in the X direction and three in the negative Y direction during each frame until a new thrust vector is applied. The resultant position can be summarized in the table below.

FRAME	X	Y	VX	VY	
0	10	100	2	-1	X = X + VX
1	12	99	2	-1	Y = Y + VY
2	14	98	2	-1	
3	16	97	2	-3	Thrust applied here.
4	18	94	2	-3	
5	20	91			

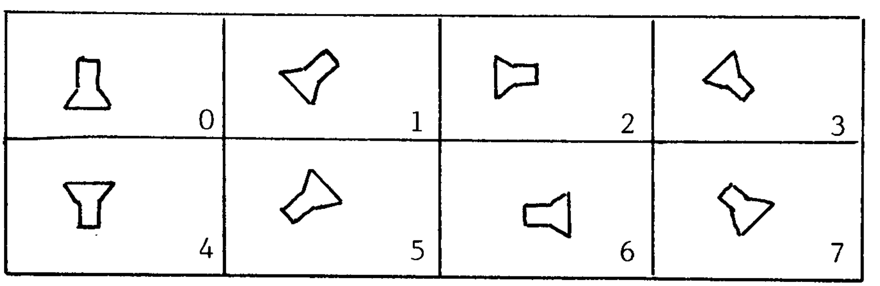
A paddle will control the ship's direction in our simulation. The paddle's range (0-255) will be divided into eight directions (0-7). Dividing by 32 is simple in machine language. An arithmetic shift right (LSR, four times) will accomplish the task. After the division, paddle values 0-31 are equal to direction one, 32-63 to direction two, etc.

Now that we can control our ship in eight directions, we need shape tables for each of these directions. That means eight separate shapes. Rather than complicate matters unnecessarily, we will use a white ship and move it horizontally in one byte (7 pixel) increments, and vertically in eight line jumps. This way, we won't need extra sets of tables for the various offsets. Also, by conveniently keeping the shape within one of the 24 screen subsections, we can use an abbreviated set of YVERT tables.



TROTATE
(0–7)

PADDLE DIRECTION



The ship's thrust vector is completely dependent on the ship's paddle-controlled direction. If TROTATE, our paddle direction's value is four and the ship points down, it's thrust vector or velocity vector is VX = 0 and VY = 1. If TROTATE were seven, the ship points diagonally upward and to the left. The velocity vector is VX = −1 and VY = −1.

Note that many of our ship's directions produce negative velocity values, while others produce positive values. Separate routines are required for adding and subtracting in machine language. BASIC, however, just adds a negative number (X = 5 + (−1)). That's the clue. Adding a negative number is exactly the same as adding a positive number in machine language. Both use an ADC instruction. The difference is that negative numbers, like −1, are represented by the two's complement which, for −1, is $FF. There is a limit for signed numbers of + or −127, because the BMI instruction tests the carry bit and considers the value negative if it is set.

If you add $FF to $03, the result is $02. Technically, the operation causes an overflow and the carry is set. But this doesn't concern us. With the simplification of our thrust vector addition problem, we can construct a table of velocity values for each TROTATE value.

THRUST VECTOR

	0	1	2	3	4	5	6	7
XT	00	01	01	01	00	FF	FF	FF
YT	FF	FF	00	01	01	01	00	FF

The thrust in this example is not cumulative. If the thrust button is on or pressed, the ship moves; if off, it stops. The ship drives like a car rather than floats, like it would in zero-gravity space. This is shown in the following:

XS = XS + XT and YS = YS + YT

where XS & YS is the ship's current position and XT & YT are the ship's velocity vector components.

With XT and YT both a function of TROTATE, the equations become:

XS = XS + XT(TROTATE) and YS = YS + YT(TROTATE)

Thus, we can use table lookup to access the correct thrust for any ship direction.

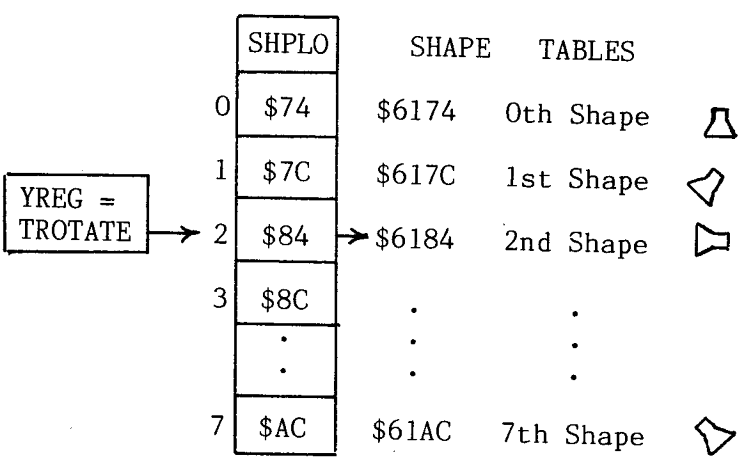
```
LDX  TROTATE
CLC
LDA  XT,X      ;GET X THRUST VECTOR FOR TROTATE VALUE
ADC  XS        ;ADD TO X POSITION
STA  XS        ;STORE NEW VALUE
```

Now that the ship can be moved around the screen by both steering and thrusting, several tests must be implemented at the screen boundaries. Our Apple screen is 40 bytes wide by 24 subgroups deep. To index beyond the end of our tables would create unforeseen graphics, especially at the bottom of the screen.

XS can be tested for values greater than 39 and less than 0. In our case, with a ship moving only one position per frame, the test for less than 0 would be equal to the value FF or −1. If wrap-a-round is needed for an object leaving the right side of the screen, just set XS = 0 and it will reenter on the left. Likewise, setting XS = 39 works for objects leaving the left side of the screen. If the wrap-a-round effect is not desired, it requires setting XS = 39 for any attempt to leave the right side of the screen, and XS = 0 for any attempt to leave the left hand side of the screen. Essentially, the ship gets stuck at the edge. The boundary conditions at the top and bottom are similar.

Our drawing setup routine takes the paddle value into consideration to obtain the correctly rotated shape from the shape table for plotting. We can find the correct lo byte of the shape by the following formula:

```
SHPL = SHPLO (TROTATE)
```



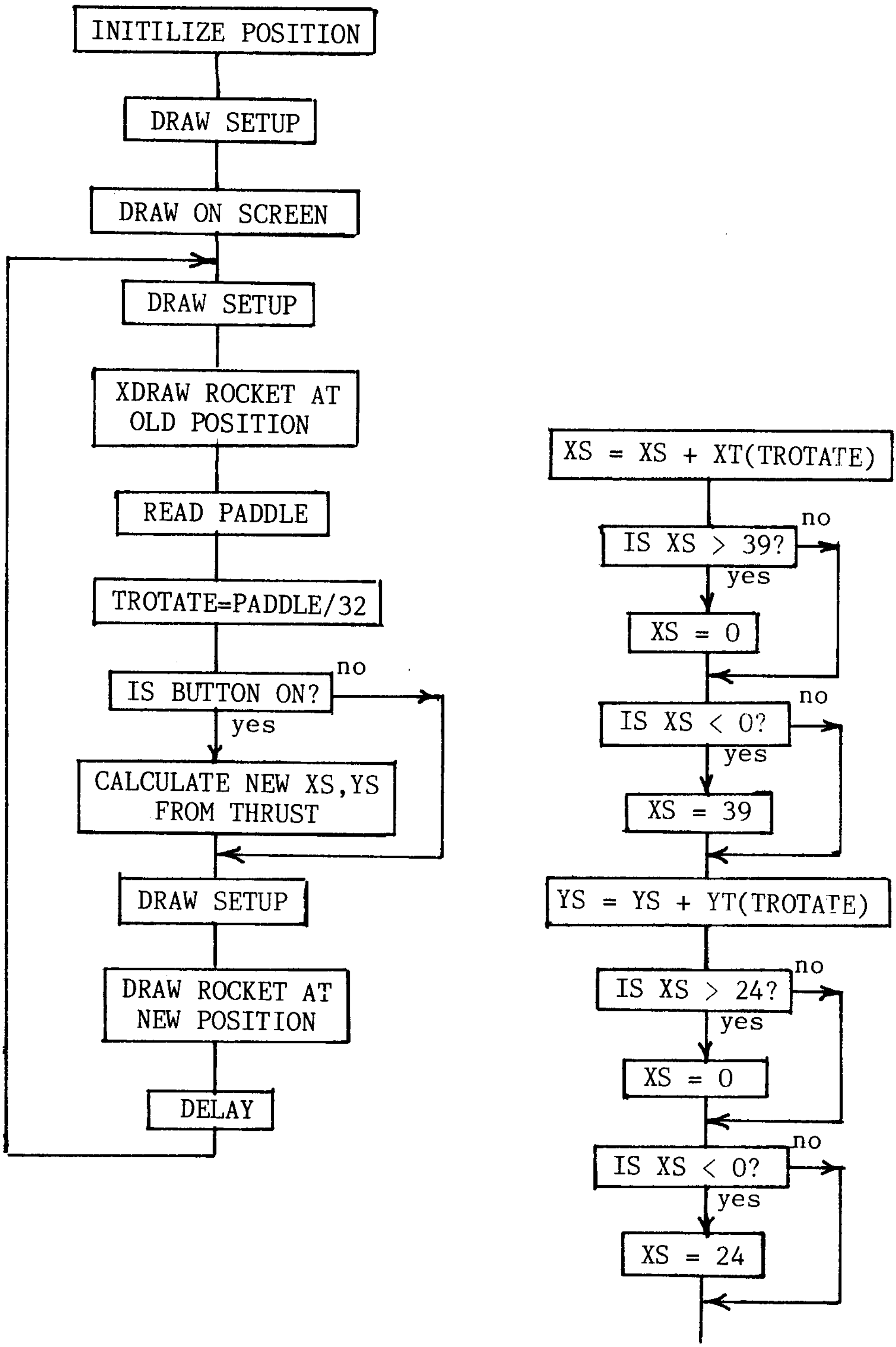
```
LDY  TROTATE   ;USE VALUE FOR DIRECTION OF ROTATED SHAPE
LDA  SHPLO,Y   ;AS INDEX TO PROPER LO BYTE OF SHAPE
STA  SHPL      ;STORE LO BYTE POINTER ON ZERO PAGE
LDA  #>SHAPES  ;GET HI BTE OF SHAPE TABLE
STA  SHPH      ;STORE IN ZERO PAGE
```

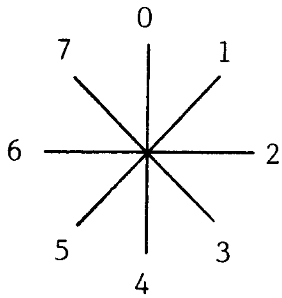
If the ship were turned so that it was pointing right, then TROTATE = 2 and SHPLO (2) = $84. This lo byte of the shape table is stored as SHPL. The drawing routine will now plot the second shape from our shape table.

As we mentioned earlier, the ship is being moved eight lines at a time vertically to take advantage of plotting the ship within one of the 24 subsections on the Hi-Res screen. We can use the eight-line deep plotting routine, which was developed in the last chapter, if we don't cross any screen boundaries. This also simplifies and shortens our 192 element YVERT tables to two, 24 byte-long tables. Each table, one for the hi byte and one for the lo byte, stores the line address for the beginning of each of these blocks. The correct starting block for plotting our shape is a function of the ship's vertical position, YS (0-23). We index into the tables as before, using the Y register.

```
LDY  YS         ;SHIP'S VERTICAL POSITION (0-23)
LDA  YBLOCKL,Y  ;LOOK UP LO BYTE ADDRESS OF LINE
STA  HIRESL
LDA  YBLOCKH,Y  ;LOOK UP HI BYTE ADDRESS OF LINE
STA  HIRESH
```

Moving a space ship about the screen by paddle control is actually a simple case in the overall design of a game. One XDRAWs (erases) the ship at the old position, reads the paddle controller, calculates the ship's new position, and plots it at its new position. This is performed for each animation frame in an endless loop. Because the code is rather short, a considerable delay is needed to slow down the animation frame rate. With very short delays in the monitor delay subroutine, the frame rate exceeds the 30 frame-per-second scan rate of the television. The ship appears to blink at random during its movement. The television hasn't finished drawing the first animation cycle while you moved your ship two or three times in between. A longer delay, wherein the WAIT subroutine has a value of $C0 to $FF in the Accumulator, works fine. The flow chart of this steerable rocket program is shown below.


INITILIZE POSITION
DRAW SETUP
DRAW ON SCREEN
DRAW SETUP
XDRAW ROCKET AT OLD POSITION
READ PADDLE
TROTATE=PADDLE/32
IS BUTTON ON?
no
yes
CALCULATE NEW XS,YS FROM THRUST
DRAW SETUP
DRAW ROCKET AT NEW POSITION
DELAY
XS = XS + XT(TROTATE)
IS XS > 39?
no
yes
XS = 0
IS XS < 0?
no
yes
XS = 39
YS = YS + YT(TROTATE)
IS XS > 24?
no
yes
XS = 0
IS XS < 0?
no
yes
XS = 24



TROTATE
(0-7)

PADDLE DIRECTION

THRUST VECTOR

	0	1	2	3	4	5	6	7
XT	00	01	01	01	00	FF	FF	FF
YT	FF	FF	00	01	01	01	00	FF

DRAWING SETUP

LOOKUP LO BYTE OF LINE TO PLOT
HIRESL = YBLOCKL (YS)

LOOKUP HI BYTE OF LINE TO PLOT
IRESH = YBLOCKH (YS)

LOOKUP LO BYTE LOCATION OF SHAPE TABLE
SHPL = SHPLO (TROTATE)

LOOKUP HI BYTE OF TABLE
SHPH = HI BYTE OF SHAPES

```
                 *ROCKET (DRIVES LIKE CAR)
                          ORG  $6000
6000: 4C 09 60            JMP  PROG
                 XS       DS   1
                 YS       DS   1
                 PDL      DS   1
                 LNGH     DS   1
                 ROTATE   DS   1
                 TROTATE  DS   1
                 HIRESL   EQU  $FB
                 HIRESH   EQU  HIRESL+$1
                 SHPL     EQU  $FD
                 SHPH     EQU  SHPL+$1
                 PREAD    EQU  $FB1E
                 *ENTER HERE FIRST TIME ACCESS
6009: AD 50 C0   PROG     LDA  $C050
600C: AD 52 C0            LDA  $C052
600F: AD 57 C0            LDA  $C057
6012: 20 13 61            JSR  CLRSCR
                 *INITILIZE ROCKET'S STARTING POSITION
6015: A9 14               LDA  #$14
6017: 8D 03 60            STA  XS
601A: A9 0A               LDA  #$0A
601C: 8D 04 60            STA  YS
601F: A9 00               LDA  #$00
6021: 8D 07 60            STA  ROTATE
6024: 20 F6 60            JSR  DSETUP
6027: 20 CF 60            JSR  DRAW      ;DRAW INITIAL POSITION ROCKET
                 * PADDLE READ
602A: 20 F6 60   START    JSR  DSETUP
602D: 20 CF 60            JSR  DRAW      ;ERASE ROCKET
6030: A2 01               LDX  #$01
6032: 20 1E FB            JSR  PREAD
6035: C0 F9               CPY  #$F9      ;CLIP VALUE (0-250)
6037: 90 02               BLT  SKIPP
6039: A0 F8               LDY  #$F8
603B: 8C 05 60   SKIPP    STY  PDL
603E: 98                  TYA
603F: CD 07 60            CMP  ROTATE    ;PADDLE<ROTATE POS THEN SUBTRACT 5
6042: B0 1B               BGE  PADDLE3
6044: AD 07 60            LDA  ROTATE
6047: 38                  SEC
6048: E9 05               SBC  #$05
604A: B0 05               BGE  PADDLE1   ;MAKE SURE =>0
604C: A9 00               LDA  #$00
604E: 8D 07 60            STA  ROTATE
6051: CD 05 60   PADDLE1  CMP  PDL       ;DON'T WANT TO GO PAST PADDLE POS
6054: B0 03               BGE  PADDLE2
6056: AD 05 60            LDA  PDL
6059: 8D 07 60   PADDLE2  STA  ROTATE
605C: 4C 72 60            JMP  PADDLE5
605F: CD 07 60   PADDLE3  CMP  ROTATE    ;PADDLE>ROTATE POS THEN ADD 5
6062: F0 0B               BEQ  PADDLE4
6064: AD 07 60            LDA  ROTATE
6067: 18                  CLC
6068: 69 05               ADC  #$05
606A: CD 05 60            CMP  PDL       ;DON'T WANT TO GO PAST PADDLE POS
606D: 90 03               BLT  PADDLE5
606F: AD 05 60   PADDLE4  LDA  PDL
6072: 8D 07 60   PADDLE5  STA  ROTATE
```

```
6075: 4A             LSR            ;DIVIDE BY 32 TO GET ROTATION (0-7)
6076: 4A             LSR
6077: 4A             LSR
6078: 4A             LSR
6079: 4A             LSR
607A: 8D 08 60       STA   TROTATE
            *
607D: AD 62 C0       LDA   $C062    ;NEG IF BUTTON PRESSED
6080: 30 03          BMI   THRUST
6082: 4C C0 60       JMP   NOTHRUST
6085: AE 08 60 THRUST LDX  TROTATE
6088: 18             CLC
6089: BD 5D 61       LDA   XT,X     ;GET X THRUST VECTOR
608C: 6D 03 60       ADC   XS       ;ADD TO X POSITION
608F: C9 28          CMP   #$28     ;CHECK IF OFF SCREEN RT
6091: D0 08          BNE   NWRAP1   ;O.K.
6093: A9 00          LDA   #$00     ;NO! THEN WRAP-A-ROUND
6095: 8D 03 60       STA   XS
6098: 4C A4 60       JMP   NOWY
609B: C9 FF    NWRAP1 CMP  #$FF     ;LESS THAN 0? (-1)
609D: D0 02          BNE   NWRAP2   ;O.K.
609F: A9 27          LDA   #$27     ;NO! THEN WRAP-A-ROUND
60A1: 8D 03 60 NWRAP2 STA  XS
60A4: 18       NOWY  CLC
60A5: BD 65 61       LDA   YT,X     ;GET Y THRUST VECTOR
60A8: 6D 04 60       ADC   YS       ;ADD TO Y POSITION
60AB: C9 18          CMP   #$18     ;CHECK IF OFF SCREEN BOTTOM
60AD: D0 08          BNE   NWRAP3   ;O.K.
60AF: A9 00          LDA   #$00     ;NO! THEN WRAP-A-ROUND
60B1: 8D 04 60       STA   YS
60B4: 4C C0 60       JMP   NOTHRUST
60B7: C9 FF    NWRAP3 CMP  #$FF     ;LESS THAN 0? (-1)
60B9: D0 02          BNE   NWRAP4   ;O.K.
60BB: A9 17          LDA   #$17     ;NO! THEN WRAP-A-ROUND
60BD: 8D 04 60 NWRAP4 STA  YS
60C0: EA       NOTHRUST NOP
            *
60C1: 20 F6 60       JSR   DSETUP
60C4: 20 CF 60       JSR   DRAW     ;DRAW ROCKET
60C7: A9 70          LDA   #$70
60C9: 20 A8 FC       JSR   $FCA8    ; SHORT DELAY
60CC: 4C 2A 60       JMP   START
            *SUBROUTINE TO DRAW ROCKET 1 BYTE BY 8 ROWS
60CF: A2 00    DRAW  LDX   #$00
60D1: A9 01          LDA   #$01
60D3: 8D 06 60       STA   LNGH
60D6: A1 FD    DRAW2 LDA   (SHPL,X)    ;GET BYTE FROM SHAPE TABLE
60D8: 51 FB          EOR   (HIRESL),Y
60DA: 91 FB          STA   (HIRESL),Y ;PUT ON HIRES SCREEN
60DC: A5 FC          LDA   HIRESH
60DE: 18             CLC
60DF: 69 04          ADC   #$04     ;THIS GETS TO NEXT ROW IN BLOCK
60E1: 85 FC          STA   HIRESH
60E3: E6 FD          INC   SHPL     ;NEXT BYTE OF SHAPE TABLE
60E5: C9 40          CMP   #$40     ;ARE WE FINISHED WITH 8 ROWS
60E7: 90 ED          BCC   DRAW2    ;NO DO NEXT BYTE
60E9: E9 20          SBC   #$20     ;RETURN TO TOP ROW
60EB: 85 FC          STA   HIRESH
60ED: CE 06 60       DEC   LNGH
60F0: F0 03          BEQ   DRAW3    ;FINISHED?
```

```
60F2: C8                   INY               ;NEXT COLUMN OF 8 ROWS
60F3: D0 E1                BNE   DRAW2
60F5: 60         DRAW3     RTS
                 *DRAWING SETUP SUBROUTINE
60F6: AC 04 60   DSETUP    LDY   YS          ;SHIP'S VERTICAL POS (0-23)
60F9: B9 45 61             LDA   YBLOCKL,Y   ;LOOK UP LO BYTE OF LINE
60FC: 85 FB                STA   HIRESL
60FE: B9 2D 61             LDA   YBLOCKH,Y   ;LOOK UP HI BYTE OF LINE
6101: 85 FC                STA   HIRESH
6103: AC 08 60             LDY   TROTATE
6106: B9 6D 61             LDA   SHPLO,Y
6109: 85 FD                STA   SHPL
610B: A9 61                LDA   #>SHAPES
610D: 85 FE                STA   SHPH
610F: AC 03 60             LDY   XS          ;DISPLACEMENT INTO LINE
6112: 60                   RTS
                 *CLEAR SCREEN SUBROUTINE
6113: A9 00      CLRSCR    LDA   #$00
6115: 85 FB                STA   HIRESL
6117: A9 20                LDA   #$20
6119: 85 FC                STA   HIRESH
611B: A0 00      CLR1      LDY   #$00
611D: A9 00                LDA   #$00
611F: 91 FB      CLR2      STA   (HIRESL),Y
6121: C8                   INY
6122: D0 FB                BNE   CLR2
6124: E6 FC                INC   HIRESH
6126: A5 FC                LDA   HIRESH
6128: C9 40                CMP   #$40
612A: 90 EF                BCC   CLR1
612C: 60                   RTS
                 *TABLES OF STARTING VALUE OF EACH OF 24 BLOCKS
612D: 20 20 21
6130: 21 22 22
6133: 23 23 20
6136: 20         YBLOCKH   HEX   20202121222223232020
6137: 21 21 22
613A: 22 23 23
613D: 20 20 21
6140: 21                   HEX   21212222232320202121
6141: 22 22 23
6144: 23                   HEX   22222323
6145: 00 80 00
6148: 80 00 80
614B: 00 80 28
614E: A8         YBLOCKL   HEX   008000800080008028A8
614F: 28 A8 28
6152: A8 28 A8
6155: 50 D0 50
6158: D0                   HEX   28A828A828A850D050D0
6159: 50 D0 50
615C: D0                   HEX   50D050D0
                 *TABLES OF DIRECTION VECTORS FOR 8 ROTATION VALUES
615D: 00 01 01
6160: 01 00 FF
6163: FF FF      XT        HEX   0001010100FFFFFF
6165: FF FF 00
6168: 01 01 01
616B: 00 FF      YT        HEX   FFFF0001010100FF
```

```
                *GENERATE SHPLO TABLE
                *( INDEX TO LO BYTE OF EACH ROCKET SHAPE)
616D: 75        SHPLO    DFB  SHAPES
616E: 7D                 DFB  SHAPES+$08
616F: 85                 DFB  SHAPES+$10
6170: 8D                 DFB  SHAPES+$18
6171: 95                 DB  SHAPES+$20
6172: 9D                 DFB  SHAPES+$28
6173: A5                 DFB  SHAPES+$30
6174: AD                 DFB  SHAPES+$38
                *
                *ROCKET SHAPES
6175: 00 08 08
6178: 08 1C 1C
617B: 36 00     SHAPES   HEX  000808081C1C3600
                *2ND
617D: 00 00 20
6180: 14 0F 1C
6183: 08 08              HEX  000020140F1C0808
                *3RD
6185: 00 00 02
6188: 0E 7C 0E
618B: 02 00              HEX  0000020E7C0E0200
                *4TH
618D: 00 08 08
6190: 1C 0F 14
6193: 20 00              HEX  0008081C0F142000
                *5TH
6195: 00 00 36
6198: 1C 1C 08
619B: 08 08              HEX  0000361C1C080808
                *6TH
619D: 00 08 08
61A0: 1C 78 14
61A3: 02 00              HEX  0008081C78140200
                *7TH
61A5: 00 00 20
61A8: 38 1F 38
61AB: 20 00              HEX  000020381F382000
                *8TH
61AD: 00 00 02
61B0: 14 78 1C
61B3: 08 08              HEX  00000214781C0808

--END ASSEMBLY--   437 BYTES
```

Objects in the real world, once started in motion, tend to remain in motion. Isaac Newton stated it more formally in his first law of motion. Objects remain at rest or in motion along a straight line unless a force is applied on them to change that motion. The force in most games is thrust.

In the last section, we dealt with a spaceship that had a velocity only when thrust was applied to it. We avoided any sustained velocity by zeroing our velocity vector when there was no thrust. Normally, the equations for determining the velocity and position of an object in motion are as follows (They were discussed briefly under the section on bullets and bomb drops.):

$$V_{NEW} = V_{OLD} + \Delta V \qquad \Delta V = \text{CHANGE IN VELOCITY}$$
$$D_{NEW} = D_{OLD} + \Delta D \qquad \Delta D = \text{CHANGE IN POSITION OVER AN ANIMATION FRAME DUE TO VELOCITY}$$

OR

$$D_{NEW} = D_{OLD} + V_{NEW}$$

This breaks down into components in the X and Y directions.

$$VX_{NEW} = VX_{OLD} + \Delta VX$$

$$VY_{NEW} = VY_{OLD} + \Delta VY$$

$$X_{NEW} = X_{OLD} + VX$$
$$Y_{NEW} = Y_{OLD} + VY$$

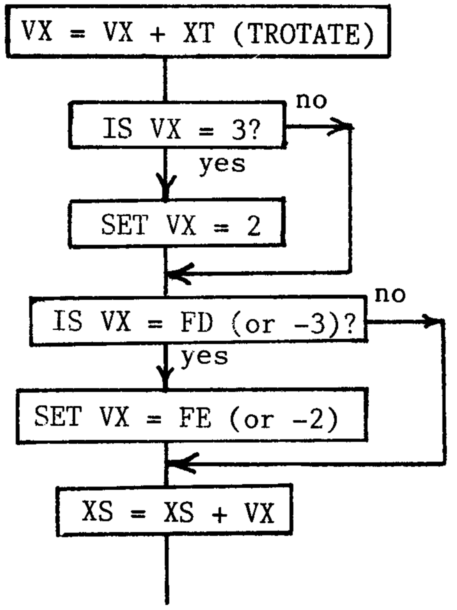
Now, when an object is thrusted in any direction, the increase in velocity is cumulative. For example, if thrust were applied in the positive X direction with a force of 1 unit/ frame, the new VX would increase from zero by units of one for each animation frame.

	CYCLE	VX	X		CYCLE	VY	Y
	0	0	0		0	0	0
	1	1	1		1	2	2
VX = 1	2	2	3	similarly VY = 2	2	4	6
	3	3	6		3	6	12
	4	4	10		4	8	20

It becomes clear from our example that if you accelerate for too many animation frames, the space ship will be moving fairly fast. While the amount of relative movement depends on your choice of scale, the ship moves to the left or right seven pixels for every unit change instead of by individual pixels. If, by

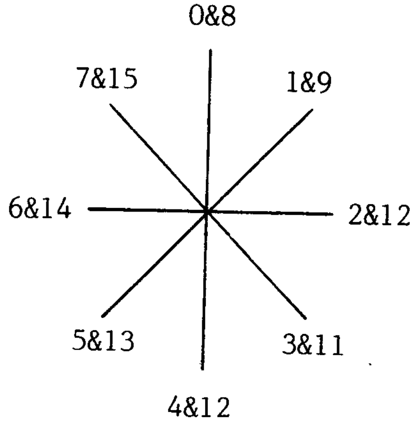
the fourth frame, our velocity were 4 units/frame, we would actually be moving 28 pixels horizontally per frame. With a slow program, framing at 10 frames/ second, the ship would move entirely across the screen in 1 second. More likely, with faster animation, it would take less than half a second. This may be too fast.

A speed brake can be incorporated into the algorithm to prevent the velocity from exceeding a preset value. This would be analogous to wind resistance on a fast moving automobile. It prevents a vehicle from reaching ever-increasing speeds. I chose a maximum velocity of 2 units/ frame. It was an arbitrary choice based on keeping the animation smooth. Discontinuous jumps at higher velocities produced degraded animation. The brake is placed just after the velocity equations. If the value of VX or VY exceeds 2 units/frame, it is trimmed back to 2 units/frame.



The flow chart, as shown for the X direction (horizontal), is relatively straight-forward. Again, the velocity vector is a function of the ship's paddle-controlled direction.

The paddle control in the non-free-floating ship was restrictive. It prevented you from directly reaching the straight-up position (0) from a position pointing upwards and to the left (7). When the paddle's value was divided by 32, giving TROTATE values 0-7, it lacked wrap-a-round capability. It would be better to be able to turn the ship nearly twice around with one twist of the paddle. This is accomplished by dividing the paddle reading by 16. This gives TROTATE values 0-15.



TROTATE
(0–15)

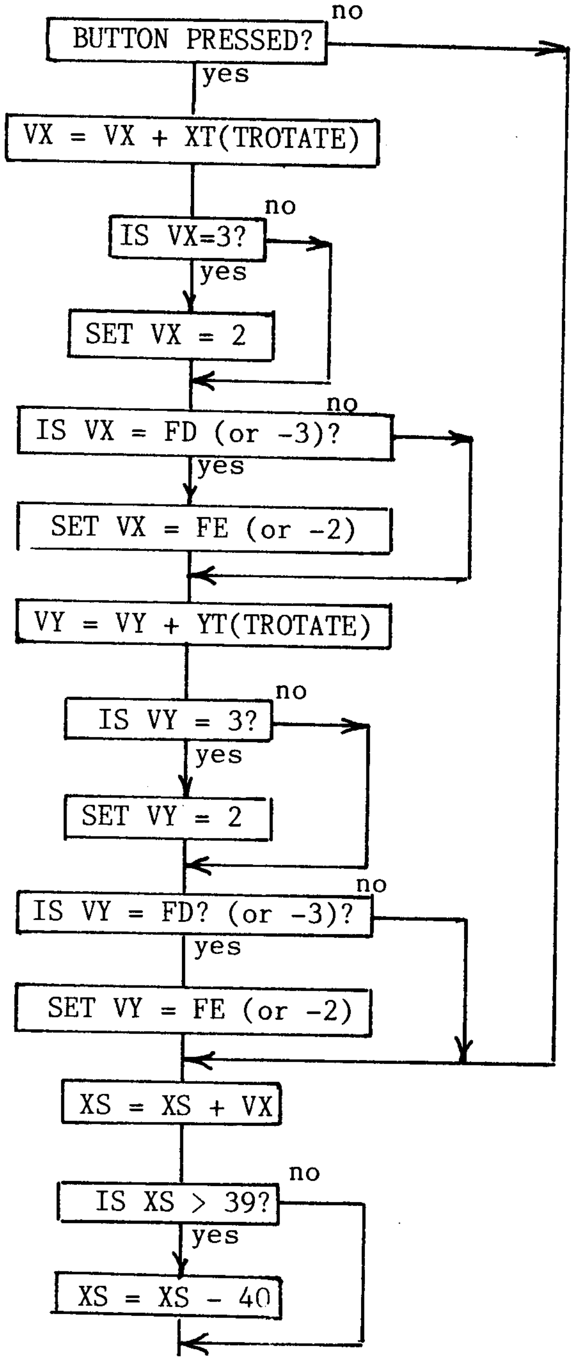
PADDLE DIRECTION

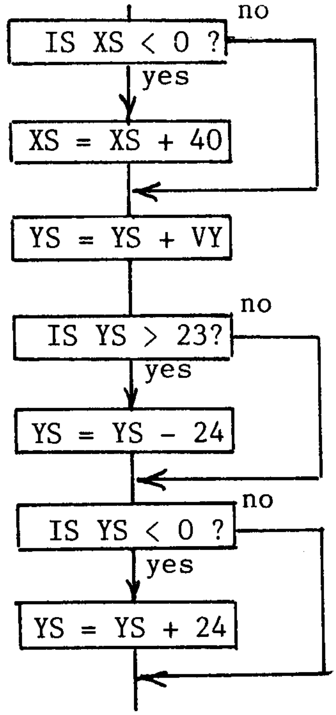
THRUST VECTOR

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
XT	01	01	01	01	00	FF	FF	FF	00	01	01	01	00	FF	FF	FF
YT	FF	FF	00	01	01	01	00	FF	FF	FF	00	01	01	01	00	FF

Since the proper shape is drawn from the correct section of the shape table by setting the appropriate lo and hi byte pointers for that shape, the index to these pointers must be corrected for the extra number of rotation angles. With TROTATE doubled to 16 values, the SHPLO table, which contains the 16 pointers to each shape, must also contain 16 values. Since TROTATE values are duplicated after 8 values, the SHPLO table, as well as the XT and YT tables, are duplicated after eight values.

Except for the changes discussed above, the steerable and free-floating ship routine is much like the former routine, in which the ship drives around like a car. The flow chart and code are shown below. It might be instructive to change the delay in line #129 to a small value like $05 to see what happens when the animation frame rate exceeds the television's scan rate.


