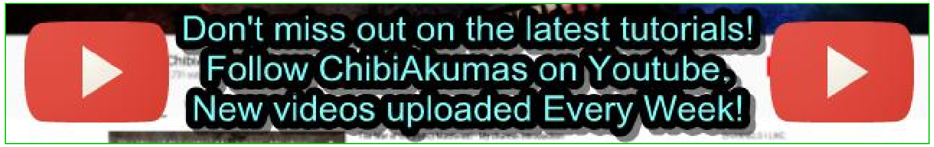
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Hello World Series - Super simple Hello world examples

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ChibiAkumas Series - Lets look at the chibiakuams sourcecode, see how it works, and how to change it!

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Appendix

	Details on the Amstrad CPC
	Details on the Camputers Lynx
	Details on the Elan Enterprise
	Details on the Gameboy and Gameboy Color

Work in Progress
Learn 65816 Assembly
Learn eZ80 Assembly

Misc bits
Ruby programming

Other series - No need to just limit yourself to the Z80... still want more, check out these series!

[Learn Multi platform 6502 Assembly Programming... For Monsters!](#)
[Learn Multi platform 68000 Assembly Programming... By Magic!](#)

Platforms covered in these tutorials

[Amstrad CPC](#)
[Elan Enterprise](#)
[Gameboy and Gameboy Color](#)
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Z80 Links

Zilog Z80 manual - The official manual , it's compelx, but if you need a definitive answer you'll find it here so this should be in your toolkit
Z80 Documented - Details of undocumented opcodes
Learn ASM in 28 days - I learned from this tutorial, it's aimed at the TI-83 calc, but that uses a Z80... if you don't like my tutorial, try this one!
Down to the silicon - Not remotely needed for programming, but this amazing technical breakdown of how the Z80 works is really something
Vasm - The recommended assembler is WinApe, however if you don't want to use windows, the Open source VASM in 'OldStyle' mode will work too.

ASM Tutorials for Z80,6502,68000 8086,ARM and more On my Youtube Channel

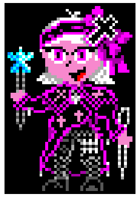
Introduction

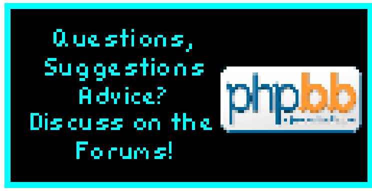
Welcome to my Assembly programming tutorials, These will be split into parts, the first will teach you the bare basics of assembly language, then we'll jump into some simple programs, once you've learned the basics we're going to jump straight into real game development!

We'll start by learning the basics of Z80 on the Amstrad CPC via Winape - as its combined Emulator, Assembler and Debugger... but then we'll look at the specific techniques related to the other systems in the 'Platform Specific series'

*If you want to learn Z80 get the **Cheatsheet**! it has all the Z80 commands, and useful info on the CPC, Spectrum and MSX!*
It will give you a quick reference when you're stuck or confused - and it's what the author used to develop ChibiAkumas!
Print it in color at high resolution on 2 sides of A4 for maximum performance!

*If you're interested in the 24 bit eZ80 - there's a special **eZ80 CheetSheet here***
*If you're interested in the Gameboy GBZ80 - there's a special **GBZ80 CheetSheet here***



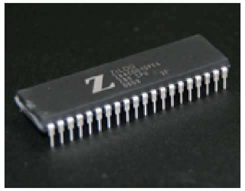


*The next few chapters are quite technical and confusing, but if you want, just skip them for now, and **jump** straight into the coding!*
This tutorial is designed so you can do that!
You'll need to know the technical stuff explained below one day, but you can come back to it later when you feel you want to!

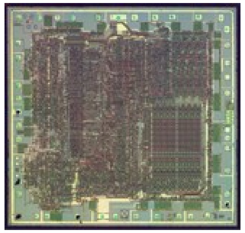
We'll be using the excellent VASM for our assembly in these tutorials to build for everything except the Amstrad CPC... VASM is an assembler which supports Z80, 6502, 68000, ARM and many more, and also supports multiple syntax schemes...

You can get the source and documentation for VASM from the official website ***HERE***

Feel the power... of the Z80!



The Z80 is a 4mhz 8 bit processor from the 1980's... now by modern standards, it's slow and ridiculously out of date, so why would you want to learn to develop for it?
Well, you can learn a lot about modern computer concepts from the simple Z80, and 4mhz is 4 million commands a second, Which is a heck of a lot when you know how to use them!
These old 8 bits give a simple system with a lot of potential for the creative person... and while one person could never create a game up to the standards of the latest 'AAA' titles... you could very easily create a game that's as good or better than the best games of the 80's!



Whether you're a fan of the CPC, MSX, Spectrum or even the Gameboy these 8 bits have all the power and potential for you to show what you can really do - and you'll learn things doing assembly that you would miss out on with years of C++ or Java development!

If you want to make a game with the latest graphics, of course go download Unity... but if you really want to be in control, and to understand everything that's happening in your code, Assembly gives you the power! No operating system, no drivers, you can take control of everything and make anything you want with it!

Assembly development can be confusing at first... but it has very few commands to learn, Everyone has to start simply, so try not to compare what you're doing to others... just look at what you're achieving, and knowing however 'simple' what you're doing is... it's something you made yourself!

What is the Z80 and what are 8 'bits'

The Z80 is an 8-Bit processor with a 16 bit Data bus!
What's 8 bit... well, one 'Bit' can be 1 or 0
four bits make a Nibble (0-15)
two nibbles (8 bits) make a byte (0-255)
two bytes (16 bits) make a word (0-65535)

And what is 65535? well that's 64 kilobytes ... in computers 'Kilo' is 1024, because binary works in powers of 2, and 2^10 is 1024
64 kilobytes is the amount of memory a basic 8-bit system can access

Z80 is 8 bit so it's best at numbers less than 256... it can do numbers up to 65535 too more slowly... and really big numbers will be much harder to do! - we can design our game round small numbers so these limits aren't a problem.

You probably think 64 kilobytes doesn't sound much when a small game now takes 40 gigabytes, but that's 'cos modern games developers have gotten lazy! there's no need to worry about making games small anymore now everyone has 10 TB hard drives...

Z80 code is small, fast, and super efficient - with ASM you can do things in 1k that will amaze you!

Numbers in Assembly can be represented in different ways.
A 'Nibble' (half a byte) can be represented as Binary (0000-1111) , Decimal (0-15) or Hexadecimal (0-F)... unfortunately, you'll need to learn all three for programming!

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SNES Hardware sprites - 6502 ASM YQuest13

Vector drawing on the Vectrex

Graphics on the Fujitsu FM7

CPC ASM: Tape loading on the Amstrad CPC (5K subs special)

68000 YQuest7 - Atari ST Specific code

Hardware Sprites on the NES - Lesson YQuest12

Hardware Sprites on the PC Engine / Turbografix

Joystick reading on the Vectrex - 6809 ASM

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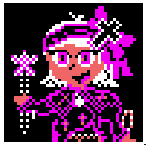
Also a letter can be a number... Capital 'A' is stored in the computer as number 65!

$150 calculator: Unboxing the Ti-84 Plus CE (eZ80 cpu)

Think of Hexadecimal as being the number system invented by someone wit h 15 fingers, ABCDEF are just numbers above 9!
Decimal is just the same, it only has 1 and 0.

In this guide, Binary will shown with a % symbol... eg. %11001100 ... hexadecimal will be shown with & eg.. &FF.

Assemblers will use a symbol to denote a hexadecimal number, some use $FF or FFh or even 0x, but this guide uses & - as this is how hexadecimal is represented in CPC basic
All the code in this tutorial is designed for compiling with WinApe's assembler - if you're using something else you may need to change a few things.
But remember, whatever compiler you use, while the text based source code may need to be slightly different, the compiled "BYTES' will be the same!



Decimal	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	...	255
Binary	0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111		11111111
Hexadecimal	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F		FF

Another way to think of binary is think what each digit is 'Worth' ... each digit in a number has it's own value... lets take a look at %11001100 in detail and add up it's total

Bit position	7	6	5	4	3	2	1	0
Digit Value (**D**)	128	64	32	16	8	4	2	1
Our number (**N**)	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**0**
D x **N**	128	64	0	0	8	4	0	0
128+64+8+4= 204	So %11001100 = **204** !							

If a binary number is small, it may be shown as %11 ... this is the same as %00000011
Also notice in the chart above, each bit has a number, the bit on the far right is no 0, and the far left is 7... don't worry about it now, but you will need it one day!

If you ever get confused, look at Windows Calculator, Switch to 'Programmer Mode' and it has binary and Hexadecimal view, so you can change numbers from one form to another!
If you're an Excel fan, Look up the functions DEC2BIN and DEC2HEX... Excel has all the commands to you need to convert one thing to the other!

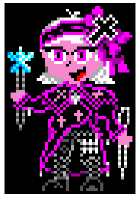
But wait! I said a Byte could go from 0-255 before, well what happens if you add 1 to 255? Well it overflows, and goes back to 0!... The same happens if we add 2 to 254... if we add 2 to 255, we will end up with 1
this is actually useful, as if we want to subtract a number, we can use this to work out what number to add to get the effect we want

Negative number	-1	-2	-3	-5	-10	-20	-50	-254	-255
Equivalent Byte value	255	254	253	251	246	236	206	2	1
Equivalent Hex Byte Value	FF	FE	FD	FB	F6	EC	CE	2	1

All these number types can be confusing, but don't worry! Your Assembler will do the work for you!
You can type %11111111 , &FF , 255 or -1 ... but the assembler knows these are all the same thing! Type whatever you prefer in your ode and the assembler will work out what that means and put the right data in the compiled code!

If you need more help, check out 'Convert.bas' on the tools.dsk in the sources file...

This is a Hex / Bin calculator that's designed to help you see how binary and hexidecimal compare to decimal - it should help you understand how Hex & Bin work!



Working with numbers in the Z80

We know what numbers we can have on the Z80, but how do we work with them?
When we need to save our results, we will store them to that 64k of memory mentioned earlier, but the memory is some distance away from the processor... to be fast we want to use the memory built in to the processor.
This z80 memory is called the 'Registers'... there's not much of it, but its really fast - so try to use them to do as much as you can! Each Register can only store one byte (0-255)... but some registers can be paired ... so HL together are 16 bits, and can store 0-65535!

Each of the registers has a 'purpose' it is intended for... Of course you can use any register for anything you want! but they all have 'strengths' because many commands will only work with certain ones... and some commands may be slower or need more code if you use the wrong one!

A	This is used during all our main calculations - you'll use it all the time when adding up (Accumulation)!
F	The Flags � we don�t tend to use this directly, it�s set by mathematical operations, and we respond to it�s contents via conditional jumps and calls.
HL	This often stores memory locations, as there are a lot of special commands that use it to quickly read or write whatever memory locations.. it's also good at 16 bit maths, so if you want to add two numbers above 255, you'll probably need it!
BC	These are often used as a byte count or loop counter... sometimes you'll use B and C together, for a count of up to 65535, or just B on its own for up to 255...
DE	Destination - if you're reading from one place and writing to another, you'll probably use HL as the source, and DE as the destination
IX	Sometimes we want to get to memory by specifying a relative position - Indirect Registers allow us to do this ... for example if we have sprites, and each 4 bytes for X,Y,Width,Height.. just point IX to the start of the data for the sprite we want - and read the rest out as IX+1 , IX+2 etc... Don't worry about this - we'll explain it later... IX is actually a pair of two registers called IXH and IXL - we can use them alone for whatever we want - but they are slower!
IY	IY works the same as IX
PC	This is the place in memory that the Z80 is running - we don't change this directly - but CALL, JP and RET all affect it.
SP	This is the stack pointer - it's points to a big temporary store that we'll use for 'backing up' values we need to remember for a short while
R	This is the Refresh register - the system uses it to know when to refresh the memory... don't change it ! you could mess something up - but it can be used for getting simple 'random' numbers!
I	This is the Interrupt point... on the CPC and MSX it's pretty useless so you can use it as a 'temporary' store... but on the spectrum it's really important and you'll have to leave it alone!

Main Registers:

I

Register group	8 Bit High	8 Bit Low	Use cases
A Reg	x	A	Accumulator
F Reg	x	F	Flags
BC Reg	B	C	Byte Count
DE Reg	D	E	Destination
HL Reg	H	L	Source / 24 bit accumulator
IX Index Reg	IXH	IXL	Base+Offset
IY Index Reg	IYH	IYL	Base+Offset
Stack Pointer (16 bit)	SP		Stack
Refresh	x	R	Used by Ram
Interrupt Vector	I	IM2 Byte	Used in Interrupt Mode 2
Program Counter	PC		Current running code

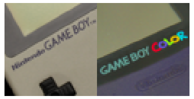
Flags: SZ-H-PNC

	Name	Meaning
S	Sign	Positive / Negative
-		
Z	Zero	Zero Flag (0=zero)
-		
H	Half Carry	Used by DAA
-		
P / V	Parity / Overflow	Used if a sign changes because a register is too small
N	Add / Subtract	Used by DAA
C	Carry	Carry / Borrow

Command format

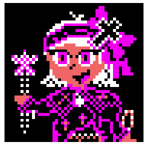
The format of Z80 commands is as follows
  Command   Destination,Source
and brackets () around a register pair like HL mean 'Address in register __'

so... **LD (HL),A** means "**Load A into the address in HL**"
Whereas.... **LD HL,&4000** means "**Load &4000 into HL**"
and... **LD B,A** means "**Load A into B**"?



The Gameboy is not a Z80, but it's similar in some ways... however, the Gameboy '**GBZ80**' CPU has no IX or IY, and no shadow registers!
We'll be covering the gameboy's weirdness more later!

The shadow registers are a 'copy' of the main ones... on the CPC the system firmware uses these during 'Interrupts' so you can't have them!
But if we stop the interrupts then we can use them for even more power!
Interrupts do things like read the keyboard and update the system - but we can replace the firmware and take over these jobs ourselves and take total control of the Z80 so we have all the power!



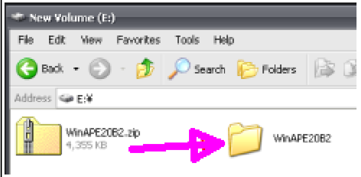
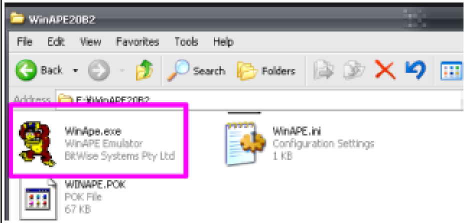
Lesson 1 - Getting started with Winape!

For our Z80 development we'll be using the WINAPE Amstrad CPC Emulator - it's free and does everything you need for development in one place, so I highly recommend you use it.
Winape works great in Windows XP - so you can run it in a virtual machine if you are a Linux or Mac fan, and I believe it works with WINE too.

There's a video of this lesson, just click the icon to the right to watch it ->

Get The DevTools!
File Available in sources.7z Click to Download
sources
Discuss on the forums!
?
!
Video Available Click to watch!

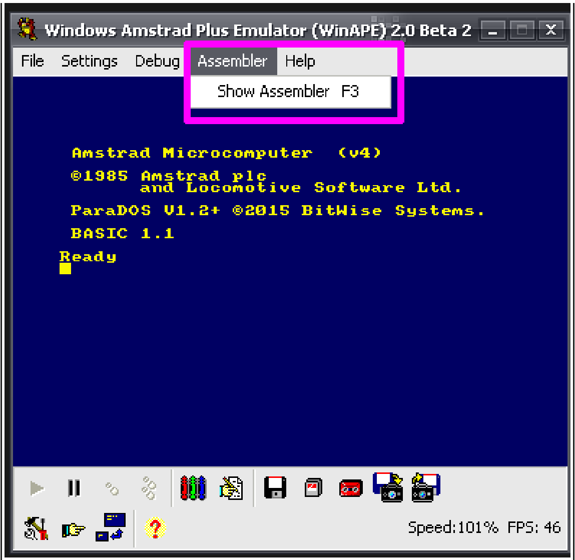
You may want to develop for the ZX spectrum or MSX, but you should start with the CPC and WINAPE!
Winape has a built in Assembler and Debugger that are second to none! In the early days you will make a lot of mistakes, and having the compiler , emulator and debugger in one place will save you a lot of time and problems! You can even develop MSX and SPECTRUM code with it - the MSX and Spectrum versions of ChibiAkumas are compiled in winape too!.... If you dont't use widows, Winape works OK with WINE!

To get started, Download Winape from **this Link** (I'm using V2.0b2) and **extract it** to a folder,	 New Volume (E:) File Edit View Favorites Tools Help Back Search Folders Address E:\ WinAPE20B2.zip 4,355 KB WinAPE20B2
Start Winape by clicking on the **icon**	 WinAPE20B2 File Edit View Favorites Tools Help Back Search Folders Address E:\WinAPE20B2 WinApe.exe WinAPE Emulator BitWise Systems Pty Ltd WinAPE.ini Configuration Settings 1 KB WINAPE.POK POK File 67 KB
You should see the emulator window open and show the Amstrad CPC blue screen... the CPC starts straight away into Basic... and Amstrad's basic is great for testing ASM code!	

Don't worry if you've never used a CPC before, this tutorial assumes you know nothing about basic or the CPC!

Now, Let's get straight into it and code something!

Click on the **Assembler menu and select "Show Assembler"** - or press F3 on your keyboard!


Windows Amstrad Plus Emulator (WinAPE) 2.0 Beta 2
File Settings Debug Assembler Help
Show Assembler F3
Speed:101% FPS: 46

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 Amstrad Microcomputer  (v4)
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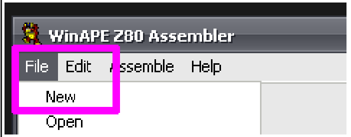
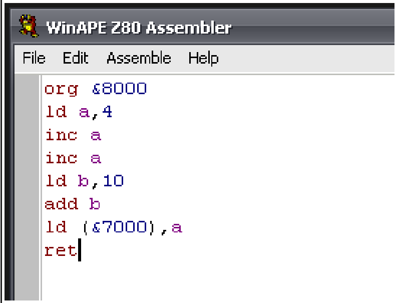
         and Locomotive Software Ltd.
 ParaDOS V1.2+ ©2015 BitWise Systems.
 BASIC 1.1
Ready
```

Select the **File Menu, then New** to create an empty ASM program



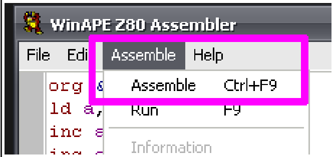
Type in all the lines shown to the right - Don't worry about what they do, We'll look at that in a bit!

Also, don't worry about the case as Winape isn't case sensitive.... ORG &8000 is the same as org &8000



```
org &8000
ld a,4
inc a
inc a
ld b,10
add b
ld (&7000),a
ret
```

Select **Assemble from the Assemble menu** to compile the program!

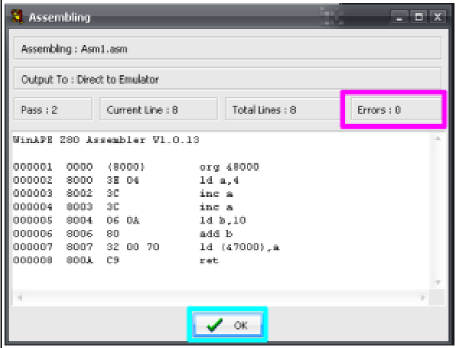


You will see the Assembler output. This shows the actual bytes of code that what you typed ends up as!

Check there are **Zero Errors** ... if there are then you've made a mistake typing!

Click on **OK**!

Now this is the magic of Winape - your code is now immediately in the emulators memory - so lets go run it!



Assembling : Asm1.asm

Output To : Direct to Emulator

Pass : 2 Current Line : 8 Total Lines : 8 Errors : 0

```
WinAPE Z80 Assembler V1.0.13

000001  0000  (8000)        org &8000
000002  8000  3E 04         ld a,4
000003  8002  3C            inc a
000004  8003  3C            inc a
000005  8004  06 0A         ld b,10
000006  8006  80            add b
000007  8007  32 00 70      ld (&7000),a
000008  800A  C9            ret
```

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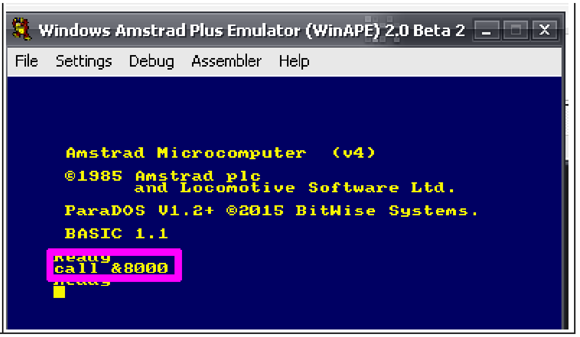
Now go back to the blue screen... and type in **Call &8000** and hit your **enter key**

Basic should return the message **Ready**

if something else happened, check your code matches the screenshot above!

What did it do? well we'll look at that in more detail next!



```
Amstrad Microcomputer  (v4)
©1985 Amstrad plc
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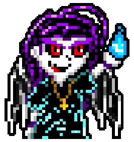
ParaDOS V1.2+ ©2015 BitWise Systems.
BASIC 1.1
Ready
call &8000
Ready
```



Congratulations! You just wrote and ran your first assembly program - and you now officially Kick Ass!

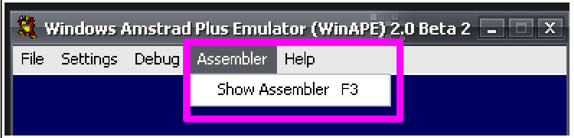
Now we'll look in detail at what the program did, and how to use Winape's debugger to look at it in detail!

Now you've had a a quick go at assembly, lets look in detail at what that program does! We'll look at each line of the program, and explain what it means.

org &8000	ORG sets the ORIGIN of the code in memory - the Z80 has a 16 bit address bus, so memory goes from &0000-&FFFF - but we can't just use anywhere, as some bits are used by other things - for example &C000-&FFFF on the CPC is used by the screen. &8000 is a good 'safe area' on the Amstrad for your code to start
ld a,4	load A (the accumulator) with the number 4 - The Accumulator A is the main register used for calculations - registers are used for very short term memory storage
inc a	INCrease A by 1... A will now contain 5
inc a	INCrease A by 1... hopefully you can guess it now contains 6
ld b,10	Set B to 10 ... B is another register... it can't do as much as A, but it can do a lot... notice the destination is on the left, and the source (the number) is on the right... this is always the case with Z80 assembly
add b	this adds B to A ... although A isn't mentioned in the command, since the Accumulator A is used for almost all maths any time a destination isn't mentioned, it will be A this command could be written as ADD A,B... winape will compile this, but the "A," is superfluous, so you're better off learning not to need it
LD (&7000),A	When Brackets () are used in assembly they define a MEMORY location... &7000 is the a number (&7000) is the content of that memory point! So this command puts A into memory location &7000!
RET	RET returns back to whatever called the program... in this case basic!

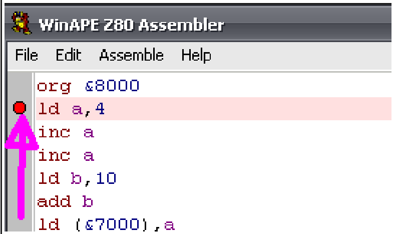
Ok, we've read over the code, lets use the debugger to see the Z80 run the code!

If you still have your assembler open, just click on its window
If you closed it, just click **Show Assembler from the Assembler menu**



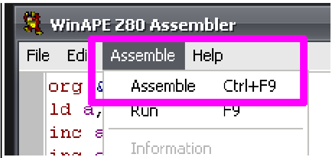
Click on the Grey Area next to the command "LD A,4"

A red blob will appear! This means before the Z80 runs the command "LD A,4" it will stop, and the Debugger will appear!



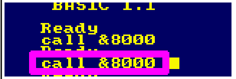
```
org &8000
ld a,4
inc a
inc a
ld b,10
add b
ld (&7000),a
```

Select **Assemble from the Assemble menu** to recompile the program!



