The Link Between C and Assembly

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. . .How would you like to be able to access a machine language routine the same way you would access a C function?

If you own "Power C" from Spinnaker, you own an excellent and powerful implementation of the C language. If you don't, but have been thinking about buying a copy, the possibilities opened by this article may be enough to push you over the edge. Even if you don't own and don't plan to buy Power C, the techniques mentioned in this article may apply to other compilers that compile in two separate stages (from source into object, then from object into executable) or even for other types of programs.

The Problem. . .

I was writing some graphics routines to be used from C programs. I decided that, while Power C is probably the fastest compiler for the C-64 ("A Comparison of Language Speeds", Volume 7, Issue 5), nothing can beat hand-coding a piece of code for speed. I promptly set about coding assembly language routines to clear the bitmap, plot points, and all the other nice things you like to do to graphics screens quickly. In looking for a good way to use these routines from my C programs, I came across the SYS function. I tried it. I gave up on it. The main trouble with the SYS function is that it is little better than the BASIC SYS command. It assumes the code is already in memory (if it isn't, a special disk access is needed to put it there). It does *not* provide very descriptive access to the routines. The one thing it has over BASIC's SYS command is that it can handle parameters - three bytes' worth. Some of the functions I wanted to access, however, required more than 24 bits' worth of information.

So, giving up on the SYS function, I looked around and about and inside out for a better way. And I found it! My search led me to the internals of the object files - those mysterious files that are the limbo between pure source code and pure executable machine language. I didn't have a lot of hope. I've looked in real spaghetti files before and was afraid the object files would turn out to be too complicated for me to figure out without the aid of extensive documentation and weeks of personal interviews with Power C author Brian Hilchie. My fears were groundless.

Starting My Quest

To begin with, I already sort of knew what the linker does. It takes an object file, moves it to a specific address in memory, and then checks to see what the file needs to be linked with. It then gets those files, puts them at unique addresses, and checks what files they need. Finally, when all the files are linked in with everything they need and the linker can't find anything else to add, it writes the executable file containing all the object files all linked up nicely. But what is in an object file? How does it let the linker know what it wants and what it has to offer?

My first clue to the general format of the object files came from the mysterious and totally undocumented (in my manual, at least) LIB.C file. This is a nice utility that puts a list of all the global identifiers from multiple object files into one file so that the linker can find their functions and variables very easily. The first four files on the library side of the disk (STDLIB.L, STDLIB2.L, SYSLIB.L and SYSLIB2.L) can be examined and modified with this utility.

By looking at how LIB.C scans object files, I was able to determine that object files are divided into four sections. I call them the Code section, the Relocate section, the Global section, and the External section. Each section begins with a word (two bytes in low/high order) indicating how long the section is in bytes (for the Code section) or entries (for the other sections). The general format is summarized in Table 1.

Section 1: The Code Section

The first section looks familiar when viewed through a machine language monitor. It is straight machine language. Well, almost straight. There are a few differences that will be straightened out by the linker.

To begin with, there is some information that isn't known at the time the code is created. Any instruction referencing external functions or variables is going to have to have its operand filled in by the linker, so it doesn't matter what value is in the operand.

Secondly, one of the jobs of the linker is to decide where in memory to place the code. In order to enable the linker to do that easily, the code is generated by the compiler as if it were assembled to location $0000. In other words, if somewhere in the code you had a JMP instruction to transfer execution to the first instruction in the code section, it would be a JMP $0000 instruction. The linker can then relocate the code by calculating a new base address and adding it to the offsets contained in the operands of any instructions referencing a part of the code. But how does the linker know which instructions need to be adjusted for the new address and which are already pointing at the correct location (i.e. a ROM routine, a zero page location, etc.)? This is where the second section comes in:

Section 2: The Relocate Section

This section points out to the linker which instructions need to be adjusted during the address relocation process. If, for example, the instruction JSR $0073 is flagged by this section and the linker decided to relocate the code to base address $1153, then the instruction will be changed to JSR $11c6. If the JSR were *not* flagged by this section, if would remain JSR $0073.

This section consists of a list of addresses (as offsets from $0000) of instructions that need their operands relocated. The length word indicates how many addresses (of two bytes each) are in this section.