BUTTON PRESSED?
no
yes
VX = VX + XT(TROTATE)
IS VX=3?
no
yes
SET VX = 2
IS VX = FD (or -3)?
no
yes
SET VX = FE (or -2)
VY = VY + YT(TROTATE)
IS VY = 3?
no
yes
SET VY = 2
IS VY = FD? (or -3)?
no
yes
SET VY = FE (or -2)
XS = XS + VX
IS XS > 39?
no
yes
XS = XS - 40




```
                *ROCKET (FREE FLOATING)
                        ORG  $6000
6000: 4C 0B 60          JMP  PROG
                XS      DS   1
                YS      DS   1
                VX      DS   1
                VY      DS   1
                PDL     DS   1
                LNGH    DS   1
                ROTATE  DS   1
                TROTATE DS   1
                HIRESL  EQU  $FB
                HIRESH  EQU  HIRESL+$1
                SHPL    EQU  $FD
                SHPH    EQU  SHPL+$1
                PREAD   EQU  $FB1E
                *ENTER HERE FIRST TIME ACCESS
600B: AD 50 C0  PROG    LDA  $C050
600E: AD 52 C0          LDA  $C052
6011: AD 57 C0          LDA  $C057
6014: 20 49 61          JSR  CLRSCR
                *INITILIZE ROCKET'S STARTING POSITION
6017: A9 14             LDA  #$14
6019: 8D 03 60          STA  XS
601C: A9 0A             LDA  #$0A
```

```
601E: 8D 04 60          STA  YS
6021: A9 00             LDA  #$00
6023: 8D 05 60          STA  VX
6026: 8D 06 60          STA  VY
6029: 8D 09 60          STA  ROTATE
602C: 20 2C 61          JSR  DSETUP
602F: 20 05 61          JSR  DRAW
               * PADDLE READ
6032: 20 2C 61 START    JSR  DSETUP
6035: 20 05 61          JSR  DRAW
6038: A2 01             LDX  #$01
603A: 20 1E FB          JSR  PREAD
603D: C0 F9             CPY  #$F9       ;CLIP VALUE (0-250)
603F: 90 02             BLT  SKIPP
6041: A0 F8             LDY  #$F8
6043: 8C 07 60 SKIPP    STY  PDL
6046: 98                TYA
6047: CD 09 60          CMP  ROTATE     ;PADDLE<ROTATE POS THEN SUBTRACT 5
604A: B0 1B             BGE  PADDLE3
604C: AD 09 60          LDA  ROTATE
604F: 38                SEC
6050: E9 05             SBC  #$05
6052: B0 05             BGE  PADDLE1    ;MAKE SURE =>0
6054: A9 00             LDA  #$00
6056: 8D 09 60          STA  ROTATE
6059: CD 07 60 PADDLE1  CMP  PDL        ;DON'T WANT TO GO PAST PADDLE POS
605C: B0 03             BGE  PADDLE2
605E: AD 07 60          LDA  PDL
6061: 8D 09 60 PADDLE2  STA  ROTATE
6064: 4C 7A 60          JMP  PADDLE5
6067: CD 09 60 PADDLE3  CMP  ROTATE     ;PADDLE>ROTATE POS THEN ADD 5
606A: F0 0B             BEQ  PADDLE4
606C: AD 09 60          LDA  ROTATE
606F: 18                CLC
6070: 69 05             ADC  #$05
6072: CD 07 60          CMP  PDL        ;DON'T WANT TO GO PAST PADDLE POS
6075: 90 03             BLT  PADDLE5
6077: AD 07 60 PADDLE4  LDA  PDL
607A: 8D 09 60 PADDLE5  STA  ROTATE
607D: 4A                LSR             ;DIVIDE BY 16 TO GET ROTATION(0-15)
607E: 4A                LSR             ;-(OR TWO ROATIONS AROUND)
607F: 4A                LSR
6080: 4A                LSR
6081: 8D 0A 60          STA  TROTATE
               *
6084: AD 62 C0          LDA  $C062      ;NEG IF BUTTON PRESSED
6087: 30 03             BMI  THRUST
6089: 4C C1 60          JMP  NOTHRUST
608C: AE 0A 60 THRUST   LDX  TROTATE
               *UPDATE VELOCITY VX AND VY
608F: 18                CLC
6090: BD 93 61          LDA  XT,X       ;GET X THRUST VECTOR
6093: 6D 05 60          ADC  VX
6096: C9 FD             CMP  #$FD
6098: D0 05             BNE  NOCLIP
609A: A9 FE             LDA  #$FE
609C: 4C A5 60          JMP  NOCLIP1
609F: C9 03    NOCLIP   CMP  #$03       ;CLIP MAX VELOCITY AT 2
60A1: D0 02             BNE  NOCLIP1
60A3: A9 02             LDA  #$02
```

```
60A5: 8D 05 60     NOCLIP1  STA  VX          ;STORE X VELOCITY
60A8: 18                    CLC
60A9: BD A3 61              LDA  YT,X
60AC: 6D 06 60              ADC  VY
60AF: C9 FD                 CMP  #$FD
60B1: D0 05                 BNE  NOCLIP2
60B3: A9 FE                 LDA  #$FE
60B5: 4C BE 60              JMP  NOCLIP3
60B8: C9 03        NOCLIP2  CMP  #$03        ;CLIP MAX VELOCITY AT 2
60BA: D0 02                 BNE  NOCLIP3
60BC: A9 02                 LDA  #$02
60BE: 8D 06 60     NOCLIP3  STA  VY          ;STORE Y VELOCITY
                   *UPDATE SHIP'S X POSITION XS
60C1: 18           NOTHRUST CLC
60C2: AD 05 60              LDA  VX
60C5: 6D 03 60              ADC  XS
60C8: C9 E0                 CMP  #$E0        ;CHECK FOR WRAPAROUND LEFT
60CA: 90 06                 BLT  NWRAP1
60CC: 18                    CLC
60CD: 69 28                 ADC  #$28        ;FIX BY ADDING 40
60CF: 4C D9 60              JMP  NWRAP2
60D2: C9 28        NWRAP1   CMP  #$28        ;CHECK FOR WRAPAROUND RIGHT
60D4: 90 03                 BLT  NWRAP2
60D6: 38                    SEC
60D7: E9 28                 SBC  #$28        ;FIX BY SUBTRACTING 40
60D9: 8D 03 60     NWRAP2   STA  XS          ;STORE SHIP'S NEW X POS
                   *UPDATE SHIP'S Y POSITION YS
60DC: 18                    CLC
60DD: AD 06 60              LDA  VY
60E0: 6D 04 60              ADC  YS
60E3: C9 E0                 CMP  #$E0        ;CHECK FOR WRAPAROUND TOP
60E5: 90 06                 BLT  NWRAP3
60E7: 18                    CLC
60E8: 69 18                 ADC  #$18        ;FIX BY ADDING 24
60EA: 4C F4 60              JMP  NWRAP4
60ED: C9 18        NWRAP3   CMP  #$18        CHECK FOR WRAPAROUND BOTTOM
60EF: 90 03                 BLT  NWRAP4
60F1: 38                    SEC
60F2: E9 18                 SBC  #$18        ; FIX BY SUBTRACTING 24
60F4: 8D 04 60     NWRAP4   STA  YS          ; STORE NEW Y POSITION
                   *
60F7: 20 2C 61              JSR  DSETUP
60FA: 20 05 61              JSR  DRAW
60FD: A9 C0                 LDA  #$C0
60FF: 20 A8 FC              JSR  $FCA8       ; SHORT DELAY
6102: 4C 32 60              JMP  START
                   *SUBROUTINE TO DRAW ROCKET 1 BYTEBY 8 ROWS
6105: A2 00        DRAW     LDX  #$00
6107: A9 01                 LDA  #$01
6109: 8D 08 60              STA  LNGH
610C: A1 FD        DRAW2    LDA  (SHPL,X)    ;GET BYTE FROM SHAPE TABLE
610E: 51 FB                 EOR  (HIRESL),Y
6110: 91 FB                 STA  (HIRESL),Y ;PUT ON HIRES SCREEN
6112: A5 FC                 LDA  HIRESH
6114: 18                    CLC
6115: 69 04                 ADC  #$04        ;THIS GETS TO NEXT ROW IN BLOCK
6117: 85 FC                 STA  HIRESH
6119: E6 FD                 INC  SHPL        ;NEXT BYTE OF SHAPE TABLE
611B: C9 40                 CMP  #$40        ;ARE WE FINISHED WITH 8 ROWS
611D: 90 ED                 BCC  DRAW2       ;NO DO NEXT BYTE
```

```
611F: E9 20              SBC  #$20          ;RETURN TO TOP ROW
6121: 85 FC              STA  HIRESH
6123: CE 08 60           DEC  LNGH
6126: F0 03              BEQ  DRAW3         ;FINISHED?
6128: C8                 INY                ;NEXT COLUMN OF 8 ROWS
6129: D0 E1              BNE  DRAW2
612B: 60        DRAW3    RTS
                *DRAWING SETUP SUBROUTINE
612C: AC 04 60  DSETUP   LDY  YS
612F: B9 7B 61           LDA  YBLOCKL,Y     ;LOOK UP LO BYTE OF LINE
6132: 85 FB              STA  HIRESL
6134: B9 63 61           LDA  YBLOCKH,Y
6137: 85 FC              STA  HIRESH
6139: AC 0A 60           LDY  TROTATE
613C: B9 B3 61           LDA  SHPLO,Y
613F: 85 FD              STA  SHPL
6141: A9 62              LDA  #>SHAPES
6143: 85 FE              STA  SHPH
6145: AC 03 60           LDY  XS            ;DISPLACEMENT INTO LINE
6148: 60                 RTS
                *CLEAR SCREEN SUBROUTINE
6149: A9 00     CLRSCR   LDA  #$00
614B: 85 FB              STA  HIRESL
614D: A9 20              LDA  #$20
614F: 85 FC              STA  HIRESH
6151: A0 00     CLR1     LDY  #$00
6153: A9 00              LDA  #$00
6155: 91 FB     CLR2     STA  (HIRESL),Y
6157: C8                 INY
6158: D0 FB              BNE  CLR2
615A: E6 FC              INC  HIRESH
615C: A5 FC              LDA  HIRESH
615E: C9 40              CMP  #$40
6160: 90 EF              BCC  CLR1
6162: 60                 RTS
                *TABLES OF STARTING VALUE OF EACH OF 20 BLOCKS
6163: 20 20 21
6166: 21 22 22
6169: 23 23 20
616C: 20        YBLOCKH  HEX  20202121222223232020
616D: 21 21 22
6170: 22 23 23
6173: 20 20 21
6176: 21                 HEX  21212222232320202121
6177: 22 22 23
617A: 23                 HEX  22222323
617B: 00 80 00
617E: 80 00 80
6181: 00 80 28
6184: A8        YBLOCKL  HEX  00800080008000802 8A8
6185: 28 A8 28
6188: A8 28 A8
618B: 50 D0 50
618E: D0                 HEX  28A828A828A850D050D0
618F: 50 D0 50
6192: D0                 HEX  50D050D0
                *
6193: 00 01 01
6196: 01 00 FF
6199: FF FF     XT       HEX  0001010100FFFFFF
```

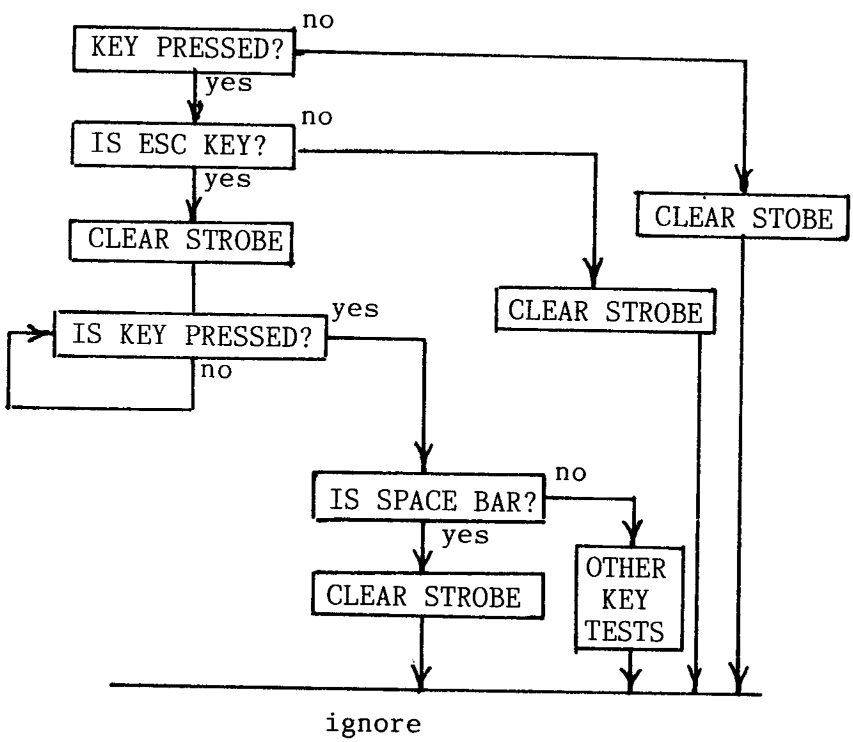
```
619B: 00 01 01
619E: 01 00 FF
61A1: FF FF                   HEX  0001010100FFFFFF
61A3: FF FF 00
61A6: 01 01 01
61A9: 00 FF         YT        HEX  FFFF0001010100FF
61AB: FF FF 00
61AE: 01 01 01
61B1: 00 FF                   HEX  FFFF0001010100FF
                    *
61B3: 13            SHPLO     DFB  SHAPES
61B4: 1B                      DFB  SHAPES+$08
61B5: 23                      DFB  SHAPES+$10
61B6: 2B                      DFB  SHAPES+$18
61B7: 33                      DFB  SHAPES+$20
61B8: 3B                      DFB  SHAPES+$28
61B9: 43                      DFB  SHAPES+$30
61BA: 4B                      DFB  SHAPES+$38
                    *NEXT GROUP BECAUSE PADDLE (0-15) INDEXES
                    *INTO SHAPE TABLE TWICE
61BB: 13                      DFB  SHAPES
61BC: 1B                      DFB  SHAPES+$08
61BD: 23                      DFB  SHAPES+$10
61BE: 2B                      DFB  SHAPES+$18
61BF: 33                      DFB  SHAPES+$20
61C0: 3B                      DFB  SHAPES+$28
61C1: 43                      DFB  SHAPES+$30
61C2: 4B                      DFB  SHAPES+$38
                    *
                    SPACE     DS   80
                    *ROCKET SHAPES
6213: 00 08 08
6216: 08 1C 1C
6219: 36 00         SHAPES    HEX  000808081C1C3600
                    *2ND
621B: 00 00 20
621E: 14 0F 1C
6221: 08 08                   HEX  000020140F1C0808
                    *3RD
6223: 00 00 02
6226: 0E 7C 0E
6229: 02 00                   HEX  0000020E7C0E0200
                    *4TH
622B: 00 08 08
622E: 1C 0F 14
6231: 20 00                   HEX  0008081C0F142000
                    *5TH
6233: 00 00 36
6236: 1C 1C 08
6239: 08 08                   HEX  0000361C1C080808
                    *6TH
623B: 00 08 08
623E: 1C 78 14
6241: 02 00                   HEX  0008081C78140200
                    *7TH
6243: 00 00 20
6246: 38 1F 38
6249: 20 00                   HEX  000020381F382000
                    *8TH
```

```
624B: 00 00 02
624E: 14 78 1C
6251: 08 08     229          HEX  00000214781C0808

--END ASSEMBLY--     595 BYTES
```

DEBUG PACKAGE

The debug package that was mentioned earlier is a very useful tool for programmers. It allows you to single step animation by stopping the animation with the ESC key. Once the ESC key is pressed, the program goes into a tight loop while waiting for another key press. Any key except the ESC key will release it. But since every key, with the exception of the space bar, fails to clear the keyboard strobe, the computer thinks a key has been pressed when it encounters the debug subroutine during the next animation frame. Of course, if the key last pressed was the ESC, it will be caught in that small loop once again, and stop or single step. Yet if it is another key, it won't stop the animation, but would proceed to other tests in the package. The space bar would release it totally from the subroutine by clearing the keyboard strobe.



The debug package is designed so that you can't activate any other debug test without first hitting the ESC key. This way, no matter what uses your keys have during a game, they can't activate debug functions inadvertently.

```
*DEBUG PACKAGE TO SINGLE STEP
         LDA  $C000       ;KEY PRESSED?
         BPL  IGNORE      ;EXIT IF NO KEY PRESSED
         CMP  #$9B        ;ESC KEY?
         BNE  IGNORE
CAUGHT   BIT  $C010       ;CLEAR STROBE
         LDA  $C000       ;KEY PRESSED?
         BPL  *-3         ;LOOP BY BRANCHING BACK 3 BYTES
         CMP  #$A0        ;SPACE KEY?
         BNE  IGNORE+3    ;NO,DON'T CLEAR STROBE
IGNORE   BIT  $C010       ;CLEAR STROBE
         NOP
```

You could expand the code to do other functions if the code is placed at the block labeled "other tests". Examples of this would be pressing the K key to kill an alien, or the A key to advance to a higher level. This would allow you to reach modules in your code that might take considerable playing time to achieve without your debug module.

Another use for this type of code is to insert a user-controlled pause control into a game. Pause control has just recently been incorporated into arcade games. It is too bad that most programmers hadn't thought of leaving part of the debug module in the game before to offer a pause option.

LASER FIRE & PADDLE BUTTON TRIGGERS

Paddle button switches are used in many games as triggers to fire rockets, bullets and lasers, or to drop bombs. The Apple computer has three; they are numbered 0-2. They are accessed through the addresses $C061 to $C063.

To test if a paddle button is pressed, you load the address for that switch into the Accumulator, then test if the value is negative.

```
        LDA  $C061     ;TEST PADDLE #0
        BMI  FIRE      ;NEGATIVE, THEN BUTTON PRESSED
NOFIRE  JMP  CONTINUE
FIRE    JSR  LASER     ;FIRE LASER
```

Game designers often want to limit the amount of ammunition that can be fired at one time. A flag can be set to on when a bullet is fired, and to off when the bullet either reaches the opposite end of the screen or if it hits something. The player can't fire again until the flag is in the off position.

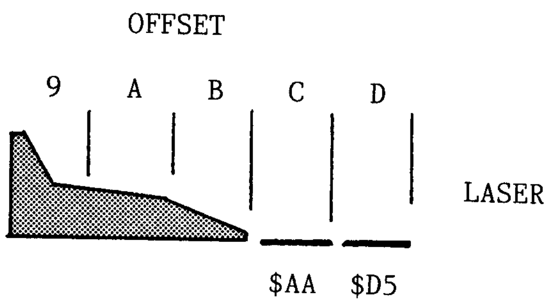
Laser fire presents another problem. The beam travels from the gun or

spaceship to the opposite end of the screen in one frame. If the player held the button, the laser would fire for each frame. Essentially; it would always be on.

The test for a pressed button must include code that would inhibit the button being held down continuously. You can accomplish this by setting a flag to 1 when the laser is fired. If the button is pressed and the laser was just fired without the player releasing it first, the test for the flag prevents it from firing again. The flag is reset to 0 only if the button isn't pressed.

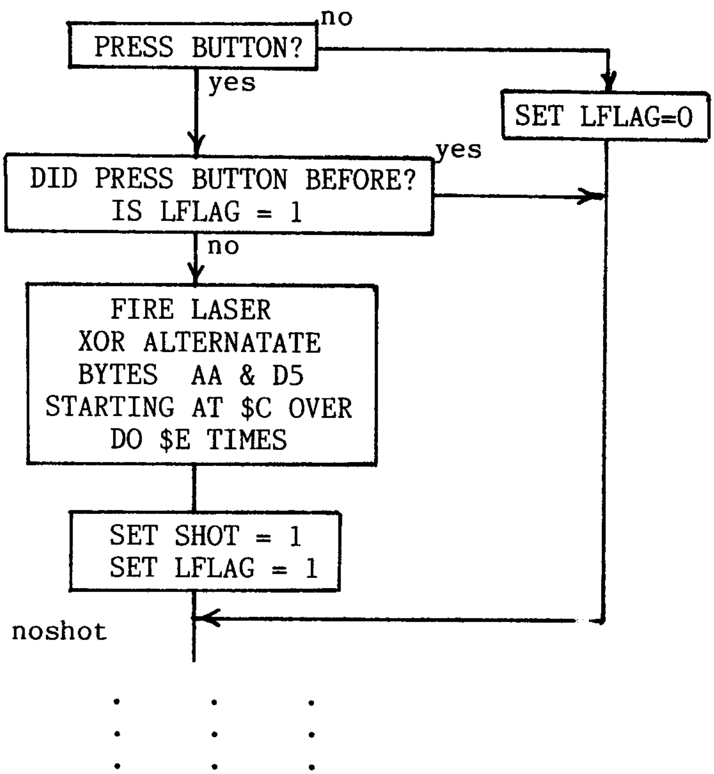
We set another flag called SHOT to one if the laser is fired. This is because we want to XDRAW the laser much later in the animation cycle. If we XDRAW it immediately, it would be barely seen. Yet, if it were automatically XDRAWn later without some sort of test, it would always appear, regardless of whether it was previously fired or not. The XDRAW laser subroutine tests to determine if the SHOT is set before it XDRAWs the laser shot; it will consequently skip this routine if the laser hasn't been fired.

Red lasers look more impressive than white lasers. They also require more work to plot properly. As usual, our nemesis, the even/ odd color offset problem , comes into play. The first position that our laser can be plotted is at horizontal offset $0C or 12 decimal. This is on an even offset.

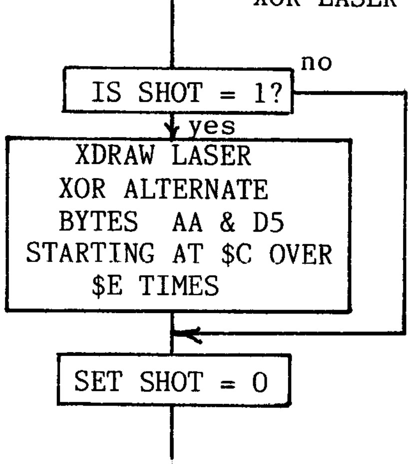


A value of $AA will produce a red line in even offsets, and a $D5 will do so in odd offsets. If you plot these two bytes in pairs for $0E (14 decimal) number of times, you will produce a red laser beam that extends from the plane to the right screen boundary.

A flow chart of our algorithm and its accompaning code follows:



XOR LASER (XLASER)



NOTE: Button has to be released to reset LFLAG = 0

```
                 *LASER SUBROUTINE
                 *
63D3: AD 62 C0   LASER    LDA  $C062        ;NEG IF BUTTON PRESSED
63D6: 30 08               BMI  FIRE1
63D8: A9 00               LDA  #$00         ;BUTTON NOT PRESSED,SET FLAG TO 0
63DA: 8D 14 60            STA  LFLAG
63DD: 4C 13 64            JMP  NOSHOT
63E0: AD 14 60   FIRE1    LDA  LFLAG        ;IS BUTTON BEING HELD DOWN?
63E3: C9 01               CMP  #$01
63E5: B0 2C               BGE  NOSHOT
63E7: A9 01               LDA  #$01
63E9: 8D 13 60            STA  SHOT         ;SET LASER FIRED FLAG
63EC: 8D 14 60            STA  LFLAG        ;SET BUTTON PRESSED FLAG
63EF: 18                  CLC
63F0: AD 0C 60            LDA  VERT         ;TOP OF SHIP
63F3: 69 07               ADC  #$07
63F5: A8                  TAY               ;Y REG CONTAINS VERT. LSER POS.
63F6: A9 0C               LDA  #$0C         ;START AT HORIZ=$0C
63F8: 8D 0E 60            STA  HORIZ
63FB: 20 1C 63            JSR  GETADR       ;FIND ADDRESS OF LASER BEAM LINE
63FE: A2 0E               LDX  #$0E         ;SET UP LOOP FOR E TIMES
6400: A9 AA      LASER1   LDA  #$AA         ;DRAW PAIRS OF AA & D5 BYTES(RED)
6402: 51 26               EOR  (HIRESL),Y   ;BY ORING AGAINST SCREEN
6404: 91 26               STA  (HIRESL),Y
6406: E6 26               INC  HIRESL       ;NEXT SCREEN POSITION
6408: A9 D5               LDA  #$D5
640A: 51 26               EOR  (HIRESL),Y
640C: 91 26               STA  (HIRESL),Y
640E: E6 26               INC  HIRESL       ;NEXT SCREEN POSITION
6410: CA                  DEX               ;DECREMENT INDEX TO LOOP
6411: D0 ED               BNE  LASER1       ;DONE?
6413: 60         NOSHOT   RTS               ;YES! EXIT
                 *XDRAW LASER SUBROUTINE
6414: AD 13 60   XLASER   LDA  SHOT
6417: C9 01               CMP  #$01         ;HAS LASER BEEN SHOT?
6419: D0 24               BNE  NXSHOT       ;NO! SKIP XDRAWING LASER
641B: 18                  CLC
641C: AD 0C 60            LDA  VERT
641F: 69 07               ADC  #$07
6421: A8                  TAY
6422: A9 0C               LDA  #$0C
6424: 8D 0E 60            STA  HORIZ
6427: 20 1C 63            JSR  GETADR
642A: A2 0E               LDX  #$0E
642C: A9 AA      LASER2   LDA  #$AA
642E: 51 26               EOR  (HIRESL),Y
6430: 91 26               STA  (HIRESL),Y
6432: E6 26               INC  HIRESL
6434: A9 D5               LDA  #$D5
6436: 51 26               EOR  (HIRESL),Y
6438: 91 26               STA  (HIRESL),Y
643A: E6 26               INC  HIRESL
643C: CA                  DEX
643D: D0 ED               BNE  LASER2
643F: A9 00      NXSHOT   LDA  #$00         ;RESET LASER FIRED FLAG TO OFF
6441: 8D 13 60            STA  SHOT
6444: 60                  RTS
```

COLLISIONS

One of the most important aspects in any arcade game, especially shoot-'em-up type games, is whether an object collides with another object or the background. As a particular object is drawn to the screen, (one byte at a time, or even by single pixels, as some programmers prefer), you can simultaneously test to determine if any other pixels are within that byte's (or pixel's) screen location. The test is performed using the AND instruction.

The truth table for the AND instruction is as follows:

ACC.	MEMORY	RESULT
0	0	0
0	1	0
1	0	0
1	1	1

Both Accumulator and memory must be on (set) for the result to be on (set).

If we take a Hi-Res screen memory location that has an object in it and AND it with a byte from our shape table, any duplication in any bit location because something is already on the screen, will give a non-zero result.

	X	X	X	X			BACKGROUND
			X	X	X	X	SHAPE
			X	X			AND BACKGROUND WITH SHAPE
							RESULT $18 > ZERO

The hi bit, (the color control bit), which isn't used to activate any of the seven pixel positions within the byte, could cause a problem. It is possible that if the hi bit were set in an empty or black background ($80), and a blue or orange shape were ANDed against the screen, the result would be non-zero. Obviously, this is an invalid result, because you can't collide with a black background. The problem can be avoided if the background is first ANDed with #$7F to mask the hi bit.

B	O	B	O	B	O	B	HI	
0	0	0	0	0	0	0	1	BACKGROUND
1	1	1	1	1	1	1	0	AND #$7F
0	0	0	0	0	0	0	0	RESULT ZERO
0	0	1	0	1	0	1	1	AND BLUE SHAPE
0	0	0	0	0	0	0	0	RESULT ZERO

Usually, in any game, if a collision is detected, the object is to be removed. The first instinct is to stop drawing the object since it is to be removed, anyway. But if you are Exclusive-ORing (EORing) the screen and you stop in the middle of your shape, you are going to leave a mess. It is much better to set a collision flag, finish drawing the shape, then remove the object later by completely EORing the shape off the screen.

Any two objects of byte size or larger will usually have no problem with collision detection, especially if the graphics are in B & W. But I can think of a very specific case involving color in which a collision would not be detected in a game. Take our space ship or plane from Chapter Five. Let us assume it is violet. Let's assume a green alien collides with it. The question is: Will it be detected, and if not, how can we detect a collision?

Let's map the pixel positions of the bottom row of bytes for both the violet ship and green alien.

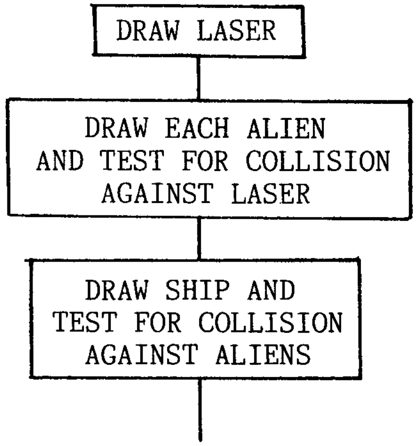
V	G	V	G	V	G	V	G	V	G	V	G	V	G	V	G	V	G	V	G	V	
		X		X		X		X		X		X		X		X		X			SHIP
	X		X						X		X										ALIEN

It is quite obvious that if you logical AND the two together, you are going to obtain zero in all three bytes; in fact, zero over the entire shape. While it is quite easy to tell you not to use complementary colors in a game, a red alien, which involves turning on the hi byte in its shape table, would also achieve an identical result of no collision. Besides, limiting colors hampers your artistic expression.

The solution is to test the ship against screen memory with what is called a "mask" of the ship's shape, as if the ship were a solid white. We take this mask of the ship, which has both violet and green pixels lit, and AND it against the alien occupying the same screen locations. A collision will be detected in this case. We set a flag and then take the appropriate byte from the violet ship's shape table and XOR it against the screen.

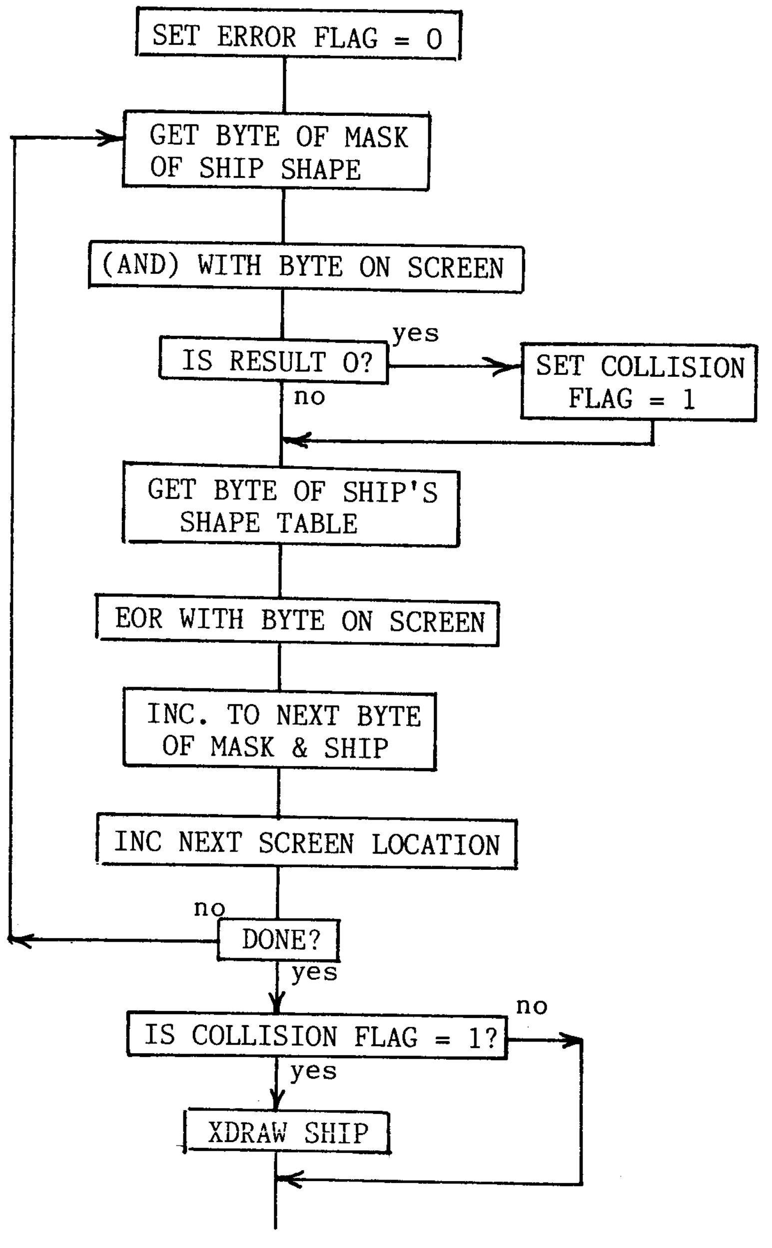
There is always some order with which objects must be drawn to the screen to allow our program to detect collisions properly. In a game with a laser-armed ship pitted against several unarmed aliens (our example), something must be drawn last. It is that final test that can sometimes get tricky. In many games, the user's ship is often the last to be placed on the screen. If a collision is detected, you end up wondering which alien hit it. Very often the screen coordinates of each alien must be compared to that of the ship to determine which object was killed. This is sometimes harder to do than it looks. That is why, when you collide with an enemy in many games, the enemy is not wiped out when the screen refreshes and you receive your next ship. What obviously happened is: they skipped the test.

The order that each object is drawn is shown in the flow chart below.



There isn't any satisfactory way to avoid the problem of the last test without elaborate testing. Even if we drew the ship first and the aliens last, we wouldn't know if an alien collided with a laser or a ship. It is important that these collision tests be performed before any background, like stars, are drawn to the screen. Also, any permanent background such as ground terrain will always cause a collision.

Single pixel background stars, in some games, are often set in motion to achieve an illusion of speed where stationary ships are involved. Of course, they are drawn and Xdrawn before being moved. Programmers usually keep the star field from intersecting with the ship's range of operation, which usually takes place at the bottom of the screen. However, sometimes it is desirable not to worry about background stars in a program and only draw them at the start of a game. You could adjust the collision counter to ignore single collisions while drawing a complex shape. It is likely that a ship's 24 byte shape would collide with a 16 byte alien shape in more than one place. Small one byte bullets, however, might pose a problem if the collision detector's value were upped to two instead of the usual one.