```
org &
ld a,
inc a
```

Type **Call &8000** again into basic, and hit **Enter**



```
BASIC 1.1
Ready
call &8000
Ready
call &8000
```

If you've done everything right, the debugger will immediately pop up! Lets take a look at what it offers!

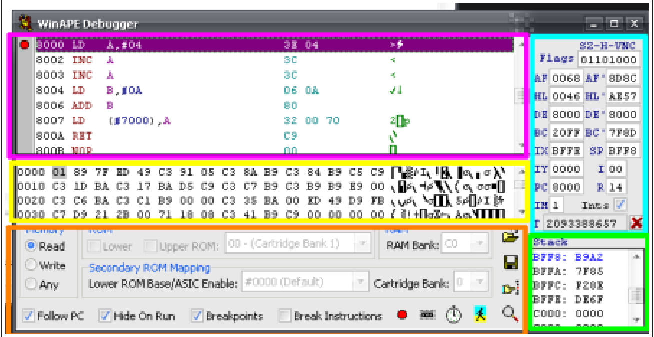
At the top of the screen you can see the **Compiled code**... the line the Z80 is running is highlighted.

On the Right you can see all the **Registers** - you should recognize the names! remember our code uses A and B... A is the first half of AF and B is the first half of BC

In the middle of the screen you can see the **Memory**

At the bottom of the screen you can see the **Rom and other debugger options**... don't worry about them now!

In the bottom right is the **Stack**... we'll cover that very soon!



```
8000 LD    A,#04        3E 04
8002 INC   A            3C
8003 INC   A            3C
8004 LD    B,#0A        06 0A
8006 ADD   B            80
8007 LD    (#7000),A    32 00 70
800A RET                C9
800B NOP                00
```

```
0000 01 89 7F ED 49 C3 91 05 C3 8A B9 C3 84 B9 C5 C9
0010 C3 1D BA C3 17 BA D5 C9 C3 C7 B9 C3 B9 B9 E9 00
0020 C3 C6 BA C3 C1 B9 00 00 C3 35 BA 00 ED 49 D9 FB
0030 C7 D9 21 2B 00 71 18 08 C3 41 B9 C9 00 00 00 00
```

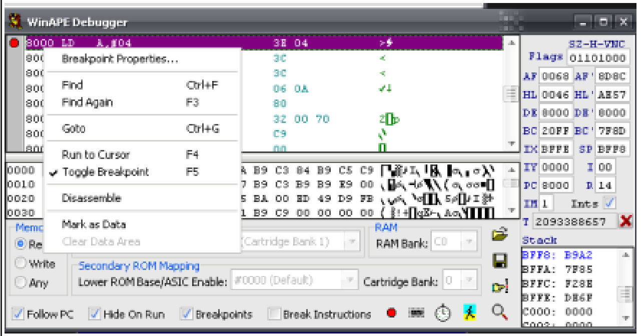
```
Flags 01101000
AF 0068  AF' 8D8C
HL 0046  HL' AE57
DE 8000  DE' 8000
BC 20FF  BC' 7F8D
IX BFFE  SP  BFF8
IY 0000  I   00
PC 8000  R   14
IM 1     Ints ☑
T 2093388657
```

```
BFF8: B9A2
BFFA: 7F85
BFFC: F28E
BFFE: DE6F
C000: 0000
```

The Debugger has tons of options we're not going to use right now, but feel free to try them later! Try right clicking on things for more options!

You can even change the registers and memory by typing new values in! and remember - The worst you can do is crash your emulator, so there's no real harm you can do - so don't be afraid to mess!

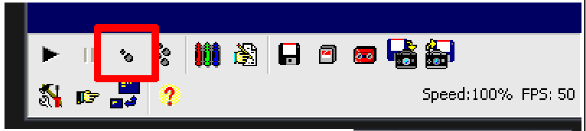
If you crash your emulator, the memory will be erased, so you'll have to re-assemble your code from the Assembler before Call &8000 will work again!

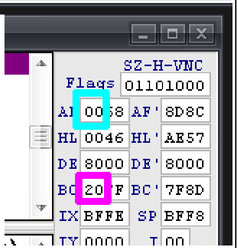


Now Lets look at what your code does!

Press the **F7 key on your keyboard** (or the **single step** button on the main window)

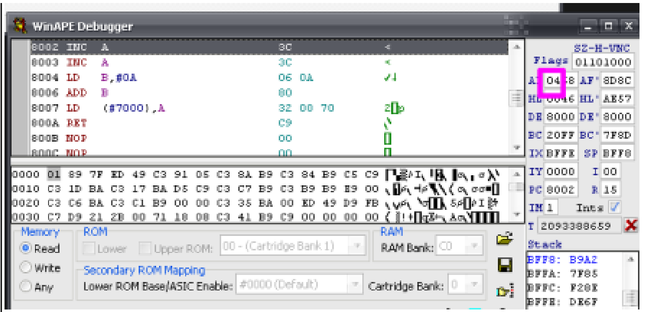
Keep an eye on the **A** and **B** registers in the debugger!





```
SZ-H-VNC
Flags 01101000
AF 0068  AF' 8D8C
HL 0046  HL' AE57
DE 8000  DE' 8000
BC 20FF  BC' 7F8D
IX BFFE  SP  BFF8
IY 0000  I   00
```

You should see A change to 4... press F7 a few more times and watch what happens

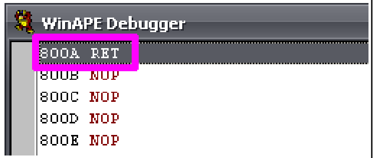


```
8002 INC  A              3C
8003 INC  A              3C
8004 LD   B,#0A          06 0A
8006 ADD  B              80
8007 LD   (#7000),A      32 00 70
800A RET                 C9
800B NOP                 00
800C NOP                 00
```

```
0000 01 89 7F ED 49 C3 91 05 C3 8A B9 C3 84 B9 C5 C9
0010 C3 1D BA C3 17 BA D5 C9 C3 C7 B9 C3 B9 B9 E9 00
0020 C3 C6 BA C3 C1 B9 00 00 C3 35 BA 00 ED 49 D9 FB
0030 C7 D9 21 2B 00 71 18 08 C3 41 B9 C9 00 00 00 00
```

keep pressing F7 again and again until you get to the RET command!

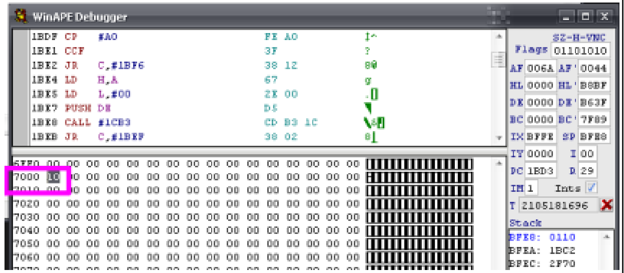
You can press it even more if you want, but remember... the debugger isn't just debugging your code, but the whole CPC... so you'll end up debugging the whole of basic!



```
800A RET
800B NOP
800C NOP
800D NOP
800E NOP
```

When your code has finished running we have one thing left to do....
Remember the program wrote to &7000 ?

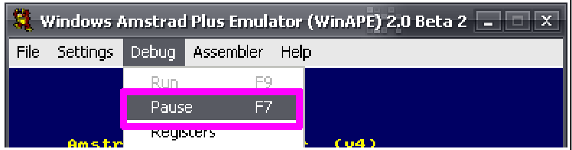
Scroll through the memory browser to **find &7000** - and you should see our final value for A has been saved there!



```
1BDF CP   #A0            FE A0
1BE1 CCF                 3F
1BE2 JR   C,#1BF6        38 12
1BE4 LD   H,A            67
1BE5 LD   L,#00          2E 00
1BE7 PUSH DE             D5
1BE8 CALL #1CB3          CD B3 1C
1BEB JR   C,#1BEF        38 02
```

```
6FF0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
7000 10 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
7010 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
7020 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
7030 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
7040 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
7050 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
7060 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
```

You can open the debugger by selecting **Pause from the Debug menu** at any time, or by pressing F7 - and just close it when you've seen enough and want your emulator to run normally!



Think back on what you've just done, You've written a program, compiled it, run it, and watched everything the program did at the CPU level in more detail than you've probably ever seen any computer work before! Not bad for a days work! - and this is just lesson 1!

Adding a few numbers may not seem much, but it's just the start, and you'll soon find you can make the computer do amazing thing!
Also, don't forget, once you understand the basics, you can use pieces of other people's code to do the work you don't want to! These tutorials will show you how to build on the open source code of the Chibi Akumas game to allow you to make big progress super-fast!

I highly recommend you type the programs in yourself, but you can download the source code with comments Here (Contains source for all lessons)

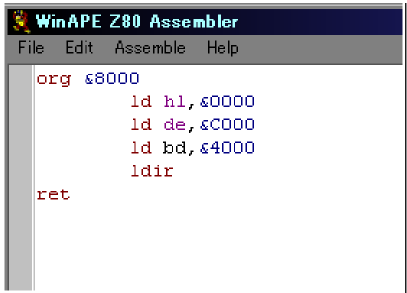
Lesson 2 - Memory copy, Symbol definitions, Loops and Conditional Jumps!

Now you've got Winape up and running, and had a go at programming, we can get on with learning some more commands!
We're still going to do simple things, but let's use the CPC's screen this time, so you can see the results of your code!

The CPC screen memory is at &C000 and takes up &4000 bytes!

Open up the assembler
(Remember: Press **F3** or select Show Assembler from the Assembler menu)
Create a new document
(File... New)
Type in exactly what you see to the right!... there is a typo in this code - so we're going to have to debug it

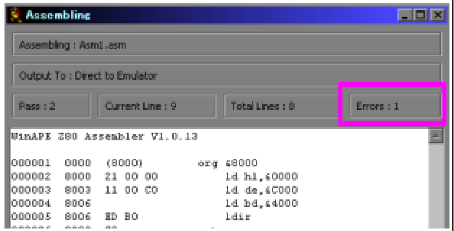
Once you've typed it in assemble it!
(**Ctrl-F9** or Assemble from the Assemble menu)



```
org &8000
        ld hl,&0000
        ld de,&C000
        ld bd,&4000
        ldir
ret
```

Oh no! there's an error!... what a surprise!

Click OK to close the assembling window, and lets sort that error out!



Assembling : Asm1.asm
Output To : Direct to Emulator
Pass : 2 Current Line : 9 Total Lines : 8 Errors : 1

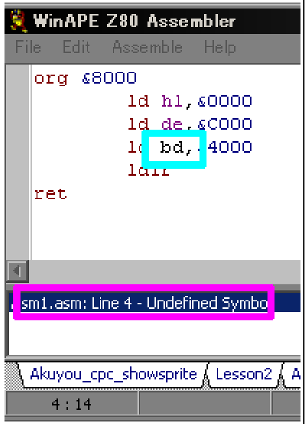
```
WinAPE Z80 Assembler V1.0.13

000001  0000  (8000)        org &8000
000002  8000  21 00 00          ld hl,&0000
000003  8003  11 00 C0          ld de,&C000
000004  8006                    ld bd,&4000
000005  8006  ED B0             ldir
```

The error that occurred will be show at the bottom of the screen... **double click on it**, and the cursor will jump to the error!

Whoops, we've put BD ... theres no such pair! **correct the error to BC**

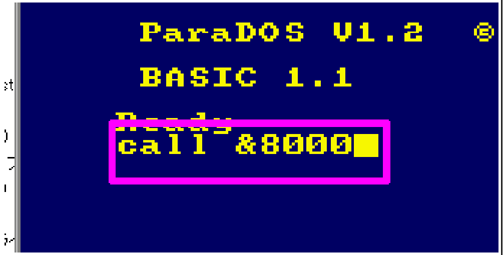
Now reassemble the program, and you should get no errors!



```
org &8000
        ld hl,&0000
        ld de,&C000
        ld bd,&4000
        ldir
ret
```

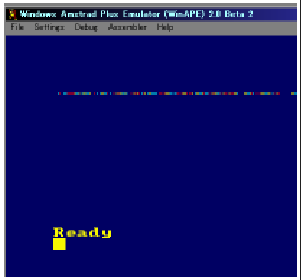
sm1.asm: Line 4 - Undefined Symbo

Type **Call &8000** and hit Enter



```
ParaDOS V1.2 ©
BASIC 1.1
Ready
call &8000
```

The screen will clear, and the top line or two will have some weird junk on it!


Windows Amstrad Plus Emulator (WinAPE) 2.0 Beta 2
File Settings Debug Assembler Help
Ready

SNES Hardware sprites - 6502 ASM YQuest13

Vector drawing on the Vectrex

Graphics on the Fujitsu FM7

CPC ASM: Tape loading on the Amstrad CPC (5K subs special)

68000 YQuest7 - Atari ST Specific code

Hardware Sprites on the NES - Lesson YQuest12

Hardware Sprites on the PC Engine / Turbografix

Joystick reading on the Vectrex - 6809 ASM

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Emily The Strange (DS) - Live full playthrough

$150 calculator: Unboxing the Ti-84 Plus CE (eZ80 cpu)

You probably think this is weird, but when we look at the code, This is exactly what we'd expect to happen... so lets break it down line by line!

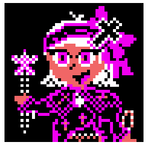
Our code is at &8000 - that's where we call to run it	org &8000
Set HL to &0000 - in this case HL is a source memory address	ld hl,&0000
set DE to &C000 - in this case DE is a Destination, and &C000 is the start of the CPC screen	ld de,&C000
set BC to &4000 - in this case BC is a byte count - and &4000 is 16k, the size of the CPC screen!	ld bc,&4000
LDIR means " Load, Increment Repeat"... in effect it copies BC bytes from memory pos HL to DE	ldir
return to basic	ret

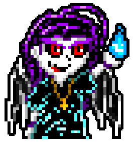
So we've copied 16k from &0000 to the screen - and what is at &0000 - well some system junk, and any basic programs!
don't believe me?... type:

```
10 print "moo"
Call &8000
```

and you'll see some more junk appeared! that new junk is your program as it appears in memory!
Of course if you set DE to &0000 and HL to &C000 - you'd copy the screen to your system area - and your machine will hang!
it will also hang if you set BC to &5000... why? well when the destination gets to &FFFF it rolls over to &0000 - again overwriting your system area - but give it a go if you want, there's no harm crashing an emulated machine!

By default the CPC screen starts with &C000 at the 'top' but if you make basic scroll up and down, the 'Top' will move somewhere else, if you press the down cursor until the screen scrolls - then call &8000 again you'll see the junk appear somewhere else
You can always reset the cpc by typing "Mode 1" in basic (reset to screen mode 1)

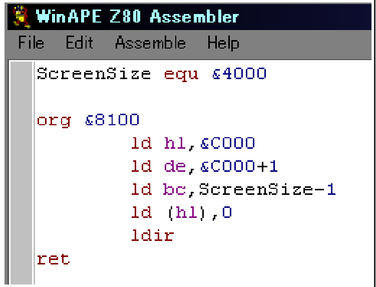




If your crazy enough to try this on a different system, you'd need to make a few changes, The ZX Spectrum screen starts at &4000 not &C000, and the size is &1800
On the MSX the screen isn't in memory so you can't see the effect on screen - and you'll crash the system if you write to &F000 or higher, but you could set the size to &1000, and see the change in memory between &C000-&D000 with a debugger if you want!

Ok, you've had a quick look at LDIR,
Now lets try another more useful example,

Type in the example code to the right, and assemble it as before

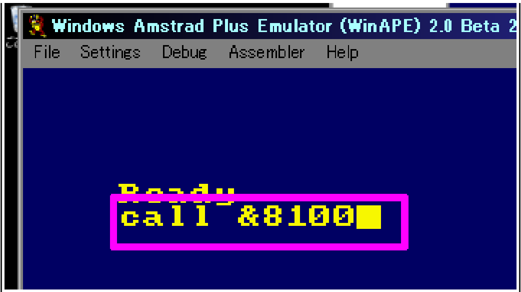


```
ScreenSize equ &4000

org &8100
        ld hl,&C000
        ld de,&C000+1
        ld bc,ScreenSize-1
        ld (hl),0
        ldir
ret
```

Assuming you got no errors, lets run the program.

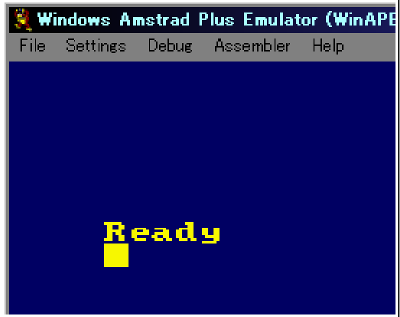
The ORG was different this time, so type Call &8100


Windows Amstrad Plus Emulator (WinAPE) 2.0 Beta 2
File Settings Debug Assembler Help

```
Ready
call &8100
```

The screen will clear!

What's interesting is that this simple ASM code is faster at clearing the screen than the firmware's own CLS command!... and there's a lot of tricks we can do to speed it up even more... but we'll leave them for another day!


Windows Amstrad Plus Emulator (WinAPE
File Settings Debug Assembler Help

```
Ready
```

What did that code do? well lets break it down!

This line defines a 'symbol' ... we're telling the assembler 'ScreenSize' EQUals &4000 A symbol is a constant in your code - basically every time the assembler sees 'ScreenSize' it will put in &4000 there's a couple of reasons to do this, firstly it's makes your code easier to read, and secondly, if you need to change it to &2000 - then you can just change this definition in one place, rather than all the places you've used it!	ScreenSize equ &4000
set the origin to &8100 (I'm using a different one, as all these examples are in the same 'lesson2.asm' in the download file)	org &8100
Set the source HL to the start of the screen memory... yes, you read that right, the SOURCE	ld hl,&C000
set the destination DE to one byte after the source... note that the assembler calculates what &C000+1 actually equals - not the Z80	ld de,&C000+1
set the Byte count to our defined symbol -1 (this will compile to ld bc,&3FFF)	ld bc,ScreenSize-1
set the first byte of the source to 0	ld (hl),0
Run our LDIR copy... now here's the trick... at first LDIR copies the byte from HL (&C000 we just set to 0) to DE (&C001) next LDIR copies the byte from HL (now &C001 which IT just set to 0) to DE (now &C002) after that LDIR copies the byte from HL (now &C002 which IT just set to 0) to DE (now &C003)... and so on! We tricked LDIR into copying it's own data, and acting as a quick(ish) FILL command!	ldir
return to basic	ret

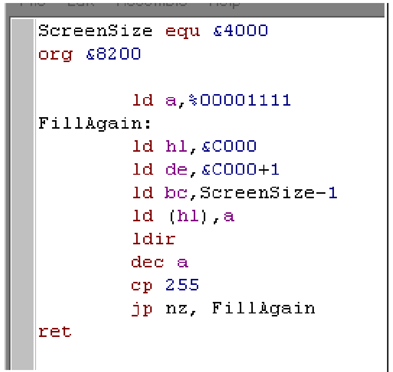
Mathematics in ASM code in Winape code is pretty dumb... it can't do brackets like 2(5+1)... and it doesn't do multiplication first.... Usually you'd expect 5+1*2 to be equal 7... but in winape this equals 12!*
*Why? well winape does each command from left to right, so 5+1=6... then 6*2=12...it takes some getting used to, but it does work fine!*

Conditions and Loops!

We have one last version of this program to try!

Type in the code to the right, and compile it... you should get no errors.

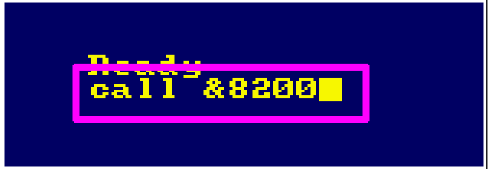
There's some new commands in here, but take a look at them in a minute!