Section 3: The Global Section

This section tells the linker what the module has to offer to other modules. Any functions or variables that may be used by external routines are flagged in this section.

The length word indicates how many entries are in this section. Each entry will contain a name or identifier, a byte flag, and an address.

The name will be the one or more characters by which this variable or routine can be accessed. Remember that C is case sensitive and that identifiers coming out of the C compiler will be truncated to 8 characters. Terminate the name with a NULL (chr$(0)).

The byte flag tells the linker whether the entry is referring to a location in the code section or an absolute location. If the byte is a one, then the linker will know that it is referencing the code section and will adjust the address when the code section is relocated. A zero tells the linker that the address does not need to be relocated (it may be pointing to a ROM routine or some other stable location).

Section 4: The External Section

This section is sort of the opposite of the global section. It tells the linker what external routines and variables are needed by this module. It contains entries similar to those in the global section. Each entry consists of the name of the routine or variable to link in, a word specifying how to link it in (offset), and the address of the instruction accessing the external entity.

The word following the name allows several possibilities for linking in the address of the external entity. First of all, it allows you to link in the address of the entity, the address plus one, the address plus two, etc. You can add up to 8191 bytes to the address. Secondly, you can decide to either link in the whole address (for absolute instructions such as LDA xxxx) or just the high or low byte of the address (for immediate instructions such as LDA #<xxxx or LDA #>xxxx).

The way to specify these options is to take the number of bytes you want to add to the base address and multiply by four (to shift it into the upper 14 bits). Then you add 0, 1, or 2 depending on whether you want the whole address, the high byte, or the low byte respectively. The resulting value would go in this offset word.

Finishing up

To finish up the object file, just terminate it with two NULLs. Now you can give it the linker test! Beware, because the linker was created to link together modules created by the C compiler. Since the linker knows what type of object files the compiler is capable of creating, it isn't very error tolerant and will lock up on just about any irregularity. If you say there are five global entries, make sure you include exactly five. Make sure you terminate all identifiers with NULLs and the file with two NULLs. Et cetera.

Special Routines

There are several special external routines you may need to use when writing code to be linked in to work under the C environment. First is the **c$start** routine. This routine is included in every C program and is responsible for setting up the C environment. It does some setup work, calls the **main()** function, then does some clean-up work before returning control to the shell or BASIC. Thus, **c$start** must be the first thing to be called. The first instruction of the first file to be linked in must call this routine. But how do you know which of several files will be linked in first? To solve this, the C compiler puts a JMP c$start instruction as the first instruction in every module it generates. If there is a chance that your module might be linked in first, you would also want to put in a jump to the **c$start** external routine as the first instruction in your module.

Another important routine you will want to use is the **c$funct_init** routine. This is a routine that would be called first thing in any function you create. Normally, C functions call the routines **c$105** on entry and **c$106** just before returning instead of **c$funct_init**. **c$105** copies the local variables (locations $2b-4a) and parameters (cassette buffer $033c-$03fb) out of the way so the space can be used for new variables and parameters; **c$106** copies them in again upon completion of the function. These require a lot of overhead, so the **c$funct_init** routine comes in handy for small routines that will *not* need to use the local variable area (they can use the temporary locations $22-$2a and $4b-$60) and that will *not* call other routines that will use the variable area or the parameter area.

Unfortunately, to explain **c$105** and **c$106** in more detail would take us out of the scope of this article and into memory management.

Parameter Passing

One of the advantages of linking machine language routines through the object file as opposed to the SYS function is the ability to pass dozens of parameters. On the originating end, the values of the variables you are passing (or their addresses, if you are passing pointers) are stored in memory starting at $033c and in the same order as they were declared in the function descriptor. The accumulator is then set to reflect the number of bytes used up by the parameters, and the new function is called; it can then access the parameters directly from this memory. As an example, the function **FRED (Age, Name, Weight, Height)**; where **Age** is a character type, **Name** is a pointer to an array of characters, **Weight** is a floating point number, and **Height** is an integer; would store:

```
$033c  – Age (one byte)
$033d  – Name (low byte of pointer)
$033e  – Name (high byte of pointer)
$033f  – Weight \
$0340  – Weight |
$0341  – Weight >(FP representation)
$0342  – Weight |
$0343  – Weight /
$0344  – Height (low byte)
$0345  – Height (high byte)
```

The accumulator would be set to 10. The called routine would naturally have to know what order the parameters are in and what type of variable each parameter is. If the called function needs to return a value, it should put it back into the cassette buffer at location $033c. Since the value is not written until just before returning, you don't have to worry about overwriting what is already there.