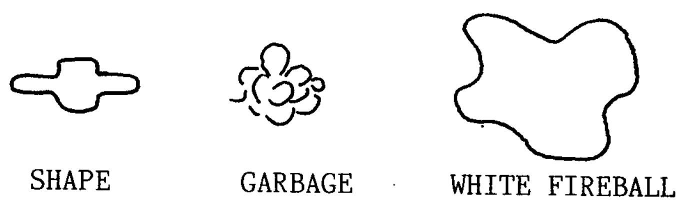

SET ERROR FLAG = 0
GET BYTE OF MASK OF SHIP SHAPE
(AND) WITH BYTE ON SCREEN
IS RESULT 0?
yes
SET COLLISION FLAG = 1
no
GET BYTE OF SHIP'S SHAPE TABLE
EOR WITH BYTE ON SCREEN
INC. TO NEXT BYTE OF MASK & SHIP
INC NEXT SCREEN LOCATION
no
DONE?
yes
IS COLLISION FLAG = 1?
no
yes
XDRAW SHIP

```
*DRAW SHIP SUBROUTINE
*DRAW SHAPE ONE LINE AT A TIME-LNGH BYTES ACROSS
*
SDRAW    LDA  #$00
         STA  ESET
SDRAW1   LDY  TVERT         ;VERTICAL POSITION
         JSR  GETADR
         LDX  #$00
SDRAW2   LDA  (STESTL,X) ;GET BYTE OF SHIP MASK SHAPE
         AND  #$7F          ;MASK OUT HI BIT
         AND  (HIRESL),Y ;(AND) IT AGAINST SCREEN
         CMP  #$00          ; IF ANYTHING IN WAY GET>0
         BEQ  SDRAW3
         LDA  #$01          ;SET BECAUSE IF DON'T FINISH DRAW-
         STA  ESET          ;ING SHIP,PIECE LEFT WHEN XDRAW
*-                          ;DURING EXPLOSION
SDRAW3   LDA  (SSHPL,X)  ;GET BYTE OF SHIP'S SHAPE
         EOR  (HIRESL),Y
         STA  (HIRESL),Y ;PLOT
         INC  STESTL        ;NEXT BYTE OF MASK
         INC  SSHPL         ; NEXT BYTE OF TABLE
         INY                ;NEXT SCREEN POSITION
         DEC  SLNGH
         BNE  SDRAW2        ;IF LINE NOT FINISHED BRANCH
         INC  TVERT         ;OTHERWISE NEXT LINE DOWN
         DEC  DEPTH
         BNE  SDRAW1        ;DONE DRAWING?
         LDA  ESET          ;IS EXPLOSION FLAG SET?
         CMP  #$00
         BEQ  SDRAW4        ;NO!, EXIT
         JMP  EXPLODE       ;YES!, EXPLODE SHIP
SDRAW4   RTS
```

EXPLOSIONS

A game wouldn't be complete without the enemy blowing apart when killed. The more dramatic the explosion, the better the effect. Although every programmer has tried it, most have done it the easy way.

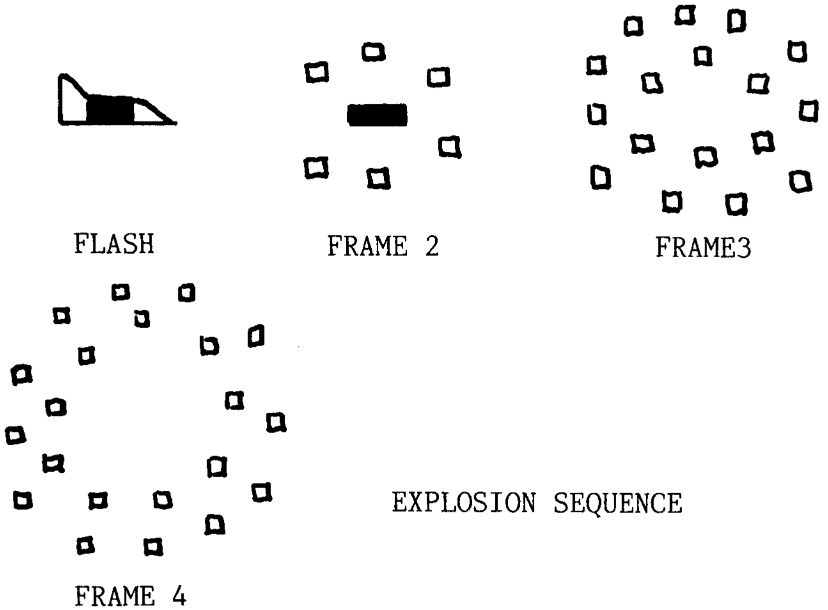
Explosions are divided into two types: shape explosions and particle explosions. Shape explosions are simple, because once an object is targeted for removal, it is replaced first by a garbage-looking shape and then by a white blob, which is larger and resembles a debris-filled fireball.



The animation is done in successive frames with delays between them. A nice sound routine, which can also act as a delay between plots, is often incorporated. These explosion shapes are stored in a table and are drawn to the screen with drawing subroutines.

Particle explosions are much more complex. They either involve mathematical and random number routines to keep particles streaming outwards from the exploded shape, or they resort to a series of tables to position the particles on the screen. I've chosen the latter case for the following example.

I envisioned a particle fireball that sometimes appears in arcade games like Defender. When the object begins to blow apart, there is a bright flash, then the white hot debris begins expanding in a roughly circular fireball. These fireballs in the arcade grow to be nearly a third the area of the screen and then fade to dull red before blanking out. While fading the particles to red can be included, coding it would be rather difficult. Actually, anything can be done on the Apple if you put your mind to it, but one should weigh the benefits against the time involved. I achieved the basic effect of the explosion in the following manner:

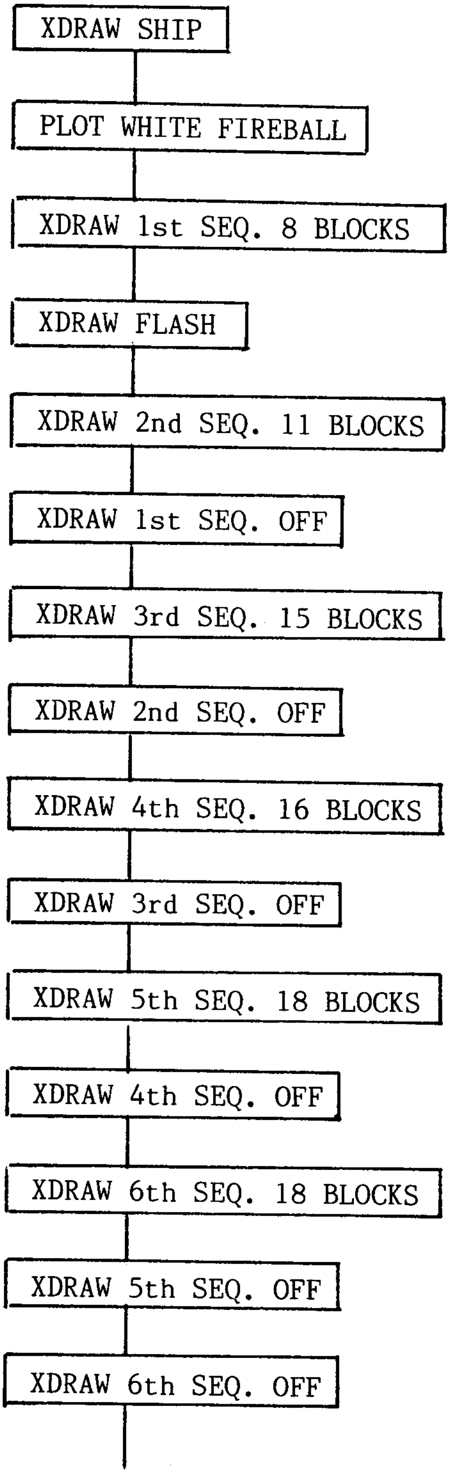


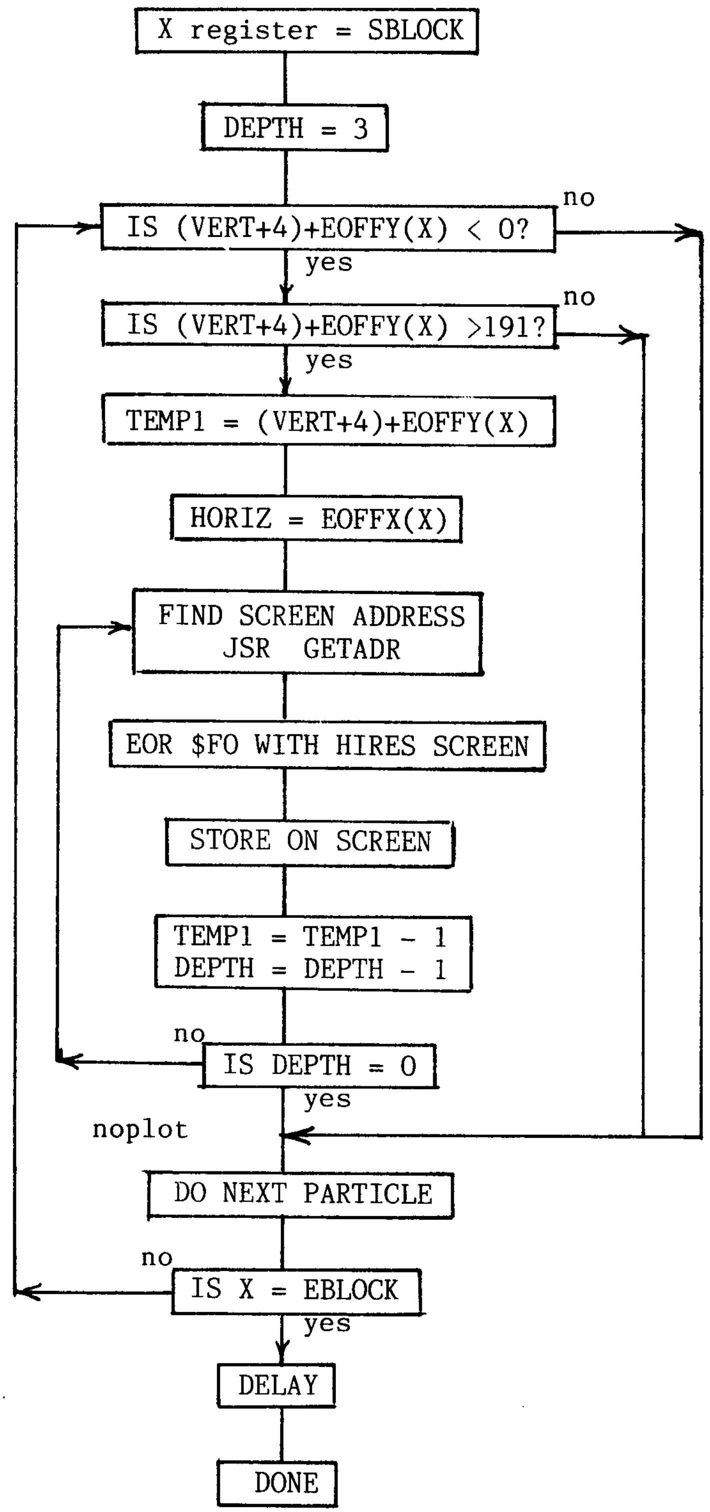
EXPLOSION SEQUENCE

The explosion fills almost 1/9th of the screen. The ship is XDRAWn off the screen and replaced by a bright white block at the ship's center. Then, white particles, each three pixels by four pixels, are drawn in successive expanding but randomized rings. Each frame has a ring of particles, two layers deep. Each successively larger ring requires more particles. The closest ring has only 8 particles, whose positions are stored in two tables, EOFFX and EOFFY. The largest rings have 18 particles.

The two position tables contain the locations of each particle. EOFFX contains the true horizontal offset. EOFFY contains the relative position in relation to the ship's vertical position. For example, the center of the fireball is at VERT + 12. If EOFFY = 8, then the particle is plotted at VERT + 12. And if EOFFY is negative or above the center at − 4 ,it is stored as $FC (the two's complement), so that it can be added to VERT + 4 directly without testing to see if it is negative, and then subtracting. The number of particles to be plotted in any ring is controlled by SBLOCK and EBLOCK. They determine the start and end points of the data table that is used to draw a ring.

The sequence for drawing the expanding fireball is shown below. It was my choice that only two layers be shown at any one time while the fireball expands. Readers might like to experiment by leaving all of the layers on the screen until the fireball reaches its limit, then XDRAWing them off from the inside out. The time delay in my game may seem fast for most readers. The explosion occurs much too rapidly, but longer delays looked strange using only two layers of debris. Experiment!


XDRAW SHIP
PLOT WHITE FIREBALL
XDRAW 1st SEQ. 8 BLOCKS
XDRAW FLASH
XDRAW 2nd SEQ. 11 BLOCKS
XDRAW 1st SEQ. OFF
XDRAW 3rd SEQ. 15 BLOCKS
XDRAW 2nd SEQ. OFF
XDRAW 4th SEQ. 16 BLOCKS
XDRAW 3rd SEQ. OFF
XDRAW 5th SEQ. 18 BLOCKS
XDRAW 4th SEQ. OFF
XDRAW 6th SEQ. 18 BLOCKS
XDRAW 5th SEQ. OFF
XDRAW 6th SEQ. OFF


X register = SBLOCK
DEPTH = 3
IS (VERT+4)+EOFFY(X) < 0?
no
yes
IS (VERT+4)+EOFFY(X) >191?
no
yes
TEMP1 = (VERT+4)+EOFFY(X)
HORIZ = EOFFX(X)
FIND SCREEN ADDRESS
JSR GETADR
EOR $FO WITH HIRES SCREEN
STORE ON SCREEN
TEMP1 = TEMP1 - 1
DEPTH = DEPTH - 1
no
IS DEPTH = 0
yes
noplot
DO NEXT PARTICLE
no
IS X = EBLOCK
yes
DELAY
DONE

```
                *EXPLOSION SUBROUTINE
                *
6513: 20 1E 65  EXPLODE  JSR  EXPSUB
6516: A9 FE              LDA  #$FE
6518: 20 A8 FC           JSR  $FCA8
651B: 4C DA 61           JMP  FIN
651E: AD 0C 60  EXPSUB   LDA  VERT
6521: 8D 0D 60           STA  TVERT
6524: 20 33 63           JSR  SSETUP       ;XDRAW SHIP
6527: 20 FD 62           JSR  SXDRAW
652A: A9 04     EDRAW    LDA  #$04         ;PLOT WHITE FIREBALL 4 LINES
652C: 8D 11 60           STA  DEPTH
652F: A9 0A              LDA  #$0A         ;HORIZ POS SHIP'S CENTER
6531: 8D 0E 60           STA  HORIZ
6534: AD 0C 60           LDA  VERT         ;VERT POS TOP OF SHIP
6537: 18                 CLC
6538: 69 04              ADC  #$04         ;TO REACH CENTER
653A: 8D 0D 60           STA  TVERT
653D: AC 0D 60  EDRAW1   LDY  TVERT        ;SHIP'S CENTER
6540: 20 1C 63           JSR  GETADR
6543: A9 FF              LDA  #$FF         ;WHITE LINE
6545: 51 26              EOR  (HIRESL),Y
6547: 91 26              STA  (HIRESL),Y
6549: EE 0D 60           INC  TVERT        ;NEXT LINE
654C: CE 11 60           DEC  DEPTH
654F: D0 EC              BNE  EDRAW1       ;DONE?
6551: A9 80              LDA  #$80
6553: 20 A8 FC           JSR  $FCA8        ;DELAY
                *XDRAW SEQ1 -8 BLOCKS
6556: A9 00              LDA  #$00
6558: 8D 0A 60           STA  SBLOCK
655B: A9 08              LDA  #$08
655D: 8D 0B 60           STA  EBLOCK
6560: 20 1A 66           JSR  EPLOT
                *XDRAW BEGINING FLASH
6563: A9 04     EDRAW2   LDA  #$04
6565: 8D 11 60           STA  DEPTH
6568: A9 0A              LDA  #$0A
656A: 8D 0E 60           STA  HORIZ
656D: 18                 CLC
656E: AD 0C 60           LDA  VERT
6571: 69 04              ADC  #$04
6573: 8D 0D 60           STA  TVERT
6576: AC 0D 60  EDRAW3   LDY  TVERT
6579: 20 1C 63           JSR  GETADR
657C: B1 26              LDA  (HIRESL),Y
657E: 51 26              EOR  (HIRESL),Y
6580: 91 26              STA  (HIRESL),Y
6582: EE 0D 60           INC  TVERT
6585: CE 11 60           DEC  DEPTH
6588: D0 EC              BNE  EDRAW3
                *XDRAW SEQ2-11BLOCKS
658A: A9 08              LDA  #$08
658C: 8D 0A 60           STA  SBLOCK
658F: A9 13              LDA  #$13
6591: 8D 0B 60           STA  EBLOCK
6594: 20 1A 66           JSR  EPLOT
                *XDRAW SEQ1- 8 OFF
6597: A9 00              LDA  #$00
```

```
6599: 8D 0A 60         STA  SBLOCK
659C: A9 08            LDA  #$08
659E: 8D 0B 60         STA  EBLOCK
65A1: 20 1A 66         JSR  EPLOT
               *XDRAW SEQ3-15
65A4: A9 13            LDA  #$13
65A6: 8D 0A 60         STA  SBLOCK
65A9: A9 22            LDA  #$22
65AB: 8D 0B 60         STA  EBLOCK
65AE: 20 1A 66         JSR  EPLOT
               *XDRAW SEQ2-11 OFF
65B1: A9 08            LDA  #$08
65B3: 8D 0A 60         STA  SBLOCK
65B6: A9 13            LDA  #$13
65B8: 8D 0B 60         STA  EBLOCK
65BB: 20 1A 66         JSR  EPLOT
               *XDRAW SEQ4-16
65BE: A9 22            LDA  #$22
65C0: 8D 0A 60         STA  SBLOCK
65C3: A9 32            LDA  #$32
65C5: 8D 0B 60         STA  EBLOCK
65C8: 20 1A 66         JSR  EPLOT
               *XDRAW SEQ3-15 OFF
65CB: A9 13            LDA  #$13
65CD: 8D 0A 60         STA  SBLOCK
65D0: A9 22            LDA  #$22
65D2: 8D 0B 60         STA  EBLOCK
65D5: 20 1A 66         JSR  EPLOT
               *XDRAW SEQ5- 18
65D8: A9 32            LDA  #$32
65DA: 8D 0A 60         STA  SBLOCK
65DD: A9 44            LDA  #$44
65DF: 8D 0B 60         STA  EBLOCK
65E2: 20 1A 66         JSR  EPLOT
               *XDRAW SEQ4-16 OFF
65E5: A9 22            LDA  #$22
65E7: 8D 0A 60         STA  SBLOCK
65EA: A9 32            LDA  #$32
65EC: 8D 0B 60         STA  EBLOCK
65EF: 20 1A 66         JSR  EPLOT
               *XDRAW SEQ6-18
65F2: A9 44            LDA  #$44
65F4: 8D 0A 60         STA  SBLOCK
65F7: A9 56            LDA  #$56
65F9: 8D 0B 60         STA  EBLOCK
65FC: 20 1A 66         JSR  EPLOT
               *XDRAW SEQ5-18 OFF
65FF: A9 32            LDA  #$32
6601: 8D 0A 60         STA  SBLOCK
6604: A9 44            LDA  #$44
6606: 8D 0B 60         STA  EBLOCK
6609: 20 1A 66         JSR  EPLOT
               *XDRAW SEQ6-18 OFF
660C: A9 44            LDA  #$44
660E: 8D 0A 60         STA  SBLOCK
6611: A9 56            LDA  #$56
6613: 8D 0B 60         STA  EBLOCK
6616: 20 1A 66         JSR  EPLOT
6619: 60               RTS
```

```
             *EXPLOSION PLOTTING SUBROUTINE
             *
661A: AE 0A 60  EPLOT    LDX  SBLOCK       ;LOCATION IN PARTICLE POSITION
             *-                             ;TO START DRAWING
661D: A9 03     EPLOT1   LDA  #$03          ;EACH BLOCK 3 LINES DEEP
661F: 8D 11 60           STA  DEPTH
6622: 18        ELOOP1   CLC
6623: AD 0C 60           LDA  VERT          ;TOP OF SHIP
6626: 69 04              ADC  #$04          ;NOW CENTER OF SHIP
6628: 18                 CLC
6629: 7D 9A 69           ADC  EOFFY,X       ;ADD RELATIVE Y POS OF PARTICLE.
662C: C9 00              CMP  #$00          ;TEST NOT OFF TOP SCREEN
662E: 90 21              BLT  NOPLOT        ;IF OFF, DON'T LOT
6630: C9 C0              CMP  #$C0          ;TEST NOT OFF BOTTOM SCREEN
6632: B0 1D              BGE  NOPLOT        ;IF OFF, DON'T PLOT
6634: 8D 09 60           STA  TEMP1          ;STORE VALUE IN TEMP1
6637: BD 44 69           LDA  EOFFX,X       ;LOCATE X POSITION
663A: 8D 0E 60           STA  HORIZ
663D: AC 09 60  ELOOP3   LDY  TEMP1         ;FIND LINE ADRESS TO PLOT ON SCREEN
6640: 20 1C 63           JSR  GETADR
6643: A9 F0              LDA  #$F0          ;VALUE OF ALL SHAPE BYTES
6645: 51 26              EOR  (HIRESL),Y    ;XOR WITH SCREEN
6647: 91 26              STA  (HIRESL),Y    ;PLOT ON SCREEN
6649: CE 09 60           DEC  TEMP1         ;NEXT LINE, IN THIS CASE DRAWING --
664C: CE 11 60           DEC  DEPTH         ;FROM BOTTOM TO TOP
664F: D0 EC              BNE  ELOOP3        ;DONE?
6651: E8        NOPLOT   INX                ;DO NEXT PARTICLE
6652: EC 0B 60           CPX  EBLOCK        ;DONE WITH ALL PARTICLES IN GROUP?
6655: D0 C6              BNE  EPLOT1        ;NO,CONTINUE
6657: A9 30              LDA  #$30
6659: 20 A8 FC           JSR  $FCA8         ;DELAY
665C: 60                 RTS
```

SCOREKEEPING

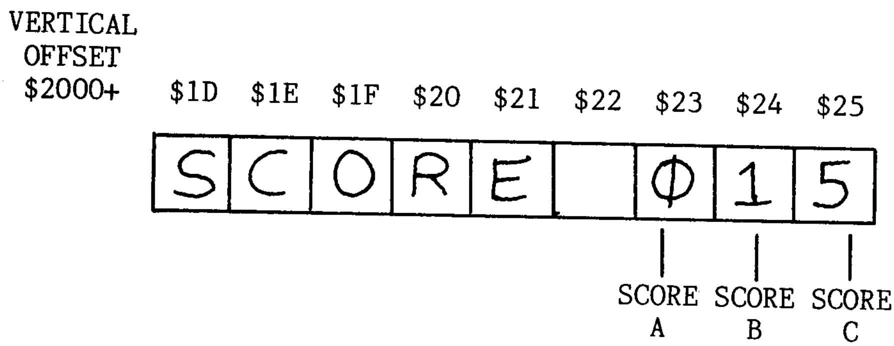
It is a rare exception for machine language games to include a Hi-Res character generator with a complete character set. It is basically a waste of space, because only one or two words are written to the Hi-Res screen along with the numbers 0 through 9 for the numerical score.

For example, in our game, only the word SCORE is written at the top of the screen. This is done once at the start of the game. The numbers, however, change with each alien killed. It would appear that the scoring subroutine would need to convert hexadecimal numbers to decimal numbers, since the computer stores the numerical score as hexadecimal numbers in memory. There is a simple method to avoid this messy approach.

The scoring registers can be broken down into three separate digits, one each for the hundred's digit, ten's digit and one's digit. This is just like the decimal system. Each time an enemy is killed, the one's digit storage location is incremented. This value is tested to see if it becomes greater than 9. If so, the one's digit memory location is reset to zero, and the ten's digit memory location is incremented by one.

If some objects were worth two points instead of one point, we could JSR to SCORE twice. If a target was worth ten points, one could JSR to the middle of the longer SCORE subroutine at a point called SCORE10. This is the place in the subroutine where the ten's digit is incremented. Returning to the main program would be through the usual RTS.

In the following routine, SCOREA represents the one's digit, SCOREB the ten's digit, and SCOREC the hundred's digit. The three variables are drawn on the screen just after the words SCORE, which is on the very first line at the top of the Hi-Res screen.



Since our three digit score doesn't move, the numbers don't change position during the game. Therefore, they don't need to be XDRAWn before being updated. New values can be drawn over the old numbers. This necessitated adding another drawing subroutine that is virtually identical to our standard eight-line deep XDRAW subroutine, but lacks the EOR code. An alternative would be to use your XDRAW drawing subroutine after first blacking out the previous number.

The scoring setup routine is divided into three sections for each of the three digits. SCOREC is to be drawn to the screen at location $2023, so HIRESL and HIRESH are set appropriately. The ten number shapes which are stored at SCORESH are individually referenced by indexing into a table of lo byte addresses stored at SCOREP.

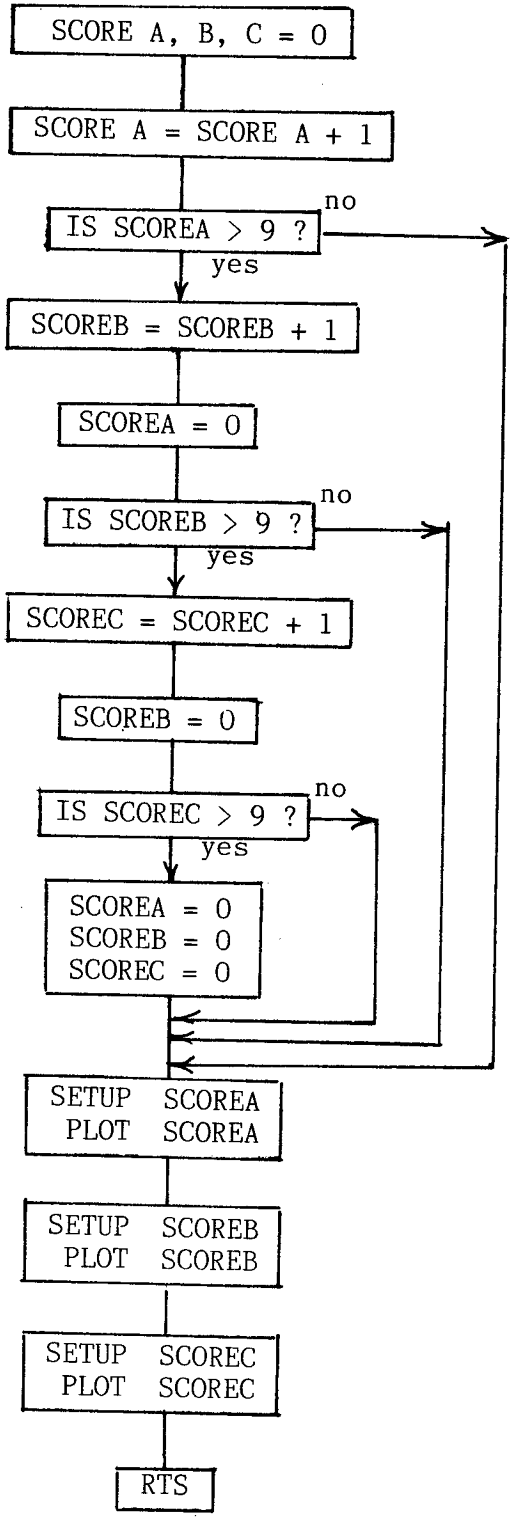
```
6A00   SCORESH  HEX 1C 22 .......
6A08            HEX 08 0C .......
6A10            HEX ............

         SCOREP  00 08 10 18 ..
```

For example, if SCOREC = 2 (hundred's digit), then the Y register contains a 2. LDA SCOREP,Y loads $10 in the Accumulator and stores the value as SHPL. The hi byte of SCORESH is stored as SHPH. Our drawing routine, using zero page indirect addressing LDA (SHPL),X with X = 0, will reference the correct shape at $6A10, which in this case are the bytes that form the number 2 on the screen.

The word SCORE stored as a five byte wide, eight-line deep shape, is drawn only once on the screen. This is done at the beginning before the program's main loop.

```
                  *SCORE SETUP ROUTINE FOR DRAW
                  *
6693: A9 20       SCRSET  LDA  #$20
6695: 85 27               STA  HIRESH
6697: A9 23               LDA  #$23        ;SETUP SCREEN LOCATION TO PLOT --
6699: 85 26               STA  HIRESL      ;SCOREC ,100'S DIGIT
669B: A9 01               LDA  #$01        ;DIGIT 1 BYTE WIDE
669D: 8D 10 60            STA  LNGH
66A0: A9 6A               LDA  #>SCORESH
66A2: 85 51               STA  SHPH
66A4: AC 20 60            LDY  SCOREC
66A7: B9 30 6A            LDA  SCOREP,Y    ;INDEX TO CORRECT SHAPE FOR DIGIT--
66AA: 85 50               STA  SHPL        ;DRAWN
66AC: 20 E8 66            JSR  SCOREDR     ;DRAW 100'S DIGIT
66AF: A9 20               LDA  #$20        ;SETUP SCREEN LOCATION TO
66B1: 85 27               STA  HIRESH
66B3: A9 24               LDA  #$24        ;PLOT SCOREB ,10'S DIGIT
66B5: 85 26               STA  HIRESL
66B7: A9 01               LDA  #$01
66B9: 8D 10 60            STA  LNGH
66BC: A9 6A               LDA  #>SCORESH
66BE: 85 51               STA  SHPH
66C0: AC 1F 60            LDY  SCOREB
66C3: B9 30 6A            LDA  SCOREP,Y
66C6: 85 50               STA  SHPL
66C8: 20 E8 66            JSR  SCOREDR     ;DRAW 10'S DIGIT
66CB: A9 20               LDA  #$20
66CD: 85 27               STA  HIRESH
66CF: A9 25               LDA  #$25        ;SETUP SCREEN LOCATION TO
66D1: 85 26               STA  HIRESL      ;PLOT SCOREA, 1'S DIGIT
66D3: A9 01               LDA  #$01
66D5: 8D 10 60            STA  LNGH
66D8: A9 6A               LDA  #>SCORSH
66DA: 85 51               STA  SHPH
66DC: AC 1E 60            LDY  SCOREA
66DF: B9 30 6A            LDA  SCOREP,Y
66E2: 85 50               STA  SHPL
66E4: 20 E8 66            JSR  SCOREDR     ;DRAW 1'S DIGIT
66E7: 60                  RTS
```


SCORE A, B, C = 0
SCORE A = SCORE A + 1
IS SCOREA > 9 ?
no
yes
SCOREB = SCOREB + 1
SCOREA = 0
IS SCOREB > 9 ?
no
yes
SCOREC = SCOREC + 1
SCOREB = 0
IS SCOREC > 9 ?
no
yes
SCOREA = 0
SCOREB = 0
SCOREC = 0
SETUP SCOREA
PLOT SCOREA
SETUP SCOREB
PLOT SCOREB
SETUP SCOREC
PLOT SCOREC
RTS

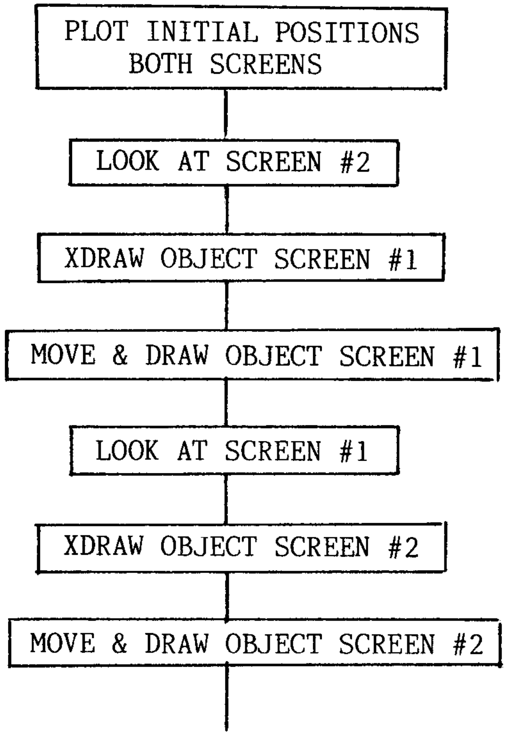
```
                 *SCORE SUBROUTINE
                 *
665D: EE 1D 60   SCORE    INC  KILLNUM     ;ANOTHER ALIEN KILLED
6660: EE 1E 60            INC  SCOREA      ;INCREMENT COUNTER
6663: AD 1E 60            LDA  SCOREA
6666: C9 0A               CMP  #$0A
6668: 90 29               BLT  SCRSET      ;IF <10 DON'T CARRY TENS DIGIT
666A: A9 00               LDA  #$00        ;ZERO OUT 1'S DIGIT
666C: 8D 1E 60            STA  SCOREA
666F: EE 1F 60   SCORE10  INC  SCOREB      ;ADD CARRY IN TENS
6672: AD 1F 60            LDA  SCOREB
6675: C9 0A               CMP  #$0A
6677: 90 1A               BLT  SCRSET      ;IF <10 DON'T CARRY TO 100'S DIGIT
6679: A9 00               LDA  #$00        ;ZERO OUT 10'S DIGIT & 1'S DIGIT
667B: 8D 1F 60            STA  SCOREB
667E: EE 20 60            INC  SCORC       ;ADD CARRY IN 100'S
6681: AD 20 60            LDA  SCOREC
6684: C9 0A               CMP  #$0A
6686: 90 0B               BLT  SCRSET      ;SKIP IF LESS 999
6688: A9 00               LDA  #$00        ;RESET TO 0 IF 1000
668A: 8D 1E 60            STA  SCOREA
668D: 8D 1F 60            STA  SCOREB
6690: 8D 20 60            STA  SCOREC
                 *
```

```
                 *SCORE DRAWING ROUTINE
                 *
66E8: A2 00      SCOREDR  LDX  #$00
66EA: A0 00               LDY  #$00        ;OFFSET INTO LINE ALREADY SET --
66EC: A1 50      SCORED2  LDA  (SHPL,X)    ;IN SCRSET
66EE: 91 26               STA  (HIRESL),Y
66F0: A5 27               LDA  HIRESH
66F2: 18                  CLC
66F3: 69 04               ADC  #$04
66F5: 85 27               STA  HIRESH
66F7: E6 50               INC  SHPL
66F9: C9 40               CMP  #$40
66FB: 90 EF               BCC  SCORED2
66FD: E9 20               SBC  #$20
66FF: 85 27               STA  HIRESH
6701: CE 10 60            DEC  LNGH
6704: F0 03               BEQ  SCORED3
6706: C8                  INY
6707: D0 E3               BNE  SCORED2
6709: 60         SCORED3  RTS
```

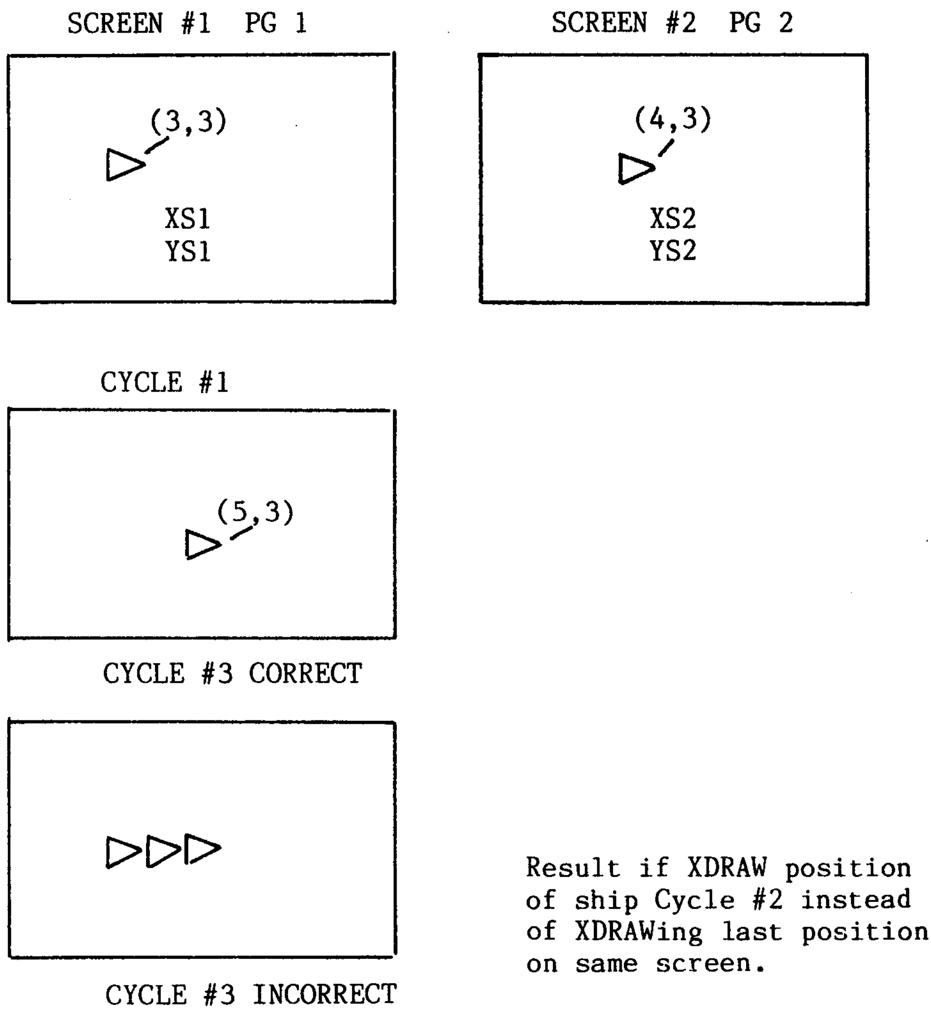
PAGE FLIPPING

One of the most successful methods for eliminating screen flicker while simultaneously smoothing animation is screen or page flipping. The principle involves drawing on one graphics screen while viewing the other. However, it uses an additional 8K of memory for screen display, and involves elaborate logic to keep track of what and when to draw or erase on a particular screen.