```
ScreenSize equ &4000
org &8200

        ld a,%00001111
FillAgain:
        ld hl,&C000
        ld de,&C000+1
        ld bc,ScreenSize-1
        ld (hl),a
        ldir
        dec a
        cp 255
        jp nz, FillAgain
ret
```

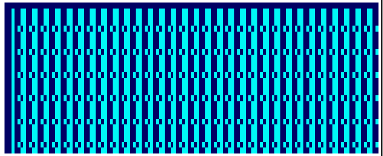
Type **Call &8200** and hit enter



```
Ready
call &8200
```

The screen will do a strange 'fading clear'... Weird huh?

Ok, it's not very useful, but it teaches us a lot of good stuff!



Lets take a look at the code, and see why it does what it does!

Define our constant symbol "ScreenSize" as &4000	ScreenSize equ &4000
Start our program at &8200	org &8200
Set A to %00001111 - this sets all 4 pixels of a screen byte to cyan on the cpc screen	ld a,%00001111
This is the definition of a label... it's like a the constant "screensize" in that the assembler converts future mentions of 'FillAgain' to a number when it compiles... however unlike 'screensize' that was defined with 'equ'... a label points to a memory location in the compiled code... if you take a look at the assembled code you'll see it is in the position &8202... that's because 'ld a,%00001111' takes 2 bytes	FillAgain:
set HL to the start of the screen	ld hl,&C000
set DE to one byte later (the same as last time)	ld de,&C000+1
set BC to ScreenSize -1 ... you should recognize all this from last time!	ld bc,ScreenSize-1
load the first byte with A - remember it will set all the pixels Cyan	ld (hl),a
Just like last time LDIR will fill the whole screen	ldir
Decrease A by 1	dec a
Compare A with 255... when A=0 and we do DEC A... A will become 255...	cp 255
if A does not match 255 , **jump** back to label 'FillAgain' The next command the Z80 will run will be 'ld hl,&C000'	jp nz, FillAgain

Now you know how to do a loop! in fact JP Z and JP NZ can be used like LOOPs, IF statements and even CASE statements!
Actually - you don't have a lot of choice as assembly has so few commands - but remember... all other programming languages compile down to Assembly - so anything Basic or C can do is possible in ASM - and ASM will always be fastest if you do it right!

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So we've used a Label, and a jump (JP) to create a loop!
there are three kinds of Jump command that you should know!

Command	Meaning	Example
JP ##	This is like a GOTO command in basic, it will just jump to the label or memory address you specify every time. this command takes 3 bytes	JP &4000
JP c,##	This is like an 'IF X THEN GOTO' command in basic. if condition is met the jump will occur, otherwise it will continue otherwise program execution will continue... there is no such thing as an ELSE, but you can always immediately do another jump! this command takes 3 bytes	JP Z,&4000
JR #	do a **J**ump **R**elative to the current location... This is a bit tricky, but all you need to know is it takes 1 byte less than JP, but can only jump nearby - so it saves memory, but you can't always use it!	JR label
JR c,#	Same as above, a 2 byte relative jump - saves one byte over JP c,## - but can't always be used if you need to jump far away	JR Z,label
djnz #	This is a special 'quick small loop' command... it automatically **Decreases** B and **J**umps if b is **N**ot**Z**ero DJNZ only takes up 2 bytes, so it's small if you only need a basic loop. a jr jump can only jump to a label that is nearby - so if you get an error use this alternative which can jump anywhere dec b jp nz,label	DJNZ label
JP (HL)	Jump to memory location in HL, this is quite advanced, so don't worry about it now... but you can load HL with a label, then use this to perform a jump if you need to	JP (HL)

So those are the Jumps we have available, but some of them need a condition too!...
we have 4 main conditions we need to so lets take a look at an example - you don't need to type it in

load the accumulator with 4	LD a,4
Compare A to 10	CP 10

There are 4 basic conditions we can use in this situation - it's annoying, but what the condition officially means, and what it does in this case are different

Flag	**example**	**Official meaning *****	**Basic program equivalent**	**What it means when using CP**
Carry	JP C,label	Carry is used with bitshifts and addition - if a byte goes over 255, it will go back to zero, but Carry will be True	A<CP	if A < CP Value then C is true and JP C,label will make the jump to label
No**C**arry	JP NC,label	NC is true when there is no carry	A>=CP	if A > CP Value then NC is true and JP NC,label will make the jump to label
Zero	JP Z,label	Z is true when the last mathematical operation resulted in zero	A=CP	if A=CP then Z is true and JP Z,label will make the jump to label
Non**Z**ero	JP NZ,label	NZ is true when the last mathematical operation did not result in zero	A<>CP or A!=CP	if A<>CP then NZ is true and JP NZ,label will make the jump to label
Parity **O**dd	JP PO,label	Odd number of 1 bits		
Parity **E**ven	JP PE,label	Even number of 1 bits		
Sign **P**ositive	JP P,label	Top bit (Bit 7) is 0		
Sign	JP	Top bit (Bit 7) is 1		

Minus	M,label			

*** **Note:** while CP always works, not all mathematical commands affect all flags - see the **cheatsheet** for full details! - eg "inc hl" does not set the zero flag!

NC NC Z and NZ don't make a lot of sense for < > = and <> ... and they're a real pain to remember!
Z and NZ are = and <> ... so try to think of them as 'is the difference Zero - or Non Zero?'
C and NC are < and >= ... so think of them as Chibi (smaller) and NonChibi (bigger or equal)
They're on the Cheatsheet, but if you can come up with a way of remembering which is which - all the better!

Well done! You finished Lesson 2! But there's no reason to finish with these programs if you don't want to!
Try changing some of the numbers!
What happens if you change 'ld a,%00001111' to 'ld a,%11110000' or 'ld a,%11111111',
or change 'ScreenSize equ &4000' to 'ScreenSize equ &2000'...
Have some fun! and try lots of things!...
There's a video available describing more about how CPC & Spectrum screen memory work if you want to learn more now!

Lesson 3 - 'Case Statement' , 8 bit basic Maths, Writing to Ram and Reading from basic

We used a Jump to effect a loop last time, but sometimes we'll need to jump to different places depending on a value.

Also, lets take a look at how to do some everyday maths in 8 bit... and finally, we'll use a simple basic program to act as a 'frontend' to our assembly

Lets get straight into coding!

We're going to write a little Assembly calculator

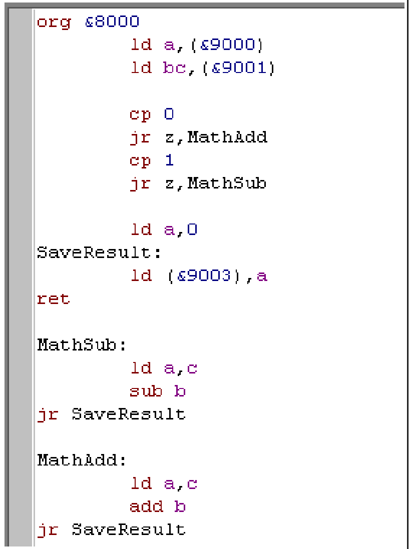
Create a new assembly document, and type in the program to the right.

Compile it - you should get no errors!

You'll notice that the program takes it's input and output from 4 memory locations:

&9000	Command Num
&9001	Var 1
&9002	Var 2
&9003	Result

We're going to access these from a basic program - which we'll write now!



```
org &8000
        ld a,(&9000)
        ld bc,(&9001)

        cp 0
        jr z,MathAdd
        cp 1
        jr z,MathSub

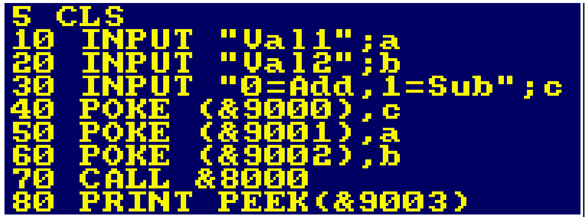
        ld a,0
SaveResult:
        ld (&9003),a
ret

MathSub:
        ld a,c
        sub b
jr SaveResult

MathAdd:
        ld a,c
        add b
jr SaveResult
```

Type the program in to the right in basic

if you're not familiar with Basic, Don't worry about what the commands do, we'll look at them in a moment



```
5 CLS
10 INPUT "Val1";a
20 INPUT "Val2";b
30 INPUT "0=Add,1=Sub";c
40 POKE (&9000),c
50 POKE (&9001),a
60 POKE (&9002),b
70 CALL &8000
80 PRINT PEEK(&9003)
```

ADD and SUB in assembly can add or subtract up to 255 from a register, but if you only need to add or subtract one, use INC or DEC, they increase or decrease a register by 1...
INC and DEC commands take only 1 byte, so they're faster than ADD and SUB... and they work on 16 bit registers like HL
ADD and SUB only work on the 8 Bit Accumulator, but we'll learn how to do 16 bit equivalents later!

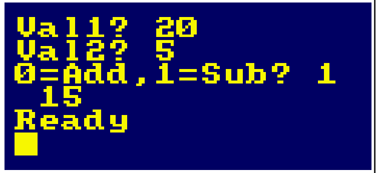
CPC basic is really easy, just start typing the lines in after the emulator starts.
If you make a mistake it's easy to fix- for example to edit line 30, just type "Edit 30" and hit enter!
CPC basic also has a strange 'copy' command, which allows you to 'copy' text already onscreen... just hold down shift and use cursor keys to create a 'shadow cursor' and use Alt to copy the letters under the shadow cursor... on the CPC the 'Alt' key was marked 'Copy'

Type RUN to start the program and hit enter.

Enter the values for the Variables as 20 and 5, hit enter after each value

When asked if you want to Add or Subtract, Enter 1 for subtract

The result will be show onscreen!



```
Val1? 20
Val2? 5
0=Add,1=Sub? 1
 15
Ready
```

Feel free to try other values in the program, but it only uses 8 bit registers, so it can only do up to 255, and can't do negative values right!
Right now it'll only do Addition and Subtraction because there aren't any built in Multiply or Divide commands on the Z80 - we're going to work around that next!

Lets take a look at the ASM code!

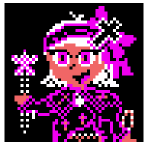
program starts at &8000	org &8000
Read memory position &9000 into A	ld a,(&9000)
read two bytes into 16 bit register BC... on the Z80, 16 bit registers are stored in memory in reverse So C is loaded from &9001 and B is loaded from &9002	ld bc,(&9001)
We want to do a 'Case statement' where we do different commands depending on A, but no such command exists! No problem! we just do is lots of CP x commands and JR Z,label commands Remember, **CP #** always compares with A... and **JR Z** will do a jump if A matches with the compared value **#**	cp 0
Command 0 is add, so if this is what the user selected jump to the **MathAdd** label	jr z,MathAdd
Compare A to 1	cp 1
Command1 is subtract, so if this is what the user selected jump to the **MathSub** label	jr z,MathSub
if we got here, then A was something weird, so set A to 0	ld a,0
This is our SaveResult label, if a command was run then it will finish here, if the user put a strange number in, execution will also end up here	SaveResult:
Load the result (in A) to memory point &9003	ld (&9003),a
return to basic	ret
The start of out subtract routine	MathSub:

we need our result in A, so load from C (Val1) into it	ld a,c
Subtract B (Val2) from A	sub b
we've finished, so Jump to our saveresult label	jr SaveResult
The start of our addition routine	MathAdd:
we need our result in A, so load from C (Val1) into it	ld a,c
Add B (Val2) to A	add b
we've finished, so Jump to our saveresult label	jr SaveResult

Sometimes in ASM there's a smaller, faster command that has the exact same result as another!
For example, you can use "OR A" instead of "CP 0"... and "XOR A" instead of "LD A,0"
The result is identical, but you'll save some speed and memory!... it'll just look a bit odd in your code!
It's something you'll want to learn to use.. so why not give it a try now!

In case you're not familiar with CPC basic, lets take a look at the basic code!

Clear the screen	CLS
INPUT asks the user a question, and stores the users response in a variable So this will show "Val1?" onscreen, and store input from user into a Note: a/b/c in basic is nothing to do with A/B/C in ASM!	INPUT "Val1";a
Show "Val2?" onscreen, and store input from user into b	INPUT "Val2";b
ask the user what command to run	INPUT "0=Add,1=Sub";c
POKE writes a byte into memory, this writes our command number into memory point &9000... this is how we'll get our values from basic to ASM	POKE (&9000),c
Store Value from A into &9001	POKE (&9001),a
Store Value from B into &9002	POKE (&9002),b
Call our ASM program	CALL &8000
PEEK reads a byte from memory, allowing us to get the result our ASM program produced. PRINT just shows it onscreen	PRINT PEEK(&9003)



Using basic to 'launch' and test your ASM code is a great way to develop quickly and ease testing
Using PEEK and POKE to get data to and from your program is a good solution, but you can also pass variables using the CALL command, but it's a little tricky, so we'll cover it later!

Multiply and Divide

We want to add Multiply and Divide commands, but unfortunately the Z80 does not have these commands! but we can simulate them by repeatedly using the ADD or SUBtract commands!

Add **These Lines** to the bottom of your code below MathAdd	

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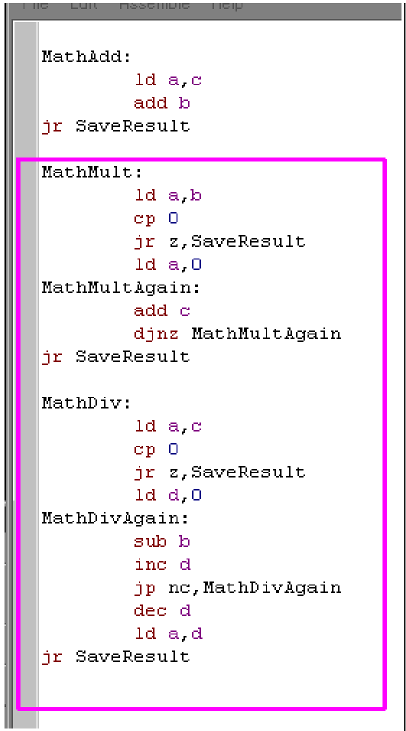
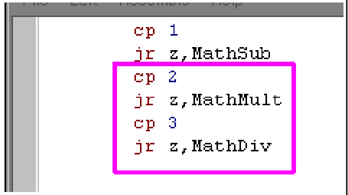


```
MathAdd:
        ld a,c
        add b
jr SaveResult

MathMult:
        ld a,b
        cp 0
        jr z,SaveResult
        ld a,0
MathMultAgain:
        add c
        djnz MathMultAgain
jr SaveResult

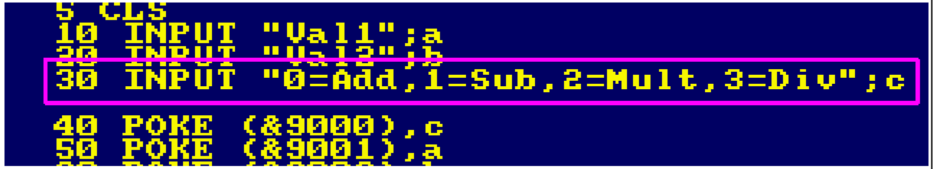
MathDiv:
        ld a,c
        cp 0
        jr z,SaveResult
        ld d,0
MathDivAgain:
        sub b
        inc d
        jp nc,MathDivAgain
        dec d
        ld a,d
jr SaveResult
```

Add **These Lines** to 'case' condition block



```
        cp 1
        jr z,MathSub
        cp 2
        jr z,MathMult
        cp 3
        jr z,MathDiv
```

use **EDIT 30** to edit the line showing the options, make it the same as **This**



```
5 CLS
10 INPUT "Val1";a
20 INPUT "Val2";b
30 INPUT "0=Add,1=Sub,2=Mult,3=Div";c
40 POKE (&9000),c
50 POKE (&9001),a
```

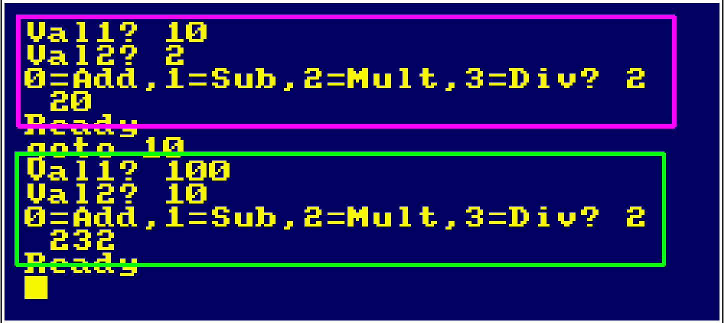
Run the program!

You'll now be able to do **multiplication**, but only if the result is less than 255! You'll also see that negative numbers don't work!

If you try a number that **ends up too high**, or below zero, you'll get a strange number, that's because the numbers 'roll around' from zero back to 255

Later we'll upgrade the program to use 16 bit numbers, so we can go from -32768 to 32767!

Take a look at the **Hexadecimal tutorial** at the start of this document if you want to know more about negative numbers now!

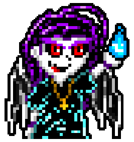


```
Val1? 10
Val2? 2
0=Add,1=Sub,2=Mult,3=Div? 2
 20
Ready
goto 10
Val1? 100
Val2? 10
0=Add,1=Sub,2=Mult,3=Div? 2
 232
Ready
```

You can get the source code for this lesson (and all the others) in the **sources.7z** file... the basic code can be found on the included disk image!

Repeatedly adding or subtracting a number to 'fake' Multiplication or Division is silly and slow, but if you only need to Double or Halve a number you can use bit shifts... we'll cover them soon!
You want to try avoid needing Multiplication and division if you can in your code, so design your game not to need anything except halving and doubling... of course you can do x4 or x8 by doubling twice or three times!

There are clever ways of doing Multiplication and Division that are much faster than this... but they are to complex to cover yet... but fear not - they're documented here when you're ready for them!



Lesson 4 - Stack, Strings,Compiler Directives, Indirect registers, CPC Call

That was a nice little program, but we still have some basics to cover!

You'll have noticed there's not many Registers, and you'll often wish you had more. So what can you do if you have a value you need later, but you need to do something else first?

We need some temporary storage, and we have something called the stack for that!

Lets suppose we have a value in A ... we need the value again later, but we need all our registers now too... what can we do? Well that's what the stack is for, it's a temporary store!
The stack is like a letter tray - we can put an extra sheet on the top of - and take it off later, but we can't get one from the middle, so we always get the Last one we put in - this is known as LIFO - Last in First Out
We use PUSH and POP to push a new item onto the stack, and pop it off later.

Lets look at two examples, and see why we want the stack!

Suppose we have a Call 'PrintChar' which will print the character in A ... and another call 'DoStuff' which will change all the registers - how can we keep A the same before and after this 'DoStuff' command? Well, we could save A to some temp memory - or let the stack take the slack!

don't type this in, it won't actually work!

Without the stack	With the stack
ld a,'1' LD (Temp),a call PrintChar call DoStuff ld a,(Temp)	ld a,'1' push af call PrintChar call DoStuff pop af call Printchar

call PrintChar Temp: db 0	

Both these do the same thing, but commands like LD (temp),a takes 3 bytes, and PUSH AF takes only 1.. and it's faster! also you no longer need that Temp: db 0 ... so that's another byte saved!

the stack always works in 16 bit - so even if you only want to save B - you'll have to PUSH BC - but don't worry , it's so fast you won't mind!
note: the F in AF is the 'Flags' (the Z NZ C NC in comparisons) - they're saved with A when you do a push.

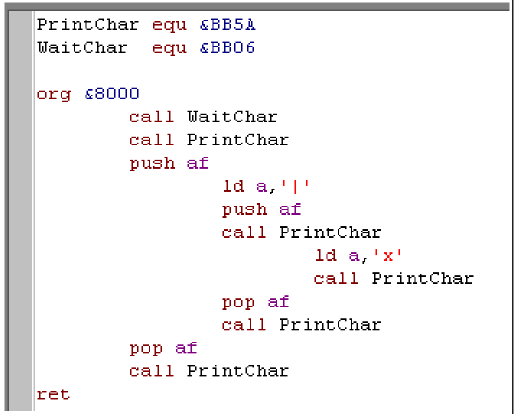
You can push lots of different things onto the stack, but remember they will come out in the same order... you can even do PUSH BC then POP DE to copy BC into DE

The order is important! if you're unclear on how the stack works, you can use the Debugger in winape to step through your program, and see what the stack does as your program works!
seeing things happen step by step in the Z80 is a great way to see how things are happening

The Stack

Lets do an example of the stack!

Type in the program to the right!



```
PrintChar equ &BB5A
WaitChar  equ &BB06

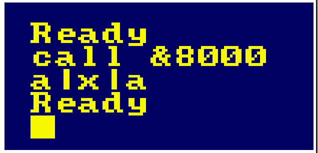
org &8000
        call WaitChar
        call PrintChar
        push af
                ld a,'|'
                push af
                call PrintChar
                        ld a,'x'
                        call PrintChar
                pop af
                call PrintChar
        pop af
        call PrintChar
ret
```

Type Call &8000 and hit enter.

The screen will 'Pause' so press A

You should see A|x|A onscreen

Run the program again, and press a different letter!



```
Ready
call &8000
a|x|a
Ready
```

What was the point of that? well lets take a look at what the program does! I've colored the PUSH, POP commands so you can see what POP gets the matching value that was PUSHED

This is a definition pointing at a command in the CPC firmware - it will print A to the screen as a character	PrintChar equ &BB5A
This is a definition pointing at a command in the CPC firmware - it will wait until a key is pressed and save it in A	WaitChar equ &BB06
Start of the program at &8000	org &8000
Get a character from the user -this is why the screen paused - lets assume the user pressed A	call WaitChar
Print the character to the screen	call PrintChar
Push the character onto the stack - in this example 'A'	push af
Load a bar symbol into A	ld a,'|'
Push the bar onto the stack for later	push af
Print the bar to the screen	call PrintChar

Load an 'X' into A	ld a,'x'
Print the X to the screen	call PrintChar
pop an item off the stack... we will get the Bar we just pushed	pop af
Print the bar onto the screen	call PrintChar
pop an item off the stack, we get the character the user entered - in this example 'A'	pop af
print the character ('A') to the screen	call PrintChar
Return to basic	ret

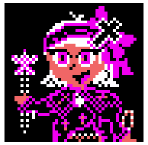
So we can push items onto the stack, and get them back later so long as we need them in the same order! But the stack doesn't just operate for us.. the Z80 uses it too
When we do a 'CALL label' command, the current running address is pushed onto the stack - effectively the Z80 does 'Push PC   JP Label'
When we do a 'Ret' command... the Z80 effectively does 'pop PC'
Pc is the program counter - the current address the z80 is running... now this Push PC and Pop PC command don't really exist, but that's what the Z80 does - and you need to know this so you know why this program won't work:

Command	What happens
Ld a,'Z'	Accumulator set to character 'Z'
push af	AF pushed onto the stack
Call ShowIT	the address of the next command (ret) is pushed onto the stack
Ret	end of the program
ShowIT:	
pop AF	we wanted to get 'Z' back - but we actually got the address of the command after Callit
call PrintChar	We wanted to print 'Z" but we actually printed half the address!
ret	we wanted to return from the call - but we stole that off the stack - return jumps to the AF value we pushed - and the computer will crash!

If you don't understand the stack yet, try making some test programs, or editing the one you just typed in!
The stack's used so much you'll see plenty of examples - and you'll soon get used to it!

The stack is the fastest way to read and write memory on the Z80 - if you're clever you can use it in a 'tricky way' to quickly do things like fill the screen.

We'll learn how to do it later - it's an advanced trick, but if you want to make the Z80 as fast as possible - that's how to do it!



Compiler Directives

We'll move on from the stack - Lets have a look at another little program! - we're going to use the previous PrintChar command to make a string printing routine.

Type in the program to the right. Assemble it - you should get no errors We'll explain what each line does after we run it!	

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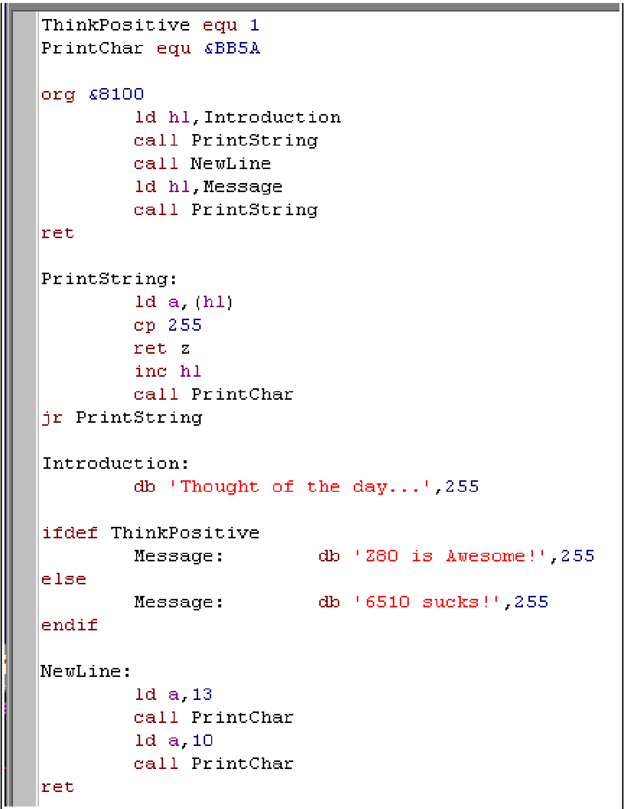


```
ThinkPositive equ 1
PrintChar equ &BB5A

org &8100
        ld hl,Introduction
        call PrintString
        call NewLine
        ld hl,Message
        call PrintString
ret

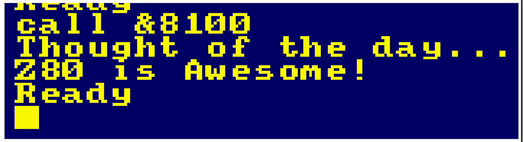
PrintString:
        ld a,(hl)
        cp 255
        ret z
        inc hl
        call PrintChar
jr PrintString

Introduction:
        db 'Thought of the day...',255

ifdef ThinkPositive
        Message:        db 'Z80 is Awesome!',255
else
        Message:        db '6510 sucks!',255
endif

NewLine:
        ld a,13
        call PrintChar
        ld a,10
        call PrintChar
ret
```

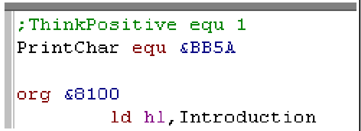
Use Call &8100 to run the program
It will print a little two-line message to the screen!