An Example Is Worth Two Thousand Bytes

In order to clear up any questions you may still have, I will present a practical example of creating an object file from an assembly language file. While I used PAL as my assembler, you should be able figure out how to get your assembler to do some of the unusual things necessary to create an object file. Unfortunately, the current version of SYMASS, the PAL-compatible assembler, will not be able to assemble my example because it requires assembling to disk (since the code is assembled to location $0000).

Listing 2 is a Doodle program written in C. It requires four external routines, which it will get from Listing 1, the assembly language portion. You will have to compile the C portion, assemble the assembly language portion, and then link them together with the linker. You will then have an executable program that will let you draw on the hires screen with the IJKM diamond. The +, –, and / keys set the drawing mode to on, off, and flip respectively. RUN/STOP restores the normal text screen and exits the program. The program doesn't do any boundary checking – so don't try to draw off the screen or you may destroy something vital!

Listing 1 provides four functions: **Clear**, **Plot**, **FastKeys**, and **SlowKeys**. **Clear** fills any block of memory of any size with any byte. **Plot** allows you to manipulate any pixel on the graphic screen. **FastKeys** sets up an interrupt routine to speed up the keyboard repeat, and **SlowKeys** turns it off again.

Line 5 in listing 1 opens the object file to which it will write the object file. I am following a convention (which I suspect the author of Power C followed) of suffixing object files created from C source with a **.O** and object files created from Assembly source with **.OBJ**.

Lines 10 and 20 "fix" PAL so it writes the object file correctly for our purposes. Normally a machine language file begins with the object code origin address so that the kernal LOAD routine knows where to place the routine when you load it. The linker does not require that address and, in fact, gets confused by it. The pokes in line 20 replace the two JMP $FFD2 instructions that write the address to the file with do-nothing BIT $FFD2 instructions. If you have another assembler you will have to find a way to get around this problem. You may have to write a little program to strip the first two bytes off the object file after creating it.

Line 30 invokes PAL, and line 40 tells it to assemble to the file opened in line 10. In line 50 I tell the assembler to start assembling to location $0000 (minus two for the length word). I then define the filler label xxxxxx in line 60. I use this label in references to external entities since the assembler requires something. The linker will fill in the correct address. Line 120 sets up the jump to the setup routine in case this object file is the first one to be linked in.

Lines 100, 7010, 8020, and 9020 set up the length word for each of the sections. In line 100 it is just a matter of putting the end of the code section since the code starts at $0000. The length in line 7010 is calculated by taking the number of bytes defined in the relocate section, dividing by two (since the length is expressed in words instead of bytes), and subtracting one (to skip the length word). Calculating the length in the global and external sections is a little different. Here I use a label as if it were a variable, adding one for each entry, using PAL's left-arrow temporary assignment operator. Since calculating labels happens in the first pass and the code is written the second pass, it doesn't matter that the lines that increment the label (lines 8040, 8090, 8140, etc.) appear after the line putting the word in the file (line 8020 or 9020).

The **Clear** routine is in lines 160-390 and the global entry at lines 8090-8120 open this routine to allow access by other functions. Likewise, **Plot** in lines 500-1010 is opened by lines 8140-8170 as are the **FastKeys** and **SlowKeys** routines by the entries at lines 8190-8220 and 8240-8270 respectively.

Notice the global entry at lines 8290-8320 and the two external entries at lines 9280-9360 for the **irq%%** routine. Sometimes you may need to access a local routine or variable in a more specialized way than just by absolute addressing. Lines 1120 and 1140 need to access the local routine **irqkeys** by immediate addressing. The relocate section, however, only relocates absolute addressing instructions. In order to get it to work I had to treat the **irqkeys** routine as an external routine. This shows that local routines can be treated as external routines if necessary. Also, I chose to add two % symbols to the name to ensure that it doesn't interfere if you happen to define another routine named **irq** somewhere else.