The logic loop for moving an object across the screen is as follows:



This appears to be rather simple and straight-forward, but it can be tricky. Let's take an object on screen #1, located at X,Y coordinates 3,3. We move it to the right one position to coordinates 4,3 and display it on screen #2. Now, we move it right once more to 5,3 and plot it on screen #1. Before we plot it, we must XDRAW it at its previous position 3,3 , because that was its last location on screen #1. This is different from the last location plotted, which is on screen #2. The last time we plotted on screen #1, we plotted our object at 3,3. If you make this mistake and just erase the last object's position, which was actually on the opposite screen, you will XDRAW an object at 3,4 and get an object at that location. Recall that XDRAWing is EORing, and it will plot if nothing is there and erase if something is there.



The solution to keeping track of the objects is to store the previous location of all objects for both screens. In the above case, XS1,YS1 is always the previous location for the object on screen #1, while XS2,YS2 is the previous screen position for the object on screen #2. While this isn't awkward for one or two objects, a multitude of objects may prove difficult for most programmers. If you are determined to pursue this, I would suggest storing the previous object locations for each screen in tables, which can then be indexed by object number.

To demonstrate a working example of page flipping, the free-floating rocket ship program has been converted to dual screen. Actually, you won't see any

difference in flicker, because only one small object is being drawn. It would require at least a dozen or more objects before you might begin to see the effects of flicker. A small minus sign was added to the bottom left corner of screen #1 as a page reference to determine which screen was being viewed. A single step debug package was also incorporated to allow you to step from screen to screen.

Screen #1 is considered the odd screen and screen #2 the even screen. A counter is incremented for each screen cycle. It is tested for its odd/even character by dividing by two (LSR)and testing the carry bit. Depending on whether COUNTER is odd or even, you might store coordinate values and draw on one screen while displaying the other; then, when COUNTER changes, switch to the opposite screen. For example, if you look at the flow

page flipping DSETUP

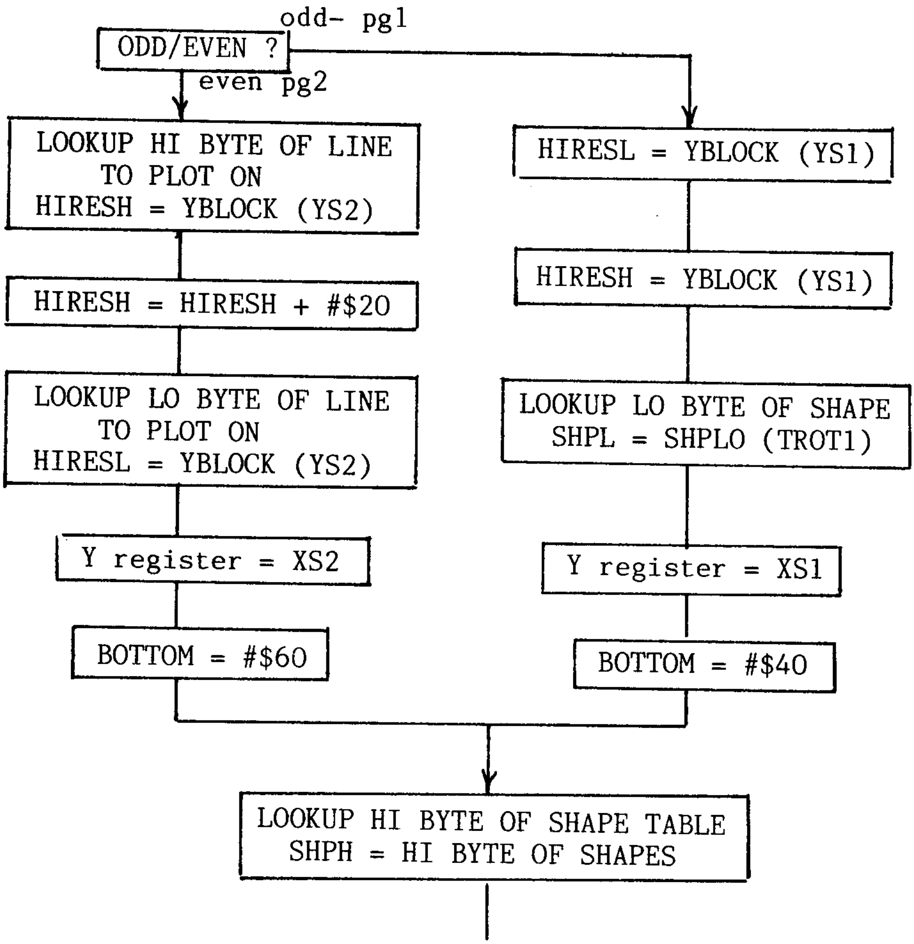
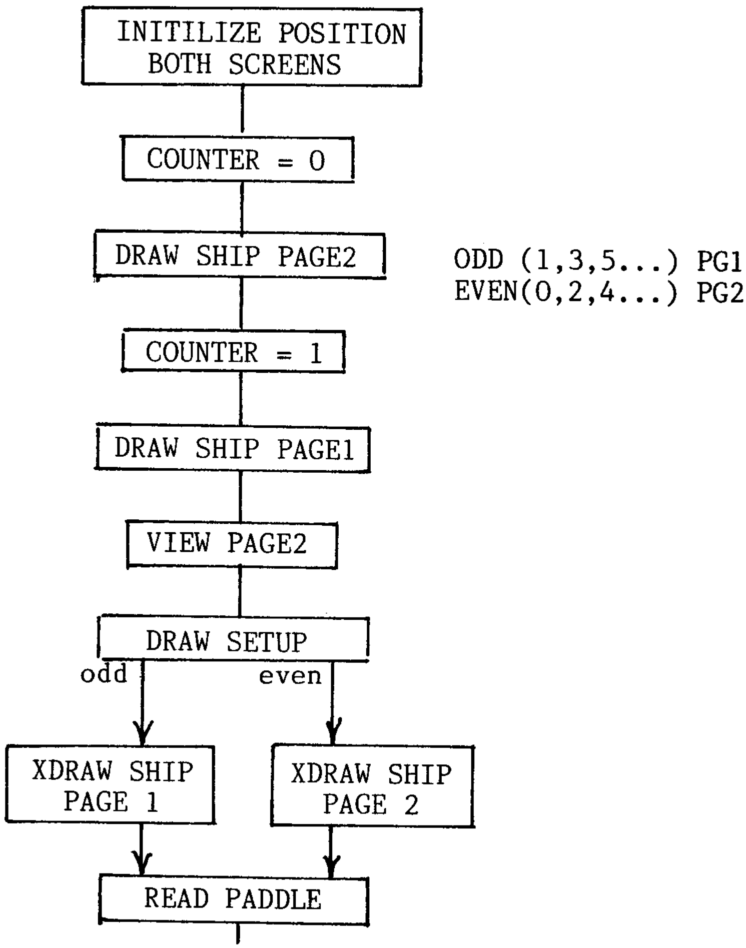
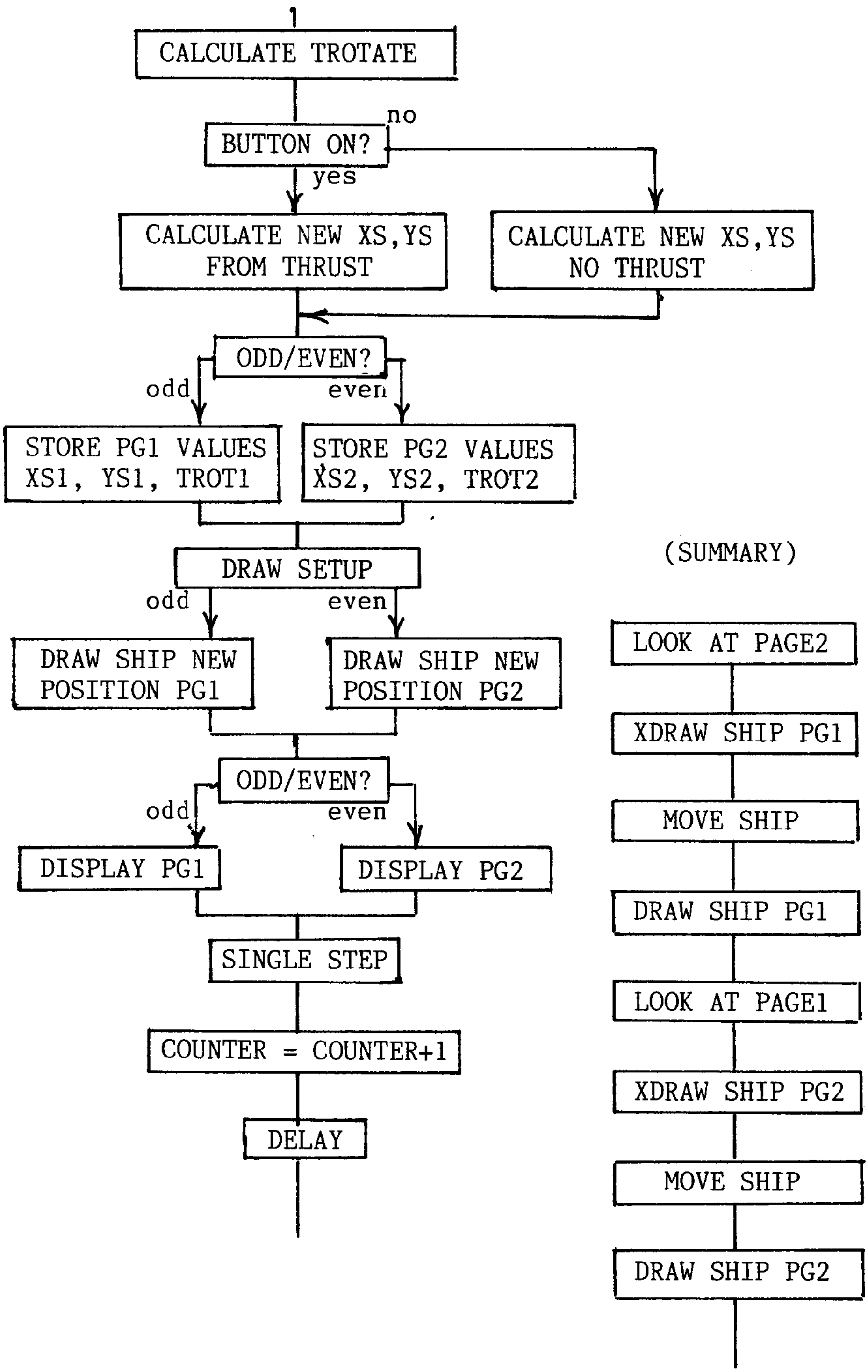


chart below - when COUNTER is even, you store screen #2's values, XS2, YS2, and TROT2 after calculating the ship's new position, and draw the ship on screen #2 while displaying screen #1. When you are finished, you shift the view to screen #2.

Likewise, the drawing setup subroutine must set the pointers to the proper line on the proper screen. An even-valued COUNTER needs to locate the screen line for YS2 and the offset for XS2. In addition, #$20 must be added to the hi byte line pointer HIRESH for screen #2. Also, the test to determine if all eight lines have been plotted - a comparison with BOTTOM - becomes > = #$60, which is the end of the second Hi-Res screen.

The flow chart and code is shown below.




CALCULATE TROTATE
BUTTON ON?
no
yes
CALCULATE NEW XS,YS FROM THRUST
CALCULATE NEW XS,YS NO THRUST
ODD/EVEN?
odd
even
STORE PG1 VALUES XS1, YS1, TROT1
STORE PG2 VALUES XS2, YS2, TROT2
DRAW SETUP
odd
even
DRAW SHIP NEW POSITION PG1
DRAW SHIP NEW POSITION PG2
ODD/EVEN?
odd
even
DISPLAY PG1
DISPLAY PG2
SINGLE STEP
COUNTER = COUNTER+1
DELAY
(SUMMARY)
LOOK AT PAGE2
XDRAW SHIP PG1
MOVE SHIP
DRAW SHIP PG1
LOOK AT PAGE1
XDRAW SHIP PG2
MOVE SHIP
DRAW SHIP PG2

```
                 *FREE FLOATING ROCKET (PAGE FLIPPING)
                          ORG  $6000
6000: 4C 14 60            JMP  PROG        ;JUMP TO START OF PROGRAM
                 XS       DS   1
                 YS       DS   1
                 XS1      DS   1
                 XS2      DS   1
                 YS1      DS   1
                 YS2      DS   1
                 VX       DS   1
                 VY       DS   1
                 PDL      DS   1
                 LNGH     DS   1
                 COUNTER  DS   1
                 BOTTOM   DS   1
                 ROTATE   DS   1
                 TROTATE  DS   1
                 TROT1    DS   1
                 TROT2    DS   2
                 HIRESL   EQU  $FB
                 HIRESH   EQU  HIRESL+$1
                 SHPL     EQU  $FD
                 SHPH     EQU  SHPL+$1
                 PREAD    EQU  $FB1E
                 *ENTER HERE FIRST TIME ACCESS
6014: AD 50 C0   PROG     LDA  $C050
6017: AD 52 C0            LDA  $C052
601A: AD 57 C0            LDA  $C057
601D: 20 0B 62            JSR  CLRSCR
6020: 20 25 62            JSR  CLRSCR2
                 *INITILIZE ROCKET'S STARTING POSITION
6023: A9 14               LDA  #$14
6025: 8D 03 60            STA  XS
6028: 8D 05 60            STA  XS1
602B: 8D 06 60            STA  XS2
602E: A9 0A               LDA  #$0A
6030: 8D 04 60            STA  YS
6033: 8D 07 60            STA  YS1
6036: 8D 08 60            STA  YS2
6039: A9 00               LDA  #$00
603B: 8D 09 60            STA  VX
603E: 8D 0A 60            STA  VY
6041: 8D 0F 60            STA  ROTATE
6044: 8D 11 60            STA  TROT1
6047: 8D 12 60            STA  TROT2
604A: A9 00               LDA  #$00
604C: 8D 0D 60            STA  COUNTER
604F: 20 BF 61            JSR  DSETUP      ;DRAW EVEN OR PAGE 2 START POS
6052: 20 97 61            JSR  DRAW
6055: A9 01               LDA  #$01
6057: 8D 0D 60            STA  COUNTER
605A: 20 BF 61            JSR  DSETUP      ;DRAW ODD OR PAGE 1 START POS
605D: 20 97 61            JSR  DRAW
6060: AD 55 C0            LDA  $C055       ;DISPLAY PG 2 WHILE DRAWING ON PG 1
                 *PUT MINUS SIGN AT BOTTOM LEFT PAGE 2 FOR REFERENCE
6063: A9 FF               LDA  #$FF
6065: 8D D0 5F            STA  $5FD0
                 *
```

```
                   ** M A I N   P R O G R A M   L O O P **
                   *
                   * PADDLE READ
6068: 20 BF 61     START    JSR  DSETUP     ;WILL SETUP NON DISPLAYED SCREEN
                   *FOR SHIP XDRAW
606B: 20 97 61              JSR  DRAW       ;XDRAW SHIP ON NON DISPLAY SCREEN
606E: A2 01                 LDX  #$01
6070: 20 1E FB              JSR  PREAD
6073: C0 F9                 CPY  #$F9       ;CLIP VALUE (0-250)
6075: 90 02                 BLT  SKIPP
6077: A0 F8                 LDY  #$F8
6079: 8C 0B 60     SKIPP    STY  PDL
607C: 98                    TYA
607D: CD 0F 60              CMP  ROTATE     ;PADDLE<ROTATE POS THEN SUBTRACT 5
6080: B0 1B                 BGE  PADDLE3
6082: AD 0F 60              LDA  ROTATE
6085: 38                    SEC
6086: E9 05                 SBC  #$05
6088: B0 05                 BGE  PADDLE1    ;MAKE SURE =>0
608A: A9 00                 LDA  #$00
608C: 8D 0F 60              STA  ROTATE
608F: CD 0B 60     PADDLE1  CMP  PDL        ;DON'T WANT TO GO PAST PADDLE POS
6092: B0 03                 BGE  PADDLE2
6094: AD 0B 60              LDA  PDL
6097: 8D 0F 60     PADDLE2  STA  ROTATE
609A: 4C B0 60              JMP  PADDLE5
609D: CD 0F 60     PADDLE3  CMP  ROTATE     ;PADDLE>ROTATE POS THEN ADD 5
60A0: F0 0B                 BEQ  PADDLE4
60A2: AD 0F 60              LDA  ROTATE
60A5: 18                    CLC
60A6: 69 05                 ADC  #$05
60A8: CD 0B 60              CMP  PDL        ;DON'T WANT TO GO PAST PADDLE POS
60AB: 90 03                 BLT  PADDLE5
60AD: AD 0B 60     PADDLE4  LDA  PDL
60B0: 8D 0F 60     PADDLE5  STA  ROTATE
60B3: 4A                    LSR             ;DIVIDE BY 16 TO GET ROTATION(0-15)
60B4: 4A                    LSR             ;OR WO ROTATIONS
60B5: 4A                    LSR
60B6: 4A                    LSR
60B7: 8D 10 60              STA  TROTATE
                   *
60BA: AD 62 C0              LDA  $C062      ;NEG BUTTON PRESSED
60BD: 30 03                 BMI  THRUST
60BF: 4C F7 60              JMP  NOTHRUST
60C2: AE 10 60     THRUST   LDX  TROTATE
                   *UPDATE VELOCITY VX AND VY
60C5: 18                    CLC
60C6: BD 6F 62              LDA  XT,X       ;GET X THRUST VECTOR
60C9: 6D 09 60              ADC  VX
60CC: C9 FD                 CMP  #$FD
60CE: D0 05                 BNE  NOCLIP
60D0: A9 FE                 LDA  #$FE
60D2: 4C DB 60              JMP  NOCLIP1
60D5: C9 03        NOCLIP   CMP  #$03       ;CLIP MAX VELOCITY AT 2
60D7: D0 02                 BNE  NOCLIP1
60D9: A9 02                 LDA  #$02
60DB: 8D 09 60     NOCLIP1  STA  VX         ;STORE X VELOCITY
60DE: 18                    CLC
60DF: BD 7F 62              LDA  YT,X
```

```
60E2: 6D 0A 60                ADC  VY
60E5: C9 FD                   CMP  #$FD
60E7: D0 05                   BNE  NOCLIP2
60E9: A9 FE                   LDA  #$FE
60EB: 4C F4 60                JMP  NOCLIP3
60EE: C9 03          NOCLIP2  CMP  #$03      ;CLIP MAX VELOCITY AT 2
60F0: D0 02                   BNE  NOCLIP3
60F2: A9 02                   LDA  #$02
60F4: 8D 0A 60       NOCLIP3  STA  VY        ;STORE Y VELOCITY
                     *UPDATE SHIP'S X POSITION XS
60F7: 18             NOTHRUST CLC
60F8: AD 09 60                LDA  VX
60FB: 6D 03 60                ADC  XS
60FE: C9 E0                   CMP  #$E0      ;CHECK FOR WRAPAROUND LEFT
6100: 90 06                   BLT  NWRAP1
6102: 18                      CLC
6103: 69 28                   ADC  #$28      ;FIX BY ADDING 40
6105: 4C 0F 61                JMP  NWRAP2
6108: C9 28          NWRAP1   CMP  #$28      ;CHECK FOR WRAPAROUND RIGHT
610A: 90 03                   BLT  NWRAP2
610C: 38                      SEC
610D: E9 28                   SBC  #$28      ;FIX BY SUBTRACTNG 40
610F: 8D 03 60       NWRAP2   STA  XS        ;STORE SHIP'S NEW X POS
                     *UPDATE SHIP'S Y POSITION YS
6112: 18                      CLC
6113: AD 0A 60                LDA  VY
6116: 6D 04 60                ADC  YS
6119: C9 E0                   CMP  #$E0      ;CHECK FOR WRAPAROUND TOP
611B: 90 06                   BLT  NWRAP3
611D: 18                      CLC
611E: 69 18                   ADC  #$18      ;FIX BY ADDING 24
6120: 4C 2A 61                JMP  NWRAP4
6123: C9 18          NWRAP3   CMP  #$18      CHECK FOR WRAPAROUND BOTTOM
6125: 90 03                   BLT  NWRAP4
6127: 38                      SEC
6128: E9 18                   SBC  #$18      ; FIX BY SUBTRACTING 24
612A: 8D 04 60       NWRAP4   STA  YS        ; STORE NEW Y POSITION
612D: 18                      CLC
612E: AD 0D 60                LDA  COUNTER
6131: 4A                      LSR
6132: B0 15                   BCS  ODD
6134: AD 03 60       EVEN     LDA  XS
6137: 8D 06 60                STA  XS2       ;STORE SHIP'S CURRENT VARIABLES-PG 2
613A: AD 04 60                LDA  YS
613D: 8D 08 60                STA  YS2
6140: AD 10 60                LDA  TROTATE
6143: 8D 12 60                STA  TROT2
6146: 4C 5B 61                JMP  DONE
6149: AD 03 60       ODD      LDA  XS
614C: 8D 05 60                STA  XS1       ;STORE SHIP'S CURRENT VARIABLES -PG 1
614F: AD 04 60                LDA  YS
6152: 8D 07 60                STA  YS1
6155: AD 10 60                LDA  TROTATE
6158: 8D 11 60                STA  TROT1
615B: EA             DONE     NOP
                     *
615C: 20 BF 61                JSR  DSETUP    ;SETUP SHIP'S NEW DRAWING POS
                     *FOR NON DISPLAY SCREEN
615F: 20 97 61                JSR  DRAW      ;DRAW SHIP ON NON DISPLAYED SCREEN
6162: 18                      CLC
```

```
6163: AD 0D 60          LDA  COUNTER     ;TEST COUNTER TO DETERMINE
                 *NEW PAGE DISPLAYE
6166: 4A                LSR              ;DISPLAY PAGE JUST DRAWN TO
6167: B0 06             BCS  ODD1        ;ODD SHIFT TO PAGE 1
6169: AD 55 C0   EVEN1  LDA  $C055       ;EVEN SHIFT TO PAGE 2
616C: 4C 72 61          JMP  SKIP0
616F: AD 54 C0   ODD1   LDA  $C054
6172: EA         SKIP0  NOP
                 *DEBUG PACKAGE TO SINGLE STEP
6173: AD 00 C0          LDA  $C000       ;KEY PRESSED?
6176: 10 10             BPL  IGNORE      ;EXIT IF NO KEY PRESSED
6178: C9 9B             CMP  #$9B        ;ESC KEY?
617A: D0 0C             BNE  IGNORE
617C: 2C 10 C0   CAUGHT BIT  $C010       ;CLEAR STROBE
617F: AD 00 C0          LDA  $C000       ;KEY PRESSED?
6182: 10 FB             BPL  *-3         ;LOOP BY BRANCHING BACK 3 BYTES
6184: C9 A0             CMP  #$A0        ;SPACE KEY?
6186: D0 03             BNE  IGNORE+3    ;NO,DON'T CLEAR STROBE
6188: 2C 10 C0   IGNORE BIT  $C010       ;CLEAR STROBE
618B: EA                NOP
618C: EE 0D 60          INC  COUNTER     ;INCREMENT COUNTER FOR NEXT FRAME
618F: A9 C0             LDA  #$C0
6191: 20 A8 FC          JSR  $FCA8       ; SHORT DELAY
6194: 4C 68 60          JMP  START
                 *
                 * S U B R O U T I N E S *
                 *
                 *SUBROUTINE TO DRAW ROCKET 1 BYTEBY 8 ROWS
6197: A2 00      DRAW   LDX  #$00
6199: A9 01             LDA  #$01
619B: 8D 0C 60          STA  LNGH
619E: A1 FD      DRAW2  LDA  (SHPL,X)    ;GET BYTE FROM SHAPE TABLE
61A0: 51 FB             EOR  (HIRESL),Y
61A2: 91 FB             STA  (HIRESL),Y  ;PUT ON HIRES SCREEN
61A4: A5 FC             LDA  HIRESH
61A6: 18                CLC
61A7: 69 04             ADC  #$04        ;THIS GETS TO NEXT ROW IN BLOCK
61A9: 85 FC             STA  HIRESH
61AB: E6 FD             INC  SHPL        ;NEXT BYTE OF SHAPE TABLE
61AD: CD 0E 60          CMP  BOTTOM      ;ARE WE FINISHED WITH 8 ROWS
61B0: 90 EC             BCC  DRAW2       ;NO DO NEXT BYTE
61B2: E9 20             SBC  #$20        ;RETURN TO TOP ROW
61B4: 85 FC             STA  HIRESH
61B6: CE 0C 60          DEC  LNGH
61B9: F0 03             BEQ  DRAW3       ;FINISHED?
61BB: C8                INY              ;NEXT COLUMN OF 8 ROWS
61BC: D0 E0             BNE  DRAW2
61BE: 60         DRAW3  RTS
                 *DRAWING SETUP SUBROUTINE
61BF: AD 0D 60   DSETUP LDA  COUNTER     ;ODD PAGE 1 :EVEN PAGE 2
61C2: 18                CLC
61C3: 4A                LSR              ;TEST ODD OR EVEN BY SHIFTING -
                 *-                    ;INTO CARRY BIT
61C4: B0 23             BCS  PAGE1
61C6: AC 08 60   PAGE2  LDY  YS2
61C9: B9 3F 62          LDA  YBLOCKH,Y
61CC: 18                CLC
61CD: 69 20             ADC  #$20        ;ADD TO REFRENCE SCREEN 2 MEMORY
61CF: 85 FC             STA  HIRESH
61D1: B9 57 62          LDA  YBLOCKL,Y
```

```
61D4: 85 FB                    STA  HIRESL
61D6: AC 12 60                 LDY  TROT2      ;SETUP POINTER TO CORRECT SHAPE -
               *-                              ;TABLE
61D9: B9 8F 62                 LDA  SHPLO,Y
61DC: 85 FD                    STA  SHPL
61DE: A9 60                    LDA  #$60       ;THIS WILL CORRECT DRAWING TEST
               *FOR END OF 8 LINES - PG 2
61E0: 8D 0E 60                 STA  BOTTOM
61E3: AC 06 60                 LDY  XS2
61E6: 4C 06 62                 JMP  SKIPPY
61E9: AC 07 60 PAGE1           LDY  YS1
61EC: B9 3F 62                 LDA  YBLOCKH,Y  ;LOOK UP HI BYTE OF LINE
61EF: 85 FC                    STA  HIRESH
61F1: B9 57 62                 LDA  YBLOCKL,Y
61F4: 85 FB                    STA  HIRESL
61F6: AC 11 60                 LDY  TROT1
61F9: B9 8F 62                 LDA  SHPLO,Y
61FC: 85 FD                    STA  SHPL
61FE: A9 40                    LDA  #$40
6200: 8D 0E 60                 STA  BOTTOM
6203: AC 05 60                 LDY  XS1        ;DISPLACEMENT INTO LINE
6206: A9 63    SKIPPY          LDA  #>SHAPES
6208: 85 FE                    STA  SHH
620A: 60                       RTS
               *CLEAR SCREEN SUBROUTINE
620B: A9 00    CLRSCR          LDA  #$00
620D: 85 FB                    STA  HIRESL
620F: A9 20                    LDA  #$20
6211: 85 FC                    STA  HIRESH
6213: A0 00    CLR1            LDY  #$00
6215: A9 00                    LDA  #$00
6217: 91 FB    CLR2            STA  (HIRESL),Y
6219: C8                       INY
621A: D0 FB                    BNE  CLR2
621C: E6 FC                    INC  HIRESH
621E: A5 FC                    LDA  HIRESH
6220: C9 40                    CMP  #$40
6222: 90 EF                    BCC  CLR1
6224: 60                       RTS
               *CLEAR SCREEN 2 SUBROUTINE
6225: A9 00    CLRSCR2         LDA  #$00
6227: 85 FB                    STA  HIRESL
6229: A9 40                    LDA  #$40
622B: 85 FC                    STA  HIRESH
622D: A0 00    CLR3            LDY  #$00
622F: A9 00                    LDA  #$00
6231: 91 FB    CLR4            STA  (HIRESL),Y
6233: C8                       INY
6234: D0 FB                    BNE  CLR4
6236: E6 FC                    INC  HIRESH
6238: A5 FC                    LDA  HIRESH
623A: C9 60                    CMP  #$60
623C: 90 EF                    BCC  CLR3
623E: 60                       RTS
               *TABLES OF STARTING VALUE OF EACH OF 20 BLOCKS
623F: 20 20 21
6242: 21 22 22
```

```
6245: 23 23 20
6248: 20        YBLOCKH  HEX  20202121222223232020
6249: 21 21 22
624C: 22 23 23
624F: 20 20 21
6252: 21                  HEX  21212222232320202121
6253: 22 22 23
6256: 23                  HEX  22222323
6257: 00 80 00
625A: 80 00 80
625D: 00 80 28
6260: A8        YBLOCKL  HEX  008000800080008028A8
6261: 28 A8 28
6264: A8 28 A8
6267: 50 D0 50
626A: D0                  HEX  28A828A828A850D050D0
626B: 50 D0 50
626E: D0                  HEX  50D050D0
                *
626F: 00 01 01
6272: 01 00 FF
6275: FF FF     XT        HEX  0001010100FFFFFF
6277: 00 01 01
627A: 01 00 FF
627D: FF FF               HEX  0001010100FFFFFF
627F: FF FF 00
6282: 01 01 01
6285: 00 FF     YT        HEX  FFFF0001010100FF
6287: FF FF 00
628A: 01 01 01
628D: 00 FF               HEX  FFFF0001010100FF
                *
628F: 03        SHPLO     DFB  SHAPES
6290: 0B                  DFB  SHAPES+$08
6291: 13                  DFB  SHAPES+$10
6292: 1B                  DFB  SHAPES+$18
6293: 23                  DFB  SHAPES+$20
6294: 2B                  DFB  SHAPES+$28
6295: 33                  DFB  SHAPES+$30
6296: 3B                  DFB  SHAPES+$38
                *NEXT GROUP BECAUSE PADDLE (0-15) INDEXES INTO
                *SHAPE TABLE TWICE
6297: 03                  DFB  SHAPES
6298: 0B                  DFB  SHAPES+$08
6299: 13                  DFB  SHAPES+$10
629A: 1B                  DFB  SHAPES+$18
629B: 23                  DFB  SHAPES+$20
629C: 2B                  DFB  SHAPES+$28
629D: 33                  DFB  SHAPES+$30
629E: 3B                  DFB  SHAPES+$38
                *
                SPACE     DS   100
                *ROCKET SHAPES
6303: 00 08 08
6306: 08 1C 1C
6309: 36 00     SHAPES    HEX  000808081C1C3600
                *2ND
```

```
630B: 00 00 20
630E: 14 0F 1C
6311: 08 08     328          HEX  000020140F1C0808
                329   *3RD
6313: 00 00 02
6316: 0E 7C 0E
6319: 02 00     330          HEX  0000020E7C0E0200
                331   *4TH
631B: 00 08 08
631E: 1C 0F 14
6321: 20 00     332          HEX  0008081C0F142000
                333   *5TH
6323: 00 00 36
6326: 1C 1C 08
6329: 08 08     334          HEX  0000361C1C080808
                335   *6TH
632B: 00 08 08
632E: 1C 78 14
6331: 02 00     336          HEX  0008081C78140200
                337   *7TH
6333: 00 00 20
6336: 38 1F 38
6339: 20 00     338          HEX  000020381F382000
                339   *8TH
633B: 00 00 02
633E: 14 78 1C
6341: 08 08     340          HEX  00000214781C0808

--END ASSEMBLY--

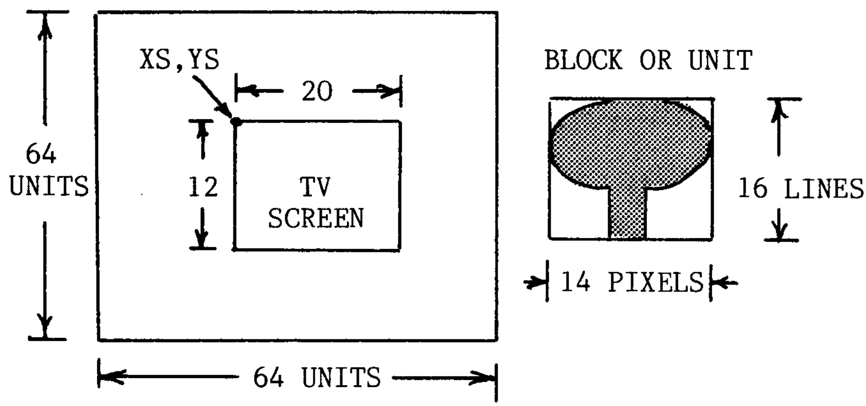
ERRORS: 0

835 BYTES
```

CHAPTER 7

GAMES THAT SCROLL

Scrolling games are dynamic in nature, in that the entire background moves as the player traverses the game's terrain. True scrolling arcade games, such as Pegasus II on the Apple, or Scramble and Rally X in the arcades, have multi-screen worlds which scroll on or off the screen as the player's plane or car moves. These games show only a window or part of the entire background world at one time. They differ from games that have background stars and aliens that appear to be traveling towards you from top to bottom. Scrolling games have objects or terrain in relatively stable positions within the game's world. They can be reached by traveling to that particular section of the world. And this technique isn't just limited to arcade games. Ultima, an adventure game, uses a large map that scrolls as the player moves around. Your screen view is only a small window on the game's world.