```
Ready
call &8100
Thought of the day...
Z80 is Awesome!
Ready
```

Chage the first line - put a Semicolon ; at the start of it - this marks it as a 'comment' - which means it does nothing in the code

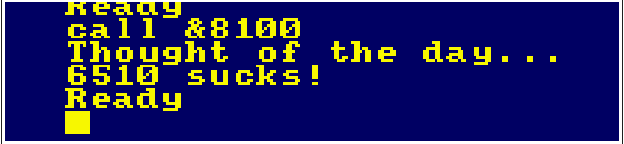
Assemble it - you should get no errors



```
;ThinkPositive equ 1
PrintChar equ &BB5A

org &8100
        ld hl,Introduction
```

Run the program again - The message has changed!



```
Ready
call &8100
Thought of the day...
6510 sucks!
Ready
```

Writing somthing as simple as a print string routine may seem a pain - and you're probably wondering why the firware can't do it for you,
But writing your own routines is the best idea - firstly - you'll know exactly what they do, and you can change them later to add special functions - and more importantly - you can port them to other systems and they will work the same!
The less you use the system firware the better! your Z80 code will work the same on a CPC / Spectrum or MSX - firmware calls will not!

That program probably seems rather long, but there's lots of good stuff in there! Lets take a look at it line by line!

Define a symbol called 'ThinkPositive' and set it to 1	ThinkPositive equ 1

Define PrintChar, and point it to the memory address in the Amstrad Firmware that Prints ascii character A to screen	PrintChar equ &BB5A
Start of our program - the two lines above are instructions to the assembler, they do no compile to anything the Z80 sees	org &8100
load the address of the **Introduction** string into HL	ld hl,Introduction
call our PrintString function	call PrintString
Call our NewLine function	call NewLine
Load the address of the **Message** into HL	ld hl,Message
call our PrintString function	call PrintString
Return to basic	ret
Start of out Printstring function	**PrintString**:
Load a Byte (character) into A from the address HL we were given	ld a,(hl)
Was the byte 255?	cp 255
If it was (the difference is Zero) then we're reached the end of the string - so return to the calling program	ret z
increase the HL address counter	inc hl
call our PrintChar routine to show the letter in A onscreen	call PrintChar
Repeat the procedure.	jr PrintString
A label defining the address of our introduction message	**Introduction**:
a string of letters, ending with 255 - the assembler will convert these to their equivalent bytes according to their Ascii code.	db 'Thought of the day...',255
remember that 'ThinkPositive' symbol? well we're telling the assembler that we only want to do the following if we've defined it!	ifdef ThinkPositive
A label 'Message' and a message that will compile when the IF statement above is true.	**Message:** db 'Z80 is Awesome!',255
If 'ThinkPositive' is not defined (for example - when we put a semicolon in front of it)	else
A label 'Message' and a message that will compile when the IF statement above is false - Note: Normally you can't have two labels with the same name, BUT because the IF statement means only one will compile there ARE NOT TWO in the final program	**Message:** db '6510 sucks!',255
End of the Assembler directive	endif
	NewLine:
A newline command	ld a,13
Load Character 13 into A (Carriage return)	call PrintChar
Print it	ld a,10
Load Character 10 into A (New Line)	call PrintChar
Print it	ret

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Feel free to try other values in the program, It's important to note that the IFDEF is actually changing the Compiled code - the 'message' that is not shown DOES NOT EXIST in the compiled data!

This allows you to compile multiple versions of your program - Chibi Akumas uses this to compile different builds of the game for CPC, ZX spectrum and MSX - and for different languages - all with one code base!

The Indirect registers IX and IY

Suppose we have some bytes of data we want to read from a 'bank' of data - but we want to read those bytes by specifying an offset relative to the start address - we can use the

Indirect register IX or IY to do this - lets look at an example

Type in the program to the right, and compile it.

It's pretty long, but The **bottom part** is identical to your previously entered one, so just copy and paste it, from your last example - or just add the **new code** to the bottom of your old one.

If it's too long, you can always download the sources file and just run it from there.

```
PrintChar equ &BB5A
org &8200
        ld ix,SquareBrackets
        ld hl,Message
        ld de,PrintString
        call DoBrackets

        call NewLine

        ld ix,CurlyBrackets
        ld hl,Message
        ld de,PrintString
        call DoBrackets

ret

DoBrackets:
        ld a,(ix+0)
        call PrintChar
        Call DoCallDE
        ld a,(ix+1)
        call PrintChar
ret

DoCallDE:
        push de
ret

SquareBrackets: db '[]'
CurlyBrackets: db '{}'
```

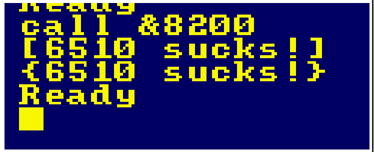
```
PrintString:
        ld a,(hl)
        cp 255
        ret z
        inc hl
        call PrintChar
jr PrintString

NewLine:
        ld a,13
        call PrintChar

        ld a,10
        call PrintChar
ret

ifdef ThinkPositive
        Message:        db 'Z80 is Awesome!',255
else
        Message:        db '6510 sucks!',255
endif
```

Run the program by typing Call &8200
It prints a message inside two kinds of brackets



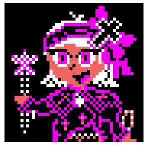
```
Ready
call &8200
[6510 sucks!]
{6510 sucks!}
Ready
```

Don't underestimate calls from basic! A great way to make your first game is to write the logic and input routines in basic, and call out to assembly for things

like drawing sprites and music!
The important thing is the result you achieve, not the method - so why not make things easy for yourself and do some of the work in basic - you can always convert it to ASM later once you've worked out exactly what you need to do!

Lets look at the program and see how it works!

Start of the program	org &8200
Load the Indirect register IX with the address of the square brackets	ld ix,SquareBrackets
Load the address of 'Message' into HL	ld hl,Message
load DE with the address of the Printstring function	ld de,PrintString
Call the DoBrackets function - we'll take a look at it in a second	call DoBrackets
Call the Newline command	call NewLine
Load the Indirect register IX with the address of the curly brackets	ld ix,CurlyBrackets
Load the address of 'Message' into HL	ld hl,Message
load DE with the address of the Printstring function	ld de,PrintString
Call the DoBrackets function - we'll take a look at it in a second	call DoBrackets
return to basic	ret
Start of the Dobrackets function	DoBrackets:
Load A from the address in IX (plus zero - so just IX)	ld a,(ix+0)
Print character A	call PrintChar
Run the function DoCallDE - we'll look at it in a moment.	Call DoCallDE
Load A from the address IX plus 1 - note this does not change the value in IX	ld a,(ix+1)
Print character A	call PrintChar
	ret
The function DoCallDE	DoCallDE:
Push DE onto the stack	push de
Return will take two bytes off the stack, and continue execution from that point - effectively we have done the command Call (DE) - the Z80 has no such command, but we have simulated it here	ret



The Chibi Akumas game uses IX to point to the Player settings - the Player routine gets the Life - position - health etc of the player via IX+... references
This allows the same routine to handle both players just by changing the IX reference when the function is called - the first time it points to Player1's data - the second time Player2's

Call with parameters

That example of IX was rather useless, but the IX register has a far more useful function on the CPC - we can use it to get data from the Call statement! Lets take a look at an example!

Type in the example to the right - it's rather long - if it's too much trouble, remember all the examples are in the downloadable sources file. The **Printstring function** is the same as before - so you can just copy and paste it.	

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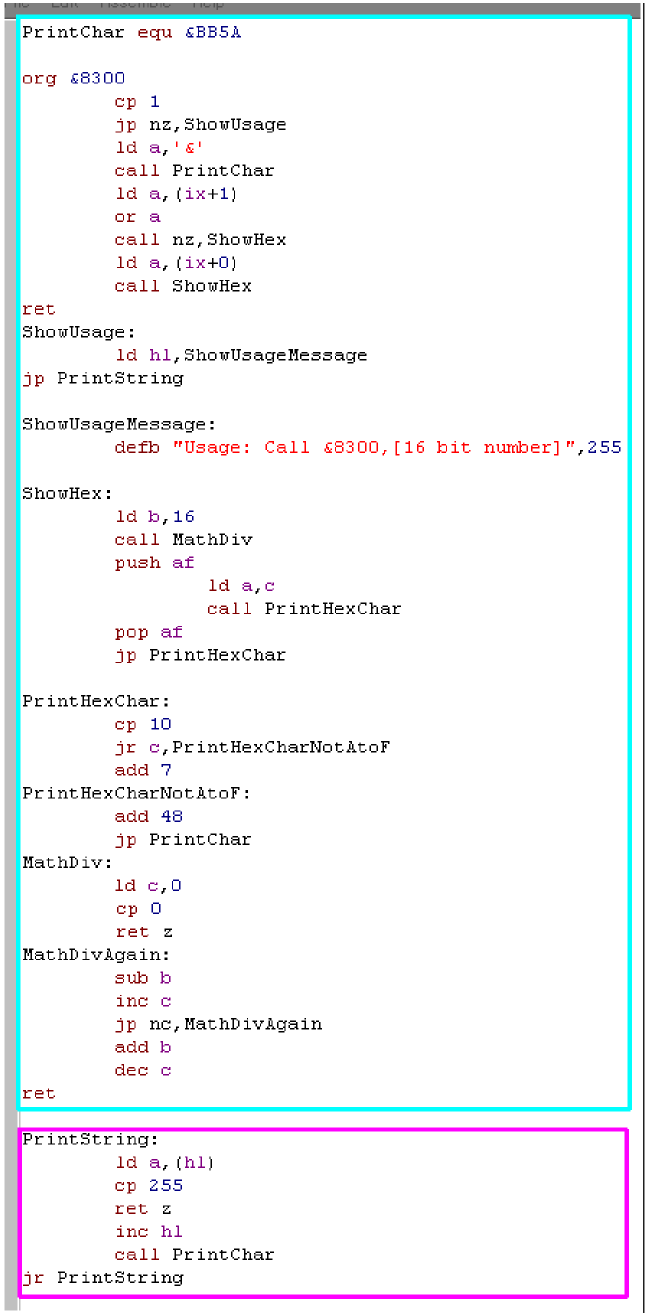


```
PrintChar equ &BB5A

org &8300
        cp 1
        jp nz,ShowUsage
        ld a,'&'
        call PrintChar
        ld a,(ix+1)
        or a
        call nz,ShowHex
        ld a,(ix+0)
        call ShowHex
ret
ShowUsage:
        ld hl,ShowUsageMessage
jp PrintString

ShowUsageMessage:
        defb "Usage: Call &8300,[16 bit number]",255

ShowHex:
        ld b,16
        call MathDiv
        push af
                ld a,c
                call PrintHexChar
        pop af
        jp PrintHexChar

PrintHexChar:
        cp 10
        jr c,PrintHexCharNotAtoF
        add 7
PrintHexCharNotAtoF:
        add 48
        jp PrintChar
MathDiv:
        ld c,0
        cp 0
        ret z
MathDivAgain:
        sub b
        inc c
        jp nc,MathDivAgain
        add b
        dec c
ret
PrintString:
        ld a,(hl)
        cp 255
        ret z
        inc hl
        call PrintChar
jr PrintString
```

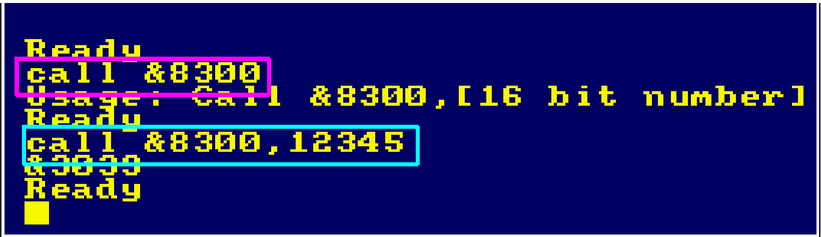
Try typing **Call &8300**

Because you didn't give a parameter You will see a 'usage message'

Type **Call &8300,12345**

You will see '12345' converted to 16bit hexadecimal!

Feel free to try it with some other numbers!



```
Ready
call &8300
Usage: Call &8300,[16 bit number]
Ready
call &8300,12345
&3039
Ready
```

We've created a Decimal to Hexadecimal converter! and it gets its data straight from basic!

Lets take a look at the code and see how it works

	org &8300
When the program starts CPC basic will store the number of parameters passed in A	cp 1
If the user did not pass 1 parameter, show how to use the program	jp nz,ShowUsage
Print an & symbol onscreen	ld a,'&' call PrintChar
Numbers are passed as 16 bit integers... The first parameter location is passed by basic in IX - because the data is passed in little Endian it's backwards, so we load the larger part from IX+1 into A	ld a,(ix+1)
if the high byte is not zero, call our ShowHex function	or a call nz,ShowHex
Load the smaller part from IX+0 (IX) int A	ld a,(ix+0)
Call ShowHex	call ShowHex
return to basic	ret
Show the usage message to the user - as the last command is a JP there is no need for a return command.	ShowUsage: ld hl,ShowUsageMessage jp PrintString
Message string we show the user if they used the program wrong	ShowUsageMessage: defb "Usage: Call &8300,[16 bit number]",255
ShowHex function - this shows an 8 bit byte in Hex	ShowHex:
we want to Divide the number in A by 16	ld b,16
Call our Divide function	call MathDiv
The remainder is returned in A - we need it later - so we Push it now	push af
Load the result of the divide - this is how many 16's there were in the byte - so this is the first symbol in the hex string	ld a,c
Print the hex string	call PrintHexChar
get back A - this is now the second digit with a pop	pop af
jump to the PrintHexChar - because we don't use CALL there is no need for a return	jp PrintHexChar
This function prints a single hex digit 0-F	PrintHexChar:
Compare A to 10	cp 10
if A is less than 10 we need to print a digit.	jr c,PrintHexCharNotAtoF
Add 7 to A - this is the Ascii difference between 9 and A	add 7
	PrintHexCharNotAtoF:
Add 48 (0) to the digit - this converts A to an Ascii character	add 48
Print it	jp PrintChar

This mathDiv function is different from lastweeks, it stores the result in C and the remainder in B	MathDiv:
Reset C - it will store the result	ld c,0
ifA is zero then return	cp 0 ret z
	MathDivAgain:
Subtract B from A	sub b
increase C (the result counter)	inc c
Repeat if we've not gone below zero	jp nc,MathDivAgain
we've gone over zero, so add b again, so A contains the correct remainder	add b
we've gone over zero, so decrease C to get the correct result	dec c
	ret

Using IX is great - but it only works on the CPC - the MSX can pass one variable (see the basic documentation) but other systems cannot really do this - just use the POKE function in the previous example instead!

Other than CALL commands IX functions are great for settings data - you can use them for passing references to sets of data that you want to access and alter 'randomly'

Lesson 5 - Bit level operations, Self modifying code

File Available in sources.7z Click to Download

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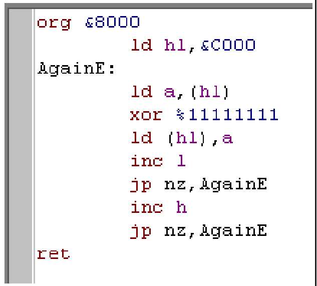
Because memory and commands are limited, you'll quite often want to do things at the bit level, You can use bits to alter numbers, create patterns, and with conditions control actions from the different bits in a single byte

Lets use the CPC screen to see what bit commands do!

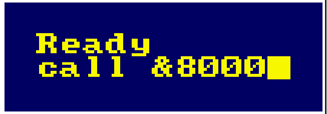
AND, OR and XOR

Type in the program to the right, and compile it



```
org &8000
        ld hl,&C000
AgainE:
        ld a,(hl)
        xor %11111111
        ld (hl),a
        inc l
        jp nz,AgainE
        inc h
        jp nz,AgainE
ret
```

Type in **Call &8000**, and see what happens

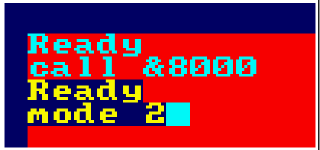


```
Ready
call &8000
```

The screen colors will have gone weird!

It's not clear what happened in 4 color Mode 1

Type in **Mode 2**... and Call &8000 again!



```
Ready
call &8000
Ready
mode 2
```

Try changing the **XOR** to AND or OR

Change **%11111111** to other values like %11110000

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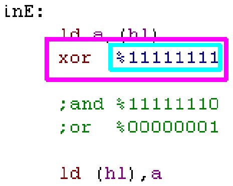
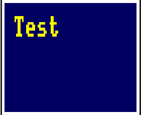
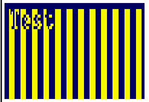
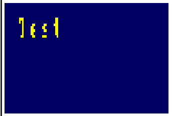
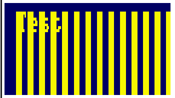


```
inE:
        ld a,(hl)
        xor   %11111111

        ;and %11111110
        ;or  %00000001

        ld (hl),a
```

Lets take a look at what that does to Mode 2 - where each bit is a pixel!

Sample	**XOR %11110000** Invert Bits that are 1	**AND %11110000** Keep Bits that are 1	**OR %11110000** Set Bits that are 1
			

Lets see how that works at the bit level!

Command	LD A,%10101010 **XOR** %11110000	LD A,%10101010 **AND** %11110000	LD A,%10101010 **OR** %11110000
Result	%**0101**1010	%1010**0000**	%**1111**1010
Meaning	Invert the bits where the mask bits are 1	return 1 where both bits are1	Return 1 when either bit is 1

Each Bit is a pixel in Mode 2 - but in Mode 1 it takes 2 bits
the right half of the byte (%----XXXX) is color 1, the left half (%XXXX----) is color 2 - if both are set the result is color 3, eg (%00010001) will set the right hand pixel to color 3

It sounds weird, but just give it a try and see the results - and you'll soon understand it!

Single Bit Operations

You can use NOT AND and OR to do operations on all the bits, but you need to use A - BIT SET AND RES can check, set and reset bits but can be used on other registers without affecting A

Lets give it a go!

Type the program in to the right and run it. If you remember from before, you'll know IX is used to get parameters.	

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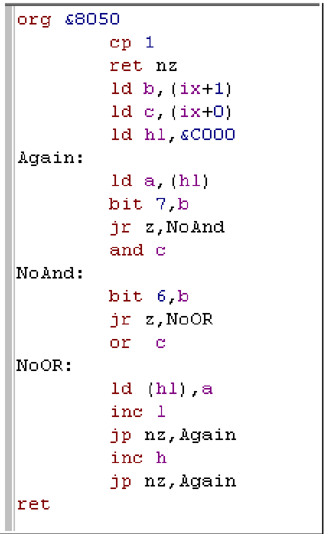


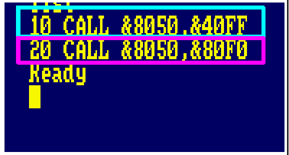
```
org &8050
        cp 1
        ret nz
        ld b,(ix+1)
        ld c,(ix+0)
        ld hl,&C000
Again:
        ld a,(hl)
        bit 7,b
        jr z,NoAnd
        and c
NoAnd:
        bit 6,b
        jr z,NoOR
        or  c
NoOR:
        ld (hl),a
        inc l
        jp nz,Again
        inc h
        jp nz,Again
ret
```

Switch to **Mode 2**

Try **Call &8050,&40FF**

Also give **Call &8050,&80F0** a go!

The first part of the parameter must be &80 or &40 - but try other values for the second part!