In line 970 I am storing a value back into location $033c. This is to provide a return value so that the calling routine can check the new state of the pixel after the **Plot** routine is called.

In Conclusion...

I would like to thank Brian Hilchie for a powerful compiler that has raised the productivity value of the Commodore 64 by several notches. Thanks also for an elegant and straightforward object format. But why didn't he include this information in the documentation – to allow someone to make some money writing articles about it? I would suggest to Brian that, given the nature of C, machine language, and his specific implementation, it should not have been hard for him to include a #ASM and #ENDM set of compiler directives to allow inline assembly language. This would have made an attractive compiler virtually irresistible. I would recommend him adding it to a future update. After all, compared to writing a compiler, adding a simple assembler should be peanuts. He may be able to use PAL or SYMASS as a skeleton. If anyone could give me Brian Hilchie's address, I would like to be able to write to him myself.

Those of you who want to take these ideas farther might want to tackle writing an assembler that would assemble source into object files of the type linkable by the C linker. You would probably need to add some pseudo ops like **.GLOB**, **.EXTN**, and **.FUNC**.

If you want to discuss specifics for such an assembler, or have any questions, problems, corrections or criticisms, I would love to hear from you. I can be reached at the following address:

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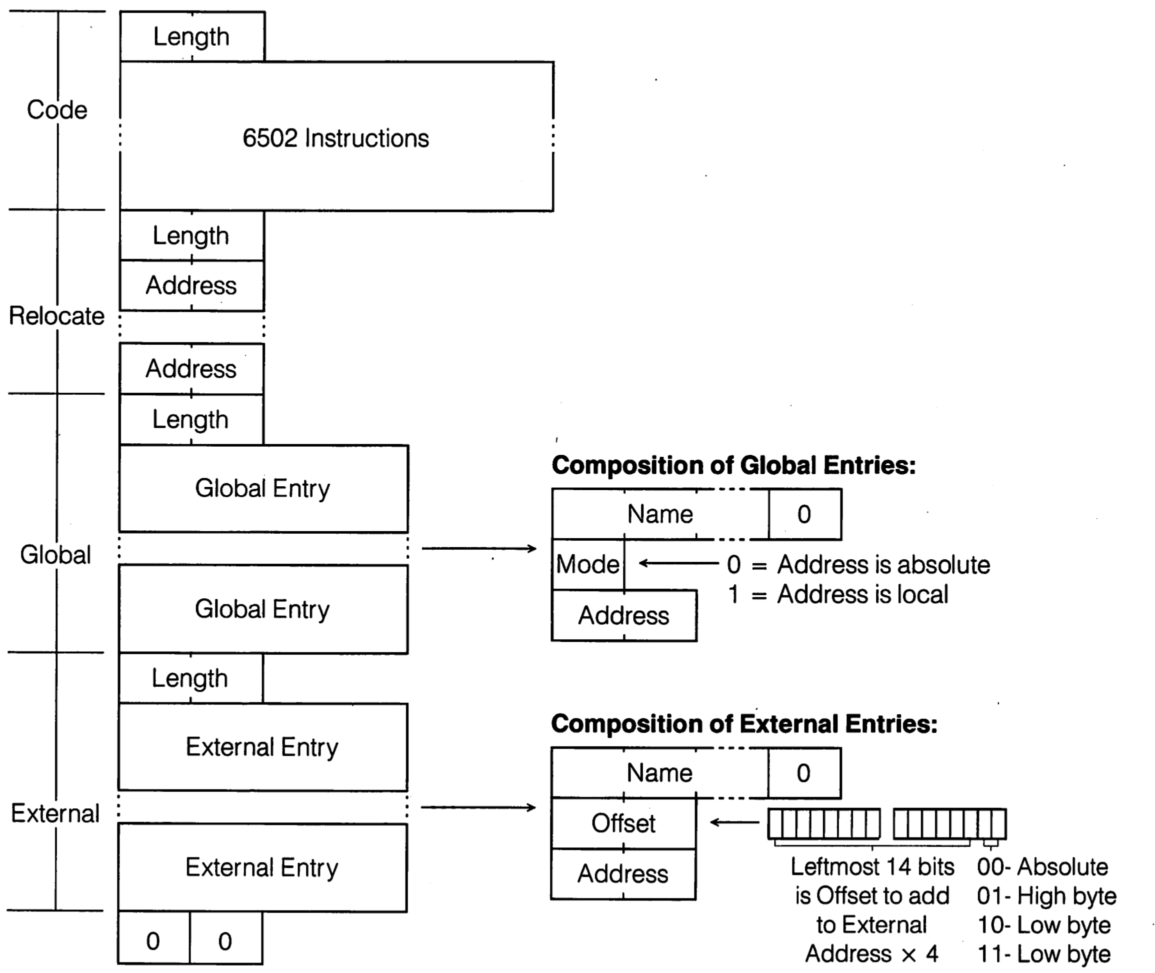
Fido-Mail or Net-Mail can be sent to me at node 11/205 – <G>oshen <T>owne <C>rier.