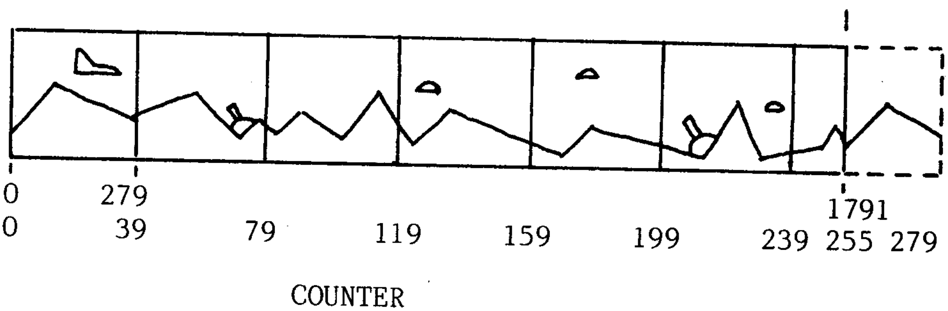
ULTIMA MAP

The data that generates these maps is stored in large arrays. A game like Ultima has a map 64 units square, with each block 14 pixels wide by 16 lines deep. If one byte is used to store which shape is used for each block, 4K of memory is needed. There is a reason why 64 units was chosen for a side. When referencing the location of your viewing window, which is located at position XS, YS on the large map, you retrieve data from a table or array, in which each row of blocks is stored $40 below the previous row. Sixty-four units per side is not etched in concrete, but some multiple of 16 is convenient. A map 128 units by 32 units would also work well.

Games like Pegasus II on the Apple allow as many as ten screen lengths to scroll past the viewer before repeating. The horizontal scrolling is done a byte at a time, and the data is stored in tables. Pegasus II, which uses page flipping to smooth the animation, gains added speed by scrolling only sections of the screen.

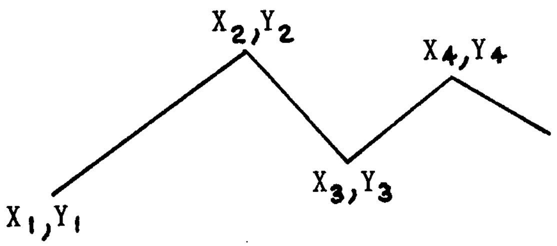
In this section, we are going to develop a scrolling game much like Pegasus II. It will be defined in much more detail than my previous examples, yet it won't be complete. Aliens will appear, but they won't shoot back. You'll be able to kill the aliens with your lasers and accumulate points as you do so, but you'll find that there is no finish, nor even a goal. Consider the unfinished game a test bench to develop your graphics skills.

The first step is to define and develop a fast scrolling subroutine. Since it is easier to move objects horizontally one byte per animation frame, our scrolling should be linked with that speed if objects are to remain synchronzied with the terrain. A counter can be used to determine the screen's location within our much larger world. With the counter limited to 256 and screen scrolling set at 7 pixels per frame, the most logical length for a world would be 1792 pixels or seven screen lengths.



When the counter reaches 256, it wraps back to zero for a repeat of screen #1. You have to be careful when approaching the upper end of the database. Once the counter indexes beyond 215, it begins accessing data beyond the 1791st position. This can be remedied by enlarging the table to 2048 data points, with the last 279 points a duplicate of the first 279 points. The terrain level at the end of the seventh screen should match the terrain level at the beginning of the first frame, as shown above.

The data points are Y axis screen coordinates (0-191) for each of the 1792 positions along the X axis. The data was placed into the table by an Applesoft program called Mountain Maker. It takes a series of X,Y points corresponding to each change in direction of our terrain and, by simple slope equations, generates the data points in between. The program is listed below.

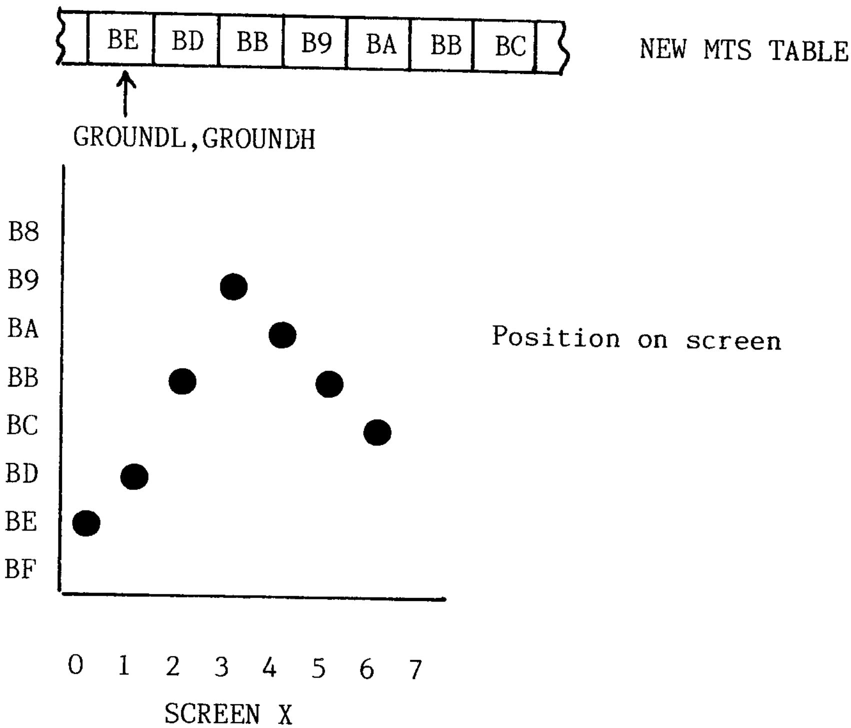


$$\text{SLOPE} = \frac{\Delta Y}{\Delta X} = \frac{Y2-Y1}{X2-X1} = \frac{Y-Y1}{X-X1}$$

$$Y = Y1 + \left[\left(\frac{Y2-Y1}{X2-X1}\right)(X-X1)\right]$$

```
5  DIM NAME$(20)
10  TEXT : HOME : PRINT : PRINT "   MOUNTAIN BACKGROUND GENE
RATOR"
20  PRINT : HTAB 15: PRINT "WORKING"
25 SH = 4000
30 START = 16384
35 J = START
40  READ A,B
50 X2 = A:Y2 = B
60  READ C,D
70  IF C =  - 1 THEN 1000
80 X1 = X2:Y1 = Y2:X2 = C:Y2 = D
90 SLOPE = (Y2 - Y1) / (X2 - X1)
100  FOR I = X1 TO X2 - 1
105 Y =  INT (Y1 + (SLOPE * (I - X1)))
110  POKE J,Y
120 J = J + 1
130  NEXT I: GOTO 60
150  END
1000  POKE J,Y2
1010  PRINT : INPUT "DATABASE NAME ?";NAME$
1020  PRINT "BSAVE";NAME$;",A$";SH;",L$2000"
2000  DATA 0,10,80,40,175,25,250,65,335,20,375,32
2010  DATA 625,32,700,15,750,70,900,45,1070,90
2020  DATA 1190,12,1220,20,1320,10,1350,17,1440,5
2030  DATA 1500,40,1540,100,1610,50,1640,40,1710,5
2040  DATA 1730,5,1810,15,1840,15,1870,35,1900,25,1920,55,19
50,30,1980,55
2050  DATA  2047,10,-1,-1
```

The scrolling subroutine works as follows. Each time the position counter, INDEX, is incremented, it adds seven to the lo byte of a pair of zero page pointers, GROUNDL and GROUNDH, through a multi-byte addition. These pointers index into a table called NEW MOUNTAINS, stored at $4000. Starting with the first data point located at GROUNDH, GROUNDL, the routine plots that point at X = 0. It increments the lo byte of the data point, then plots the second point at X = 1. It does that until all 280 points are plotted. Plotting is accomplished by EORing the proper pixel to the screen. When it is finished plotting, it reloads GROUNDH and GROUNDL, then EORs all the points off the screen. Note that GROUNDH and GROUNDL are not changed during the plotting phase because zero page locations $4 and $5 were used to store the pointers. When these are incremented, it doesn't affect our original pointers, which are stored elsewhere.



The terrain does flicker excessively because it is off the screen as much as on the screen. I'm sure ambitious readers will want to rewrite the subroutine, or convert the entire program to page flipping.

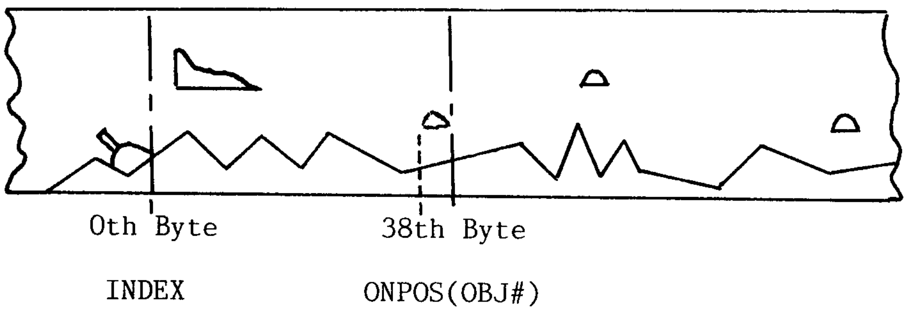
The second step in developing the game is to devise a method for determining whether an object is on or off the screen. This depends on the location of the object in our multi-screen long world in relation to that of the screen's moving window. Obviously, the two must coincide for the object to appear.

Our viewing window is controlled by the counter, INDEX (0-255). We see the terrain in that window from INDEX $*$7 to (INDEX + 39) $*$7. While our terrain is stored as individual data points for each pixel, our shapes are stored and plotted as data bytes at a particular horizontal position (0-39).

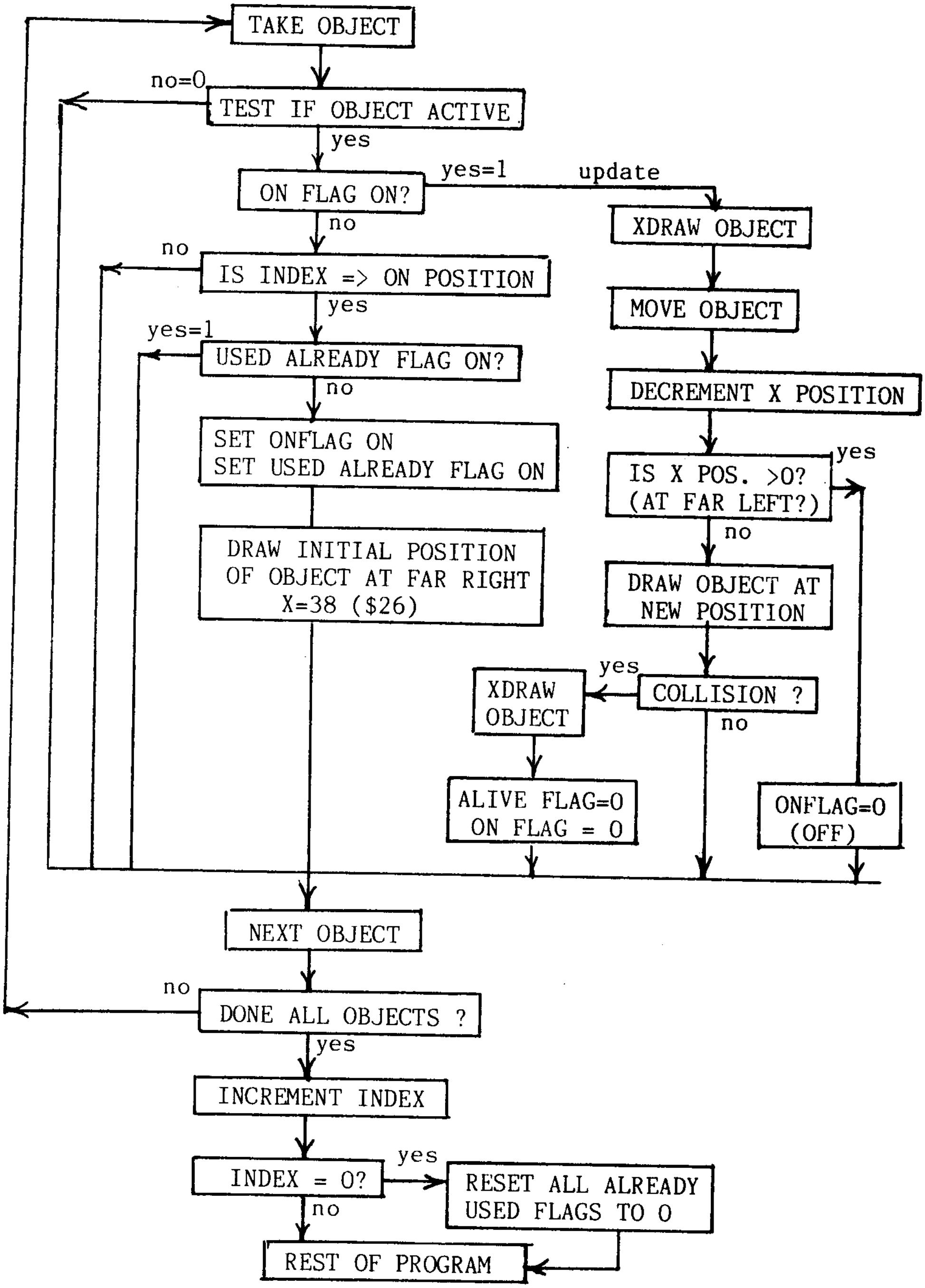
Fortunately, the choice of moving the terrain seven pixels (or one screen byte to the left with each frame) synchronizes with the easiest method of moving a raster shape in the same direction. Single byte moves require no offset shape tables.

Objects can be assigned reference positions corresponding to their horizontal byte location (0-255) in our seven screen long world. A table of these values is stored in ONPOS. Each object's vertical position is correspondingly stored in a table TABLEY. TABLEX contains the object's current screen position (0-39). This value changes during each frame, regardless of whether the object remains stationary with respect to the terrain.

An object first appears on the scrolling screen at the far right when INDEX = > ONPOS(OBJ #). The ONPOS value for an object is not actually its true horizontal position, but one that is offset by 39 bytes.



The object moves left one byte exactly in step with the ground movement with each successive animation frame. The value of TABLEX (OBJ #) is set originally to X =38 or $26. X is set to 38 rather than 39 because our alien shape is two bytes wide, and we would like to plot its full shape on the screen's right side rather than half of its shape. During each successive cycle, we decrement the X position in TABLEX table and test each time for a value less than zero. If so, we are now off the screen, and we set the ONFLAG (OBJ #) = 0


TAKE OBJECT
no=0
TEST IF OBJECT ACTIVE
yes
ON FLAG ON?
yes=1
update
XDRAW OBJECT
no
no
IS INDEX => ON POSITION
MOVE OBJECT
yes
yes=1
USED ALREADY FLAG ON?
DECREMENT X POSITION
no
SET ONFLAG ON
SET USED ALREADY FLAG ON
IS X POS. >0?
(AT FAR LEFT?)
yes
no
DRAW INITIAL POSITION
OF OBJECT AT FAR RIGHT
X=38 ($26)
DRAW OBJECT AT
NEW POSITION
yes
XDRAW
OBJECT
COLLISION ?
no
ALIVE FLAG=0
ON FLAG = 0
ONFLAG=0
(OFF)
NEXT OBJECT
no
DONE ALL OBJECTS ?
yes
INCREMENT INDEX
yes
INDEX = 0?
RESET ALL ALREADY
USED FLAGS TO 0
no
REST OF PROGRAM

There are several flags that are required to keep track of certain aspects of the game. The ONFLAG (OBJ #) is used to determine if the object is to be actively plotted on the screen. Assuming our object is actually alive, ALIVE (OBJ #) = 1 and not dead (value = 0), then the ONFLAG (OBJ #) is tested. If this flag was turned on because the object meets the INDEX = > ONPOS (OBJ #) test, it will appear for the next 38 cycles unless it is destroyed by your ship's laser. In either case, when the object reaches the end of its time on the screen, the ONFLAG (OBJ #) flag is set to off, or zero.

There is one additional flag. That is the USFLAG, or used-already flag. It is necessary because if, for example, an object were to appear on the screen when INDEX = 50 and vanish at INDEX = 88, without this flag being set equal to one (off), the object would again meet the requirements of INDEX = > ONPOS (OBJ #) as soon as the ONFLAG (OBJ #) was zero. The object would appear every 38 screen cycles after it first appeared until INDEX wrapped around to become zero again. The object should appear only once over the (0-255) INDEX cycle. Incidentally, once all objects have been tested and plotted and INDEX = 0 again, the program resets all USFLAG (OBJ #) = 0 so that they will reappear over the same terrain if they are still alive.

Collisions are tested during the draw routine. The collision flag, KILL, is set if any lit pixel occupies the screen positions, where an alien or saucer shape is drawn. The test is made by logically ANDing the shape with the screen. A non-zero value will set the flag. If a collision is detected, the alien is immediately XDRAWn off the screen, and both the ALIVE flag and the ONFLAG are set to zero (off) for that object. Of course, in a real game, you wouldn't have an alien simply disappear, but would either plot the shape of an explosion or blow it up dramatically; a fitting end that any alien who travels so far and fights so valiantly deserves.

I'll admit that the routine is quite complex and did require considerable planning and thought, but I hope that the accompanying flow chart will make it clear. Remember that this code is looped for each object successively until all objects are tested. Only then does it increment INDEX before proceeding on with the rest of the program.

Flexibility for displaying a variety and a large number of shapes, plus the ability to change the placement of these shapes, was designed into the program. This becomes extremely helpful during the play test when the quantity of targets and types are liable to change frequently. Ground based laser, radar and rocket bases, plus a dozen city buildings were envisioned as targets spread out over seven screens. While only eight different shapes were contemplated, ten of one type might be needed, while only three of another type might be used.

Because of this special need, a table called SHPADR was conceived. It would hold the shape type for each, and as many as 256 targets. The shapes would be stored in a shape table called SHAPES. Since each shape was two bytes wide by eight lines deep, and we need both even and odd offset shape tables for color, thirty two bytes would be required for each shape. To keep the

table within one page boundary (256 bytes), the scheme was limited to eight shapes.

```
SHAPES   |SHAPE #0 EVEN|        THE 8 ODD OFFSET SHAPES
         |SHAPE #1 EVEN|        FOLLOW THE 8 EVEN OFFSET
            .       .           SHAPES IN THE TABLE
            .       .           CALLED SHAPES.
         |SHAPE #7 EVEN|
         |SHAPE #0 ODD |
            .       .
            .       .
```

Another table, called SHPLO, is used to reference the lo byte of each shape. The values in this table are permanently set, starting at $00 and increasing by $10 with each shape. However, because we are using only two shapes in this example, and loading the shape table after assembling is an extra step, it is easier during program development to have the assembler construct the table for us by using the DFB pseudo-op code to define the lo order byte.

Thus, the SHPLO table is constructed as follows for the two shapes:

```
SHPLO  DFB SHAPES      ;LO BYTE ALIEN  EVEN OFFSET
       DFB SHAPES+$10  ;LO BYTE SAUCER EVEN OFFSET
       DFB SHAPES+$20  ;LO BYTE ALIEN  ODD  OFFSET
       DFB SHAPES+$30  ;LO BYTE SAUCER ODD  OFFSET
```

The table SHPADR for seven objects either points to shape #0 (alien) or shape #1 (saucer). It actually indexes into SHPLO to set the proper pointers.

```
EVEN  LDY  SHPADR,Y   ;WHERE X IS THE OBJECT #
      LDA  SHPLO,Y    ;PROPER LO BYTE OF EVEN OFFSET SHAPE
      STA  SHPL
```

The code for the odd offset is similar, except you have to index into the odd half of SHPLO which, in this case, begins with the third byte.

```
ODD  LDY  SHPADR,X
     LDA  SHPLO+2,Y ;PROPER LO BYTE OF ODD OFFSET SHAPE
     STA  SHPL
```

	#0	#1	#2	#3	#4	#5	#6	#7
SHPADR	00	00	01	00	00	00	00	01

	#0	#1	#2	#3
SHPLO	08	10	18	20
	EVEN ALIEN	EVEN SAUCER	ODD ALIEN	ODD SAUCER

SHAPES	$6908	SHAPE #0 EVEN
	$6910	SHAPE #1 EVEN
	$6918	SHAPE #0 ODD
	$6920	SHAPE #1 ODD

For example, if you were to look for object #2 (X reg = 2), which is an even number, the even code would reference $01 for the SHPADR table. This in turn would point to the #1 element in SHPLO. Thus, the code would be stored $10 in SHPL. The high byte $69 would be stored in SHPH.

In the event that you chose to place these tables into a permanent location, skip the construction of the SHPLO table. Instead, the SHPADR table contains the lo byte for each shape. The SHPADR table's length is doubled, for it now contains the locations of both the even and odd shapes.

SHAPES	$7000	SHAPE #0 EVEN
	$7008	SHAPE #1 EVEN
	$7010	SHAPE #0 ODD
	$7018	SHAPE #1 ODD

	#0	#1	#2	#3	#4	#5	#6	#7
SHPADR	00	00	08	00	00	00	00	08
	10	10	18	10	10	10	10	18

The corresponding code is as follows:

```
EVEN  LDY  SHADR,X
      STA  SHPL

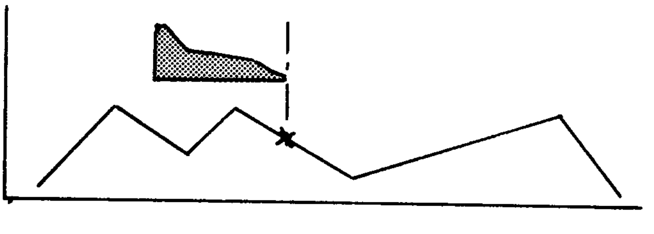
ODD   LDY  SHPADR+8,X
      STA  SHPL
```

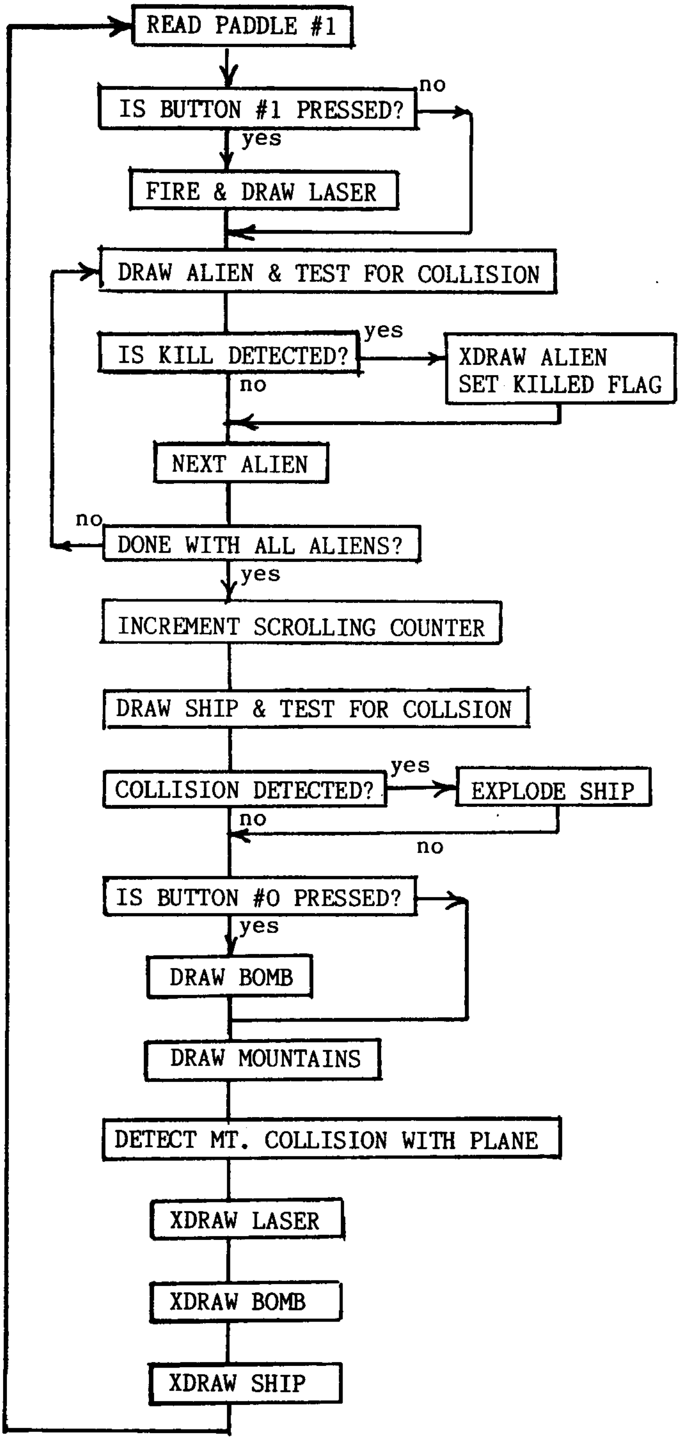
You can see that this is actually simpler code. If you wish to keep separate shape tables independent of the main program's code, then this is the preferred method. However, it does involve loading your shape table into memory when testing a program.

ORDER OF EVENTS IN GAME

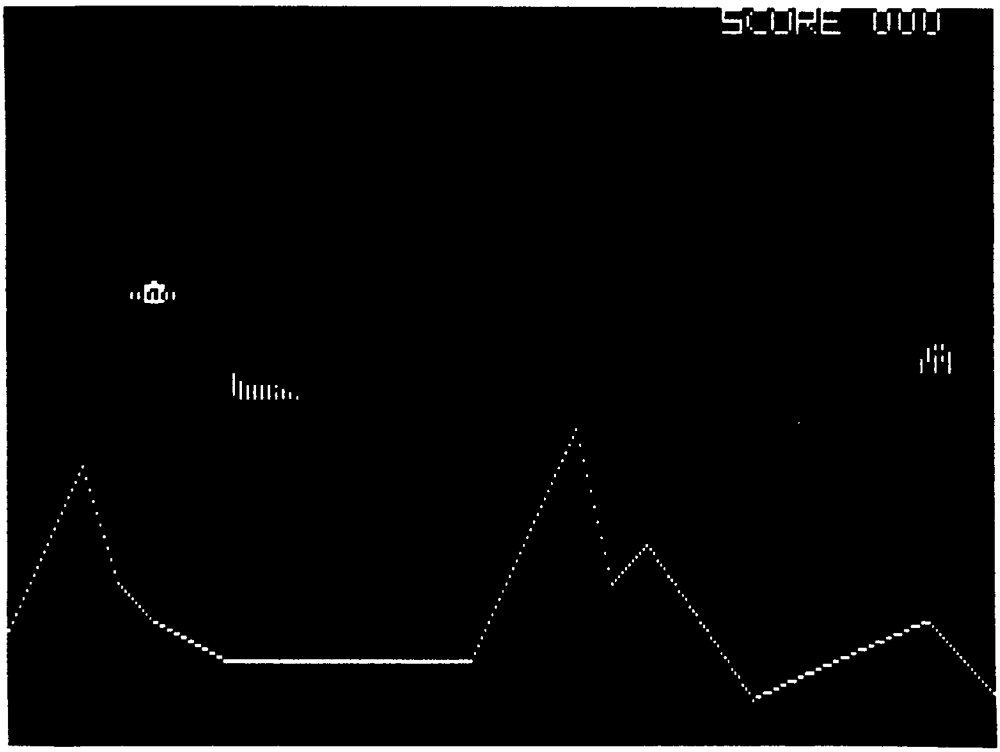
The sequence of events in any game is important. Sometimes the order is dictated by tests performed by various routines. It becomes obvious that you can't test for a collision of an alien with a laser beam unless the laser is drawn on the screen first. You can't determine if your ship collides with an alien unless the ship is drawn last. Unfortunately, something is always last. A collision of the ship with an alien at this point in the sequence requires testing each alien's screen coordinates to determine which one hit the ship.

The mountains were drawn afterwards to minimize the objects' screen flicker. Since the mountain routine takes considerably longer to draw than the rest of the objects combined, it acts as a time delay, allowing the objects to remain on the screen longer than they are off. Because the mountains are drawn after the ship's collision test, a separate test was devised for mountain collisions. The code compares the ship's vertical position with the vertical value of the mountain data drawn directly beneath it. The ship's vertical position must be less than the value referenced in the mountain data table (i.e, ship is above mountains). Remember that MTOFFL and MTOFFH points to the beginning position in the table from which the scroll subroutine draws the next 280 points of the mountain background. The tip of the ship is located at X =84 or $55. The collision test is at the nose, so $55 is added to MTOFFL. Since the carry is not cleared when $55 is added to the offset location of the mountain table, an overflow in the lo byte, which is a carry set, automatically increments the hi byte value. Both the lo and hi byte values are stored at $09 and $0A, respectively, in the zero page. These were chosen as scratch memory locations in zero page to do an indirect indexed load, (LDA ($09),Y) ,where the Y register is zero. This obtains the value of the mountain pixel directly below the ship's nose, and with only one instruction! This is compared with the vertical position of the ship's bottom. If the value in the mountain table is greater, there is no collision.