```
10 CALL &8050,&40FF
20 CALL &8050,&80F0
Ready
```

Lets take a look at the part of the program with new commands! we're going to skip over commands you should already know!

You should understand this now!	org &8050
Return if 1 parameter was not passed	cp 1 ret nz
Load the 'Operation' made up of the first two bytes of the passed parameter (eg XX in &XX--) - remember because of Little Endian these appear at IX+1	ld b,(ix+1)
load the bitmask from the second two bytes of the passed parameter (eg XX in &--XX)	ld c,(ix+0)
You should understand this now!	ld hl,&C000 Again: ld a,(hl)
Check bit 7 of B (bit 7 is the far left - so this is like CP &80 or CP %10000000 - but CP would check A, and this works with B)	bit 7,b
If it was zero, jump to our label	jr z,NoAnd
use the AND command with parameter C	AND c
	NoAnd:
Check bit 7 of B (bit 7 is the far left - so this is like CP &40 or CP %01000000 - but CP would check A, and this works with B)	bit 6,b
If it was zero, jump to our label	jr z,NoOR
use the OR command with parameter C	OR c
	NoOR:
	ld (hl),a
	...

Each bit number is a position from Right to Left

Bit Number		7	6	5	4	3	2	1	0

EG:	%	1	0	1	0	1	0	1	0

There are 3 types of single bit commands, they can work on almost any register, where as AND %00000001 or OR %00000001 and CP %00000001 only work on A - and AND or OR will change A - these will not

Command	SET b,r	RES b,r	BIT b,r
Meaning	Set Bit B in Register R	Reset bit B in register R	Check if bit B in register R is set
EG	SET 7,A	RES 6,A	BIT 5,A
Equivalent to	OR %10000000	AND %10111111	CP %00100000

These commands are great for using 'settings' variables where each bit has a different meaning - In Chibi Akumas the pressed joystick buttons are stored in a single byte and "BIT b,r" is used to test each button.

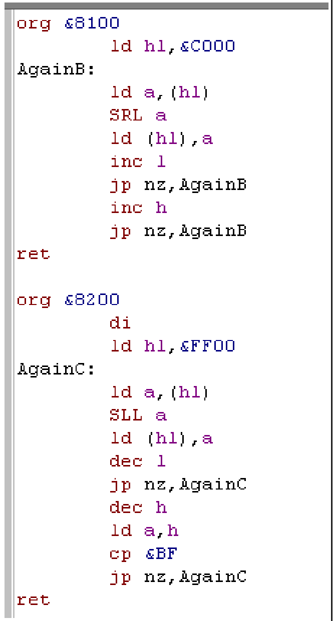
Things like object movements use different bits in a byte to allow a single byte to define all the possible move directions and types the game needs!

Bit Shifting and Rotating

Sometimes we want to move the bits around in a byte, this can be be to double or halve a value, or to take a couple of bits 'out' of a byte via the carry.

Lets try out the bit shifting commands!

Type in and compile these two examples! there are two versions because one is for shifting Right (&8100) and Left (&8200)



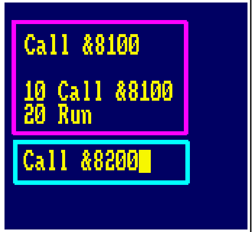
```
org &8100
        ld hl,&C000
AgainB:
        ld a,(hl)
        SRL a
        ld (hl),a
        inc l
        jp nz,AgainB
        inc h
        jp nz,AgainB
ret

org &8200
        di
        ld hl,&FF00
AgainC:
        ld a,(hl)
        SLL a
        ld (hl),a
        dec l
        jp nz,AgainC
        dec h
        ld a,h
        cp &BF
        jp nz,AgainC
ret
```

Type Call &8100 and see what happens!

You'll want to see it run continuously, so type in a little basic program to repeat the process

Try the Call &8200 version - and modify the program to Call &8200!



```
Call &8100

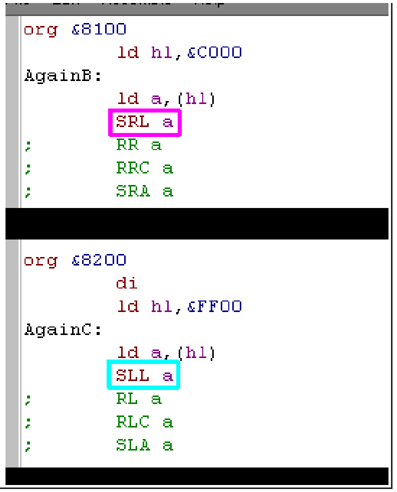
10 Call &8100
20 Run

Call &8200
```

Try replacing "**SRL A**" with "RR A" or "RRC A" or "SRA A" - see what each does!

Try replacing "**SLL A**" with "RLA" or "RLC A" or "SLA A" - see what each does!

We'll take a look at them in detail in a second!



```
org &8100
        ld hl,&C000
AgainB:
        ld a,(hl)
        SRL a
;       RR a
;       RRC a
;       SRA a

org &8200
        di
        ld hl,&FF00
AgainC:
        ld a,(hl)
        SLL a
;       RL a
;       RLC a
;       SLA a
```

Carry Flag

So what do all those commands do? well first we need to understand the **Carry Flag**!
The Carry Flag is a single bit that stores the 'overflow' from 8 bit maths.

Question: What's 192 Plus 128?
Well in 8 bit maths - it's 64 - with a carry of 1... why? because, 8 bits can only count up to 255, and if there was a 9th bit it would be 1 - and the normal 8 bits would be 64 - confused?
well lets take a look at it in binary

Command	**Carry**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
Ld a,192	0	1	1	0	0	0	0	0	0
add 128	0	1	0	0	0	0	0	0	0
(result)	1	0	1	0	0	0	0	0	0

So the Carry allows us to store the 'overflow' from maths - and allows us to use 8 bit registers for 16 bits, or 16 bit register pairs for 32 bits... but they also allow us to do clever things with bits! Some commands use the carry to shift bits in and out of the register
Now lets take a look at what all those commands do!

		Result	Carry
Start Value	(Keep an eye on the colors to see how the bits move)	10011001	0
RR A	Rotates r right with carry - Carry is put at the left, right most bit is put in carry	01001100	1
RRC A	Rotates r right with wrap (Carry unused)	11001100	1
SRA A	Shifts r right, top bit is the same as previous top bit	11001100	1
SRL A	Shifts r right, top bit is set to 0	01001100	1
RL A	Rotates r left with carry - Carry is put to the right, left most bit is put in carry	00110010	1
RLC A	Rotates r left with wrap (RLCA is actually faster)	00110011	1
SLA A	Shifts r left, bottom bit 0	00110010	1
SLL A	Shifts r left, bottom bit 1	00110011	1

Shifting bits around can be used to change values in all kinds of ways -for example shifting left doubles a value, Shifting right halves it.

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You can do repeated bit shifts to take a byte apart, and load it into other registers, or reverse it.

$150 calculator: Unboxing the Ti-84 Plus CE (eZ80 cpu)

Self Modifying code

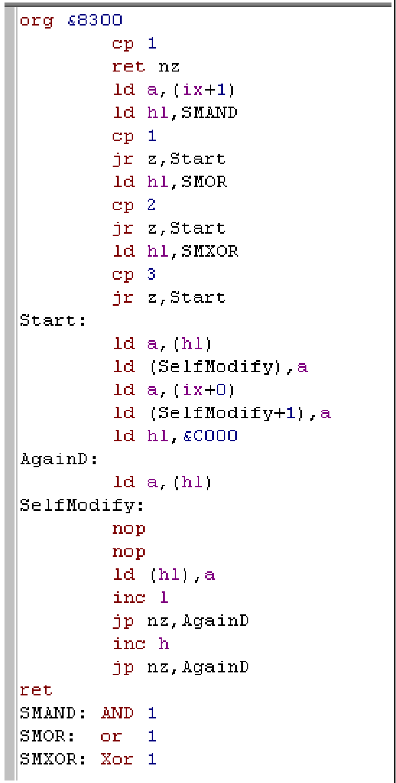
Lets change the subject a bit!
Remember the 2nd program? - it used a parameter passed by IX to decide what command to do?
The screen fill loop runs over 16,000 times, and using CP and Jump commands in that loop slows things down a lot!

What we really need is a way of comparing the parameter, and changing the action that takes no extra processing power... sounds impossible? well it's not... we make the program change its own code!

Because the program is in memory - and we can change memory, we can swap values or commands in our program whenever we want!

Type in the program to the right and compile it,

If it's too much trouble, remember, you can always just get it from the sources file!

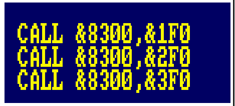


```
org &8300
        cp 1
        ret nz
        ld a,(ix+1)
        ld hl,SMAND
        cp 1
        jr z,Start
        ld hl,SMOR
        cp 2
        jr z,Start
        ld hl,SMXOR
        cp 3
        jr z,Start
Start:
        ld a,(hl)
        ld (SelfModify),a
        ld a,(ix+0)
        ld (SelfModify+1),a
        ld hl,&C000
AgainD:
        ld a,(hl)
SelfModify:
        nop
        nop
        ld (hl),a
        inc l
        jp nz,AgainD
        inc h
        jp nz,AgainD
ret
SMAND: AND 1
SMOR:  or  1
SMXOR: Xor 1
```

Run the program with Call &8300,&xxyy

Where xx is a command number from 01-03 , and yy is a bit mask from 00-FF

You'll be able to see the result best in mode 2

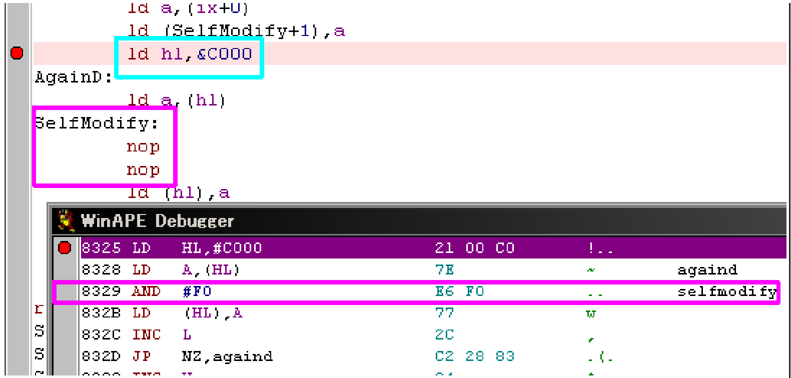


```
CALL &8300,&1F0
CALL &8300,&2F0
CALL &8300,&3F0
```

Try putting a breakpoint in before the loop (at **ld hl,&C000** , for example)

Notice the **NOP commands have disappeared** and been replaced with a different command!

(NOP means NO OPERATION - it does nothing and is just a placeholder)



```
        ld a,(ix+0)
        ld (SelfModify+1),a
        ld hl,&C000
AgainD:
        ld a,(hl)
SelfModify:
        nop
        nop
        ld (hl),a
```

WinAPE Debugger

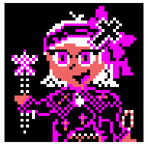
```
8325 LD   HL,#C000     21 00 C0   !..
8328 LD   A,(HL)       7E         ~      againd
8329 AND  #F0          E6 F0      ..     selfmodify
832B LD   (HL),A       77         w
832C INC  L            2C         ,
832D JP   NZ,againd    C2 28 83   .(.
```

Lets take a look at the new commands in the program, and see how it works!

Check the user gave us 1 parameter	cp 1 ret nz
Load the first part of the parameter (&XX--) into A	ld a,(ix+1)
Load the address of our template AND command into HL	ld hl,SMAND
if A =1 then jump to the start	cp 1 jr z,Start
Load the address of our template OR command into HL	ld hl,SMOR
if A =2 then jump to the start	cp 2 jr z,Start
Load the address of our template XOR command into HL	ld hl,SMXOR
if A =3 then jump to the start	cp 3 jr z,Start
Start of the main program	Start:
Load the byte of the template command into A	ld a,(hl)
Write the byte to the label Selfmodify's address	ld (SelfModify),a
Load A from the second part of the parameter (&--XX)	ld a,(ix+0)
Write the byte to the one byte after label Selfmodify's address	ld (SelfModify+1),a
	ld hl,&C000
	AgainD:
	ld a,(hl)
NOP is a one byte command that does nothing - these two bytes will be replaced by the self modifying code and the command and mask the user's parameter chose will be put here	SelfModify: nop nop
	ld (hl),a inc l jp nz,AgainD inc h jp nz,AgainD ret
These three labels have a 'template command' which we pull the correct byte from to modify the code at 'SelfModify'	SMAND: AND 1 ;1 SMOR: OR 1 ;2

	SMXOR: XOR 1 ;3

Different commands have different bytes, so when using self modifying code you need to know what bytes the commands compile to!
In this example we've read from a 'template' command at a label - but it would be faster and save memory to just replace ld hl,SMAND with something like ld h,&E6 (&E6 is the AND command in this case)
You'll never remember all the commands, but they're all on the cheat sheet, so just look them up when you need to!



Self modifying code doesn't just allow you to make slow conditions fast, you can save memory with temporary variables.

For example, both these do the same thing:

Normal:	**Self Modifying:**
ld a,(temp) inc a ld (temp),a ret temp: db 0	ld a,0 :SelfModVar_Plus1 inc a ld (SelfModVar_Plus1-1),a ret
Total: 9 Bytes	Total: 7 Bytes

See what we did? rather than storing the variable in a separate temp location, we modified the LD command - so now the variable is in the code, saving memory - and this is faster too!

Self modifying code is tricky, so don't worry about using it for now!
One day you may want to make your program as fast and efficient as possible, and Self Modifying code will be waiting to do that for you! Just get used to the normal stuff and remember this as something you need to know about, even if you don't use it!

Lesson 6 - Lookup table, Screen Co-ordinates, Vector Tables, Basic Parameters Byref

File Available in sources.7z Click to Download
sources
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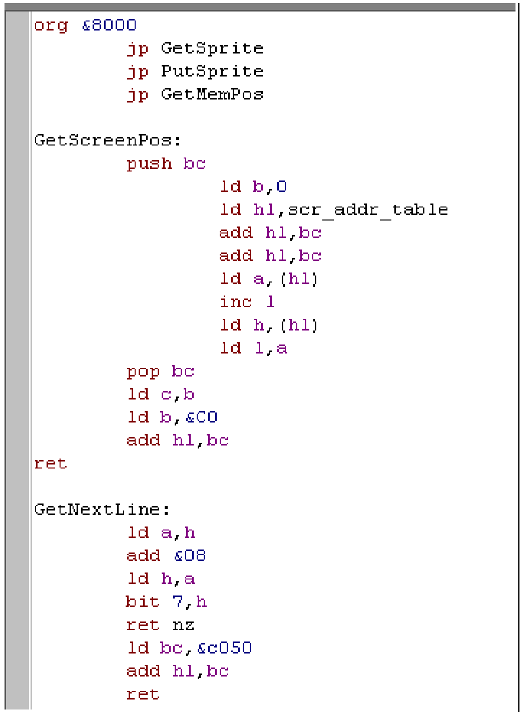
?
!
Video Available Click to watch!

We've covered most of the essential commands now, so we can do something pretty impressive this time!
We're going to create a program that grabs sprites, and prints them on screen - that you can use from your own basic programs!

Enough talk though... Lets make a start!

This lesson's code is quite big, so you may just want to download it from the Sources file. We'll enter it in sections, and look at what each section does, then run it!

Type in the code to the right You can't compile it yet, there's a lot more work to do!	



```
org &8000
        jp GetSprite
        jp PutSprite
        jp GetMemPos

GetScreenPos:
        push bc
                ld b,0
                ld hl,scr_addr_table
                add hl,bc
                add hl,bc
                ld a,(hl)
                inc l
                ld h,(hl)
                ld l,a
        pop bc
        ld c,b
        ld b,&C0
        add hl,bc
ret

GetNextLine:
        ld a,h
        add &08
        ld h,a
        bit 7,h
        ret nz
        ld bc,&c050
        add hl,bc
        ret
```

Copy-Paste the table below into your code - (It's not an image!)
Put it below the code you just entered!

Seriously - you don't want to type all this in!!!

```
align 2
scr_addr_table:
    defb &00,&00, &00,&08, &00,&10, &00,&18, &00,&20, &00,&28, &00,&30, &00,&38;1
    defb &50,&00, &50,&08, &50,&10, &50,&18, &50,&20, &50,&28, &50,&30, &50,&38;2
    defb &A0,&00, &A0,&08, &A0,&10, &A0,&18, &A0,&20, &A0,&28, &A0,&30, &A0,&38;3
    defb &F0,&00, &F0,&08, &F0,&10, &F0,&18, &F0,&20, &F0,&28, &F0,&30, &F0,&38;4
    defb &40,&01, &40,&09, &40,&11, &40,&19, &40,&21, &40,&29, &40,&31, &40,&39;5
    defb &90,&01, &90,&09, &90,&11, &90,&19, &90,&21, &90,&29, &90,&31, &90,&39;6
    defb &E0,&01, &E0,&09, &E0,&11, &E0,&19, &E0,&21, &E0,&29, &E0,&31, &E0,&39;7
    defb &30,&02, &30,&0A, &30,&12, &30,&1A, &30,&22, &30,&2A, &30,&32, &30,&3A;8
    defb &80,&02, &80,&0A, &80,&12, &80,&1A, &80,&22, &80,&2A, &80,&32, &80,&3A;9
    defb &D0,&02, &D0,&0A, &D0,&12, &D0,&1A, &D0,&22, &D0,&2A, &D0,&32, &D0,&3A;10
    defb &20,&03, &20,&0B, &20,&13, &20,&1B, &20,&23, &20,&2B, &20,&33, &20,&3B;11
    defb &70,&03, &70,&0B, &70,&13, &70,&1B, &70,&23, &70,&2B, &70,&33, &70,&3B;12
    defb &C0,&03, &C0,&0B, &C0,&13, &C0,&1B, &C0,&23, &C0,&2B, &C0,&33, &C0,&3B;13
    defb &10,&04, &10,&0C, &10,&14, &10,&1C, &10,&24, &10,&2C, &10,&34, &10,&3C;14
    defb &60,&04, &60,&0C, &60,&14, &60,&1C, &60,&24, &60,&2C, &60,&34, &60,&3C;15
    defb &B0,&04, &B0,&0C, &B0,&14, &B0,&1C, &B0,&24, &B0,&2C, &B0,&34, &B0,&3C;16
    defb &00,&05, &00,&0D, &00,&15, &00,&1D, &00,&25, &00,&2D, &00,&35, &00,&3D;17
    defb &50,&05, &50,&0D, &50,&15, &50,&1D, &50,&25, &50,&2D, &50,&35, &50,&3D;18
    defb &A0,&05, &A0,&0D, &A0,&15, &A0,&1D, &A0,&25, &A0,&2D, &A0,&35, &A0,&3D;19
    defb &F0,&05, &F0,&0D, &F0,&15, &F0,&1D, &F0,&25, &F0,&2D, &F0,&35, &F0,&3D;20
    defb &40,&06, &40,&0E, &40,&16, &40,&1E, &40,&26, &40,&2E, &40,&36, &40,&3E;21
    defb &90,&06, &90,&0E, &90,&16, &90,&1E, &90,&26, &90,&2E, &90,&36, &90,&3E;22
    defb &E0,&06, &E0,&0E, &E0,&16, &E0,&1E, &E0,&26, &E0,&2E, &E0,&36, &E0,&3E;23
```

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```
defb &30,&07, &30,&0F, &30,&17, &30,&1F, &30,&27, &30,&2F, &30,&37, &30,&3F;24
defb &80,&07, &80,&0F, &80,&17, &80,&1F, &80,&27, &80,&2F, &80,&37, &80,&3F;25
```

If you want to use this program on the Spectrum or Enterprise, you'll need a different Look Up Table and Get Next Line routine!... and MSX graphics are totally different, so you need to draw in a different way.

Don't worry, we'll get to it once we've learned all the Z80 commands - we're nearly done now!

Reading from a Lookup Table

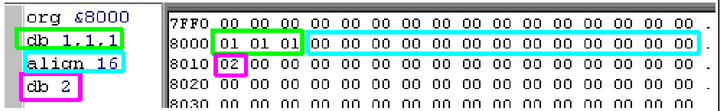
We can use a lookup table to read data from - in this case, our screen location contains 2 bytes, so we add the 'index' (ypos) twice to the start address, then rad in two byte.

The code you've entered coverts X,Y co-ordinates to screen locations - and calculates the position one pixel line down from the current memory location! this will be used to work out where our sprite will be drawn/read from, and to work through the sprite line by line

Aligned code

Aligned code is code that starts from a certain byte boundary - it is used for speeding things up, or look ups - by knowing where the data will start, we can save time by using INC L rather than INC HL - as we can know H will not need to change... the ALIGN command allows us to make assumptions about the position of the following code, without being as rigid as an ORG command

Lets take a look at what the ALIGN command does
In this example we have a few bytes of 1's defined with **DB 1,1,1**
The ALIGN xx command will align to the next xx boundary... in this case, it aligns to a 16 byte boundary
The ALIGN 16 command inserts zeros as required.
The **DB 2** inserts a 2 - note it's aligned correctly!



```
org &8000
db 1,1,1
align 16
db 2
```

```
7FF0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .
8000 01 01 01 00 00 00 00 00 00 00 00 00 00 00 00 00 .
8010 02 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .
8020 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .
8030 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
```

Aligned code allows you to do all kinds of clever things!
A common trick is to define a 256 byte aligned table - with the "Mask" to erase the background when pixels are color 0 for every possible byte a sprite could contain -
By setting H to the start of the table, and L to the byte - the mask can be applied by LD A,(HL) AND A
It sounds confusing, but you'll soon think of lots of clever things you can use Lookup tables and Aligned code for!

We can't run the code yet, because we're missing the sprite grabber - but lets take a look how it works!

This is called a Jump block, it's allows us to jump to an unknown location from a known one.
Each JP xxxx command is 3 bytes, so we know "JP Get MemPos" is at &8006 - even though we don't know where "GetMemPos" is, we can use Call &8006 and it will have the same effect as Call GetMemPos - this allows you to write programs that can easily be called from basic, or other programs that were compiled separately!
	org &8000
	    jp GetSprite
	    jp PutSprite
	    jp GetMemPos

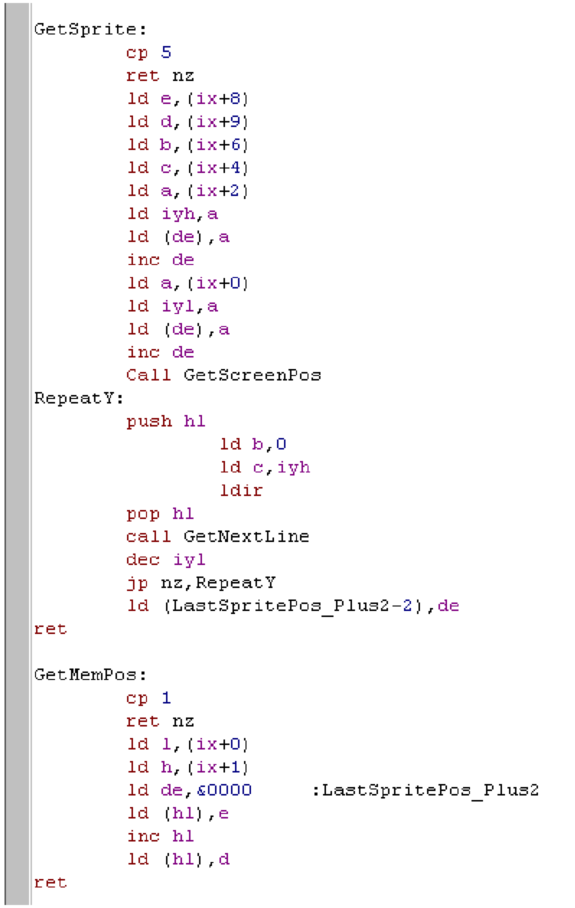
This command takes an X-pos in B , and a Y-pos in C, and converts them to a screen memory location in HL note X is measured in BYTES - so there are 80 of them across the width of the the CPC screen - Y is measured in LINES	GetScreenPos: push bc
Load the address of our LookupTable for screen line memory locations We don't need the Xpos for now - so we set B to 0 Each memory location is 16 bit (2 bytes) so we add B twice to HL, this means HL points to data containing the 16 bit Memory location of the line we want - we just need to get at it!	ld b,0 ld hl,scr_addr_table add hl,bc add hl,bc
We need to load HL with the data at the memory location IN HL - first we load the low byte into A We use the faster INC L - not the slower INC HL because we used Align 2 - this means the data won't go over a 255 byte boundary (we know we're not on &80FF) - align will have added 0 bytes to ensure we're not.	ld a,(hl) inc l ld h,(hl) ld l,a

Then we load H from (HL) - don't worry! H doesn't get erased until AFTER (HL) has given us the byte we need! Then we load L from A - which we got the line before - and we're done!	
Get back BC - we want B (the xpos) to be in the low byte - and we need to set the high byte to the position of our memory buffer (&C0 - because the screen is at &C000) We add it to HL HL now contains the screen memory position of the X,Y pos we wanted!	pop bc ld c,b ld b,&C0 add hl,bc ret
Finding the line below the current one is hard on most systems, On the CPC line tend to be &0800 below the last one, so we add &08 to H - which is faster than messing with HL	GetNextLine: ld a,h add &08 ld h,a
when we go over &FFFF we need to start back again at the top - annoying isn't it? if the top bit is zero then we've rolled back to &0000 - but otherwise we're done	bit 7,h ret nz
If we got here, then we rolled over, but we can fix things by adding &C050 - to get the correct position of the line!	ld bc,&c050 add hl,bc ret

The next part of the program is the sprite grabber!