Table 1: Composition of Object Files



Listing 1: GRPLOT.PAL

```
HC  5 open 2,8,2,"@0:grplot.obj,s,w"
FM  10 pal=peek(701)+256*peek(702)
DB  20 poke pal+1759,44:poke pal+1764,44
PO  30 sys 700
JD  40 .opt o2
OH  50 *=-2
MF  60 xxxxxx = 0
PM  89 ;
OI  97 ;--------------
CM  98 ; code section
AJ  99 ;--------------
MA  100              .word creloc
EO  110 ;
FB  120 cstart       jmp  xxxxxx
IP  130 ;
KD  131 ;"function:
DO  132 ;"Clear (Address,Length,Byte)
NH  133 ;"unsigned int Address;
KA  134 ;"unsigned int Length;
DP  135 ;"char Byte;
EG  136 ;"
FP  137 ;"global:
CI  138 ;" unsigned int Address;
BA  139 ;
FD  140 address  .word $e000
MA  150 ;
JM  160 clear        =*
NN  165 extn2    jsr  xxxxxx
DJ  170          lda  $033c      ;<addr
CB  180 rloc1    sta  !address
CI  190          sta  $22
MK  200          lda  $033d      ;>addr
JB  210 rloc2    sta  !address+1
DK  220          sta  $23
JO  230          lda  $0340      ;byte
DH  240          ldy  #$00
JE  250          ldx  $033f      ;>length
GF  260          beq  floop2
DJ  270 floop1   sta  ($22),y    ;fill a
CN  280          dey             ;page
NF  290          bne  floop1
KM  300          inc  $23        ;fill many
CJ  310          dex             ;pages
LH  320          bne  floop1
FJ  330          ldy  #0
JL  340 floop2   cpy  $033e      ;<length
FE  350          beq  fexit
IF  360          sta  ($22),y    ;fill part
ML  370          iny             ;of a page
JL  380          bne  floop2
LM  390 fexit    rts
FA  399 ;
NF  400 grrows   .word    0, 320, 640, 960,1280
AM  410          .word 1600,1920,2240,2560,2880
EL  420          .word 3200,3520,3840,4160,4480
BN  430          .word 4800,5120,5440,5760,6080
```

```
AA  440              .word 6400,6720,7040,7360,7680
HD  449 ;
AP  450 orbits    .byte 128,64,32,16,8,4,2,1
MI  460 andbits   .byte 127,191,223,239
FL  470              .byte 247,251,253,254
AG  490 ;
AI  491 ; function:
JL  492 ;*  char Plot (x,y)
NE  493 ;*  unsigned int x,y;
EG  494 ;
FG  495 ;
AH  500 plot       = *
DD  505 extn3      jsr   xxxxxx
MJ  510            lda   $033e        ;y coord
CC  520            lsr   a
MC  530            lsr   a
IE  540            and   #254
FP  550            tay
LD  560 rloc3      lda   grrows,y     ;get row
AG  570            clc                ;and add
FI  580 rloc4      adc   !address     ;bitmap
PL  590            sta   $22          ;address
MP  600 rloc5      lda   grrows+1,y
ND  610 rloc6      adc   !address+1
DD  620            sta   $23
OI  630            lda   $033c        ;x coord lo
GK  640            and   #%11111000
CA  650            adc   $22
IF  660            sta   $22
BK  670            lda   $033d        ;x coord hi
DC  680            adc   $23
JH  690            sta   $23
KF  700            lda   $033e        ;y coord
KO  710            and   #%00000111
PJ  720            tay
MP  740            lda   $033c        ;x coord lo
CB  750            and   #%00000111
CM  760            sta   $24
LJ  770            sei
ID  780            lda   $01          ;swap all
HP  790            pha                ;rom/io out
ME  800            lda   #$30
HO  810            sta   $01
LN  820            lda   ($22),y      ;check
NL  830 extn1      ldx   !xxxxxx      ;plot type
AJ  840            beq   bitoff       ;and modify
GJ  850            cpx   #1           ;pixel
LO  860            beq   biton
OE  870 bitflip    ldx   $24          ;invert
NL  880 rloc7      eor   !orbits,x
DB  890 rloc8      jmp   pexit
BA  900 biton      ldx   $24          ;pixel on
EG  910 rloc9      ora   !orbits,x
AJ  920 rloc10     jmp   pexit
LJ  930 bitoff     ldx   $24          ;pixel off
LK  940 rloc11     and   !andbits,x
JI  950 pexit      sta   ($22),y      ;replace
BI  960 rloc12     and   !orbits,x    ;byte and