READ PADDLE #1
IS BUTTON #1 PRESSED?
no
yes
FIRE & DRAW LASER
DRAW ALIEN & TEST FOR COLLISION
IS KILL DETECTED?
yes
no
XDRAW ALIEN
SET KILLED FLAG
NEXT ALIEN
no
DONE WITH ALL ALIENS?
yes
INCREMENT SCROLLING COUNTER
DRAW SHIP & TEST FOR COLLSION
COLLISION DETECTED?
yes
EXPLODE SHIP
no
no
IS BUTTON #0 PRESSED?
yes
DRAW BOMB
DRAW MOUNTAINS
DETECT MT. COLLISION WITH PLANE
XDRAW LASER
XDRAW BOMB
XDRAW SHIP

```
*DETECT FOR MT COLLISION
          LDA  PADDLEL
          CLC
          ADC  #$55      ;TIP OF SHIP @84
          STA  $09
          LDA  PADDLEH
          ADC  #$40      ;LOCATION OF MOUNTAIN TABLE
          STA  $0A
          LDY  #$00
          CLC
          LDA  VERT
          ADC  #$08      ;BECAUSE PDL IS AT TOP OF PLANE--
          STA  TEMP      ;AND MOUNTAINS HIT BOTTOM
          LDA  ($09),Y
          CMP  TEMP
          BGE  NOHIT
          JMP  EXPLODE
NOHIT     LDA  VERT
```



```
           *COMPLETE SCROLLING GAME CODE
                   ORG  $6000
6000: 4C 21 60     JMP  PROG          ;JUMP TO START OF CODE
           COUNT   DS   1
           INDEX   DS   1
           PADDLEL DS   1
           PADDLEH DS   1
           PDL     DS   1
           TEMP    DS   1
           TEMP1   DS   1
           SBLOCK  DS   1
           EBLOCK  DS   1
           VERT    DS   1
           TVERT   DS   1
           HORIZ   DS   1
           OBJ     DS   1
           LNGH    DS   1
           DEPTH   DS   1
           SLNGH   DS   1
           SHOT    DS   1
           LFLAG   DS   1
           ESET    DS   1
           BVERT   DS   1
           TBVERT  DS   1
           BVELY   DS   1
           BHORIZ  DS   1
           BMLOCK  DS   1
           TBMLOCK DS   1
           KILL    DS   1
           KILLNUM DS   1
           SCOREA  DS   1
           SCOREB  DS   1
           SCOREC  DS   1
           HIRESL  EQU  $26
           HIRESH  EQU  HIRESL+$1
           SHPL    EQU  $50
           SHPH    EQU  SHPL+$1
           SSHPL   EQU  $52
           SSHPH   EQU  $53
           STESTL  EQU  $54
           STESTH  EQU  STESTL+$1
           BOMBL   EQU  $56
           BOMBH   EQU  BOMBL+$1
           PREAD   EQU  $FB1E
6021: AD 50 C0     PROG    LDA  $C050
6024: AD 52 C0             LDA  $C052
6027: AD 57 C0             LDA  $C057
602A: 20 A4 62             JSR  CLRSCR
           *
           *I N I T I L I Z A T I O N
           *
602D: A9 00                LDA  #$00
602F: 8D 14 60             STA  LFLAG
6032: 8D 1A 60             STA  BMLOCK
6035: 8D 1C 60             STA  KILL
6038: 8D 13 60             STA  SHOT
           *INITILIZE SCORE & PUT ON SCREEN
603B: A9 20        SCOREI  LDA  #$20
603D: 85 27                STA  HIRESH
603F: A9 1D                LDA  #$1D          ;LOCATION OF SCORE WORDS
```

```
6041: 85 26              STA  HIRESL
6043: A9 05              LDA  #$05
6045: 8D 10 60           STA  LNGH
6048: A9 6A              LDA  #>SCOREWD
604A: 85 51              STA  SHPH
604C: A9 08              LDA  #<SCOREWD
604E: 85 50              STA  SHPL
6050: 20 E8 66           JSR  SCOREDR     ;PUT WORDS ON SCREEN
6053: A9 00              LDA  #$00
6055: 8D 1F 60           STA  SCOREB
6058: 8D 20 60           STA  SCOREC
605B: A9 FF              LDA  #$FF
605D: 8D 1E 60           STA  SCOREA      ;FIRST TIME SCORE USED WILL--
6060: 8D 1D 60           STA  KILLNUM     ;INCREMENT TO 0
6063: 20 5D 66           JSR  SCORE
                *INITIALIZE SHIP POSITION
6066: A9 03              LDA  #$03
6068: 8D 12 60           STA  SLNGH
606B: A9 D7              LDA  #<SHIP
606D: 85 52              STA  SSHPL
606F: A9 68              LDA  #>SHIP
6071: 85 53              STA  SSHPH
6073: A9 BF              LDA  #<MSHIP
6075: 85 54              STA  STESTL
6077: A9 68              LDA  #>MSHIP
6079: 85 55              STA  STESTH
607B: A9 50              LDA  #$50
607D: 8D 0C 60           STA  VERT
                *INITIALIZE START OF SCROLL
6080: A9 00              LDA  #$00
6082: 8D 04 60           STA  INDEX
6085: 8D 05 60           STA  PADDLEL
6088: 8D 06 60           STA  PADDLEH
                *
                *M A I N   P R O G R A M   L O O P
                *
                *READ PADDLE #1
608B: A2 01     START    LDX  #$01
608D: 20 1E FB           JSR  PREAD
6090: C0 B8              CPY  #$B8        ;CLIP VALUE (0-183)
6092: 90 02              BLT  SKIPP
6094: A0 B7              LDY  #$B7
6096: 8C 07 60  SKIPP    STY  PDL
6099: 98                 TYA
609A: CD 0C 60           CMP  VERT        ;PADDLE<VERT POS THEN SUBTRACT 5
609D: B0 1E              BGE  PADDLE3
609F: AD 0C 60           LDA  VERT
60A2: 38                 SEC
60A3: E9 05              SBC  #$05
60A5: B0 08              BGE  PADDLE1     ;MAKE SURE =>0
60A7: A9 00              LDA  #$00
60A9: 8D 0C 60           STA  VERT
60AC: 8D 0D 60           STA  TVERT
60AF: CD 07 60  PADDLE1  CMP  PDL         ;DON'T WANT TO GO PAST PADDLE POS
60B2: B0 03              BGE  PADDLE2
60B4: AD 07 60           LDA  PDL
60B7: 8D 0C 60  PADDLE2  STA  VERT
60BA: 4C D3 60           JMP  PADDLE6
60BD: CD 0C 60  PADDLE3  CMP  VERT        ;PADDLE>VERT POS THEN ADD 5
60C0: F0 0B              BEQ  PADDLE4
```

```
60C2: AD 0C 60           LDA  VERT
60C5: 18                 CLC
60C6: 69 05              ADC  #$05
60C8: CD 07 60           CMP  PDL         ;DON'T WANT TO GO PAST PADDLE POS
60CB: 90 03              BLT  PADDLE5
60CD: AD 07 60  PADDLE4  LDA  PDL
60D0: 8D 0C 60  PADDLE5  STA  VERT
60D3: 8D 0D 60  PADDLE6  STA  TVERT
60D6: 20 D3 63           JSR  LASER       ;FIRE LASER
                *PUT ALIEN OBJECTS ON SCREEN AT PROPER TIMES
60D9: A2 00              LDX  #00
60DB: 8E 0F 60           STX  OBJ
60DE: A9 69              LDA  #>SHAPES    ;GET HI BYTE OF SHAPES
60E0: 85 51              STA  SHPH
60E2: A9 02     NXT      LDA  #$02        ;EACH SHAPE 2 BYTES WIDE
60E4: 8D 10 60           STA  LNGH
60E7: AE 0F 60           LDX  OBJ
60EA: BD 98 68           LDA  ALIVE,X
60ED: D0 03              BNE  TEST        ;ALIVE?
60EF: 4C 7D 61           JMP  NOBJ
60F2: BD A6 68  TEST     LDA  ONFLAG,X
60F5: D0 3E              BNE  UPDATE      ;IS ONFLAG ALREADY ON?
60F7: BD AD 68           LDA  ONPOS,X
60FA: CD 04 60           CMP  INDEX
60FD: B0 7E              BGE  NOBJ
60FF: BD 9F 68           LDA  USFLAG,X
6102: F0 03              BEQ  TEST1       ;IS USED ALREADY FLAG ON?
6104: 4C 7D 61           JMP  NOBJ
6107: A9 01     TEST1    LDA  #$01
6109: 9D A6 68           STA  ONFLAG,X    ;SET ONFLAG ON
610C: 9D 9F 68           STA  USFLAG,X
610F: A9 26              LDA  #$26
6111: 9D 8A 68           STA  TABLEX,X    ;UPDATE TABLE
6114: BC B  68           LDY  SHPADR,X    ;WHICH TYPE SHAPE
6117: B9 BB 68           LDA  SHPLO,Y     ;WHERE LO SHAPE IS
611A: 85 50              STA  SHPL
611C: BC 91 68           LDY  TABLEY,X    ;GET Y POSITION
611F: B9 0A 67           LDA  YVERTL,Y
6122: 85 26              STA  HIRESL
6124: B9 CA 67           LDA  YVERTH,Y
6127: 85 27              STA  HIRESH
6129: A0 26              LDY  #$26        ;THIS IS X=38 FAR RIGHT
612B: 98                 TYA
612C: 9D 8A 68           STA  TABLEX,X    ;UPDATE TABLE
612F: 20 4E 63           JSR  DRAW
6132: 4C 7D 61           JMP  NOBJ
6135: AE 0F 60  UPDATE   LDX  OBJ
6138: 20 9F 63           JSR  DSETUP
613B: 20 7D 63           JSR  XDRAW
613E: AE 0F 60           LDX  OBJ
6141: DE 8A 68           DEC  TABLEX,X    ;MOVE OBJECT LEFT ONE
6144: BD 8A 68           LDA  TABLEX,X
6147: C9 00              CMP  #$00
6149: 10 08              BPL  PASS        ;>=0 THEN STILL ON SCREEN
614B: A9 00              LDA  #$00
614D: 9D A6 68           STA  ONFLAG,X
6150: 4C 7D 61           JMP  NOBJ
6153: AE 0F 60  PASS     LDX  OBJ
6156: 20 9F 63           JSR  DSETUP
6159: 20 4E 63           JSR  DRAW
```

```
615C: AD 1C 60              LDA  KILL
615F: C9 00                 CMP  #$00
6161: F0 1A                 BEQ  NOBJ
6163: AE 0F 60              LDX  OBJ
6166: 20 9F 63              JSR  DSETUP
6169: 20 7D 63              JSR  XDRAW       ;REMOVE ALIEN
616C: AE 0F 60              LDX  OBJ
616F: A9 00                 LDA  #$00
6171: 9D 98 68              STA  ALIVE,X     ;SET OBJECT TO DEAD
6174: 9D A6 68              STA  ONFLAG,X    ;TURN OFF ON FLAG
6177: 8D 1C 60              STA  KILL        ;RESET KILL DETECTOR
617A: 20 5D 66              JSR  SCORE
617D: EE 0F 60     NOBJ     INC  OBJ         ;NEXT OJECT
6180: AD 0F 60              LDA  OBJ
6183: C9 07                 CMP  #$07
6185: F0 03                 BEQ  TEST2       ;DONE WITH ALL?
6187: 4C E2 60              JMP  NXT
618A: EE 04 60     TEST2    INC  INDEX       ;UPDATE SCROLL COUNTER
618D: AD 04 60              LDA  INDEX
6190: D0 0C                 BNE  PASS1
6192: A0 00                 LDY  #00         ;RESET ALL ALREADY USED FLAGS TO 0
6194: A9 00        AGAIN    LDA  #$00
6196: 99 9F 68              STA  USFLAG,Y
6199: C8                    INY
619A: C0 08                 CPY  #$08
619C: D0 F6                 BNE  AGAIN
619E: 20 33 63     PASS1    JSR  SSETUP
61A1: 20 BE 62              JSR  SDRAW
61A4: 20 89 64              JSR  BOMB
61A7: 20 01 62              JSR  SCROLL
                   *DETECT FOR MT COLLISION
61AA: AD 05 60              LDA  PADDLEL
61AD: 18                    CLC
61AE: 69 55                 ADC  #$55        ;TIP OF SHIP @84
61B0: 85 09                 STA  $09
61B2: AD 06 60              LDA  PADDLEH
61B5: 69 40                 ADC  #$40        ;LOCATION OF MOUNTAIN TABLE
61B7: 85 0A                 STA  $0A
61B9: A0 00                 LDY  #$00
61BB: 18                    CLC
61BC: AD 0C 60              LDA  VERT
61BF: 69 08                 ADC  #$08        ;BECAUSE PDL IS AT TOP OF PLANE--
61C1: 8D 08 60              STA  TEMP        ;AND MOUNTAINS HIT BOTTOM
61C4: B1 09                 LDA  ($09),Y
61C6: CD 08 60              CMP  TEMP
61C9: B0 03                 BGE  NOHIT
61CB: 4C 13 65              JMP  EXPLODE
61CE: AD 0C 60     NOHIT    LDA  VERT
61D1: 8D 0D 60              STA  TVERT
61D4: 20 33 63              JSR  SSETUP
61D7: 20 FD 62              JSR  SXDRAW
61DA: 20 14 64     FIN      JSR  XLASER
61DD: 20 F7 64              JSR  BOMBX
                   *TEST IF ALL ALIENS KILLED AND RESET WHEN INDEX=0
61E0: AD 1D 60     RSETAL   LDA  KILLNUM
61E3: C9 07                 CMP  #$07
61E5: D0 16                 BNE  RSETAL2
61E7: AD 04 60              LDA  INDEX       ;CHECK IF START OF TERRAIN
61EA: D0 11                 BNE  RSETAL2
61EC: A9 00                 LDA  #$00        ;RESET
```

```
61EE: 8D 1D 60          STA  KILLNUM
61F1: A2 00             LDX  #$00
61F3: A9 01             LDA  #$01
61F5: 9D 98 68  RSETAL1 STA  ALIVE,X
61F8: E8                INX
61F9: E0 07             CPX  #$07
61FB: D0 F8             BNE  RSETAL1
61FD: EA        RSETAL2 NOP
61FE: 4C 8B 60          JMP  START
                *
                *S U B R O U T I N E S ********
                *
                *SCROLLING ROUTINE SETUP
                *
6201: AD 04 60  SCROLL  LDA  INDEX       ;COUNTER FOR WHERE YOU ARE INTO
                *-                       ;TERRAIN
6204: C9 00             CMP  #$00        ;IF ZERO RESET GROUND TABLE POINTER
6206: F0 11             BEQ  RSET
6208: 18                CLC
6209: AD 05 60          LDA  PADDLEL     ;EACH CYCLE ADVANCE 7 MORE INTO --
620C: 69 07             ADC  #$07        ;GROUND ARRAY
620E: 8D 05 60          STA  PADDLEL
6211: 90 03             BCC  C
6213: EE 06 60          INC  PADDLEH
6216: 4C 21 62  C       JMP  SCONT
6219: A9 00     RSET    LDA  #$00        ;RESET GROUND POSITION BACK TO 0
621B: 8D 05 60          STA  PADDLEL
621E: 8D 06 60          STA  PADDLEH
                *
                *SCROLLING ROUTINE
                *
6221: A9 02     SCONT   LDA  #$02
6223: 8D 03 60          STA  COUNT       ;COUNTER SO DRAWS 1ST TIME
6226: A9 01     ERASE   LDA  #$01
6228: 85 08             STA  $08         ;BIT COUNTER
622A: A9 00             LDA  #$00        ; START OF ARRAY LO BYTE
622C: 85 06             STA  $06
622E: A9 40             LDA  #$40        ; START OF ARRAY HI BYTE
6230: 85 07             STA  $07
6232: AD 05 60          LDA  PADDLEL     ;OFFSET INTO ARRAY LO BYT
6235: 85 04             STA  $04
6237: AD 06 60          LDA  PADDLEH     ;OFFSET HI BYTE
623A: 29 07             AND  #$07        ;SO NOT BEYOND TABLE
623C: 85 05             STA  $05
623E: A2 00             LDX  #$00
6240: 18        LOOP    CLC
6241: A5 04             LDA  $04         ;OFFSET INTO TABLE (LO)
6243: 65 06             ADC  $06         ;ADD BASE ADDRESS (LO)
6245: 85 02             STA  $02
6247: A5 05             LDA  $05         ;   (HI)
6249: 65 07             ADC  $07
624B: 85 03             STA  $03         ;REG 2&3 ACTUAL ADDRESS OF SPECI-
                *-                       ;FIC BYTE IN TABLE
624D: A0 00             LDY  #$00
624F: B1 02             LDA  ($02),Y     ;ACTUAL VALUE AT THAT BYTE
6251: A8                TAY
6252: B9 0A 67          LDA  YVERTL,Y    ;ADDRESS OF LINE ON SCREEN (LO)
6255: 85 02             STA  $02
6257: B9 CA 67          LDA  YVERTH,Y    ; (HI)
625A: 85 03             STA  $03
```

```
625C: 8A                      TXA                  ;X IS OFFSET INTO HI-RES LINE
625D: A8                      TAY
625E: B1 02                   LDA   ($02),Y        ;CONTAINS ADDRESS OF BEGINNING LINE
               *-                                  ;NOW OFFSET INTO LINE
6260: 45 08                   EOR   $08            ;NOW LEFT HAND DOT ON
6262: 91 02                   STA   ($02),Y
6264: E6 04                   INC   $04            ;INCREMENT OFFSET FOR NEXT DOT (LO)
6266: D0 09                   BNE   SKIP           ;IF HAVEN'T CROSSED 256 THEN SKIP
6268: 18                      CLC
6269: A5 05                   LDA   $05            ;INC. HI ORDER OFFSET FOR NEXT DOT
626B: 69 01                   ADC   #$01
626D: 29 07                   AND   #$C7           ;MAKES WRAP AROUND INTO TABLE--
626F: 85 05                   STA   $05            ;(IF HIT END OF TABLE)
6271: 06 08    SKIP           ASL   $08            ;SHIFT LEFT INTO BYTE FOR NEXT
               *-                                  ;DOT TO PLOT
6273: 10 CB                   BPL   LOOP           ;IF INTO BIT 7 THEN TOO FAR SO
               *-                                  ;RESTORE TO 1
6275: A9 01                   LDA   #$01           ;RESTORE BIT COUNTER TO 1
6277: 85 08                   STA   $08
6279: E8                      INX                  ;NEXT BYTE BECAUSE HAVE ALREADY
               *-                                  ;DONE 7 DOTS
627A: E0 28                   CPX   #$28           ;SEE IF COMPLETELY ACROSS 40 BYTES
627C: D0 C2                   BNE   LOOP
627E: CE 03 60                DEC   COUNT
6281: AD 03 60                LDA   COUNT
6284: C9 01                   CMP   #$01           ;IF=1 ONLY HAVE DRAWN TERRAIN
6286: 90 1B                   BLT   SKIP1          ;TERRAIN ALREADY DRAWN&XDRAWN,DONE
               *
               *SINGLE STEP DEBUG PACKAGE
               *
6288: AD 00 C0                LDA   $C000          ;KEY PRESSED?
628B: 10 10                   BPL   IGNORE         ;EXIT IF NO KEY PRESSED
628D: C9 9B                   CMP   #$9B           ;ESC KEY?
628F: D0 0C                   BNE   IGNORE
6291: 2C 10 C0 CAUGHT         BIT   $C010          ;CLEAR STROBE
6294: AD 00 C0                LDA   $C000          ;KEY PRESSED
6297: 10 FB                   BPL   *-3            ;LOOP BY BRANCHING BACK 3 BYTES
6299: C9 A0                   CMP   #$A0           ;SPACE KEY?
629B: D0 03                   BNE   IGNORE+3       ;NO DON'T CLEAR STROBE
629D: 2C 10 C0 IGNORE         BIT   $C010          ;CLEAR STROBE
               *
62A0: 4C 26 62                JMP   ERASE          ;ONLY DRAWN SO FAR; NOW GO TO ERAS
               *-                                  ;TO DRAW AGAIN
62A3: 60       SKIP1          RTS
               *
               *CLEAR SCREEN SUBROUTINE
               *
62A4: A9 00    CLRSCR         LDA   #$00
62A6: 85 26                   STA   HIRESL
62A8: A9 20                   LDA   #$20
62AA: 85 27                   STA   HIRESH
62AC: A0 00    CLR1           LDY   #$00
62AE: A9 00                   LDA   #$00
62B0: 91 26    CLR2           STA   (HIRESL),Y
62B2: C8                      INY
62B3: D0 FB                   BNE   CLR2
62B5: E6 27                   INC   HIRESH
62B7: A5 27                   LDA   HIRESH
62B9: C9 40                   CMP   #$40
62BB: 90 EF                   BCC   CLR1
```

```
62BD: 60                   RTS
                  *
                  *DRAW SHIP SUBROUTINE
                  *DRAW SHAPE ONE LINE AT A TIME-LNGH BYTES ACROSS
                  *
62BE: A9 00       SDRAW    LDA  #$00
62C0: 8D 15 60             STA  ESET
62C3: AC 0D 60    SDRAW1   LDY  TVERT        ;VERTICAL POSITION
62C6: 20 1C 63             JSR  GETADR
62C9: A2 00                LDX  #$00
62CB: A1 54       SDRAW2   LDA  (STESTL,X)   ;GET BYTE OF SHIP MASK SHAPE
62CD: 29 7F                AND  #$7F         ;MASK OUT HI BIT
62CF: 31 26                AND  (HIRESL),Y   ;(AND) IT AGAINST SCREEN
62D1: C9 00                CMP  #$00         ; IF ANYTHING IN WAY GET>0
62D3: F0 05                BEQ  SDRAW3
62D5: A9 01                LDA  #$01         ;SET BECAUSE IF DON'T FINISH DRAW-
62D7: 8D 15 60             STA  ESET         ;ING SHIP,PIECE LEFT WHEN XDRAW
                  *                          ;DURING EXPLOSION
62DA: A1 52       SDRAW3   LDA  (SSHPL,X)    ;GET BYTE OF SHIP'S SHAPE
62DC: 51 26                EOR  (HIRESL),Y
62DE: 91 26                STA  (HIRESL),Y   ;PLOT
62E0: E6 54                INC  STESTL       ;NEXT BYTE OF MASK
62E2: E6 52                INC  SSHPL        ; NEXT BYTE OF TABLE
62E4: C8                   INY               ;NEXT SCREEN POSITION
62E5: CE 12 60             DEC  SLNGH
62E8: D0 E1                BNE  SDRAW2       ;IF LINE NOT FINISHED BRANCH
62EA: EE 0D 60             INC  TVERT        ;OTHERWISE NEXT LINE DOWN
62ED: CE 11 60             DEC  DEPTH
62F0: D0 D1                BNE  SDRAW1       ;DONE DRAWING?
62F2: AD 15 60             LDA  ESET         ;IS EXPLOSION FLAG SET?
62F5: C9 00                CMP  #$00
62F7: F0 03                BEQ  SDRAW4       ;NO!, EXIT
62F9: 4C 13 65             JMP  EXLODE       ;YES!, EXPLODE SHIP
62FC: 60          SDRAW4   RTS
                  *
                  *XDRAW SHIP SUBROUTINE
                  *
62FD: AC 0D 60    SXDRAW   LDY  TVERT        ;PADDLE VALUE
6300: 20 1C 63             JSR  GETADR
6303: A2 00                LDX  #$00
6305: A1 52       SXDRAW2  LDA  (SSHPL,X)
6307: 51 26                EOR  (HIRESL),Y
6309: 91 26                STA  (HIRESL),Y
630B: E6 52                INC  SSHPL
630D: C8                   INY
630E: CE 12 60             DEC  SLNGH
6311: D0 F2                BNE  SXDRAW2
6313: EE 0D 60             INC  TVERT
6316: CE 11 60             DEC  DEPTH
6319: D0 E2                BNE  SXDRAW
631B: 60                   RTS
                  *
                  *GETADR SUBROUTINE
                  *
631C: B9 0A 67    GETADR   LDA  YVERTL,Y     ;LOOK UP LO BYTE OF LINE
631F: 18                   CLC
6320: 6D 0E 60             ADC  HORIZ        ;ADD DISPLACEMENT INTO LINE
6323: 85 26                STA  HIRESL
6325: B9 CA 67             LDA  YVERTH,Y     ;LOOK UP HI BYTE OF LINE
6328: 85 27                STA  HIRESH
```

```
632A: AD 08 60          LDA  TEMP
632D: 8D 12 60          STA  SLNGH        ;RESTORE VARIABLE
6330: A0 00             LDY  #$00
6332: 60                RTS
                 *
                 *SHIP SET UP SUBROUTINE
                 *
6333: A9 D7      SSETUP LDA  #<SHIP       ;SHAPE TABLE LOCATION
6335: 85 52             STA  SSHPL
6337: A9 68             LDA  #>SHIP
6339: 85 53             STA  SSHPH
633B: A9 08             LDA  #$08
633D: 8D 11 60          STA  DEPTH
6340: A9 09             LDA  #$09
6342: 8D 0E 60          STA  HORIZ
6345: A9 03             LDA  #$03
6347: 8D 12 60          STA  SLNGH
634A: 8D 08 60          STA  TEMP
634D: 60                RTS
                 *
                 *DRAW ALIEN SHIPS & TARGETS SUBROUTINE
                 *DRAW SHAPE ONE COLUMN AT A TIME
                 *
634E: A2 00      DRAW   LDX  #$00
6350: A1 50      DRAW2  LDA  (SHPL,X)
6352: 29 7F             AND  #$7F         ;MASK OUT HI BIT
6354: 31 26             AND  (HIRESL),Y   ;(AND) IT AGAINST SCREEN
6356: C9 00             CMP  #$00         ;IF ANYTHING IN WAY GET>0
6358: F0 03             BEQ  DRAW3        ;NO COLLISION, BRANCH TO DRAW3
635A: EE 1C 60          INC  KILL         ;COLLISION! INCREMENT KILL
635D: A1 50      DRAW3  LDA  (SHPL,X)     ;LOAD SHAPE BYTE
635F: 51 26             EOR  (HIRESL),Y   ;(EOR) WITH SCREEN
6361: 91 26             STA  (HIRESL),Y   ;PLOT
6363: A5 27             LDA  HIRESH
6365: 18                CLC
6366: 69 04             ADC  #$04
6368: 85 27             STA  HIRESH
636A: E6 50             INC  SHPL
636C: C9 40             CMP  #$40
636E: 90 E0             BCC  DRAW2
6370: E9 20             SBC  #$20
6372: 85 27             STA  HIRESH
6374: CE 10 60          DEC  LNGH
6377: F0 03             BEQ  DRAW4
6379: C8                INY
637A: D0 D4.            BNE  DRAW2
637C: 60         DRAW4  RTS
                 *
                 *XDRAW ALIEN SHIPS & TARGETS SUBROUTINE
                 *
637D: A2 00      XDRAW  LDX  #$00
637F: A1 50      XDRAW2 LDA  (SHPL,X)
6381: 51 26             EOR  (HIRESL),Y
6383: 91 26             STA  (HIRESL),Y
6385: A5 27             LDA  HIRESH
6387: 18                CLC
6388: 69 04             ADC  #$04
638A: 85 27             STA  HIRESH
638C: E6 50             INC  SHPL
638E: C9 40             CMP  #$40
```

```
6390: 90 ED          BCC  XDRAW2
6392: E9 20          SBC  #$20
6394: 85 27          STA  HIRESH
6396: CE 10 60       DEC  LNGH
6399: F0 03          BEQ  XDRAW3
639B: C8             INY
DRAW2
639E: 60      XDRAW3 RTS
              *
              *DRAWING ROUTINES SETUP
              *
639F: BC 91 68 DSETUP LDY  TABLEY,X
63A2: B9 0A 67       LDA  YVERTL,Y
63A5: 85 26          STA  HIRESL
63A7: B9 CA 67       LDA  YVERTH,Y
63AA: 85 27          STA  HIRESH
63AC: A9 02          LDA  #$02
63AE: 8D 10 60       STA  LNGH
63B1: 18             CLC
63B2: BD 8A 68       LDA  TABLEX,X
63B5: 4A             LSR
63B6: B0 0B          BCS  ODD          ;TEST FOR EVEN OR ODD OFFSET FROM
              *-                       ;X VALUE IN TABLEX
63B8: BC B4 68 EVEN   LDY  SHPADR,X
63BB: B9 BB 68       LDA  SHPLO,Y
63BE: 85 50          STA  SHPL
63C0: 4C CB 63       JMP  GOON
63C3: BC B4 68 ODD    LDY  SHPADR,X
63C6: B9 BD 68       LDA  SHPLO+2,Y
63C9: 85 50          STA  SHPL
63CB: BC 8A 68 GOON   LDY  TABLEX,X
63CE: A9 69          LDA  #>SHAPES
63D0: 85 51          STA  SHPH
63D2: 60             RTS
              *
              *LASER SUBROUTINE
              *
63D3: AD 62 C0 LASER  LDA  $C062        ;NEG IF BUTTON PRESSED
63D6: 30 08          BMI  FIRE1
63D8: A9 00          LDA  #$00         ;BUTTON NOT PRESSED,SET FLAG TO 0
63DA: 8D 14 60       STA  LFLAG
63DD: 4C 13 64       JMP  NOSHOT
63E0: AD 14 60 FIRE1  LDA  LFLAG        ;IS BUTTON BEING HELD DOWN?
63E3: C9 01          CMP  #$01
63E5: B0 2C          BGE  NOSHOT
63E7: A9 01          LDA  #$01
63E9: 8D 13 60       STA  SHOT         ;SET LASER FIRED FLAG
63EC: 8D 14 60       STA  LFLAG        ;SET BUTTON PRESSED FLAG
63EF: 18             CLC
63F0: AD 0C 60       LDA  VERT         ;TOP OF SHIP
63F3: 69 07          ADC  #$07
63F5: A8             TAY               ;Y REG CONTAINS VERT. LSER POS.
63F6: A9 0C          LDA  #$0C         ;START AT HORIZ=$0C
63F8: 8D 0E 60       STA  HORIZ
63FB: 20 1C 63       JSR  GETADR       ;FIND ADDRESS OF LASER BEAM LINE
63FE: A2 0E          LDX  #$0E         ;SET UP LOOP FOR E TIMES
6400: A9 AA   LASER1 LDA  #$AA         ;DRAW PAIRS OF AA & D5 BYTES(RED)
6402: 51 26          EOR  (HIRESL),Y   ;BY ORING AGAINST SCREEN
6404: 91 26          STA  (HIRESL),Y
6406: E6 26          INC  HIRESL       ;NEXT SCREEN POSITION
```

```
6408: A9 D5                LDA  #$D5
640A: 51 26                EOR  (HIRESL),Y
640C: 91 26                STA  (HIRESL),Y
640E: E6 26                INC  HIRESL      ;NEXT SCREEN POSITION
6410: CA                   DEX              ;DECREMENT INDEX TO LOOP
6411: D0 ED                BNE  LASER1      ;DONE?
6413: 60          NOSHOT   RTS              ;YES! EXIT
                  *XDRAW LASER SUBROUTINE
6414: AD 13 60    XLASER   LDA  SHOT
6417: C9 01                CMP  #$01        ;HAS LASER BEEN SHOT?
6419: D0 24                BNE  NXSHOT      ;NO! SKIP XDRAWING LASER
641B: 18                   CLC
641C: AD 0C 60             LDA  VERT
641F: 69 07                ADC  #$07
6421: A8                   TAY
6422: A9 0C                LDA  #$0C
6424: 8D 0E 60             STA  HORIZ
6427: 20 1C 63             JSR  GETADR
642A: A2 0E                LDX  #$0E
642C: A9 AA       LASER2   LDA  #$AA
642E: 51 26                EOR  (HIRESL),Y
6430: 91 26                STA  (HIRESL),Y
6432: E6 26                INC  HIRESL
6434: A9 D5                LDA  #$D5
6436: 51 26                EOR  (HIRESL),Y
6438: 91 26                STA  (HIRESL),Y
643A: E6 26                INC  HIRESL
643C: CA                   DEX
643D: D0 ED                BNE  LASER2
643F: A9 00       NXSHOT   LDA  #$00        ;RESET LASER FIRED FLAG TO OFF
6441: 8D 13 60             STA  SHOT
6444: 60                   RTS
                  *
                  *DRAWING ROUTINES FOR BOMB
                  *
6445: A9 EF       BSET     LDA  #<SHBOMB    ;ADDRESS BOMB SHAPE
6447: 85 56                STA  BOMBL
6449: A9 68                LDA  #>SHBOMB
644B: 85 57                STA  BOMBH
644D: AD 19 60             LDA  BHORIZ      ;BOMB'S HORIZ. POSITION
6450: 8D 0E 60             STA  HORIZ
6453: A9 03                LDA  #$03
6455: 8D 11 60             STA  DEPTH
6458: 60                   RTS
6459: AC 17 60    BDRAW    LDY  TBVERT      ;BOMB VERT POS
645C: 20 1C 63             JSR  GETADR
645F: A2 00                LDX  #$00
6461: A1 56                LDA  (BOMBL,X)   ;GET ADDRESS OF BOMB SHAPE
6463: 91 26                STA  (HIRESL),Y  ;PLOT
6465: EE 17 60             INC  TBVERT
6468: E6 56                INC  BOMBL
646A: CE 11 60             DEC  DEPTH
646D: D0 EA                BNE  BDRAW
646F: 60                   RTS
6470: AC 17 60    BXDRAW   LDY  TBVERT
6473: 20 1C 63             JSR  GETADR
6476: A2 00                LDX  #$00
6478: A1 56                LDA  (BOMBL,X)
647A: 51 26                EOR  (HIRESL),Y
647C: 91 26                STA  (HIRESL),Y
```

```
647E: EE 17 60          INC  TBVERT
6481: E6 56             INC  BOMBL
6483: CE 11 60          DEC  DEPTH
6486: D0 E8             BNE  BXDRAW
6488: 60                RTS
                  *
                  *BOMB SUBROUTINE
                  *
6489: AD 61 C0    BOMB  LDA  $C061      ;NEG IF BUTTON PRESSED
648C: 30 03             BMI  BOMB1
648E: 4C BD 64          JMP  NODROP
6491: AD 1A 60    BOMB1 LDA  BMLOCK
6494: C9 01             CMP  #$01       ;IS BOMB STILL FALLING?
6496: B0 2A             BGE  FALLIN     ;YES, GOTO FALLIN
6498: AD 0C 60    DROP  LDA  VERT
649B: 18                CLC
649C: 69 09             ADC  #$09
649E: 8D 16 60          STA  BVERT      ;INITIAL POSITION OF BOMB
64A1: 8D 17 60          STA  TBVERT
64A4: A9 0A             LDA  #$0A       ;STARTING HORIZ POSITION
64A6: 8D 19 60          STA  BHORIZ
64A9: A9 00             LDA  #$00       ;INITIAL VERTICAL VELOCITY
64AB: 8D 18 60          STA  BVELY
64AE: A9 01             LDA  #$01
64B0: 8D 1A 60          STA  BMLOCK     ;RESET TO ON
64B3: 8D 1B 60          STA  TBMLOCK    ;RESET END OF FALL TO OFF
64B6: 20 45 64          JSR  BSET
64B9: 20 59 64          JSR  BDRAW      ;DRAW BOMB
64BC: 60                RTS
64BD: AD 1A 60    NODROP LDA BMLOCK
64C0: F0 34             BEQ  BOMB3      ;IS BOMB STILL FALLING
64C2: AD 18 60    FALLIN LDA BVELY
64C5: 18                CLC
64C6: 69 05             ADC  #$05       ;ADD ACCELERATION CONSTANT
64C8: 8D 18 60          STA  BVELY      ;NEW VERTICAL VELOCITY
64CB: 6D 16 60          ADC  BVERT
64CE: 8D 17 60          STA  TBVERT
64D1: 8D 16 60          STA  BVERT      ;BOMB'S NEW VERTICAL POSITION
64D4: AD 19 60          LDA  BHORIZ
64D7: 69 01             ADC  #$01       ;BOMB'S HORIZ. VELOCITY(CONSTANT)
64D9: 8D 19 60          STA  BHORIZ     ;BOMB'S NEW HORIZ. POSITION
                  *TEMP DETECT FOR BOMB LANDING
64DC: AD 16 60          LDA  BVERT
64DF: C9 B0             CMP  #$B0       ;BOTTOM SCREEN?
64E1: 90 0D             BLT  BOMB2      ;NO! THEN BOMB2
64E3: A9 B0             LDA  #$B0
64E5: 8D 16 60          STA  BVERT
64E8: 8D 17 60          STA  TBVERT
64EB: A9 00             LDA  #$00
64ED: 8D 1B 60          STA  TBMLOCK    ;SET END OF BOMB FALL FLAG
64F0: 20 45 64    BOMB2 JSR  BSET
64F3: 20 59 64          JSR  BDRAW
64F6: 60          BOMB3 RTS
                  *BOMB XDRAW
64F7: AD 1A 60    BOMBX LDA  BMLOCK     ;IS BOMB STILL FALLING?(1=YES)
64FA: F0 16             BEQ  BOMBX1     ;SKIP IF 0
64FC: 20 45 64          JSR  BSET
64FF: AD 16 60          LDA  BVERT
6502: 8D 17 60          STA  TBVERT
6505: 20 70 64          JSR  BXDRAW     ;XDRAW BOMB
```

```
6508: AD 1B 60          LDA  TBMLOCK
650B: D0 05             BNE  BOMBX1
650D: A9 00             LDA  #$00
650F: 8D 1A 60          STA  BMLOCK      ;RESET BOMB FALLING TO OFF
6512: 60       BOMBX1   RTS
               *
               *EXPLOSION SUBROUTINE
               *
6513: 20 1E 65 EXPLODE  JSR  EXPSUB
6516: A9 FE             LDA  #$FE
6518: 20 A8 FC          JSR  $FCA8
651B: 4C DA 61          JMP  FIN
651E: AD 0C 60 EXPSUB   LDA  VERT
6521: 8D 0D 60          STA  TVERT
6524: 20 33 63          JSR  SSETUP      ;XDRAW SHIP
6527: 20 FD 62          JSR  SXDRAW
652A: A9 04    EDRAW    LDA  #$04        ;PLOT WHITE FIREBALL 4 LINES DEEP
652C: 8D 11 60          STA  DEPTH
652F: A9 0A             LDA  #$0A        ;HORIZ POS SHIP'S CENTER
6531: 8D 0E 60          STA  HORIZ
6534: AD 0C 60          LDA  VERT        ;VERT POS TOP OF SHIP
6537: 18                CLC
6538: 69 04             ADC  #$04        ;TO REACH CENTER
653A: 8D 0D 60          STA  TVERT
653D: AC 0D 60 EDRAW1   LDY  TVERT       ;SHIP'S CENTER
6540: 20 1C 63          JSR  GETADR
6543: A9 FF             LDA  #$FF        ;WHITE LINE
6545: 51 26             EOR  (HIRESL),Y
6547: 91 26             STA  (HIRESL),Y
6549: EE 0D 60          INC  TVERT       ;NEXT LINE
654C: CE 11 60          DEC  DEPTH
654F: D0 EC             BNE  EDRAW1      ;DONE?
6551: A9 80             LDA  #$80
6553: 20 A8 FC          JSR  $FCA8       ;DELAY
               *XDRAW SEQ1 -8 BLOCKS
6556: A9 00             LDA  #$00
6558: 8D 0A 60          STA  SBLOCK
655B: A9 08             LDA  #$08
655D: 8D 0B 60          STA  EBLOCK
6560: 20 1A 66          JSR  EPLOT
               *XDRAW BEGINING FLASH
6563: A9 04    EDRAW2   LDA  #$04
6565: 8D 11 60          STA  DEPTH
6568: A9 0A             LDA  #$0A
656A: 8D 0E 60          STA  HORIZ
656D: 18                CLC
656E: AD 0C 60          LDA  VERT
6571: 69 04             ADC  #$04
6573: 8D 0D 60          STA  TVERT
6576: AC 0D 60 EDRAW3   LDY  TVERT
6579: 20 1C 63          JSR  GETADR
657C: B1 26             LDA  (HIRESL),Y
657E: 51 26             EOR  (HIRESL),Y
6580: 91 26             STA  (HIRESL),Y
6582: EE 0D 60          INC  TVERT
6585: CE 11 60          DEC  DEPTH
6588: D0 EC             BNE  EDRAW3
               *XDRAW SEQ2-11BLOCKS
658A: A9 08             LDA  #$08
658C: 8D 0A 60          STA  SBLOCK
```

```
658F: A9 13          LDA  #$13
6591: 8D 0B 60       STA  EBLOCK
6594: 20 1A 66       JSR  EPLOT
            *XDRAW SEQ1- 8 OFF
6597: A9 00          LDA  #$00
6599: 8D 0A 60       STA  SBLOCK
659C: A9 08          LDA  #$08
659E: 8D 0B 60       STA  EBLOCK
65A1: 20 1A 66       JSR  EPLOT
            *XDRAW SEQ3-15
65A4: A9 13          LDA  #$13
65A6: 8D 0A 60       STA  SBLOCK
65A9: A9 22          LDA  #$22
65AB: 8D 0B 60       STA  EBLOCK
65AE: 20 1A 66       JSR  EPLOT
            *XDRAW SEQ2-11 OFF
65B1: A9 08          LDA  #$08
65B3: 8D 0A 60       STA  SBLOCK
65B6: A9 13          LDA  #$13
65B8: 8D 0B 60       STA  EBLOCK
65BB: 20 1A 66       JSR  EPLOT
            *XDRAW SEQ4-16
65BE: A9 22          LDA  #$22
65C0: 8D 0A 60       STA  SBLOCK
65C3: A9 32          LDA  #$32
65C5: 8D 0B 60       STA  EBLOCK
65C8: 20 1A 66       JSR  EPLOT
            *XDRAW SEQ3-15 OFF
65CB: A9 13          LDA  #$13
65CD: 8D 0A 60       STA  SBLOCK
65D0: A9 22          LDA  #$22
65D2: 8D 0B 60       STA  EBLOCK
65D5: 20 1A 66       JSR  EPLOT
            *XDRAW SEQ5- 18
65D8: A9 32          LDA  #$32
65DA: 8D 0A 60       STA  SBLOCK
65DD: A9 44          LDA  #$44
65DF: 8D 0B 60       STA  EBLOCK
65E2: 20 1A 66       JSR  EPLOT
            *XDRAW SEQ4-16 OFF
65E5: A9 22          LDA  #$22
65E7: 8D 0A 60       STA  SBLOCK
65EA: A9 32          LDA  #$32
65EC: 8D 0B 60       STA  EBLOCK
65EF: 20 1A 66       JSR  EPLOT
            *XDRAW SEQ6-18
65F2: A9 44          LDA  #$44
65F4: 8D 0A 60       STA  SBLOCK
65F7: A9 56          LDA  #$56
65F9: 8D 0B 60       STA  EBLOCK
65FC: 20 1A 66       JSR  EPLOT
            *XDRAW SEQ5-18 OFF
65FF: A9 32          LDA  #$32
6601: 8D 0A 60       STA  SBLOCK
6604: A9 44          LDA  #$44
6606: 8D 0B 60       STA  EBLOCK
6609: 20 1A 66       JSR  EPLOT
            *XDRAW SEQ6-18 OFF
660C: A9 44          LDA  #$44
660E: 8D 0A 60       STA  SBLOCK
```

```
6611: A9 56              LDA   #$56
6613: 8D 0B 60           STA   EBLOCK
6616: 20 1A 66           JSR   EPLOT
6619: 60                 RTS
               *
               *EXPLOSION PLOTTING SUBROUTINE
               *
661A: AE 0A 60 EPLOT     LDX   SBLOCK        ;LOCATION IN PARTICLE POSITION
               *-                            ;TO START DRAWING
661D: A9 03    EPLOT1    LDA   #$03          ;EACH BLOCK 3 LINES DEEP
661F: 8D 11 60           STA   DEPTH
6622: 18       ELOOP1    CLC
6623: AD 0C 60           LDA   VERT          ;TOP OF SHIP
6626: 69 04              ADC   #$04          ;NOW CENTER OF SHIP
6628: 18                 CLC
6629: 7D 9A 69           ADC   EOFFY,X       ;ADD RELATIVE Y POS OF PARTICLE.
662C: C9 00              CMP   #$00          ;TEST NOT OFF TOP SCREEN
662E: 90 21              BLT   NOPLOT        ;IF OFF, DON'T LOT
6630: C9 C0              CMP   #$C0          ;TEST NOT OFF BOTTOM SCREEN
6632: B0 1D              BGE   NOPLOT        ;IF OFF, DON'T PLOT
6634: 8D 09 60           STA   TEMP1          ;STORE VALUE IN TEMP1
6637: BD 44 69           LDA   EOFFX,X       ;LOCATE X POSITION
663A: 8D 0E 60           STA   HORIZ
663D: AC 09 60 ELOOP3    LDY   TEMP1         ;FIND LINE ADRESS TO PLOT ON SCREEN
6640: 20 1C 63           JSR   GETADR
6643: A9 F0              LDA   #$F0          ;VALUE OF ALL SHAPE BYTES
6645: 51 26              EOR   (HIRESL),Y    ;XOR WITH SCREEN
6647: 91 26              STA   (HIRESL),Y    ;PLOT ON SCREEN
6649: CE 09 60           DEC   TEMP1         ;NEXT LINE, IN THIS CASE DRAWING --
664C: CE 11 60           DEC   DEPTH         ;FROM BOTTOM TO TOP
664F: D0 EC              BNE   ELOOP3        ;DONE?
6651: E8       NOPLOT    INX                 ;DO NEXT PARTICLE
6652: EC 0B 60           CPX   EBLOCK        ;DONE WITH ALL PARTICLES IN GROUP?
6655: D0 C6              BNE   EPLOT1        ;NO,CONTINUE
6657: A9 30              LDA   #$30
6659: 20 A8 FC           JSR   $FCA8         ;DELAY
665C: 60                 RTS
               *
               *SCORE SUBROUTINE
               *
665D: EE 1D 60 SCORE     INC   KILLNUM       ;ANOTHER ALIEN KILLED
6660: EE 1E 60           INC   SCOREA        ;INCREMENT COUNTER
6663: AD 1E 60           LDA   SCOREA
6666: C9 0A              CMP   #$0A
6668: 90 29              BLT   SCRSET        ;IF <10 DON'T CARRY TENS DIGIT
666A: A9 00              LDA   #$00          ;ZERO OUT 1'S DIGIT
666C: 8D 1E 60           STA   SCOREA
666F: EE 1F 60 SCORE10   INC   SCOREB        ;ADD CARRY IN TENS
6672: AD 1F 60           LDA   SCOREB
6675: C9 0A              CMP   #$0A
6677: 90 1A              BLT   SCRSET        ;IF <10 DON'T CARRY TO 100'S DIGIT
6679: A9 00              LDA   #$00          ;ZERO OUT 10'S DIGIT & 1'S DIGIT
667B: 8D 1F 60           STA   SCOREB
667E: EE 20 60           INC   SCORC        ;ADD CARRY IN 100'S
6681: AD 20 60           LDA   SCOREC
6684: C9 0A              CMP   #$0A
6686: 90 0B              BLT   SCRSET        ;SKIP IF LESS 999
6688: A9 00              LDA   #$00          ;RESET TO 0 IF 1000
668A: 8D 1E 60           STA   SCOREA
668D: 8D 1F 60           STA   SCOREB
```

```
6690: 8D 20 60          STA  SCOREC
                   *
                   *SCORE SETUP ROUTINE FOR DRAW
                   *
6693: A9 20        SCRSET  LDA  #$20
6695: 85 27                STA  HIRESH
6697: A9 23                LDA  #$23       ;SETUP SCREEN LOCATION TO PLOT --
6699: 85 26                STA  HIRESL     ;SCOREC ,100'S DIGIT
669B: A9 01                LDA  #$01       ;DIGIT 1 BYTE WIDE
669D: 8D 10 60             STA  LNGH
66A0: A9 6A                LDA  #>SCORESH
66A2: 85 51                STA  SHPH
66A4: AC 20 60             LDY  SCOREC
66A7: B9 30 6A             LDA  SCOREP,Y   ;INDEX TO CORRECT SHAPE FOR DIGIT--
66AA: 85 50                STA  SHPL       ;DRAWN
66AC: 20 E8 66             JSR  SCOREDR    ;DRAW 100'S DIGIT
66AF: A9 20                LDA  #$20       ;SETUP SCREEN LOCATION TO
66B1: 85 27                STA  HIRESH
66B3: A9 24                LDA  #$24       ;PLOT SCOREB ,10'S DIGIT
66B5: 85 26                STA  HIRESL
66B7: A9 01                LDA  #$01
66B9: 8D 10 60             STA  LNGH
66BC: A9 6A                LDA  #>SCORESH
66BE: 85 51                STA  SHPH
66C0: AC 1F 60             LDY  SCOREB
66C3: B9 30 6A             LDA  SCOREP,Y
66C6: 85 50                STA  SHPL
66C8: 20 E8 66             JSR  SCOREDR    ;DRAW 10'S DIGIT
66CB: A9 20                LDA  #$20
66CD: 85 27                STA  HIRESH
66CF: A9 25                LDA  #$25       ;SETUP SCREEN LOCATION TO
66D1: 85 26                STA  HIRESL     ;PLOT SCOREA, 1'S DIGIT
66D3: A9 01                LDA  #$01
66D5: 8D 10 60             STA  LNGH
66D8: A9 6A                LDA  #>SCORSH
66DA: 85 51                STA  SHPH
66DC: AC 1E 60             LDY  SCOREA
66DF: B9 30 6A             LDA  SCOREP,Y
66E2: 85 50                STA  SHPL
66E4: 20 E8 66             JSR  SCOREDR    ;DRAW 1'S DIGIT
66E7: 60                   RTS
                   *
                   *SCORE DRAWING ROUTINE
                   *
66E8: A2 00        SCOREDR LDX  #$00
66EA: A0 00                LDY  #$00       ;OFFSET INTO LINE ALREADY SET --
66EC: A1 50        SCORED2 LDA  (SHPL,X)   ;IN SCRSET
66EE: 91 26                STA  (HIRESL),Y
66F0: A5 27                LDA  HIRESH
66F2: 18                   CLC
66F3: 69 04                ADC  #$04
66F5: 85 27                STA  HIRESH
66F7: E6 50                INC  SHPL
66F9: C9 40                CMP  #$40
66FB: 90 EF                BCC  SCORED2
66FD: E9 20                SBC  #$20
66FF: 85 27                STA  HIRESH
6701: CE 10 60             DEC  LNGH
6704: F0 03                BEQ  SCORED3
6706: C8                   INY
```

```
6707: D0 E3     901              BNE  SCORED2
6709: 60        902     SCORED3  RTS
                903     *
                904     *T A B L E S ************
                905     *
                906     *VERTICAL TABLES
670A: 00 00 00
670D: 00 00 00
6710: 00 00     907     YVERTL   HEX  0000000000000000
6712: 80 80 80
6715: 80 80 80
6718: 80 80     908              HEX  8080808080808080
671A: 00 00 00
671D: 00 00 00
6720: 00 00     909              HEX  0000000000000000
6722: 80 80 80
6725: 80 80 80
6728: 80 80     910              HEX  8080808080808080
672A: 00 00 00
672D: 00 00 00
6730: 00 00     911              HEX  0000000000000000
6732: 80 80 80
6735: 80 80 80
6738: 80 80     912              HEX  8080808080808080
673A: 00 00 00
673D: 00 00 00
6740: 00 00     913              HEX  0000000000000000
6742: 80 80 80
6745: 80 80 80
6748: 80 80     914              HEX  8080808080808080
674A: 28 28 28
674D: 28 28 28
6750: 28 28     915              HEX  2828282828282828
6752: A8 A8 A8
6755: A8 A8 A8
6758: A8 A8     916              HEX  A8A8A8A8A8A8A8A8
675A: 28 28 28
675D: 28 28 28
6760: 28 28     917              HEX  2828282828282828
6762: A8 A8 A8
6765: A8 A8 A8
6768: A8 A8     918              HEX  A8A8A8A8A8A8A8A8
676A: 28 28 28
676D: 28 28 28
6770: 28 28     919              HEX  2828282828282828
6772: A8 A8 A8
6775: A8 A8 A8
6778: A8 A8     920              HEX  A8A8A8A8A8A8A8A8
677A: 28 28 28
677D: 28 28 28
6780: 28 28     921              HEX  2828282828282828
6782: A8 A8 A8
6785: A8 A8 A8
6788: A8 A8     922              HEX  A8A8A8A8A8A8A8A8
678A: 50 50 50
678D: 50 50 50
6790: 50 50     923              HEX  5050505050505050
6792: D0 D0 D0
6795: D0 D0 D0
6798: D0 D0     924              HEX  D0D0D0D0D0D0D0D0
```

```
679A: 50 50 50
679D: 50 50 50
67A0: 50 50     925           HEX   5050505050505050
67A2: D0 D0 D0
67A5: D0 D0 D0
67A8: D0 D0     926           HEX   D0D0D0D0D0D0D0D0
67AA: 50 50 50
67AD: 50 50 50
67B0: 50 50     927           HEX   5050505050505050
67B2: D0 D0 D0
67B5: D0 D0 D0
67B8: D0 D0     928           HEX   D0D0D0D0D0D0D0D0
67BA: 50 50 50
67BD: 50 50 50
67C0: 50 50     929           HEX   5050505050505050
67C2: D0 D0 D0
67C5: D0 D0 D0
67C8: D0 D0     930           HEX   D0D0D0D0D0D0D0D0
                931  *
67CA: 20 24 28
67CD: 2C 30 34
67D0: 38 3C     932  YVERTH   HEX   2024282C3034383C
67D2: 20 24 28
67D5: 2C 30 34
67D8: 38 3C     933           HEX   2024282C3034383C
67DA: 21 25 29
67DD: 2D 31 35
67E0: 39 3D     934           HEX   2125292D3135393D
67E2: 21 25 29
67E5: 2D 31 35
67E8: 39 3D     935           HEX   2125292D3135393D
67EA: 22 26 2A
67ED: 2E 32 36
67F0: 3A 3E     936           HEX   22262A2E32363A3E
67F2: 22 26 2A
67F5: 2E 32 36
67F8: 3A 3E     937           HEX   22262A2E32363A3E
67FA: 23 27 2B
67FD: 2F 33 37
6800: 3B 3F     938           HEX   23272B2F33373B3F
6802: 23 27 2B
6805: 2F 33 37
6808: 3B 3F     939           HEX   23272B2F33373B3F
680A: 20 24 28
680D: 2C 30 34
6810: 38 3C     940           HEX   2024282C3034383C
6812: 20 24 28
6815: 2C 30 34
6818: 38 3C     941           HEX   2024282C3034383C
681A: 21 25 29
681D: 2D 31 35
6820: 39 3D     942           HEX   2125292D3135393D
6822: 21 25 29
6825: 2D 31 35
6828: 39 3D     943           HEX   2125292D3135393D
682A: 22 26 2A
682D: 2E 32 36
6830: 3A 3E     944           HEX   22262A2E32363A3E
6832: 22 26 2A
6835: 2E 32 36
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6838: 3A 3E    945            HEX  22262A2E32363A3E
683A: 23 27 2B
683D: 2F 33 37
6840: 3B 3F    946            HEX  23272B2F33373B3F
6842: 23 27 2B
6845: 2F 33 37
6848: 3B 3F    947            HEX  23272B2F33373B3F
684A: 20 24 28
684D: 2C 30 34
6850: 38 3C    948            HEX  2024282C3034383C
6852: 20 24 28
6855: 2C 30 34
6858: 38 3C    949            HEX  2024282C3034383C
685A: 21 25 29
685D: 2D 31 35
6860: 39 3D    950            HEX  2125292D3135393D
6862: 21 25 29
6865: 2D 31 35
6868: 39 3D    951            HEX  2125292D3135393D
686A: 22 26 2A
686D: 2E 32 36
6870: 3A 3E    952            HEX  22262A2E32363A3E
6872: 22 26 2A
6875: 2E 32 36
6878: 3A 3E    953            HEX  22262A2E32363A3E
687A: 23 27 2B
687D: 2F 33 37
6880: 3B 3F    954            HEX  23272B2F33373B3F
6882: 23 27 2B
6885: 2F 33 37
6888: 3B 3F    955            HEX  23272B2F33373B3F
               956  *
               957  *TABLES TO KEEP TRACK OF OBJECTS
               958  *
688A: 00 00 00
688D: 00 00 00
6890: 00       959  TABLEX    HEX  00000000000000
6891: 28 38 48
6894: 58 68 28
6897: 38       960  TABLEY    HEX  28384858682838
6898: 01 01 01
689B: 01 01 01
689E: 01       961  ALIVE     HEX  01010101010101
689F: 00 00 00
68A2: 00 00 00
68A5: 00       962  USFLAG    HEX  00000000000000
68A6: 00 00 00
68A9: 00 00 00
68AC: 00       963  ONFLAG    HEX  00000000000000
68AD: 2D 40 70
68B0: 90 C0 D0
68B3: F0       964  ONPOS     HEX  2D407090C0D0F0
68B4: 00 00 01
68B7: 00 00 00
68BA: 01       965  SHPADR    HEX  00000100000001
               966  *
68BB: 04       967  SHPLO     DFB  SHAPES
68BC: 14       968            DFB  SHAPES+$10
68BD: 24       969            DFB  SHAPES+$20
68BE: 34       970            DFB  SHAPES+$30
```