Type in the program to the right!

You still won't be able to compile it without the 3rd part!



```
GetSprite:
	cp 5
	ret nz
	ld e,(ix+8)
	ld d,(ix+9)
	ld b,(ix+6)
	ld c,(ix+4)
	ld a,(ix+2)
	ld iyh,a
	ld (de),a
	inc de
	ld a,(ix+0)
	ld iyl,a
	ld (de),a
	inc de
	Call GetScreenPos
RepeatY:
	push hl
		ld b,0
		ld c,iyh
		ldir
	pop hl
	call GetNextLine
	dec iyl
	jp nz,RepeatY
	ld (LastSpritePos_Plus2-2),de
ret

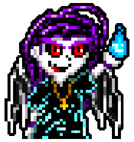
GetMemPos:
	cp 1
	ret nz
	ld l,(ix+0)
	ld h,(ix+1)
	ld de,&0000	:LastSpritePos_Plus2
	ld (hl),e
	inc hl
	ld (hl),d
ret
```

This routine grabs a sprite from the screen with "&8000,MEMDEST,X,Y,W,H" - and returns the next free MEMDEST with "Call &8006,@int"

Undocumented registers IXH, IXL,IYH,IYL

IX and IY are 16 bit register pairs like HL, they're actually made up of 2 registers we can use for whatever we want!
IX is made up of IXH (IX-High) and IXL (IX-Low)
IY is made up of IYH (IY-High) and IYL (IY-Low)

They aren't as fast as other registers - but there are times they are useful - in this example we use them as loop counters!



These registers are undocumented - That means they weren't originally in the Z80 manual - but all Z80's support them, they even work on the MSX Turbo-R's R800 - so don't be afraid to use then!

Back in the 80's people didn't know about them, so we can use them to give our programs a speed advantage over the old games!

Basic References and 16- bit integers with @ and %

In CPC basic, putting @ before a variable will pass it as a 'reference' - this means we get the address of int, not the just value - and our program can change the value that the basic variable has! This allows us to store the memory location of sprites in integers in basic!

But make sure you specify they are integers by putting % at the end of the variable - otherwise they will be a floating point number, eg s1%=0 will define s1% as an integer.

You can pass other data types, but they're harder to use, as you need to know how data such as strings and floating point numbers are stored on the CPC

16-bit integers are easiest to work with, so make sure you put the % symbol at the end of the variable name!

Lets take a look at how it works!

Start of the sprite grabber - Check we were given 5 parameters	GetSprite:
	    cp 5
	    ret nz

Parameters come in backwards - and are always 16 bit... so MEMDEST is at byte position 8 & 9 - this is where we will store the sprite	ld e,(ix+8) ld d,(ix+9)
X is at position 6, Y is at position 4 - we only expect 8 bits, so we ignore positions 7 and 5 - These are the screen position to grab from	ld b,(ix+6) ld c,(ix+4)
Load the Width from position 2 - store it in IYH, and also in the destination memory Increase the destination memory pointer	ld a,(ix+2) ld iyh,a ld (de),a inc de
Load the width from Position 0 - store it in IYL, and also in the destination memory	ld a,(ix+0) ld iyl,a ld (de),a inc de
Convert B,C to a screen memory pos	Call GetScreenPos

Back up the screen memory co-ordinate
Set BC to the number of bytes we want to copy
use LDIR to copy from the screen to DE
	RepeatY:
	    push hl
	        ld b,0
	        ld c,iyh
	        ldir

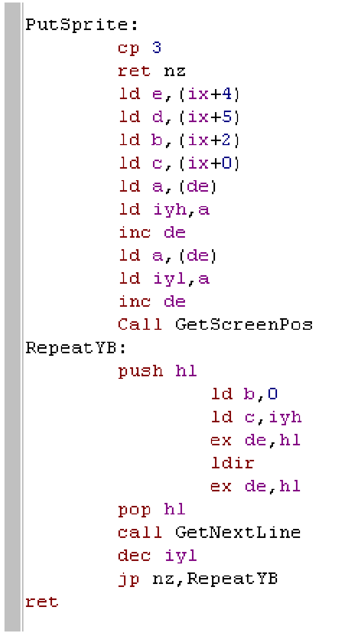
Get back the screen memory pos, and move down one line	pop hl call GetNextLine
Decrease the line counter, and repeat if we're not at zero	dec iyl jp nz,RepeatY
Store the next empty memory position using self-modifying code	ld (LastSpritePos_Plus2-2),de ret
Check we were given one parameter	GetMemPos: cp 1 ret nz
Load the reference into HL	ld l,(ix+0) ld h,(ix+1)
Load DE with a value - note we're using self-modifying code - so the value will be the end of the last sprite	ld de,&0000 :LastSpritePos_Plus2
Write the 16 bit value in DE to the memory position that HL contains	ld (hl),e inc hl ld (hl),d ret

EX DE,HL - When HL just won't do!

HL has more power than anything else, but sometimes we want to use DE for the same job - well, we can't! but we can swap HL and DE quickly to do what we need - it's faster than any kind of PUSH POP options if you just need to swap the two - in this case it allows us to use LDIR to read from HL, and write to DE!

One last bit to go! The PutSprite routine... don't give up, the finish line is in sight!

Type the code to the right!
Compile it, you should get no errors!



```
PutSprite:
        cp 3
        ret nz
        ld e,(ix+4)
        ld d,(ix+5)
        ld b,(ix+2)
        ld c,(ix+0)
        ld a,(de)
        ld iyh,a
        inc de
        ld a,(de)
        ld iyl,a
        inc de
        Call GetScreenPos
RepeatYB:
        push hl
                ld b,0
                ld c,iyh
                ex de,hl
                ldir
                ex de,hl
        pop hl
        call GetNextLine
        dec iyl
        jp nz,RepeatYB
ret
```

Now we can Grab sprites, and Print them to screen!
Here's a little Basic program to try it out!

Type in the program to the right.	

[SNES Hardware sprites - 6502 ASM YQuest13](#)

[Vector drawing on the Vectrex](#)

[Graphics on the Fujitsu FM7](#)

[CPC ASM: Tape loading on the Amstrad CPC (5K subs special)](#)

[68000 YQuest7 - Atari ST Specific code](#)

[Hardware Sprites on the NES - Lesson YQuest12](#)

[Hardware Sprites on the PC Engine / Turbografix](#)

[Joystick reading on the Vectrex - 6809 ASM](#)

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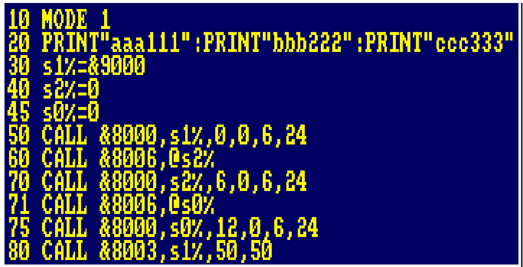
[$150 calculator: Unboxing the Ti-84 Plus CE (eZ80 cpu)](#)

It will define 3 sprites,
one of 9 numbers (Stored in S1%)
one of 9 letters (Stored in S2%)
one is blank (stored in S0%)

Run the program, it will show one of the sprites on screen!



```
10 MODE 1
20 PRINT"aaa111":PRINT"bbb222":PRINT"ccc333"
30 s1%=&9000
40 s2%=0
45 s0%=0
50 CALL &8000,s1%,0,0,6,24
60 CALL &8006,@s2%
70 CALL &8000,s2%,6,0,6,24
71 CALL &8006,@s0%
75 CALL &8000,s0%,12,0,6,24
80 CALL &8003,s1%,50,50
```

Lets see how our basic program uses the commands

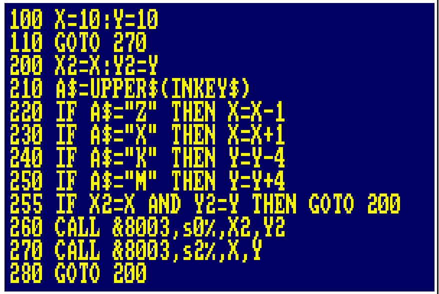
Reset the screen and print some letters to use as sprites	10 MODE 1 20 PRINT"aaa111":PRINT"bbb222":PRINT"ccc333"
Define 3 variables to store the locations of our sprites - the % symbol defines them as 16-bit integers Our sprites will start at &9000 - we'll work out the locations of the other two later	30 s1%=&9000 40 s2%=0 45 s0%=0
Grab (0,0)-(6,24) and store it at memory location in S1%	50 CALL &8000,s1%,0,0,6,24
Pass S2% by reference (the @ symbol denotes this) - our ASM program will put the next free sprite position into basic variable S2% - so we know where this sprite will start!	60 CALL &8006,@s2%
Grab (6,0)-(12,24) and store it at memory location in S2%	70 CALL &8000,s2%,6,0,6,24
Get the Next sprite memory location, and store it in S0%	71 CALL &8006,@s0%
Grab (12,0)-(18,24) and store it in position S0%	75 CALL &8000,s0%,12,0,6,24
Show sprite S1% at screen position (50,50)	80 CALL &8003,s1%,50,50

Now you can make and use your own sprites from Basic!

Need more inspiration? try adding the basic code to the right!
This will show a sprite on screen, and erase it - you can move the sprite with keys ZX K and M

Don't let the sprite go off screen though! there's no checking and it may crash the CPC

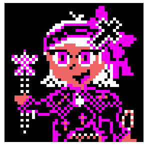
The basic program is on the Sources.DSK image!



```
100 X=10:Y=10
110 GOTO 270
200 X2=X:Y2=Y
210 A$=UPPER$(INKEY$)
220 IF A$="Z" THEN X=X-1
230 IF A$="X" THEN X=X+1
240 IF A$="K" THEN Y=Y-4
250 IF A$="M" THEN Y=Y+4
255 IF X2=X AND Y2=Y THEN GOTO 200
260 CALL &8003,s0%,X2,Y2
270 CALL &8003,s2%,X,Y
280 GOTO 200
```

INKEY$ reads a character from the keyboard, it's a quick easy way to read input!
In this example we use it to move a sprite around the screen!

I'm sure you can think of more interesting things to do with the code in todays lesson!



Vector Tables - Lookup tables for Jumps!

We can use the same code we just used in our look-up table for calling subroutines - we can take a 8 bit integer, and use it to decide on a Jump.

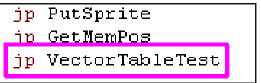
"CP X   JP Z,YYYY " uses 5 bytes per command!
A Jump block uses 3 bytes for each command!
A vector table uses only 2 bytes per command!

If memory is tight, a Vector table is the best option... and a jumpblock does not get slower when working with a lot of entries - where as repeated "CP x.. JP Z,yyyy" commands will waste CPU power for each command skipped over to find the matching label

DW - defining 2 byte 16 bit 'Words'

We use DW xxxx to define a 16 bit word - we could do the same with 2 DB commands - but that would make no sense in this case

Let's take a look at a vector table!
Add another jump to the Jump block below JP GetMemPos

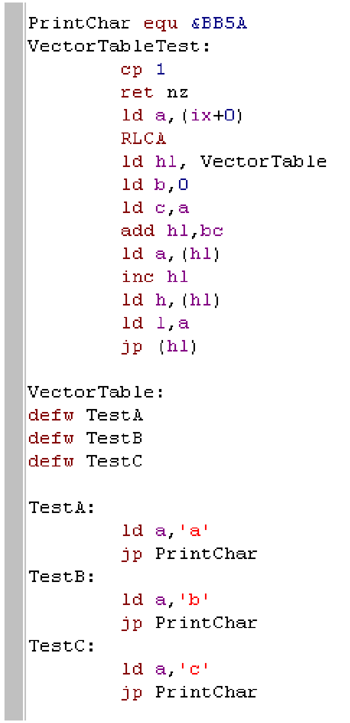


```
jp PutSprite
jp GetMemPos
jp VectorTableTest
```

Type in the program to the right and compile it

You can run it with Call &8009,x - where x is 0-2

This will call one of the commands in the VectorTable

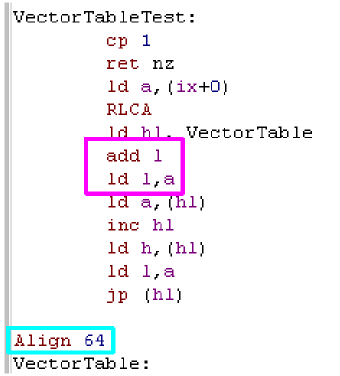


```
PrintChar equ &BB5A
VectorTableTest:
        cp 1
        ret nz
        ld a,(ix+0)
        RLCA
        ld hl, VectorTable
        ld b,0
        ld c,a
        add hl,bc
        ld a,(hl)
        inc hl
        ld h,(hl)
        ld l,a
        jp (hl)

VectorTable:
defw TestA
defw TestB
defw TestC

TestA:
        ld a,'a'
        jp PrintChar
TestB:
        ld a,'b'
        jp PrintChar
TestC:
        ld a,'c'
        jp PrintChar
```

if we **ALIGN** the vector table so all the commands are in the same byte boundary we can **make the Vector table lookup simpler**!



```
VectorTableTest:
        cp 1
        ret nz
        ld a,(ix+0)
        RLCA
        ld hl, VectorTable
        add l
        ld l,a
        ld a,(hl)
        inc hl
        ld h,(hl)
        ld l,a
        jp (hl)

Align 64
VectorTable:
```

Lets look at how the Vector Jump works!

Check we got 1 parameter, and load it into A	VectorTableTest:
	    cp 1
	    ret nz
	    ld a,(ix+0)

Rotate the bits in A left, effectively doubling it - we do this because each entry in our vector table is 2 bytes	rlca
Load our vector table into HL Set BC to the byte offset of the command we chose ADD BC to HL - HL now points to our command	ld hl, VectorTable ld b,0 ld c,a add hl,bc
load HL with the address of a command from the VectorTable	ld a,(hl) inc hl ld h,(hl) ld l,a
Jump to the address in HL	jp (hl)
The vector table - each line is a 16 bit address of a command - the first will be called if the parameter is 0	VectorTable: defw TestA defw TestB defw TestC

Lesson 7 - DI EI, RST x, Custom Interrupts, IM1/IM2, HALT, OTI / OTIR, HALT

We're going to learn how to interface with the hardware, and take over the last job of the firmware - so we're going to have to cover a lot of technical content now, so we understand what we're doing!

Both examples are included in the Sources download, just enable,or comment out the "**Eg2 equ 1**" declaration to toggle between the simple example - and the final one

RSTs and Interrupts in IM1

CALL commands take 3 bytes, but there is a special way the Z80 can do a limited call in just 1 byte! these call to an address in the first 64 bytes of the address space!

These are called with the commands RST 1 to RST 7 ... and they each call a different address - depending on the platform they may be in use, or have a special function. of course, if we don't need the firmware, then all bets are off, and we can do whatever we want with them!

Unfortunately because systems like the Spectrum and TI-83 have Read only Memory in the address range &0000-&3FFF - so we can't write our own RST's
The MSX Rom has predefined RST's, but if we page in RAM, then there are none defined

RST's are only really useful when you need to do the same call or a few commands a lot!

Sometimes you'll see RSTx followed by a byte or two... (EG EXOS - rst6 on the MSX) The RST function will be looking at the stack, and reading in the 'calling address' to get the location of these bytes as parameters - then modifying the return address to skip over them!

Lets take a look at the RST's on each system, with the firmware use of them

Command	Equivalent Call	CPC	ZX SPEC	MSX	ENTERPRISE	TI-83 Plus	SAM Coupé
RST 0	Call &0000	Reset	ROM - Reset	Rom:? Ram:free	reserved for CPM	Rom:?	Reset
RST 1	Call &0008	Low Jump	ROM - Unused	Rom:? Ram:free	free	Rom:?	Error Handler
RST 2	Call &0010	Side Call	ROM - Print Char	Rom:? Ram:free	free	Rom:?	Print char A
RST 3	Call &0018	Far Call	ROM - Get Char	Rom:? Ram:free	free	Rom:?	get Basic Char
RST 4	Call &0020	Ram Lam	ROM - Get Next Char	Rom:? Ram:free	free	Rom:?	get Basic Front char

RST 5	Call &0028	Firm Jump	ROM - Call Rom1 Routine	Rom:? Ram:free	free	Rom:Bcall	Floating point Calc
RST 6	Call &0030	free for user use	ROM - Unused	Rom:? Ram:free	EXOS call	Rom:?	Usr RST (RST30V)
RST 7	Call &0038	IM1 Interrupt Handler	IM1 Interrupt Handler	IM1 Interrupt Handler	IM1 Interrupt Handler	IM1 Interrupt Handler	IM1 Interrupt Handler

The one we're really interested in here is RST7 at &0038 - because this one is called automatically by the system hardware when IM1 is enabled.
There will be times we need to do an event with controlled frequency, for example playing music, and to do that we use the 'Interrupts' of the system
Interrupts are when the hardware forces the Z80 to process tasks for it - and up until now we've just let the firmware do them itself, but now we're going to look at how to take them over ourselves

the commands **IM0** - **IM2** change the interrupt mode of the z80

IM1 is the most useful to us, IM0 is pretty irrelevant to us as programmers, but on the spectrum we can't write our own IM1 interrupt handler, as the rom stops us writing to &0038, but we can use IM2 - but it's more complex... so we'll look at that **later**!

Not only does writing our own interrupt handler and do 'timed' actions, but if we take over this task from the firmware, then we can be in control of all the Z80 resources - and this includes the 'shadow registers' that' we've not seen until now!

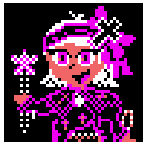
Shadow Registers

Now we've taken total control of the Z80 from the firmware - and we can use all it's registers without worrying about the effect on the firmware (unless we return to basic!)
This gives us access to the Shadow registers - the Z80's 'spare' set of the registers AF BC DE and HL - these are switched in by the firmware so that the main registers are not altered and the program can resume once the interrupt is done!

	Normal Registers		Shadow Registers	
Accumulator	**A**		A'	
Flags		F		F'
HighLow Memory Location	**H**	**L**	H	L
ByteCount	B	C	B	C
DEstinaton	D	E	D	E
IX	IXH	IXL		
IY	IYH	IYL		

You'll notice that there are no shadow versions if IX or IY

The shadow registers cannot be used in combination their normal counterparts, instead we 'toggle' the shadow versions in or out using two special commands which 'swap' the normal and shadow versions.
Of course we could just use PUSH and POP to get the same effect - but swapping the shadow registers is faster - which is why they exist, to allow the Interrupt handler it's own registers to quickly use without affecting normal ones!



Command	**Effect**
EX AF,AF'	Swap A and F with the shadow versions
EXX	swap BC,DE and HL with the shadow versions

So we can swap just AF... or all the other main registers... because we can's swap just some of the 16 bit registers, if we just need to use one pair such as DE or HL for a while, PUSH and POP are better...
EXX only works when we need to use ALL the registers... so times when a separate job needs to be done for a while before carrying on with the main job may be the usage case of shadow registers.
For example In Chibiakumas this is used in the bullet loops, where the main registers are used for calculating bullet position, then the shadow registers are used for player collision detection, before switching back the main registers to continue the loop.

Interrupts

On the systems we're looking at interrupts only occur based on the screen refresh, but the frequency varies depending on the system, some systems need you to 'tell' the hardware the interrupt it's been processed otherwise it'll keep happening immediately again! - lets look at all the Interrupt facts by system so we know what we're dealing with for the systems we're interested in

System	Interrupt frequency	HZ	If interrupt is missed	How to clear the interrupt	Firmware / Interrupt register usage
CPC	6 times per screen draw (CPC+ can have line interrupts)	300hz	Interrupt happens as soon as possible	no need	All shadow registers used Shadow register BC' must not be changed or firmware will crash
ZX SPEC	Once per screen draw	50hz	Interrupt never occurs	no need	Shadow registers are not affected IY must be preserved for firmware to work properly (IY Should be &5C3A?)
MSX	Once per screen draw	50hz	Interrupt happens as soon as possible	in a,(&99) (when chosen VDP status reg is set to default of 0)	Shadow registers are not affected No registers need to be preserved
ENTER PRISE	Once per screen draw	50hz	Interrupt happens as soon as possible	ld a,30h out (0b4h),a	Shadow registers are not affected No registers need to be preserved
SAM Coupé	Various such as line based	?	?	?	Shadow registers are not affected No registers need to be preserved

HALT, DI, EI

The Interrupts will occur automatically at the appropriate time, but we can wait for one to occur, by using the **HALT** command... this will cause the Z80 to wait for an interrupt to occur.

There may be times we cannot allow interrupts to occur - We can stop interrupts from being allowed for a while by using **DI** - and allow them again using **EI**...
On most systems if an interrupt is missed it will occur immediately, but on the Spectrum it never happens - see the table above for details.

There are many times you may need to stop interrupts: if you're interrupt handler uses the shadow registers and you need them... if you're communicating with a series of OUTS that interrupts would conflict with (Keyboard and sound chip are on the same CPC ports)...
Disabling Interrupts reduces the complexity of debugging too, so if you don't need them, you may as well disable them.
Finally there's one special reason why interrupts can't run... If we've altered the stack pointer then the RST7 call cannot occur... we'll learn why you may decide to do that next time!

Communicating with hardware - OUT and IN

Interrupts are the only time the hardware takes over the CPU - but there are times we need to give instructions to the hardware, or receive data from the hardware... and we use the commands OUT and IN to send data to the hardware.