ML  970            sta   $033c        ;return
FP  980            pla                ;bit state.
DB  990            sta   $01          ;restore
FD  1000            cli                ;io/roms.
ON  1010            rts
IL  1090 ;
IN  1091 ; function:
AA  1092 ;*  FastKeys ()
LL  1093 ;
OA  1100 fastkey     = *
```

```
PO  1110            sei
IJ  1120 extn4      lda   #<irqkeys
FC  1130            sta   $0314
IK  1140 extn5      lda   #>irqkeys
KD  1150            sta   $0315
GB  1160            cli
OH  1170            rts
JI  1299 ;
GB  1300 irqkeys    = *
FE  1310            lda   #$01
KA  1320            sta   $028b
FF  1330            lda   #$00
PB  1340            sta   $028c
PG  1350            jmp   $ea31
EO  1390 ;
EA  1391 ; function:
MG  1392 ;*  SlowKeys ()
HO  1393 ;
IG  1400 slowkey    = *
LB  1410            sei
HD  1420            lda   #<$ea31
BF  1430            sta   $0314
HE  1440            lda   #>$ea31
GG  1450            sta   $0315
CE  1460            cli
KK  1470            rts
OD  1480 ;
AD  6997 ;-----------------
CI  6998 ; relocate section
CD  6999 ;-----------------
PA  7000 creloc     = *
ED  7010            .word (cglobal-creloc)>1-1
CO  7020 ;
EE  7030            .word rloc1
AF  7040            .word rloc2
DO  7050            .word rloc3  ;the addrs
BD  7060            .word rloc4  ;of all
DL  7070            .word rloc5  ;instructions
GG  7080            .word rloc6  ;accessing
FD  7090            .word rloc7  ;local
II  7100            .word rloc8  ;variables.
EK  7110            .word rloc9
OC  7120            .word rloc10
LD  7130            .word rloc11
IE  7140            .word rloc12
CL  7996 ;
LG  7997 ;---------------
AO  7998 ; global section
NG  7999 ;---------------
LJ  8000 cglobal    = *
PP  8010 numglob =   0
MF  8020            .word numglob
EN  8030 ;
JB  8040 numglob _ numglob + 1
FO  8050            .asc "Address":.byt 0
IL  8060            .byt 1
KG  8070            .word address
GA  8080 ;
LE  8090 numglob _ numglob + 1
EL  8100            .asc "Clear":.byt 0
KO  8110            .byt 1
AI  8120            .word clear
ID  8130 ;
NH  8140 numglob _ numglob + 1
KG  8150            .asc "Plot":.byt 0
MB  8160            .byt 1
DG  8170            .word plot
KG  8180 ;
```

```
PK  8190 numglob _ numglob + 1
ED  8200          .asc "FastKeys":.byt 0
OE  8210          .byt 1
JD  8220          .word fastkey
MJ  8230 ;
BO  8240 numglob _ numglob + 1
JI  8250          .asc "SlowKeys":.byt 0
AI  8260          .byt 1
JJ  8270          .word slowkey
OM  8280 ;
DB  8290 numglob _ numglob + 1
FJ  8300          .asc "irq%%":.byt 0
CL  8310          .byt 1
NN  8320          .word irqkeys
AA  8330 ;
KJ  8996 ;
AA  8997 ;-------------------
HM  8998 ; external section
CA  8999 ;-------------------
DP  9000 cextern  = *
KO  9010 numext   =    0
BG  9020          .word numext
ML  9030 ;
BE  9040 numext   _ numext + 1
BE  9050          .asc "c$start":.byt 0
JC  9060          .word 0
NI  9080          .word cstart
IP  9090 ;
NH  9100 numext   _ numext + 1
EL  9110          .asc "PlotType":.byt 0
FG  9120          .word 0
LK  9140          .word extn1
ED  9150 ;
JL  9160 numext   _ numext + 1
CO  9170          .asc "c$funct[]init":.byt 0
BK  9180          .word 0
JO  9200          .word extn2
AH  9210 ;
FP  9220 numext   _ numext + 1
OB  9230          .asc "c$funct[]init":.byt 0
NN  9240          .word 0
HC  9260          .word extn3
MK  9270 ;
BD  9280 numext   _ numext + 1
DH  9290          .asc "irq%%":.byt 0
NB  9300          .word 2
LF  9310          .word extn4
ON  9320 ;
DG  9330 numext   _ numext + 1
FK  9340          .asc "irq%%":.byt 0
NE  9350          .word 1
PI  9360          .word extn5
EI  9998 ;
DB  9999          .word 0          ;done!
```