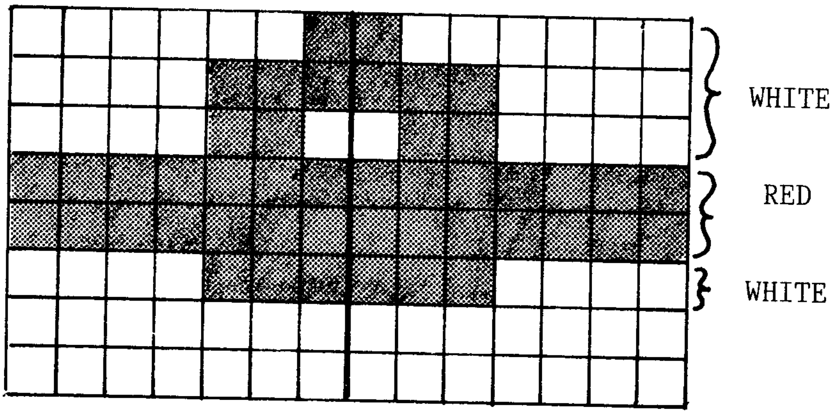
```
                971  *
                972  *MASK SHIP TABLE
68BF: 01 00 00
68C2: 03 00 00
68C5: 07 00     973  MSHIP    HEX  0100000300000700
68C7: 00 0F 00
68CA: 00 7F 7F
68CD: 00 7F     974           HEX  000F00007F7F007F
68CF: 1F 07 7F
68D2: 7F 1F 78
68D5: 7F 7F     975           HEX  1F077F7F1F787F7F
                976  *SHAPE TABLE SHIP
68D7: 80 00 00
68DA: 82 00 00
68DD: 82 00     977  SHIP     HEX  8000008200008200
68DF: 00 8A 00
68E2: 00 AA D5
68E5: 80 AA     978           HEX  008A0000AAD580AA
68E7: 95 82 AA
68EA: D5 8A A8
68ED: D5 AA     979           HEX  9582AAD58AA8D5AA
                980  *
                981  *SHAPE BOMB
68EF: 07 7E 07  982  SHBOMB   HEX  077E07
                983           DS   18
                984  *
                985  *SHAPE ALIEN EVEN
6904: 28 28 0A
6907: 2A 2A 22
690A: 22 22     986  SHAPES   HEX  28280A2A2A222222
690C: 00 01 01
690F: 01 05 04
6912: 04 04     987           HEX  0001010105040404
                988  *SHAPE SAUCER EVEN
6914: 40 70 30
6917: AA AA 70
691A: 00 00     989           HEX  407030AAAA700000
691C: 01 07 06
691F: D5 D5 07
6922: 00 00     990           HEX  010706D5D5070000
                991  *ODD ALIEN SHAPE
6924: 50 54 04
6927: 54 55 11
692A: 11 11     992           HEX  5054045455111111
692C: 00 00 02
692F: 02 02 02
6932: 02 02     993           HEX  0000020202020202
                994  *ODD SAUCER SHAPE
6934: 40 70 30
6937: D5 D5 70
693A: 00 00     995           HEX  407030D5D5700000
693C: 01 07 06
693F: AA AA 07
6942: 00 00     996           HEX  010706AAAA070000
                997  *
                998  *EXPLOSION TABLES
6944: 08 09 0A
6947: 0B 0B 0A
694A: 09 08     999  EOFFX    HEX  08090A0B0B0A0908
694C: 07 08 09
```

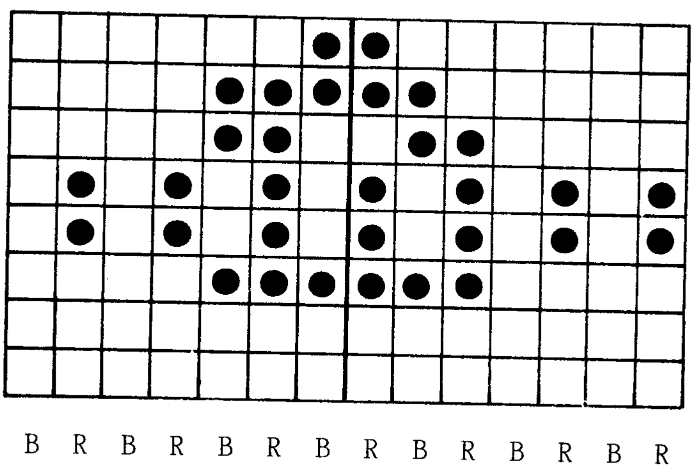
```
694F: 0A 0B 0C
6952: 0C 0B     1000          HEX  0708090A0B0C0C0B
6954: 0A 08 07
6957: 05 06 08
695A: 09 0A     1001          HEX  0A0807050608090A
695C: 0C 0D 0E
695F: 0E 0D 0C
6962: 0B 09     1002          HEX  0C0D0E0E0D0C0B09
6964: 07 06 04
6967: 05 06 08
696A: 0A 0C     1003          HEX  0706040506080A0C
696C: 0E 0F 0F
696F: 0E 0D 0B
6972: 09 07     1004          HEX  0E0F0F0E0D0B0907
6974: 05 04 02
6977: 03 05 08
697A: 0B 0D     1005          HEX  0504020305080B0D
697C: 0F 10 11
697F: 10 0F 0D
6982: 0B 08     1006          HEX  0F1011100F0D0B08
6984: 06 04 03
6987: 02 00 01
698A: 04 07     1007          HEX  0604030200010407
698C: 0A 0E 11
698F: 12 13 12
6992: 11 0F     1008          HEX  0A0E11121312110F
6994: 0B 07 04
6997: 02 01 00  1009          HEX  0B0704020100
699A: FC F8 F8
699D: FC 04 08
69A0: 08 04     1010 EOFFY    HEX  FCF8F8FC04080804
69A2: F8 F0 EC
69A5: EC F0 F8
69A8: 04 0C     1011          HEX  F8F0ECECF0F8040C
69AA: 10 0C 04
69AD: F8 EC E4
69B0: E0 E4     1012          HEX  100C04F8ECE4E0E4
69B2: E4 EC F4
69B5: 00 0C 14
69B8: 18 1C     1013          HEX  E4ECF4000C14181C
69BA: 14 08 F0
69BD: E4 DC D4
69C0: D4 DC     1014          HEX  1408F0E4DCD4D4DC
69C2: E4 F0 00
69C5: 14 20 24
69C8: 28 20     1015          HEX  E4F0001420242820
69CA: 14 00 EC
69CD: E0 D4 CC
69D0: C8 D0     1016          HEX  1400ECE0D4CCC8D0
69D2: D8 E8 FC
69D5: 14 24 2C
69D8: 34 34     1017          HEX  D8E8FC14242C3434
69DA: 2C 20 10
69DD: 00 E4 D0
69E0: C8 C0     1018          HEX  2C201000E4D0C8C0
69E2: B8 C4 D4
69E5: E4 FC 18
69E8: 2C 38     1019          HEX  B8C4D4E4FC182C38
69EA: 48 40 38
69ED: 28 10 00  1020          HEX  484038281000
```

```
              1021          DS    24
              1022 *
              1023 *SHAPES FOR SCOREKEEPING
6A08: 3F 01 01
6A0B: 3F 20 20
6A0E: 3F 00   1024 SCOREWD  HEX   3F01013F20203F00
6A10: 3C 02 01
6A13: 01 01 02
6A16: 3C 00   1025          HEX   3C02010101023C00
6A18: 1E 21 21
6A1B: 21 21 21
6A1E: 1E 00   1026          HEX   1E21212121211E00
6A20: 3F 21 21
6A23: 3F 09 11
6A26: 21 00   1027          HEX   3F21213F09112100
6A28: 3F 01 01
6A2B: 1F 01 01
6A2E: 3F 00   1028          HEX   3F01011F01013F00
              1029 *INDEX TO LO BYTE SCORE NUMBER SHAPES
6A30: 3A      1030 SCOREP   DFB   SCORESH
6A31: 42      1031          DFB   SCORESH+$08
6A32: 4A      1032          DFB   SCORESH+$10
6A33: 52      1033          DFB   SCORESH+$18
6A34: 5A      1034          DFB   SCORESH+$20
6A35: 62      1035          DFB   SCORESH+$28
6A36: 6A      1036          DFB   SCORESH+$30
6A37: 72      1037          DFB   SCORESH+$38
6A38: 7A      1038          DFB   SCORESH+$40
6A39: 82      1039          DFB   SCORESH+$48
              1040 *
              1041 *NUMBER SHAPES
6A3A: 1C 22 22
6A3D: 22 22 22
6A40: 1C 00   1042 SCORESH  HEX   1C22222222221C00
6A42: 08 0C 08
6A45: 08 08 08
6A48: 1C 00   1043          HEX   080C080808081C00
6A4A: 1C 22 20
6A4D: 18 04 02
6A50: 3E 00   1044          HEX   1C22201804023E00
6A52: 3E 20 10
6A55: 08 10 22
6A58: 1C 00   1045          HEX   3E20100810221C00
6A5A: 18 14 12
6A5D: 11 3F 10
6A60: 10 00   1046          HEX   181412113F101000
6A62: 3E 02 02
6A65: 3E 20 22
6A68: 1C 00   1047          HEX   3E02023E20221C00
6A6A: 38 04 02
6A6D: 1E 22 22
6A70: 1C 00   1048          HEX   3804021E22221C00
6A72: 3E 20 10
6A75: 08 04 04
6A78: 04 00   1049          HEX   3E20100804040400
6A7A: 1C 22 22
6A7D: 1C 22 22
6A80: 1C 00   1050          HEX   1C22221C22221C00
6A82: 1C 22 22
6A85: 1E 20 10
```

```
6A88: 0E 00     1051          HEX  1C22221E20100E00
6A8A: 1C 22 22
6A8D: 22 22 22
6A90: 1C 00     1052          HEX  1C22222222221C00

--END ASSEMBLY--    2706 BYTES
```





EVEN		ODD	
40	01	40	01
70	07	70	07
30	06	30	06
AA	D5	D5	AA
AA	D5	D5	AA
70	07	70	07
00	00	00	00
00	00	00	00

EVEN OFFSET SHAPE

HI-RES SCREEN SCROLLING

There are an increasing number of games that require fast scrolling. Racing car games, where the screen (or at least sections of the screen scroll) rapidly vertically, are good examples. It is certainly much easier to scroll the screen in

that direction, because only two adjacent lines are involved, and the screen addresses for those two lines are easily referenced from lookup tables.

The algorithm for scrolling down the screen involves taking the bytes from one line and storing them in the line directly below. This is done across a row for each column. The most important thing is that you start from the bottom of the screen or you will overwrite lines. Also, the bottom line must be transferred to the top of the screen if a wrap-a-round effect is desired. A cute trick which minimizes the code considerably is to extend the YVERT table one extra byte. That byte is the address of the 0th line. Therefore, line #191 can be moved to line #192, which is actually line #0.

Moving an entire screen upwards a single line by this method is not that fast, but usually, as in racing games, only narrow background strips need to be scrolled. This produces more reasonable scrolling rates. Other techniques involve using a background that occupies every other screen line, then scrolling it two lines at a time. The Phantom's Five game appears to use this method. Another approach is to utilize straight in-line code, where scrolling for all the lines is done a column at a time. Bytes are moved upwards with the following code

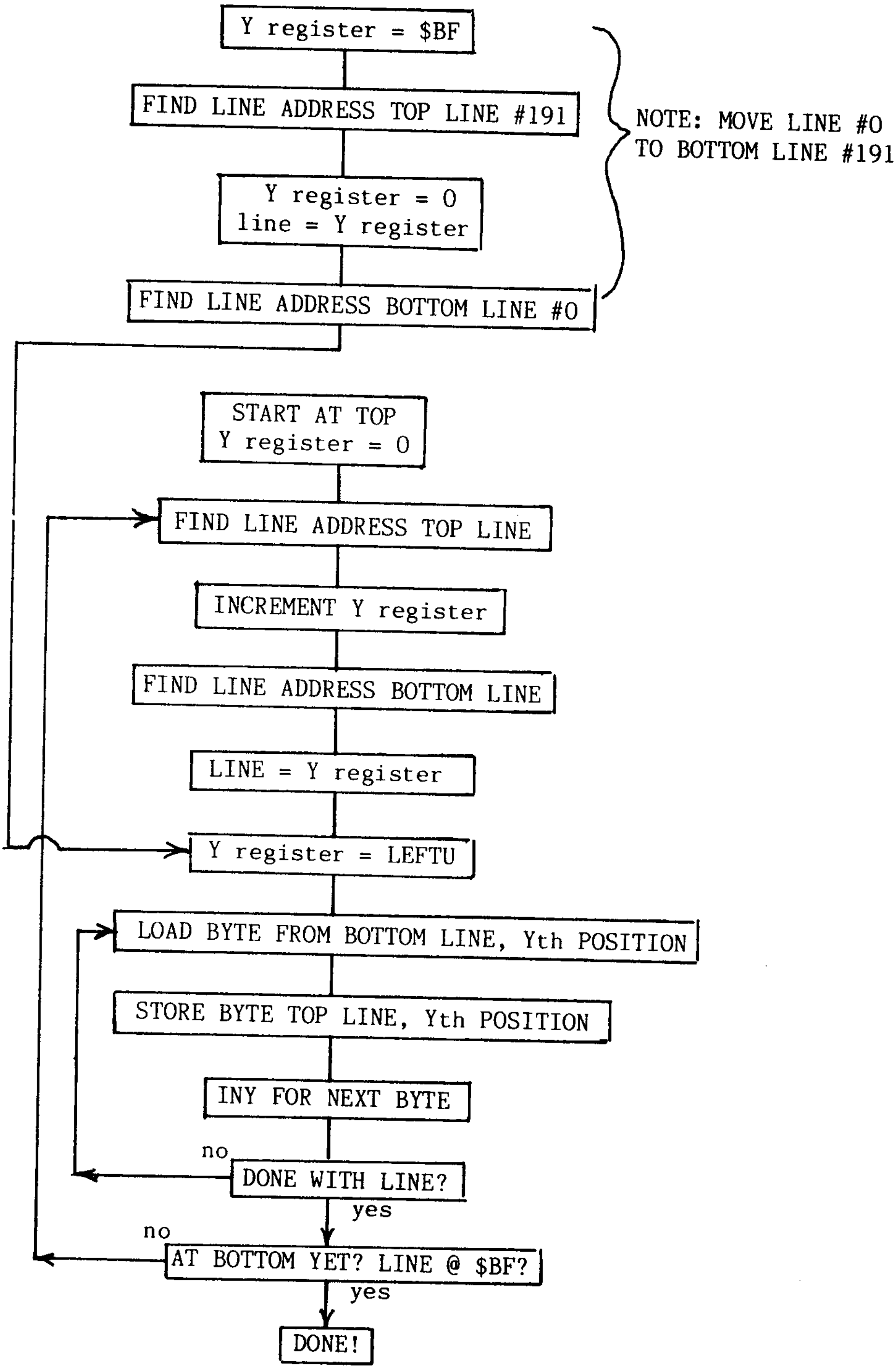
```
LDA $3CD0,Y
STA $3FD0,Y
 .    .   .
 .    .   .
LDA $2800,Y
STA $2C00,Y
LDA $2400,Y
STA $2800,Y
LDA $2000,Y
STA $2400,Y
```

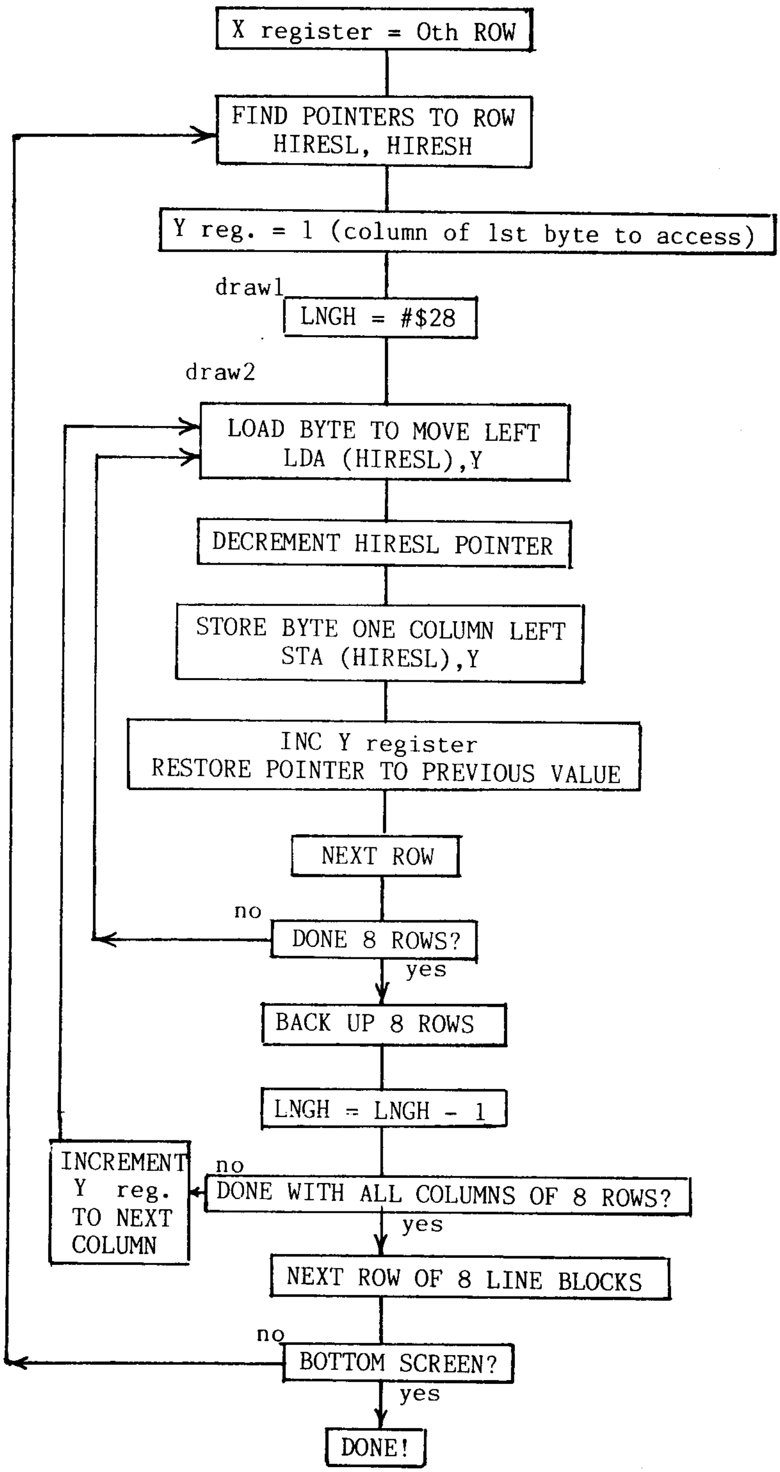
where Y is looped from $0 to $27 across the screen. This code is at least three times faster than the first method.