If you think of the computer hardware as a telephone system, and each piece of hardware has a phone numbers from 0-255 (called a port)

OUT (xx),yy will call the hardware at number xx - and give it message yy

IN (xx),yy will call the hardware at number xx - and receive a message which will be stored in yy

Hardware you may access will be things like screen hardware, memory bank switchers, disk systems,joysticks and keyboards - the ports that you'll want to use, and how to use them varies depending on the system..

Now! there's a catch! The Z80 in the ZX spectrum, Sam Coupe and the CPC are wired oddly... they use 16 bit ports and use BC as the port number - even though the assembly command is Out (C) the command in the assembly code is not the one that effectively occurs when the Z80 runs it....

Even worse, some devices are listening to many ports, so OUT ing to &7F00-&7FFF on the CPC should have the same effect - usually one port is the 'recommended' one, and others just 'may' work (I had color changing code that sometimes worked fine, and other times corrupted disks)

Let's make this command confusion clear, or this will waste a load of your time!

System	Command in ASM code	Command the system actually runs
CPC ZX SPEC SAM Coupé	Out (C),A Out (C),C Out (n),A OTIR	Out (BC),A Out (BC),C *** Does not work *** *** Malfunctions ***
MSX ENTERPRISE	Out (C),A Out (C),C Out (n),A OTIR	Out (C),A Out (C),C Out (n),A OTIR

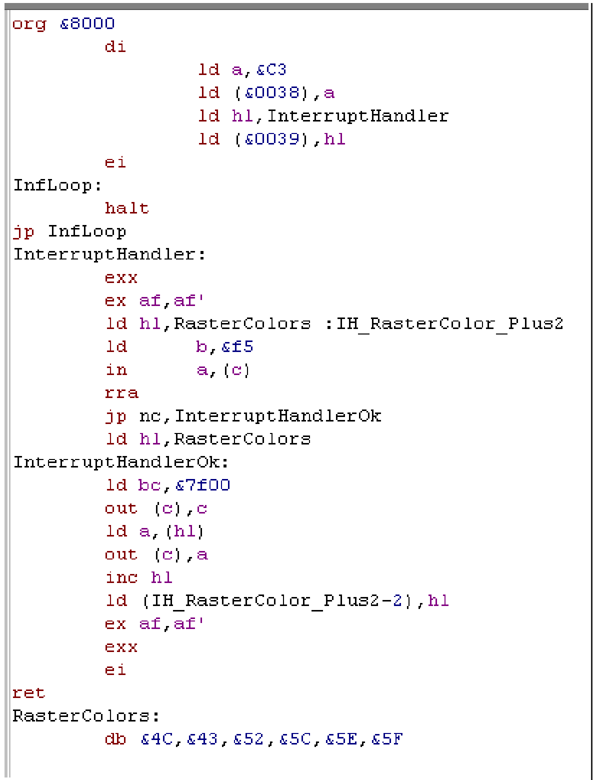
The Z80 has some 'incremental' commands for OUT like OTIR that are functionally similar to LDIR ... because these commands alter B, and B is used as the address of the OUT command these commands will malfunction...

On the Amstrad CPC we can use port &7F to control the screen colors - and because the CPC interrupt occurs 6 times a screen, by changing the color every interrupt, we can get more colors on screen than normally possible - This is how Chibiakumas gets around 8-10 colors on the 4 color mode 1 screen!
We're going to do this ourselves, in the next example

Outs are confusing and hard work! but you won't want to write them very often!
In practice what you'll do is write a function to control the hardware, then you'll forget about how it works and just use that function, so just find a good example online of what you need to do, and just stick to the safe code they use!

Well, that was a lot of theory! but it all fits together into a really neat example!

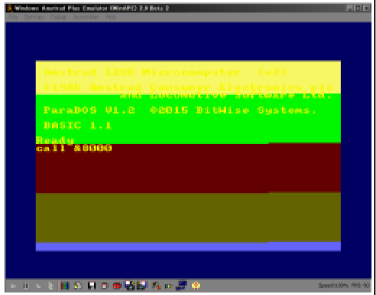
Type in the program to the right. Compile it, and run it by using Call &8000 Note, this example does not return to basic, so you will need to reset your emulator	



```
org &8000
        di
                ld a,&C3
                ld (&0038),a
                ld hl,InterruptHandler
                ld (&0039),hl
        ei
InfLoop:
        halt
jp InfLoop
InterruptHandler:
        exx
        ex af,af'
        ld hl,RasterColors :IH_RasterColor_Plus2
        ld      b,&f5
        in      a,(c)
        rra
        jp nc,InterruptHandlerOk
        ld hl,RasterColors
InterruptHandlerOk:
        ld bc,&7f00
        out (c),c
        ld a,(hl)
        out (c),a
        inc hl
        ld (IH_RasterColor_Plus2-2),hl
        ex af,af'
        exx
        ei
ret
RasterColors:
        db &4C,&43,&52,&5C,&5E,&5F
```

This program will change the background color each interrupt.

You will see the background color change six times during the screen refresh!
(the first one is offscreen!)



Windows Amstrad Plus Emulator (WinAPE) 2.0 Beta 2
File Settings Debug Assembler Help

```
Amstrad 128K Microcomputer  (v3)
©1985 Amstrad Consumer Electronics plc
         and Locomotive Software Ltd.
ParaDOS V1.2  ©2015 BitWise Systems.
BASIC 1.1
Ready
call &8000
```

How does it work? well lets take a look at the code!

	org &8000
Turn off interrupts - We're going to mess with the interrupt handler, and need to make sure an interrupt doesn't occur while we do	di
set &0038 to &C3 &0038 (RST7) is the address called when an interrupt occurs, and &C3 is the bytecode of a JP command	ld a,&C3 ld (&0038),a
After the jump, we put the address of our code that will handle the interrupt	ld hl,InterruptHandler ld (&0039),hl
Now we've finished setting up our interrupt handler, turn interrupts on!	ei
The HALT command waits for an interrupt, but this loop is just an endless loop.... we can't return to basic, because our interrupt handler will break basic!	InfLoop: halt jp InfLoop
When an interrupt occurs the Z80 will end up here... note interrupts are automatically disabled when &0038 is called	InterruptHandler:

swap HL,DE and BC with the shadow versions - we can now use these in our interrupt handler without worrying	exx
swap AF with the shadow version	ex af,af'
Load the address of our Rastercolors list - we're going to selfmodify this, so we have a label at the end	ld hl,RasterColors :IH_RasterColor_Plus2
We want to check if the screen has finished redrawing - we can do this by accessing the 'PPI' port B... rather strangely this is connected to ports &F500 to &F5FF so we do not need to set C for this	ld b,&f5
read A from port (BC) (CPC/ZX are 16 bit so use (BC) ... MSX/ENT are 8 bit, so use (C))	in a,(c)
Bit 0 is marks 'Vsync' so push the rightmost bit into the carry if it's zero, just carry on	rra jp nc,InterruptHandlerOk
if we got here, then we're vsyncing, so reset HL to the start of the array	ld hl,RasterColors
Set B to &7F this is the Gate array address set C to &00 - when we do OUT (BC),C this tells the gate array 'I want to change Color 0'	InterruptHandlerOk: ld bc,&7f00 out (c),c
Read A from the HL Effectively performs - Out (BC),A - sends a palette color to the Gate Array to set Color 0 to	ld a,(hl) out (c),a
Increase HL and remember the next address we want to read from using selfmodifying code	inc hl ld (IH_RasterColor_Plus2-2),hl
Restore the normal registers, and turn interrupts back on Return to whatever was happening when	ex af,af' exx ei ret
The 6 colors we will use for the screen - note these are not the usual 'Basic colors' you'll be used to - these are Hardware Colors!	RasterColors: db &4C,&43,&52,&5C,&5E,&5F

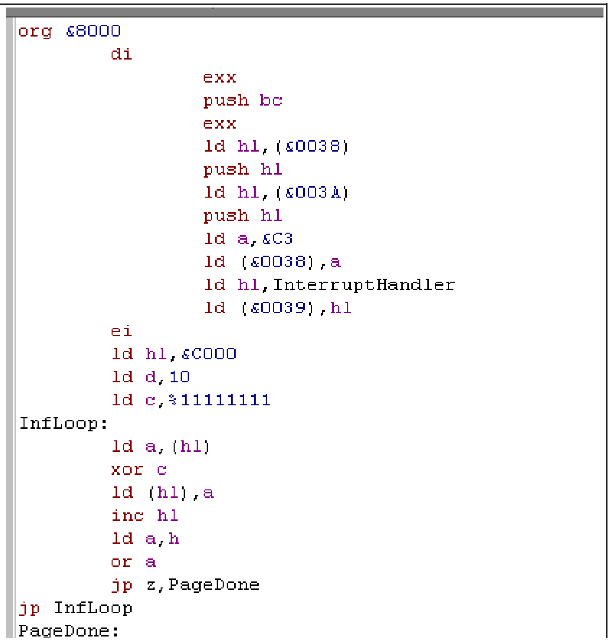
We need to take more care if we need to keep basic and the firmware happy!
You'll need to do return to basic, or use firmware calls for screen operations - or disk access!
On the CPC we need to keep the interrupt handler we replaced, and back up shadow register BC' - the the firmware will be OK

Now lets take a look at how to change all the colors, and this time we'll do some screen changes in between interrupts - and we'll back up everything so we can return to basic!

Type in the example to the right

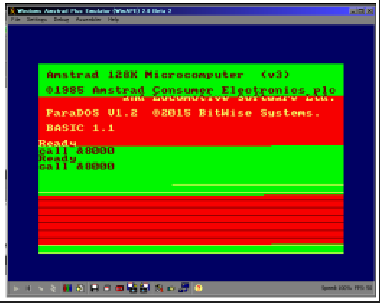
Compile it, and run with Call &8000

This example will flip the screen colors 10 times, then return to basic



```
org &8000
        di
                exx
                push bc
                exx
                ld hl,(&0038)
                push hl
                ld hl,(&003A)
                push hl
                ld a,&C3
                ld (&0038),a
                ld hl,InterruptHandler
                ld (&0039),hl
        ei
        ld hl,&C000
        ld d,10
        ld c,%11111111
InfLoop:
        ld a,(hl)
        xor c
        ld (hl),a
        inc hl
        ld a,h
        or a
        jp z,PageDone
jp InfLoop
PageDone:
        ld hl,&C000
        dec d
jp nz,InfLoop
        di
                pop hl
                ld (&003A),hl
                pop hl
                ld (&0038),hl
                exx
                pop bc
                exx
        ei
ret
InterruptHandler:
        exx
        ex af,af'
        ld hl,RasterColors :IH_RasterColor_Plus2
        ld      b,&f5
        in      a,(c)
        rra
        jp nc,InterruptHandlerOk
        ld hl,RasterColors
InterruptHandlerOk:
        ld bc,&7f00
        out (c),c
        outi
        inc b
        inc c
        out (c),c
        outi
        inc b
        inc c
        out (c),c
        outi
        inc b
        inc c
        out (c),c
        outi
        ld (IH_RasterColor_Plus2-2),hl
        ex af,af'
        exx
        ei
ret
RasterColors:
        db &4C,&43,&52,&5C
        db &52,&5C,&4C,&43
        db &4C,&43,&52,&5C
        db &52,&5C,&4C,&43
        db &4C,&43,&52,&5C
        db &52,&5C,&4C,&43
```

This version will change all 4 screen colors, at all 6 raster points - and returns to basic as if nothing had ever happened!


Windows Amstrad Plus Emulator (WinAPE) 2.0 Beta 2
File Settings Debug Assembler Help

```
Amstrad 128K Microcomputer  (v3)
©1985 Amstrad Consumer Electronics plc
          and Locomotive Software Ltd.
ParaDOS V1.2  ©2015 BitWise Systems.
BASIC 1.1
Ready
call &8000
Ready
call &8000
```

We can only easily change colors at these 5 points...

Drawing each line of the screen takes 64 ticks/cycles... if you want to change color each line, or on a specific line, you need to delay the processor with enough NOP's to get to the line you actually want!

So how does this one work? lets take a look!

Turn off interrupts while we're messing with the interrupt handler	org &8000 di
Back up BC' from the Shadow registers - The CPC firmware relies on this being intact While the CPC firmware uses HL DE and AF in the shadow registers - it doesn't mind us changing them so we don't back those up	exx push bc exx
Back up the first 4 bytes of the current interrupt handler so we can remove our changes later	ld hl,(&0038) push hl ld hl,(&003A) push hl
Set up our custom interrupt handler and turn on interrupts	ld a,&C3 ld (&0038),a ld hl,InterruptHandler ld (&0039),hl ei
Set our pointer HL to the start of the screen We use D as a loop counter - starting at 10 set C to %11111111 - we use this as our XOR mask	ld hl,&C000 ld d,10 ld c,%11111111
XOR each byte in the screen with the mask in C - when we finish the screen we jump to PageDone	InfLoop: ld a,(hl) xor c ld (hl),a inc hl ld a,h or a jp z,PageDone jp InfLoop
Reset HL to the &C000 (the start of the screen) Decrease D and repeat until it's zero	PageDone: ld hl,&C000 dec d jp nz,InfLoop
Turn off interrupts	di
Restore the Firmware default interrupt handler that we backed up before	pop hl ld (&003A),hl pop hl ld (&0038),hl
Restore Shadow register BC'	exx pop bc exx
Turn Interrupts back on and return! Basic will never know what happened!!!	ei ret
Start of the interrupt handler Switch to the shadow registers	InterruptHandler: exx ex af,af'
The same as last time! Set HL to color array (this will be self-modified) see if we're at the top of the screen, and if we are, reset HL	ld hl,RasterColors :**IH_RasterColor_Plus2** ld b,&f5 in a,(c) rra

	jp nc,InterruptHandlerOk ld hl,RasterColors
Tell the Gate Array at &7Fxx that we want to set color 0	InterruptHandlerOk: ld bc,&7f00 out (c),c
OUTI will copy one byte from HL, and INC HL unfortunately it also decreases loop counter B - which will cause problems on the Amstrad - so we do INC B to fix it... even with the 'INC BC'... it's still faster than the separate commands!	outi inc b
Increase C, and do another OUT - this tells the Gate array we want to do the same to Color 1	inc c out (c),c
Do the same for Color 1,2 and 3 A loop counter and a jump would take a bit of time - and this is going to run 300 times a second! so actually have the same commands 4 time rather than using a loop to save some speed! ... this is called 'unwrapping a loop'	outi inc b inc c out (c),c outi inc b inc c out (c),c outi
Remember the next address we want to read from. Swap the shadow and normal registers back, Enable interrupts and return.	ld (**IH_RasterColor_Plus2**-2),hl ex af,af' exx ei ret

We're totally kicking ass now!

We've now learned how to communicate with the hardware ports, we've made our own interrupt handler, and we've learned how to use the 'Shadow Registers'...

We've now learned almost all the Z80 commands! There's not much left to learn before we know everything!

Lesson 8 - Unwrapped Loops, Stack Misuse for speed & rarer Z80 commands

We've covered the all the most important commands, but there are others you may wish to use time to time...

Also there's some clever tricks you'll want to know, that are often used for graphics to make sprite and fill routines as fast as they can be!

Lets take a look at the remaining commands the Z80 has that you may wish to know!

The last two Registers!

There are two registers left that we've not looked at, they have limits, but they may be useful in some cases!

The first one is R... this is used by the system to 'refresh' the memory to keep the data ok in ram... now you should not change this register, because it could cause damage to the memory, buy you can read from it fine - it will have a value in it from 0-127... and as it constantly changes it may be useful as a random number seed!

The other is I... this is used by **Interrupt Mode 2 (IM2)** - but unless you're using the ZX Spectrum you'll be using IM1, and it does nothing in IM1 - so I is free for you to do whatever you want...
Unfortunately there are only 2 commands, one to load A into I, and another to load I into A ... but it's faster than PUSH and POP - so if you want, you can use it for temporary storage!

The I register isn't a lot of use as a general register, and you'll need it for interrupts if you end up using the Spectrum.

In Chibiakumas, The I register is used on systems except the spectrum... an assembler 'Macro' replaces LD I,A with a ld (&xxxx),a command on the spectrum - it takes a little extra memory, but means the spectrum version works without the I register for storage.

DAA and Binary Coded Decimal

Converting 16 bit bytes for screen display is hard, and sometimes you may wish to just use '**Binary Coded Decimal**'...

This is where each byte only stores a number from 0-10... this is how ChibiAkumas stores the player score, there are 10 bytes for each of the 10 digits, this makes showing the score quick and easy.

DAA is a strange command I've never had need to use, it's very complex, and you should look at the Zilog manual if you want to really know about it... the main people actually use it is nothing to do with Binary Coded Decimal, but in fact to convert a byte with a value of 0-15 to a hex char using the sample below

This code will show A onscreen as Hex where A is below 16	daa add a,&F0 adc a,&40 call PrintChar

there are two other even stranger commands! RRD and RLD, I've never used them, and I can't think why you would, but here they are!

RLD	Rotate Left 4 bit nibble at Destination (HL) using bits 0-3 of A as a carry
RRD	Rotate Right 4 bit nibble at Destination (HL) using bits 0-3 of A as a carry

Carry Flag

There are some commands which do maths which will also use the Carry flag, this allows mathematical operations to include overflow from previous calculations. There are 8 bit and 16 bit commands, lets take a look at them, Rather strangely the only 16 bit subtract command is with carry - there is no SUB HL,DE!!!

SBC #	SBC 4	Subtract a (4+Carry) from A
SBC r	SBC B	Subtract (B+Carry) from A
SBC rr,rr	SBC HL,DE	subtract (DE+Carry) from HL
ADC #	ADC 4	add (4+Carry) to A
ADC r	ADC B	add (B+Carry) to A
ADC rr,rr	ADC HL,DE	add (DE+Carry) to HL

As mentioned there is no way to subtract without the carry, so there may be times we need to set or clear the carry flag... another time will be if we want to use the Carry as a status flag - eg some disk routines set the carry flag if reading worked, and clear it if it failed.

There are two commands

SCF	Set the Carry flag (to 1)
CCF	Complement Carry Flag - inverts the carry flag

I bet you thought CCF would clear the carry flag, well it doesn't! but there is an easy way to clear the carry flag! just use

OR A	reset the carry flag

Alternatively, you can just convert a positive 16 bit number into a negative one, with the following code!

Convert DE into a negative number, then add it to HL This will have the effect of subtracting DE from HL	ld a,d cpl ld d,a ld a,e cpl ld e,a

	inc de add hl,de

Return from interrupts with RETI and RETN

There are two 'Special' interrupt return commands RETI and RETN... to my knowledge there is no benefit to using these and they have no practice use on any system I know.

Bulk copy and search

We looked before at LDIR, but there is an alternative, LDDR - this version of the command is for use when HL is pointing to the END of the range you want to copy

RETI	Return from an interrupt
RETN	Return from nonmaskable interrupt

Rather than copying, there are two 'search' commands, which will scan BC bytes from HL to find byte A ... I have never used them, but maybe I'm missing something!
Lets summarize all those commands

LDDR	same as LDIR, but HL goes down not up
CPI	Search from HL, increasing HL for BC bytes - try to find A, PO set if found
CPD	Search from HL, decreasing HL for BC bytes - try to find A, PO set if found

Special OUT and IN commands you'll probably never need!

There are a few special bulk IN and OUT commands, however as before, because BC is used as the port address on Amstrad and Spectrum, they may not work, and I doubt you'll ever need them, but here they are!

IND	In to HL and decrease HL
INDR	In to HL and decrease HL and repeat
INI	In to hl and Increase HL
INIR	In to hl and Increase HL repeat
OUTD	Out from hl and Decrease
OTDR	Out from hl and Decrease and repeat

The INI command may be useful for reading from something like the Keyboard into a buffer... just remember that it decreases B each time you use it, and the Amstrad and Spectrum won't like that one bit!
if you use it in a loop, you'll need to reset B, or do an INI, then an INC B and everything should be fine!

Stack Specials!

The stack has a couple of special commands, that may help if you're being tricky (Stack misuse - covered soon), some we'll use in a moment, but there's a couple that you should know

INC SP	increase the stack pointer - do this twice instead of a POP (it's actually slower - but if you don't want to alter your registers)
DEC SP	decrease the stack pointer
EX (SP),HL	Swap the contents of HL with the item at the top of the stack

Some commands only work with a certain selection of registers, so check the **Cheatsheet** to see the full range of 'options' available!

Now, lets move on to the lesson!

Unwrapped Loops!

There are times when we need as much speed as possible, especially when we're drawing to screen... When we loop around a command like LDIR a lot of time is wasted with compare and jump commands, If we have enough memory to spare - we can jump less, and copy more data - lets take a look!

First lets create a 'slow' version with a regular LDIR command - this program will copy the whole screen TO and FROM a 128k memory bank

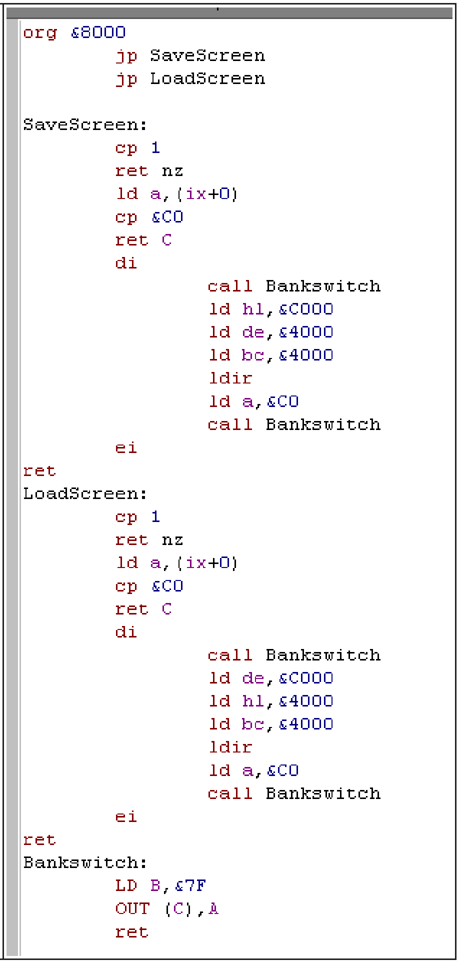
Type the program in to the right.

It gives you 2 commands

Call &8000,xx - will copy the screen TO bank xx
Call &8003,xx - will restore the screen FROM bank xx

xx should be a CPC bank number from C4-C7 or C0 ... other banks may work if you know how CPC banks work!!!