Listing 2: DOODLE.C

```
/*
   doodle.c

   by David Godshall
*/

char PlotType;

main ()
{
   char *Pointer, Key, Store1, Store2, Store3;
   unsigned int Loop, X, Y;

   highmem (0xCC00);

   Pointer = 0xDD00;
   *Pointer = (Store1 = *Pointer) & 252;
   Pointer = 0xD011;                         /* Turn on Graphics         */
   *Pointer = (Store2 = *Pointer) | 32;
   Pointer = 0xD018;
   Store3 = *Pointer;
   *Pointer = 0x38;

   Pointer = 0x028a;                         /* Turn on key repeat       */
   *Pointer = 128;
   FastKeys ();

   Clear (0xCC00, 1000, 93);                 /* Clear colour screen      */
   Clear (0xE000, 8000, 0);                  /* Clear bitmap             */
   PlotType = 1;
   X = 160;
   Y = 100;
   Plot (X,Y);
   while ((Key = waitkey()) != 3)
   {
      switch (Key)
      {
         case 'i' :
         case 'I' :  Plot (X,--Y);           /* Allow user to draw lines */
                     break;                  /* by using the I, J, K, M  */
         case 'm' :                          /* diamond. -, +, and / set */
         case 'M' :  Plot (X, ++Y);          /* clear, set, or flip mode */
                     break;                  /* respectively. STOP exits */
         case 'j' :
         case 'J' :  Plot (--X;Y);
                     break;
         case 'k' :
         case 'K' :  Plot (++X,Y);
                     break;
         case '-' :  PlotType = 0;
                     Plot (X, Y);
                     break;
         case '+':   PlotType = 1;
                     Plot (X, Y);
                     break;
         case '/' :  PlotType = 2;
                     Plot (X, Y);
      }
   }

   SlowKeys ();

   Pointer = 0xDD00;
   *Pointer = Store1;
   Pointer = 0xD011;                         /* Restore Text mode        */
   *Pointer = Store2;
   Pointer = 0xD018;
   *Pointer = Store3;
}


#define GETIN 0xFFE4

char a, x, y,
      *numkeys = 198;

/* Waits for user to press a key */

int waitkey ()

{
   while (*numkeys == 0)
      ;
   sys (GETIN, &a, &x, &y);
   return a;
}
```