Scrolling the screen upwards is quite similar to scrolling the screen downwards. It requires moving the screen memory from the lower line to the upper line, across all 40 columns. The bytes in the 0th line must be moved to the 191st line if a wrap-a-round effect is desired. This requires extra code, since we can't do any fancy tricks as we did before.

The two scrolling routines, one up and one down, have been put together in the following program. The scrolling windows have been set so that part of the screen scrolls up and part of the screen scrolls down, while the remainder remains stationary. The variables that control the windows are LEFT and RIGHT for scrolling down, and LEFTU and RIGHTU for scrolling up. These values can be modified in lines 16, 18, 20 and 22.

The flow charts and code are presented below:


Y register = $BF
FIND LINE ADDRESS TOP LINE #191
Y register = 0
line = Y register
FIND LINE ADDRESS BOTTOM LINE #0
NOTE: MOVE LINE #0
TO BOTTOM LINE #191
START AT TOP
Y register = 0
FIND LINE ADDRESS TOP LINE
INCREMENT Y register
FIND LINE ADDRESS BOTTOM LINE
LINE = Y register
Y register = LEFTU
LOAD BYTE FROM BOTTOM LINE, Yth POSITION
STORE BYTE TOP LINE, Yth POSITION
INY FOR NEXT BYTE
no
DONE WITH LINE?
yes
no
AT BOTTOM YET? LINE @ $BF?
yes
DONE!


X register = 0th ROW
FIND POINTERS TO ROW HIRESL, HIRESH
Y reg. = 1 (column of 1st byte to access)
draw1
LNGH = #$28
draw2
LOAD BYTE TO MOVE LEFT LDA (HIRESL),Y
DECREMENT HIRESL POINTER
STORE BYTE ONE COLUMN LEFT STA (HIRESL),Y
INC Y register RESTORE POINTER TO PREVIOUS VALUE
NEXT ROW
no
DONE 8 ROWS?
yes
BACK UP 8 ROWS
LNGH = LNGH - 1
INCREMENT Y reg. TO NEXT COLUMN
no
DONE WITH ALL COLUMNS OF 8 ROWS?
yes
NEXT ROW OF 8 LINE BLOCKS
no
BOTTOM SCREEN?
yes
DONE!

```
                *SCROLL UP & DOWN SUBROUTINE
                         ORG  $6000
6000: 4C 08 60           JMP  PROG
                LEFT     DS   1
                RIGHT    DS   1
                LINE     DS   1
                LEFTU    DS   1
                RIGHTU   DS   1
                TOPL     EQU  $6
                TOPH     EQU  TOPL+$1
                BOTTOML  EQU  $8
                BOTTOMH  EQU  BOTTOML+$1
6008: AD 50 C0  PROG     LDA  $C050
600B: AD 52 C0           LDA  $C052
600E: AD 57 C0           LDA  $C057
6011: A9 06              LDA  #$06
6013: 8D 03 60           STA  LEFT        ;LEFT WINDOW SCROLL DOWN
6016: A9 0A              LDA  #$0A
6018: 8D 04 60           STA  RIGHT       ;RIGHT WINDOW SCROLL DOWN
601B: A9 20              LDA  #$20
601D: 8D 06 60           STA  LEFTU       ;LEFT WINDOW SCROLL UP
6020: A9 25              LDA  #$25
6022: 8D 07 60           STA  RIGHTU      ;RIGHT WINDOW SCROLL UP
6025: 20 2E 60  CONT     JSR  SCROLL
6028: 20 5D 60           JSR  SCROLLU
602B: 4C 25 60           JMP  CONT
                *SCROLL DOWN SUBROUTINE
602E: A0 C0     SCROLL   LDY  #$C0        ;START WITH BOTTOM LINE --
                *                         ;AND WORK TO TOP
6030: B9 AA 60  START    LDA  YVERTL,Y    ;FIND SCREEN ADDRESS --
6033: 85 08              STA  BOTTOML     ;OF BOTTOM LINE
6035: B9 6B 61           LDA  YVERTH,Y
6038: 85 09              STA  BOTTOMH
603A: 88                 DEY              ;DECREMENT LINE NUMBER
603B: B9 AA 60           LDA  YVERTL,Y    ;FIND SCREEN ADDRESS  TOP LINE
603E: 85 06              STA  TOPL
6040: B9 6B 61           LDA  YVERTH,Y
6043: 85 07              STA  TOPH
6045: 8C 05 60           STY  LINE        ;TEMP STORE Y REGISTER
6048: AC 03 60           LDY  LEFT        ;START SHIFTING LINE
604B: B1 06     LOOP     LDA  (TOPL),Y    ;LOAD BYTE ON SCREEN
604D: 91 08              STA  (BOTTOML),Y;STORE BYTE ON LINE BELOW
604F: C8                 INY              ;NEXT BYTE
6050: CC 04 60           CPY  RIGHT       ;DONE WITH LINE?
6053: D0 F6              BNE  LOO        ;NO,DO NEXT BYTE ON LINE
6055: AC 05 60           LDY  LINE        ;RESET Y REGISTER WITH LINE
6058: C0 00              CPY  #$00        ;AT TOP YET?
605A: D0 D4              BNE  START
605C: 60                 RTS
                *SCROLL UP SUBROUTINE
                *FIRST TAKE TOP LINE AND PUT ON BOTTOM
                *IN THIS SPECIAL CASE THINK OF IT AS LINE #0 BELOW LINE #191
605D: A0 BF     SCROLLU  LDY  #$BF        ;LINE #191
605F: B9 AA 60           LDA  YVERTL,Y    ;FIND SCREEN ADDRESS --
6062: 85 06              STA  TOPL        ;OF TOP LINE
6064: B9 6B 61           LDA  YVERTH,Y
6067: 85 07              STA  TOPH
6069: A0 00              LDY  #$00
606B: 8C 05 60           STY  LINE
606E: B9 AA 60           LDA  YVERTL,Y    ;FIND SCREEN ADDRESS --
```

```
6071: 85 08              STA  BOTTOML      ;OF BOTTOM LINE
6073: B9 6B 61           LDA  YVERTH,Y
6076: 85 09              STA  BOTTOMH
6078: 4C 95 60           JMP  LOOP2-3      ;GOTO INSTRUCTION BEFORE LOOP2
607B: A0 00              LDY  #$00         ;START AT TOP
607D: B9 AA 60   STARTU  LDA  YVERTL,Y     ;FIND SCREEN ADDRESS --
6080: 85 06              STA  TOPL         ;OF TOP LINE
6082: B9 6B 61           LDA  YVERTH,Y
6085: 85 07              STA  TOPH
6087: C8                 INY               ;NEXT ROW
6088: B9 AA 60           LDA  YVERTL,Y     ;FIND SCREEN ADDRESS --
608B: 85 08              STA  BOTTOML      ;OF BOTTOM LINE
608D: B9 6B 61           LDA  YVERTH,Y
6090: 85 09              STA  BOTTOMH
6092: 8C 05 60           STY  LINE         ;TEMP STORE Y REGISTER
6095: AC 06 60           LDY  LEFTU        ;START SHIFTING LINE
6098: B1 08      LOOP2   LDA  (BOTTOML),Y;LOAD BYTE ON SCREEN
609A: 91 06              STA  (TOPL),Y     ;STORE BYTE ON LINE ABOVE
609C: C8                 INY               ;NEXT BYTE
609D: CC 07 60           CPY  RIGHTU       ;DONE WITH LINE?
60A0: D0 F6              BE  LOOP2        ;NO,DO NEXT BYTE ON LINE
60A2: AC 05 60           LDY  LINE         ;RESET Y REG. WITH LINE
60A5: C0 BF              CPY  #$BF         ;AT BOTTOM YET?
60A7: D0 D4              BNE  STARTU
60A9: 60                 RTS
60AA: 00 00 00
60AD: 00 00 00
60B0: 00 00      YVERTL  HEX  0000000000000000
60B2: 80 80 80
60B5: 80 80 80
60B8: 80 80              HEX  8080808080808080
60BA: 00 00 00
60BD: 00 00 00
60C0: 00 00              HEX  0000000000000000
60C2: 80 80 80
60C5: 80 80 80
60C8: 80 80              HEX  8080808080808080
60CA: 00 00 00
60CD: 00 00 00
60D0: 00 00              HEX  0000000000000000
60D2: 80 80 80
60D5: 80 80 80
60D8: 80 80              HEX  8080808080808080
60DA: 00 00 00
60DD: 00 00 00
60E0: 00 00              HEX  0000000000000000
60E2: 80 80 80
60E5: 80 80 80
60E8: 80 80              HEX  8080808080808080
60EA: 28 28 28
60ED: 28 28 28
60F0: 28 28              HEX  2828282828282828
60F2: A8 A8 A8
60F5: A8 A8 A8
60F8: A8 A8              HEX  A8A8A8A8A8A8A8A8
60FA: 28 28 28
60FD: 28 28 28
6100: 28 28              HEX  2828282828282828
6102: A8 A8 A8
6105: A8 A8 A8
```

```
6108: A8 A8     97              HEX  A8A8A8A8A8A8A8A8
610A: 28 28 28
610D: 28 28 28
6110: 28 28     98              HEX  2828282828282828
6112: A8 A8 A8
6115: A8 A8 A8
6118: A8 A8     99              HEX  A8A8A8A8A8A8A8A8
611A: 28 28 28
611D: 28 28 28
6120: 28 28     100             HEX  2828282828282828
6122: A8 A8 A8
6125: A8 A8 A8
6128: A8 A8     101             HEX  A8A8A8A8A8A8A8A8
612A: 50 50 50
612D: 50 50 50
6130: 50 50     102             HEX  5050505050505050
6132: D0 D0 D0
6135: D0 D0 D0
6138: D0 D0     103             HEX  D0D0D0D0D0D0D0D0
613A: 50 50 50
613D: 50 50 50
6140: 50 50     104             HEX  5050505050505050
6142: D0 D0 D0
6145: D0 D0 D0
6148: D0 D0     105             HEX  D0D0D0D0D0D0D0D0
614A: 50 50 50
614D: 50 50 50
6150: 50 50     106             HEX  5050505050505050
6152: D0 D0 D0
6155: D0 D0 D0
6158: D0 D0     107             HEX  D0D0D0D0D0D0D0D0
615A: 50 50 50
615D: 50 50 50
6160: 50 50     108             HEX  5050505050505050
6162: D0 D0 D0
6165: D0 D0 D0
6168: D0 D0 00  109             HEX  D0D0D0D0D0D0D0D000
                110  *
616B: 20 24 28
616E: 2C 30 34
6171: 38 3C     111  YVERTH     HEX  2024282C3034383C
6173: 20 24 28
6176: 2C 30 34
6179: 38 3C     112             HEX  2024282C3034383C
617B: 21 25 29
617E: 2D 31 35
6181: 39 3D     113             HEX  2125292D3135393D
6183: 21 25 29
6186: 2D 31 35
6189: 39 3D     114             HEX  2125292D3135393D
618B: 22 26 2A
618E: 2E 32 36
6191: 3A 3E     115             HEX  22262A2E32363A3E
6193: 22 26 2A
6196: 2E 32 36
6199: 3A 3E     116             HEX  22262A2E32363A3E
619B: 23 27 2B
619E: 2F 33 37
61A1: 3B 3F     117             HEX  23272B2F33373B3F
61A3: 23 27 2B
```

```
61A6: 2F 33 37
61A9: 3B 3F     118             HEX  23272B2F33373B3F
61AB: 20 24 28
61AE: 2C 30 34
61B1: 38 3C     119             HEX  2024282C3034383C
61B3: 20 24 28
61B6: 2C 30 34
61B9: 38 3C     120             HEX  2024282C3034383C
61BB: 21 25 29
61BE: 2D 31 35
61C1: 39 3D     121             HEX  2125292D3135393D
61C3: 21 25 29
61C6: 2D 31 35
61C9: 39 3D     122             HEX  2125292D3135393D
61CB: 22 26 2A
61CE: 2E 32 36
61D1: 3A 3E     123             HEX  22262A2E32363A3E
61D3: 22 26 2A
61D6: 2E 32 36
61D9: 3A 3E     124             HEX  22262A2E32363A3E
61DB: 23 27 2B
61DE: 2F 33 37
61E1: 3B 3F     125             HEX  23272B2F33373B3F
61E3: 23 27 2B
61E6: 2F 33 37
61E9: 3B 3F     126             HEX  23272B2F33373B3F
61EB: 20 24 28
61EE: 2C 30 34
61F1: 38 3C     127             HEX  2024282C3034383C
61F3: 20 24 28
61F6: 2C 30 34
61F9: 38 3C     128             HEX  2024282C3034383C
61FB: 21 25 29
61FE: 2D 31 35
6201: 39 3D     129             HEX  2125292D3135393D
6203: 21 25 29
6206: 2D 31 35
6209: 39 3D     130             HEX  2125292D3135393D
620B: 22 26 2A
620E: 2E 32 36
6211: 3A 3E     131             HEX  22262A2E32363A3E
6213: 22 26 2A
6216: 2E 32 36
6219: 3A 3E     132             HEX  22262A2E32363A3E
621B: 23 27 2B
621E: 2F 33 37
6221: 3B 3F     133             HEX  23272B2F33373B3F
6223: 23 27 2B
6226: 2F 33 37
6229: 3B 3F 20  134             HEX  23272B2F33373B3F20

--END ASSEMBLY--

ERRORS: 0

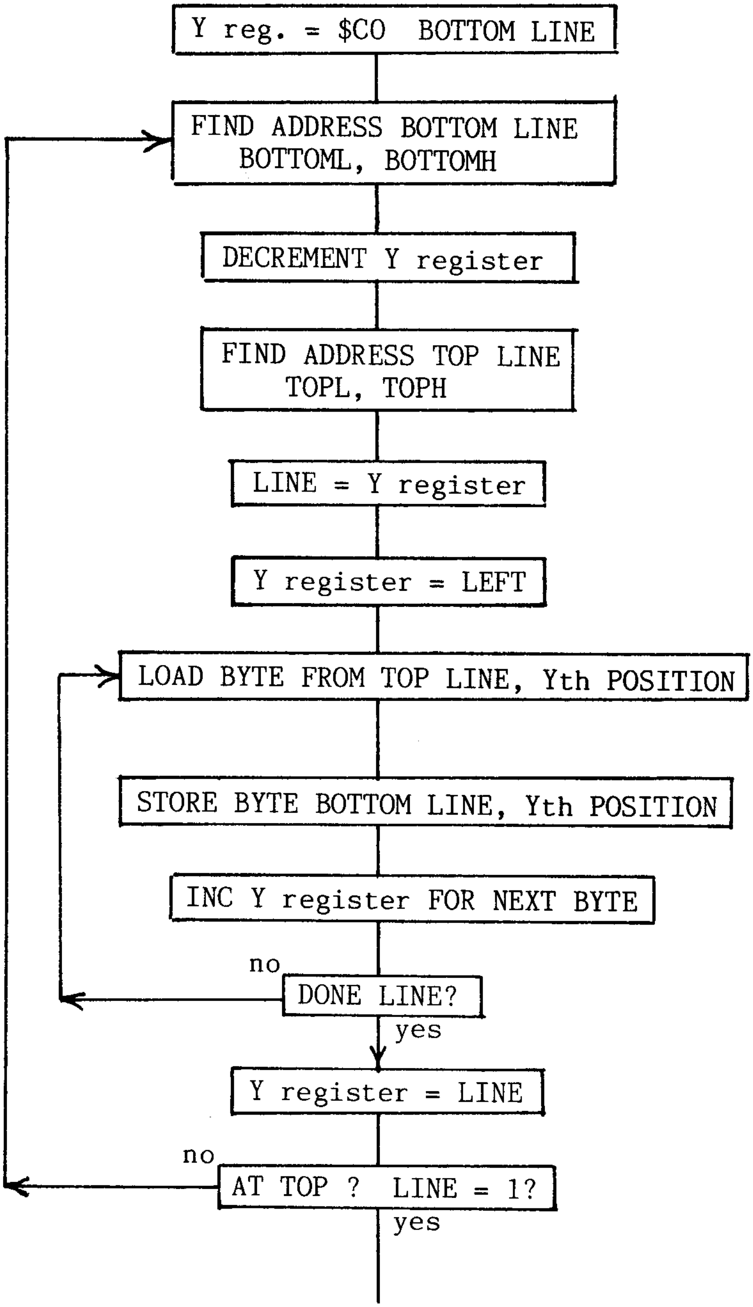
556 BYTES
```

Scrolling the screen left or right in the horizontal direction is slightly more difficult. The normal scrolling direction for games is left, because objects in most games travel from left to right, and the background terrain scrolls left. This method moves each byte in one of the 8 line subgroups leftwards, a byte at a time. Byte-shifting starts at the 1st column, moving that byte to the 0th column, then drops down to the next row, moves a byte again, until all eight rows have been moved. Then the routine increments the column number and repeats the operation until all 40 columns of eight rows have been moved. It does this for all 24 subgroups.

Normally, during scrolling, a new column of data is plotted at the 39th column. Wrap-a-round is tricky, because when a byte is moved off the screen's left side it will reappear on a line ⅓ higher on the screen. If you would like to see this strange scrolling effect, change the value in line #25 to #$28.

Both the code and flow chart are shown below.

```
                 1  *SCROLL LEFT SUBROUTINE
                 2           ORG  $6000
6000: 4C 05 60   3           JMP  PROG
                 4  BLOCK    DS   1
                 5  LNGH     DS   1
                 6  HIRESL   EQU  $FB
                 7  HIRESH   EQU  HIRESL+$1
                 8  *ENTER HERE FIRST TIME ACCESS
6005: AD 50 C0   9  PROG     LDA  $C050
6008: AD 52 C0  10           LDA  $C052
600B: AD 57 C0  11           LDA  $C057
600E: A2 00     12  START    LDX  #$00         ;0TH ROW OF 8 LINE BLOCKS
6010: BD 4A 60  13  NXBLOCK  LDA  YBLOCKH,X    ;GET SCREEN POINTERS FOR 1ST ROW -
6013: 85 FC     14           STA  HIRESH       ;OF BLOCK
6015: BD 62 60  15           LDA  YBLOCKL,X
6018: 85 FB     16           STA  HIRESL
601A: A0 01     17           LDY  #$01         ;NEED TO MOVE COLUMN #1 BYTE FIRST
601C: 20 27 60  18           JSR  DRAW1
601F: E8        19           INX               ;NEXT ROW
6020: E0 18     20           CPX  #$18         ;BOTTOM YET?
6022: 90 EC     21           BLT  NXBLOCK      ;NO, CONTINUE
6024: 4C 0E 60  22           JMP  START        ;SCROLL ENTIRE SCREEN AGAIN
                23  *SUBROUTINE TO DRAW EACH SHAPE
                24  *EACH SHAPE 1 BYTE BY 8 ROWS
6027: A9 27     25  DRAW1    LDA  #$27
6029: 8D 04 60  26           STA  LNGH
602C: B1 FB     27  DRAW2    LDA  (HIRESL),Y   ;LOAD BYTE WANT TO MOVE LEFT
602E: 88        28           DEY               ;LO BYTE POINTER TO ONE BYTE LEFT
602F: 91 FB     29           STA  (HIRESL),Y   ; STORE BYTE
6031: C8        30           INY               ;RETURN POINTER TO RIGHT
6032: A5 FC     31           LDA  HIRESH
6034: 18        32           CLC
6035: 69 04     33           ADC  #$04         ;THIS GETS TO NEXT ROW IN BLOCK
6037: 85 FC     34           STA  HIRESH
6039: C9 40     35           CMP  #$40         ;ARE WE FINISHED WITH 8 ROWS
603B: 90 EF     36           BCC  DRAW2        ;NO DO NEXT BYTE
603D: E9 20     37           SBC  #$20         ;RETURN TO TOP ROW
603F: 85 FC     38           STA  HIRESH
6041: CE 04 60  39           DEC  LNGH
```


Y reg. = $CO BOTTOM LINE
FIND ADDRESS BOTTOM LINE
BOTTOML, BOTTOMH
DECREMENT Y register
FIND ADDRESS TOP LINE
TOPL, TOPH
LINE = Y register
Y register = LEFT
LOAD BYTE FROM TOP LINE, Yth POSITION
STORE BYTE BOTTOM LINE, Yth POSITION
INC Y register FOR NEXT BYTE
no
DONE LINE?
yes
Y register = LINE
no
AT TOP ? LINE = 1?
yes

```
6044: F0 03                BEQ  DRAW3       ;FINISHED?
6046: C8                   INY              ;NEXT COLUMN OF 8 ROWS
6047: D0 E3                BNE  DRAW2
6049: 60          DRAW3    RTS
                  *TABLES OF STARTING VALUE OF EACH OF 20 BLOCKS
604A: 20 20 21
604D: 21 22 22
6050: 23 23 20
6053: 20          YBLOCKH  HEX  20202121222223232020
6054: 21 21 22
6057: 22 23 23
605A: 20 20 21
605D: 21                   HEX  21212222232320202121
605E: 22 22 23
6061: 23                   HEX  22222323
6062: 00 80 00
6065: 80 00 80
6068: 00 80 28
606B: A8          YBLOCKL  HEX  008000800080008028A8
606C: 28 A8 28
606F: A8 28 A8
6072: 50 D0 50
6075: D0                   HEX  28A828A828A850D050D0
6076: 50 D0 50
6079: D0                   HEX  50D050D0

--END ASSEMBLY--

ERRORS: 0

122 BYTES
```

CHAPTER 8

WHAT MAKES A GOOD GAME

There is no sure-fire way to predict whether a game will be successful, but there are certain attributes that may ensure success. Certainly, a game should have a goal, for, without one, what is the point in playing? The game should also be challenging, since, without requiring some skill, you would tire of it quickly. A game should evoke either a fantasy situation or your innate curiosity, for, without being novel or puzzling, it becomes boring. And lastly (especially in arcade games), a game should be easily controllable in regards to the interaction of the player with the computer game.

Game objectives take two different forms. There are games where the goal is approached, like destroying the fleet of invaders in Galaxian or Space Invaders, or landing on the moon in Lunar lander. There are also games where the goal is to avoid catastrophe. Examples of this range from preventing a nuclear power plant meltdown in Three Mile Island to saving your cities during a nuclear missile attack in Missile Command.

Goals must suit a player's expectations or fantasies. This is why certain people like certain certain types of games more than others. The battle-lines of good against evil lurk in the background of many space games, wherein evil, menacing invaders are bent on destruction of the Earth. It becomes the player's goal to protect the Earth as long as possible while scoring the most points for killing aliens. The fantasy of destroying objects during a game appeals to others. It can take the form of popping balloons by bouncing a clown off a teeter-totter, such as in Clowns and Balloons, or breaking out bricks in a wall, as in Breakout. In each case, the partially-destroyed wall or rows of balloons presents a visually compelling goal and a graphic scorekeeping device as well. Other goals that appeal to many range from accumulating the most treasure while exploring an underground cavern to escaping from a crumbling building before it collapses or before your food runs out.

Goals in most games imply that there is some end point, either when the goal is reached or when you fail. It is often important to make sure the game doesn't just go on and on forever. Limits should be set. Sometimes these take the form of time limits or the amount of ammunition, balls or ships left.

For a game to be considered challenging, it should have a goal where the outcome is uncertain. If the player is certain to reach the goal or certain not to reach it, the game is unlikely to be a challenge and the player will lose interest. It is very easy to introduce randomness into a game by either hiding important information or introducing random variables that draw the player towards disaster. But you must be careful not to overdo this, since a totally random

game lacks a skill factor. Players quickly discover that they have no control over the outcome.

A variable difficulty level is often used to alter the game's level of play. These levels, often with ego satisfying names like Star Commander or Pilot, can be set by the player. Many games are designed to become harder the further you get into them. This increasing skill level requirement presents an added challenge, while preventing the player from growing complacent. Often, the technique is to speed up the game or place additional enemy craft into the battle. The player is required to play faster and better, honing his reflexes during the process.

Any good game should offer a reward for reaching increasingly difficult levels of play. Often, bonus points, extra balls, ships, or more ammunition are rewarded for exceeding score thresholds. It is important that there be greater rewards for winning than losing. A person's ego is involved. A player wants to beat a challenging game, not to be humiliated each time he loses.

Games either need to fulfill a player's fantasy or stimulate their curiousity. Computer game fantasies derive some of their appeal from the emotional needs that they satisfy. Different fantasies appeal to different people.

Appealing to a player's curiosity is often effective in keeping a game interesting. While novelty is sometimes a crucial factor in the original purchase, if the game has little depth, it becomes repetitious and boring. One method that appeals to many game designers is to have the game progress to slightly different scenarios. Some games change the opposition, while others vary the scenery; some do both. The player has to excel if he is to satisfy his curiosity. Games like Threshold, which progresses through 24 sets of alien spacecraft, or Pegasus II, in which the scenery changes and the attacking aliens vary, offer strong curiosity incentives.

A game's controllability is one of the more important considerations in a game's design. It is sometimes referred to as human engineering. Designer's usually choose between keyboard and paddle/joystick control. While eye/hand coordination is more effective using paddles or joysticks, programmers attempting to create games with too many control functions will opt for a keyboard control system. At times, they produce a game that requires nine or ten keyboard controls which, unfortunately, only a pianist can operate. Some prefer keyboard controls because they offer a faster response time than paddle inputs, or they are easier to program, or this approach doesn't limit the market to an audience with expensive joysticks. I don't think the latter should influence your choice, but thought should be given to which method would make the game more enjoyable. Games that require considerable time to master the controls, often prove too frustrating to play.

Apparently, Apple owners like games which pit them against a competitive computer opponent. There are several multi-player games in which groups of two or more will simultaneously compete against each other. Most of these contests are sports or card games involving two or more players. The cooperative game is rarely seen, except in games where the computer com-

petitor is much too skillful. The arcade game "Ripoff" involves a computer opponent that is more than a match for two players playing simultaneously. It is the lone exception to the one-player-against-the-machine game.

So far, we have discussed theory and generalizations that should increase a game's playability and appeal to the public. Concrete examples of the more popular games should give you a much more solid foundation for your own designs.

EXAMPLE ARCADE GAMES

Space Invaders was the first really popular arcade game. It is a game wherein the object is to defend your turf against an alien horde of ferocious invaders that attack your castles and gun bases with a barrage of undulating bullets. It is actually a timed game, since you only have a limited amount of time to destroy the entire attacking wave before they descend to the ground in marching formation and overrun your lone gun base.

The elimination of each alien acts as a visual scorekeeping device. Although you can never win, only survive as long as possible (thus getting the maximum play time for your quarter), elimination of each attacking wave is an intermediate goal and a staving off of your inevitable doom. Each successive level becomes more difficult since the aliens, which begin their attack closer to Earth, limit the amount of time you have to destroy them. Their approaching proximity to your mobile gun base decreases your reaction time needed to avoid enemy fire.

Shoot-'em-up games like Sneakers, Galaxian, Threshold and Gamma Goblins are actually spin-offs of the Space Invaders theme. Whether they are set in space or on the ground, each has varieties of targets that are bent on your destruction. The targets or attackers are no longer static. Either they appear to dodge your fire, or they resort to kamikaze-type attacks.

The strong appeal of these types of games is based on curiousity and game depth. You are inspired to do better with each game just to see what the attackers are going to look like in the next level and what their tactics will consist of. The concept is variety, with each successive level slightly harder than the last. Although most offer an unlimited number of bullets, Threshold controls rapid, random, and wasteful firing by overheating your lasers. Thus, your firing must be more accurate and paced during the game.

The popularity of Pacman can be attributed to the game's design. First, it satisfies the fantasy concept of a person's childhood dreams. As children, they dreamt that they were being chased by evil monsters or ghosts, and felt powerless to stop them. They wished that there was some way to turn the tables, if only for a few moments. Pacman's four energy dots fulfill that fantasy. The game also offers the visual feedback of the number of remaining dots to be eaten at each level. And since clearing each individual level is an immediate goal, even beginners believe a level can be cleared. Because Pacman is

a game of consumption rather than one of destruction, it appeals to players of both sexes.

The game becomes a learning experience to the more advanced player, since the ghosts follow a discernible pattern rather than move randomly. A player is able to eventually predict their movements and consequently develop a technique to clear all the dots on a particular level. The long term goal is survival and the highest score. The game is designed so that you gain more pleasure as you get better. Thus, players are willing to devote the time and money to master the game.

Scrolling games, such as Scramble and Vanguard as played in the arcades, and Pegasus II on the Apple, wherein your ship travels over a multi-screen world, benefit strongly from player curiousity and visual variety. Vanguard, a shoot-'em-up game in which your ship is attacked by a variety of enemy vessels and creatures, has an extremely long sinuous tunnel with various types of chambers. The game has so many sections, combined with scrolling directions which change from horizontal to diagonal to vertical, that it is like playing many different arcade games at once. The player is given the option several times during the game to enter battle with a time-limited energized spacecraft which is equipped for ramming the enemy, or merely four plain old directional lasers. A map displayed at the lower corner informs the player of his progress. The curiousity factor is so enticing in this game, thirty seconds are provided to lure you into inserting another quarter in order to allow you to continue from where you left off with this unique form of arcade addiction.

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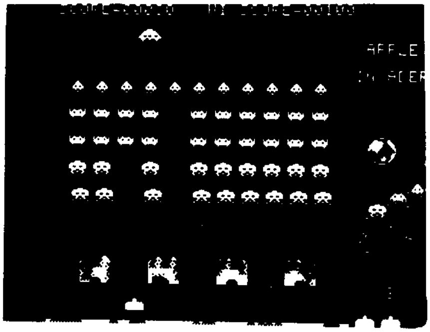

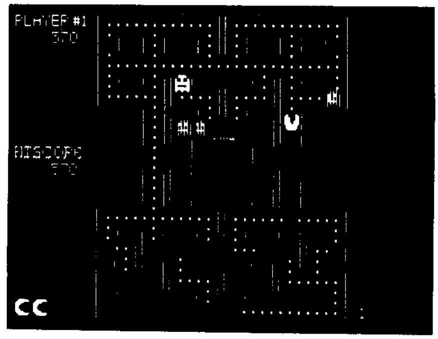

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Pegasus II, as implemented on the Apple, offers variety in terrain, targets and types of enemy. Besides trying to survive ground-launched rockets, a meteor field, attacking birds, and flying saucers, you must defeat a horde of laser-armed dragons that separate you from your refueling base. Your immediate goal is to reach the base before running out of fuel. This means accurate shooting, for enemies like dragons can delay your rendezvous with the base. Long term goals consist of reaching the tunnel and scoring the highest number of points.

In closing, I hope I have provided you with some acquired skills for creating your own visual masterpieces. The arcade versions described above are, as of this writing, being surpassed in quality by the dazzling array of games currently arriving on the personal computer market from talented graphics programmers.

My hope is that this book has provided some techniques and insights into graphics game design and programming; possibly even enough to allow you to join the ranks of successful Apple game designers.

INDEX

Jeffrey Stanton received a BME (1967) and a MSME (1969) from Rensselaer Polytechnic Institute. He worked as a control systems engineer and mechanical engineer for the aerospace industry in the early 1970's. His strong interest in computer game design sidetracked his career as a photographer and book illustrator in the late 1970's. Although he occasionally does a commercial assignment and owns a postcard company, much of his time is devoted to keeping abreast of the latest arcade game programming techniques on both the Apple and the Atari computers. He has several Apple games on the market and is writing a complex arcade game on the Atari 800. Jeffrey currently resides in Venice, California.

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