Note, This program will not work right on a CPC464 - as these banks only exist on 128k systems, all the commands will copy to the same bank!



```
org &8000
        jp SaveScreen
        jp LoadScreen

SaveScreen:
        cp 1
        ret nz
        ld a,(ix+0)
        cp &C0
        ret C
        di
                call Bankswitch
                ld hl,&C000
                ld de,&4000
                ld bc,&4000
                ldir
                ld a,&C0
                call Bankswitch
        ei
ret
LoadScreen:
        cp 1
        ret nz
        ld a,(ix+0)
        cp &C0
        ret C
        di
                call Bankswitch
                ld de,&C000
                ld hl,&4000
                ld bc,&4000
                ldir
                ld a,&C0
                call Bankswitch
        ei
ret
Bankswitch:
        LD B,&7F
        OUT (C),A
        ret
```

Most of this should be pretty clear to you by now, but lets have a look at that Bankswitch Command!

This Bankswitch command will send a Bank number to the Gate array

The gate array is at &7Fxx...

```
Bankswitch:
   LD B,&7F
   OUT (C),A
   ret
```

on the CPC there are 8 possible bank configurations, &C0 is the default, where the main 64k are in memory.... the other options are shown below:

	C0	C1	**C2**	C3	C4	C5	C6	C7
0000-3FFF	RAM_0	RAM_0	**RAM_4**	RAM_0	RAM_0	RAM_0	RAM_0	RAM_0
4000-7FFF	RAM_1	RAM_1	**RAM_5**	RAM_3	**RAM_4**	**RAM_5**	**RAM_6**	**RAM_7**
8000-BFFF	RAM_2	RAM_2	**RAM_6**	RAM_2	RAM_2	RAM_2	RAM_2	RAM_2
C000-FFFF	RAM_3	**RAM_7**	**RAM_7**	**RAM_7**	RAM_3	RAM_3	RAM_3	RAM_3

If you have more than 128k, you will have options C8,C9 and so on... up to FF if you have 512k!

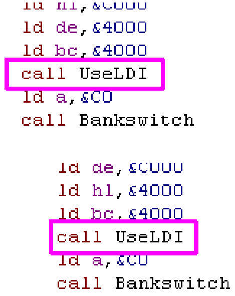
Note, you cannot use &C2... this swaps out &8000 - which is where your program is, so it would cause a crash!

Speed Up!

Now let's unwrap the loop... We're going to make a few changes, and make it faster!
Lets try this faster version we use 16 LDI commands - by skipping the R (repeat check) for most of the commands we can increase speed by around 25%!

You only need to make a few modifications to your code for this faster version!

Replace both the LDIR commands with "Call UseLDI"

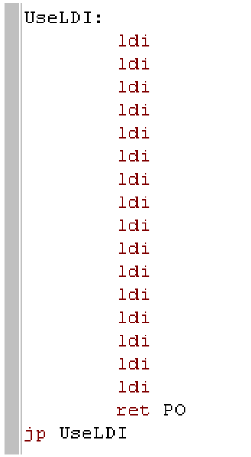


```
ld hl,&C000
ld de,&4000
ld bc,&4000
call UseLDI
ld a,&C0
call Bankswitch

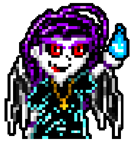
    ld de,&C000
    ld hl,&4000
    ld bc,&4000
    call UseLDI
    ld a,&C0
    call Bankswitch
```

Add this function to the bottom of your code!

Try the new commands, you should see they're noticeably faster!



```
UseLDI:
        ldi
        ldi
        ldi
        ldi
        ldi
        ldi
        ldi
        ldi
        ldi
        ldi
        ldi
        ldi
        ldi
        ldi
        ldi
        ldi
        ret PO
jp UseLDI
```



We've sped things up but of course, the code is bigger! We've traded memory for speed!

Was it worth it? well that's depends what you can spare... This often the choice you're faced with when programming in 8 bits!

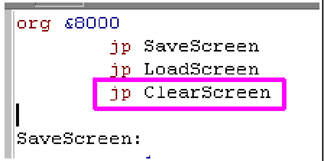
There's not much to look at here, the only thing to note is that LDI, or LDIR set the PO flag to true when BC=0... Note, BC must be a multiple of 16, or this program will miss the 'return' and overwrite all the memory!

Stack Misuse!

There may be times when we need to read or write data super quickly... and there's a clever trick for this... as mentioned before, the Stack pointer offers the fastest reading and writing the Z80 can offer.

As we know the Stack pointer is designed for PUSH and POP, and for CALL's, but if we don't need to do any of these things, we can temporarily alter the stack pointer, and use it to bulk read, or bulk write a block of data super quick!... of course, Interrupts are a call to &0038 - so we'll have to disable interrupts to be safe! (Depending on what you're doing, you MAY be able to allow interrupts - eg if you're only writing... a few bytes would be temporarily corrupted by the interrupt handler's calls and pushes - though there are **complex tricks** to avoid this)

Add "**JP ClearScreen**" to your jumpblock

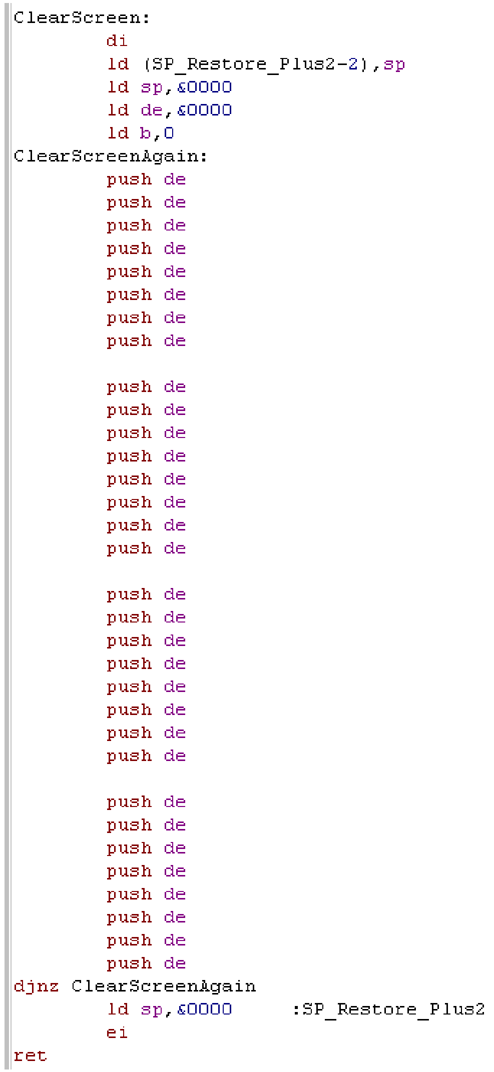


```
org &8000
        jp SaveScreen
        jp LoadScreen
        jp ClearScreen

SaveScreen:
```

Add the code to the right to the bottom of your program

There are 32 PUSH DE's in total... so get Copy-Pasting!!



```
ClearScreen:
        di
        ld (SP_Restore_Plus2-2),sp
        ld sp,&0000
        ld de,&0000
        ld b,0
ClearScreenAgain:
        push de
        push de
        push de
        push de
        push de
        push de
        push de
        push de

        push de
        push de
        push de
        push de
        push de
        push de
        push de
        push de

        push de
        push de
        push de
        push de
        push de
        push de
        push de
        push de

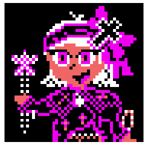
        push de
        push de
        push de
        push de
        push de
        push de
        push de
        push de
djnz ClearScreenAgain
        ld sp,&0000      :SP_Restore_Plus2
        ei
ret
```

We've done some tricky stuff, so lets take a look!

	ClearScreen:

Turn off interrupts... We're going to mess with the stack, and an Interrupt Call would use the stack, so lets stop them for safety	di
Back up the stack pointer using self modifying code	ld (**SP_Restore_Plus2**-2),sp
We're going to overwrite &C000-&FFFF Load the stackpointer as &FFFF+1 (&0000)... each push decreases the stackpointer by two before pushing the data, so we set the start point to the first byte to write+1	ld sp,&0000
We're going to push DE, so this is the byte pair we're going to fill the screen with	ld de,&0000
We're going to push 64 bytes each time, so we need to do this 256 times... setting B to 0 means the loop will occur 256 times before B reaches zero again	ld b,0
64 2 byte pushes	push de ... push de push de
Loop until B becomes zero	djnz ClearScreenAgain
Restore the correct stack pointer that we stored before	ld sp,&0000 :**SP_Restore_Plus2**
Turn Interrupts back on and return	ei ret

ChibiAkumas uses Stack in this way to flood fill the background gradient super quick... it fills the screen with a parallax gradient faster than the firmware CLS command!
It also uses POP to quickly read sprite data for transparent sprites.
In fact when a game does things super fast, it's likely PUSH or POP is being misused somewhere!
It's tricky though, so don't worry about it at first, get your game working with the normal stuff,then if you want you can add stack misuse later to up the frame rate!



Congratulations! You've reached the end of this series of lessons...
We've covered all the Z80 commands you're likely to ever need, and learned lots of great stuff!
But stick around! We've moving on to bigger and better things with new series' of lessons!

This ends the Basic series.. but the lessons are just beginning!... Tune in next week for more Z80 fun!

Appendix

Command	**Alternate form**	**Meaning**	**Example**	**Notes**
ADC r	ADC A,r	Add register r and the carry to A	ADC B	
ADC #	ADC A,#	Add number # and the carry to A	ADC 2	
ADC HL,rr		Add 16 bit register rr and the carry to HL	ADC HL,BC	
ADD r	ADD A,r	Adds register r to A	ADD B	
ADD #	ADD A,#	Adds number # to A	ADD 5	remember ADD 254 is like -2
ADD HL,rr		Add 16 bit register rr to HL	ADD HL,BC	remember ADD HL,65534 is like -2
AND r	AND A,r	bitwise AND register r with A (result in A)	AND B	
AND #	AND A,#	bitwise AND number # with A (result in A)	AND %11100000	if A=%00111000... AND %11100000 will result in %00100000
BIT b,r		get bit b from register r (0 is far right bit)	BIT 7,a	

CALL ##		Call address ##	Call &4000	this is like GOSUB.... Note: CALL pushes PC onto the stack
CALL c,##		Call address ## if condition C is true	Call Z,&4000	this is a THEN GOSUB statemenr
CCF		Invert carry flag (compliment carry flag)	CCF	if you want to clear the carry flag, do OR A ... it will set carry flag to 0 - alternatively SCF, CCF will do the same but is slower
CP r		Compare A to register r	CP A	this is your IF statement
CP #		Compare A to number #	CP 255	Use OR A instead of CP 0 - it has the same effect but is smaller and faster!
CPD		Compare and decrease... CP (HL), DEC HL,DEC BC, PO set if BC=0	CPD	
CPDR		Compare and decrease, repeat ... CP (HL), DEC HL,DEC BC, until BC=0 or found	CPDR	
CPI		Compare and increase... CP (HL), INC HL,DEC BC, PO set if BC=0	CPI	
CPIR		Compare and increase, repeat ... CP (HL), INC HL,DEC BC, until BC=0 or found	CPIR	
CPL		invert all bits of A (ones ComPLiment)	CPL	turn %11001100 to %00110011
DAA		Special command for Binary coded Decimal, update A	DAA	
DEC r		decrease value in register r by one	DEC B	
DEC rr		decrease value in register rr by one	DEC HL	
DI		Disable interrupts	DI	do this if you need to use shadow registers
djnz #		Decrease B and Jump if NonZero... only jr jump, so must be close.. +-128 bytes away	DJNZ label	this is how you do a loop
EI		Enable interrupts	EI	
EX (SP),HL		Exchange the bytes at (SP) with the value in HL	EX (SP),HL	
EX AF,AF'		Exchange A & Flags with the shadow register A' & Flags'	EX AF,AF'	
EX DE,HL		Exchange DE with HL	EX DE,HL	HL can do more than DE, so you may want to quicly swap them
EXX		Exchange BC,DE,HL with the shadow registers BC',DE',HL'	EXX	Use this if you need these register values later, but want to do another job now
HALT		Wait until interrupt occurs	HALT	force music to play... DI, HALT will force emulator to stop permanently - good for debugging a particular point in the code on MSX or SPECTRUM where defining breakpoints is hard
IM 0		Interrupt mode 0		
IM 1		Interrupt mode 1		on the MSX or CPC this is the only one you need... on spectrum the firmware uses this mode. on MSX... IM 1 does a CALL &0038 every screen refresh (50hz) on CPC... IM 1 does a CALL &0038 6 times during screen refresh (300hz)
IM 2		Interrupt mode 2		the only usable interrupt mode for our game on the ZX SPECTRUM not as easy to use as IM 1... you need to use all the memory between &8000-&8183 and the I register - but the result is the same as IM1 on the CPC/MSX
IN A,(#)		read from port # into A	IN A,(3)	Note: the Z80 on the ZX SPECTRUM & CPC are wired strangely - this function does not work right
IN R,(C)		read from port C into A	in A,(C).	Note: the Z80 on the ZX SPECTRUM & CPC are wired strangely - they actually do in (B)
IN (C)		read from port C... but do nothing with it	in (C).	Note: the Z80 on the ZX SPECTRUM & CPC are wired strangely - they actually do IN (B)
INC r		increase r by one	INC B	
INC rr		increase rr by one	INC HL	
IND		In (HL),(C)...dec HL... dec B	IND	Note: the Z80 on the ZX SPECTRUM & CPC are wired strangely - they actually do in (B) which is also the loopcounter, so this will malfunction

INDR		In (HL),(C)...dec HL... dec B until B=0	INDR	Note: the Z80 on the ZX SPECTRUM & CPC are wired strangely - they actually do in (B) which is also the loopcounter, so this will malfunction
INI		In (HL),(C).. Inc HL... Dec B	INI	Note: the Z80 on the ZX SPECTRUM & CPC are wired strangely - they actually do in (B) which is also the loopcounter, so this will malfunction
INIR		In (HL),(C).. Inc HL... Dec B until B=0		Note: the Z80 on the ZX SPECTRUM & CPC are wired strangely - they actually do in (B) which is also the loopcounter, so this will malfunction
JP (HL)		Jump to the address stored in HL	JP (HL)	if HL=&4000 then this would be the same as JP &4000
JP ##		Jump to ##	JP &4000	JP is like GOTO
JP c,##		Jump to ## if condition c is true		this is like a THEN GOTO statement
JR #		jump to # must be +- 128 bytes from current location	JR label	JR is faster than JP when FALSE (jump didn't occur) but slower when TRUE (Jump occurs) JR saves one byte over JP - which is a lot on an 8 bit!
JR c,#		jump to # if condition c is true must be +- 128 bytes from current location	JR z,label	JR is faster than JP when FALSE (jump didn't occur) but slower when TRUE (Jump occurs) JR saves one byte over JP - which is a lot on an 8 bit!
LD (rr),A		Load memory address in (rr) with value in A	LD (BC),A	
LD (##),A		Load A into memory address ##	LD (&4000),A	
LD (##),rr		load 16 bit regisers rr into memory ## and ##+1	LD (&4000),BC	bytes are loaded into memory in reverse order - though this only matters if you're doing clever things!, eg if you do: LD BC,&1122... LD (&4000),BC &4000 = 22 &4001=11
LD (##),SP		Load the Stack Pointer into ##	LD (&4000),SP	back up the stack pointer - you may want to use an alternate stack for a while or misuse the stack pointer for fast bulk reading or writing.
LD A,(rr)		Load A from memory location (rr)	LD A,(BC)	
LD A,(##)		Load A from memory location ##		LD A,(&4000)
LD A,I		Load A from the Interrupt register		The interrupt register only has a few commands, you'll need this to get data out of I
LD A,R		Load A from the Refresh register		R constantly changes - you can use it for random numbers!
LD rr,(##)		load 16 bitr registers rr from memory (##)	ld BC,(&4000)	
LD I,A		Set the Interrupt register I to A		This is the only way to get data into I
LD R,A		set Refresh register to A		NEVER USE THIS - I'm told messing with the refresh register can damage your computers memory!
LD SP,(##)		Loadthe stack pointer from memory location ##		Restore the stack pointer.
LD SP,HL		Set the Stack Pointer to HL		
ld r1,r2		Load r2 into r1	LD B,C	you can't do LD HL,BC instead do LD H,B... LD L,C
LD r,#		Load r with value #		note, rather than doing LD A,0 do XOR A... it's faster but the result is the same!
LD r,(ir+-#)		Load r from intirect register ir (IX or IY) +-# bytes	LD B,(IY+4)	IF IY=&4000 LD B,(IY+4) would do the same as LD B,(&4004)
LD rr,##		loads 16 bit number ## into rr	LD BC,&4000	
LDD		Load (DE),(HL)... DEC HL... DEC DE... DEC BC	LDD	Copy a range backwards with no repeat - faster to do this 10 times than to use LDDR with B=10
LDDR		Load (DE),(HL)... DEC HL... DEC DE... DEC BC... Repeat until B=0	LDDR	Copy a range backwards
LDI		Load (DE),(HL)... INC HL... INC DE... DEC BC		Copy a range with no repeat - faster to do this 10 times than to use LIDR with B=10
LDIR		Load (DE),(HL)... INC HL... INC DE... DEC BC... Repeat until B=0		Copy a range ... can also be used to fill a range by setting DE=HL+1

NEG		NEG		Negates A... Turns 5 into -5 (251)
NOP		Does nothing		Can be used as a placeholder for self modyfying code
OR r	OR A,r	Bitwise OR r with A	OR B	
OR #	OR A,#	Bitwise OR # with A	OR %11100000	if A=%00111000... OR %11100000 will result in %11111000
OTDR		OUT (C),(HL)... DEC HL... DEC B... repeat until B=0		Note: the Z80 on the ZX SPECTRUM, Sam Coupe &CPC are wired strangely - ZX & CPC actually do OUT (B),(HL)... DEC HL... DEC B.. note B is loop counter and port! this is dangerous!
OTIR		OUT (C),(HL)... INC HL... DEC B... repeat until B=0		Note: the Z80 on the ZX SPECTRUM, Sam Coupe & CPC are wired strangely - ZX & CPC actually do OUT (B),(HL)... INC HL... DEC B.. note B is loop counter and port! this is dangerous!
OUT (#),A		OUTput A to port # (Does not work on CPC/XZ.. see notes)		Note: the Z80 on the ZX SPECTRUM, Sam Coupe & CPC are wired strangely - this command does not work
OUT (C),r		OUTput r to port C (B on CPC/XZ.. see notes)	OUT (C),C	ZX, Sam Coupe & CPC actually do OUT (B),r... this allows port and val BC to be set in one go by LD BC,nn
OUT (C),0		OUTput 0 to port C (B on CPC/XZ.. see notes)	OUT (C),0	Note: the Z80 on the ZX SPECTRUM & CPC are wired strangely - they actually do OUT (B),0
OUTD		OUT (C),(HL)... DEC HL... DEC B		ZX, Sam Coupe & CPC actually do OUT (B),(HL)... DEC HL... DEC B.. note B is loop counter and port!
OUTI		OUT (C),(HL)... INC HL... DEC B		ZX, Sam Coupe & CPC actually do OUT (B),(HL)... INC HL... DEC B.. note B is loop counter and port!
POP rr		Pops 2 bytes off the stack and puts them in rr	POP DE	Much faster than reading DE using LD DE,(####) or LD D,(HL).. INC HL, LD E,(HL)
PUSH rr		Push 2 bytes from rr into the stack	PUSH DE	Much faster than writing DE using LD (####),DE or LD (HL),D.. INC HL, LD (HL),E
RES r,b		Reset bit b of register r (sets bit to zero)... Bit 0 is far right	RES B,0	using AND # would need loading register into accumulator - this does not
RET		Return	RET	return... Note: RET pops PC off the stack
RET f		Return if condition f is true	RET Z	
RETI		Return from Interrupt	RETI	You'll probably never need this
RETN		Return from Non maskable interrupt	RETN	You'll probably never need this
RL r		Rotate bits in r left using carry bit	RL B	RL A is faster than RL B
RLC r		Rotate Left and Copy bit 7 to bit 0 (wrapping the bits)	RLC B	doing RLC B on %10011000 results in %00110001
RLD		Rotate Left 4 bit nibble at Destination (HL) using bits 0-3 of A as a carry	RLD	
RR r		Rotate bits in register r Right with carry	RR B	RR A is faster than RR B
RRC r		Rotate Right and Copy bit 0 to bit 7 (wrapping the bits)	RRC B	doing RRC B on %00001101 results in %10000110
RRD		Rotate Right 4 bit nibble at Destination (HL) using bits 0-3 of A as a carry		
RST 0		Call &0000	RST 0	Rst's are one byte calls, they can save memory! you cant reconfigure them on SPECTRUM
RST 1-5		Call &0008 (1), &0010 (2), &0018 (3), &0020 (4), &0028 (5)	RST 3	
RST 6		Call &0030		CPC defines this as spare for user configuration
RST 7		Call &0038	RST 7	RST 7 is called by the Z80 when an interrupt occurs... put your own interrupt handler here to take over interrupts from the firmware!
SBC r	SBC A,r	SuBtract register r and the Carry from A	SBC B	
SBC #	SBC A,#	SuBtract # and the Carry from A	SBC 3	
SBC HL,rr		Subtract 16 bit register rr from HL with the	SBC	Note there is no SUB HL,rr command - so clear the carry and use this if you need to, or use

		carry	HL,DE	cpl to flip all the bits in each of the two regisers in rr, then do INC rr then ADD HL,rr
SCF		Set the Carry Flag		
SET b,r		set Bit b to 1 in register r (note bit 0 is at the far right(	Set A,0	using OR # would need loading register into accumulator - this does not
SLA r		Shift Left r and Alter bit 0 to 0	SLA B	%01111101 becomes %11111010
SLL r		Shift Left and Load bit 0 with 1	SLL B	%01111101 becomes %11111011
SRA r		Shift Right r and Alter bit 7 to same as previous bit 7	SRA B	%01111101 becomes %00111110
SRL r		Shift Right and Load bit 7 with 0	SRL B	%01111101 becomes %10111110
SUB r	SUB A,r	Subtract register r from A	SUB B	
SUB #	SUB A,#	Subtract number # from A	SUB 5	
XOR r	XOR A,r	XOR (invert bits) in X with register r	XOR B	XOR A does the same as LD A,0 ... but is smaller and faster!
XOR #		XOR (invert bits) in X with number # (when bit in # is 1)	XOR %11110000	if A=%00111000 and you do XOR %11110000 the result is %11001000

Note, as the Accumulator does most mathmatical operations you can just enter ADD 4 ... but ADD A,4 has the same meaning... the shorter form will be used in my guide

Note, On the CPC,Sam Coupe and ZX Spectrum due to the way the Z80 is wired OUT commands do not work as stated... OUT (C) will actually do OUT (B).. making commands like OTIR that use B as a counter likely to cause hardware problems (It caused random disk writes to me!)... OUT (#) will not work at all... OUT works normally on he MSX OUT (C) will do Out (C) and Out (#) works as stated