CREATIVE ASSEMBLER
How To Write Arcade Games

Jonathan Griffiths

Penguin Books

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As one of Acornsoft's games programmers, Jonathan Griffiths was responsible for such widely popular programs as Snapper and JCB Digger for the BBC Microcomputer Model B and Acorn Electron. He has prepared a cassette program, which can be used in conjunction with this book, available from Acornsoft Limited, c/o Vector Marketing Ltd, Denington Industrial Estate, Wellingborough, Northants NN8 2RL.

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This book is dedicated to all the staff at Acornsoft

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INTRODUCTION

The BASIC assembler which is available on the BBC Microcomputer and Acorn Electron is a very powerful tool for programmers. It provides a comprehensible interface between the programmer and the machine code language which the 6502 processor itself uses. Hence the programmer is able to control the machine more directly using assembler.

The main reason why people write programs in assembler rather than BASIC is probably because of the speed difference between the two. Assembler instructions can be executed extremely quickly, a program written in BASIC will take between 10 and 100 times as long. Hence assembler is particularly useful for games' programmers since it enables them to move missiles and creatures across the screen quickly and smoothly. If BASIC was used to calculate the new co-ordinates of each object and draw them at those positions then movement would tend to occur in jerky leaps.

However, speed is not the only factor to be taken into consideration. Assembler programming gives you more power to solve a problem than BASIC does. All high-level languages require programs to have a certain structure and this puts constraints on programs written in that language.

Sceptics may advise against using assembler on the grounds that it is too complex. It is true that operations such as multiplication and division which are easy to perform in BASIC are not as straightforward in assembler. For what might be considered a trivial task, for example multiplying a number by three, several assembler instructions are required instead of just a single BASIC one. A further problem is that there are no FOR ... NEXT or REPEAT … UNTIL loops in assembler; if you require a loop you must set one up yourself. The same applies to floating point arithmetic assembler only supports integer calculations.

My advice is that you ignore these sceptics. It isn't difficult to learn to program in assembler. The programs look much less like English than BASIC I ones do but nevertheless to someone who knows the language they are easy to understand. Like learning to do anything else, all that is required is a certain amount of knowledge and a lot of practice. This book has been written to provide the knowledge - the rest is up to you.

The book is divided into three sections, each of which has a different task to perform. The first part aims to introduce the more useful assembler instructions available for the 6502 processor, giving simple examples of how they can be used. The second part introduces some of the more complex programming techniques which are aimed in particular at people writing large assembler programs. The third part is aimed mainly at the games' programmer. It provides many useful routines and finally shows how these can all be linked together to produce a complete game.

1. DATA STORAGE

Before you can start writing programs in assembler you need to know a few things about how data is stored inside the computer and how that data can be accessed and changed. This chapter looks at the ways in which you can enter numbers from the keyboard and the notation which the computer uses to store these values in its memory.

1.1 Hexadecimal notation

To most people it seems natural to use base ten when dealing with numbers. We have ten digits; 0,1,... 8,9, and can use these to represent numbers as large as we please by making the value of a digit depend on which column it is in. Thus, when we consider the number 171 the first '1' represents 100, and the second '1' represents just one. Moving a digit one column to the left multiplies its value by ten; this is why our system is called base 10 or decimal.

When entering numbers into a computer you can still use base 10 if you wish, but another base - base 16 - is also available. For reasons which should become clear as you read through this chapter, base 16 (or hexadecimal) is far more suitable for working with computers. Hence it is advisable at this stage to spend some time becoming familiar with this number system.

In base 16 we need 16 different symbols to represent the 16 different 'hexadecimal digits'. For convenience we retain the symbols 0 to 9, and use the letters A to F to represent the values of ten to fifteen.

Hexadecimal	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
Decimal	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Another difference between base 10 and base 16 is what happens to a digit or hexadecimal digit when it is shifted one column to the left. Whereas we have seen that in base 10 this multiplies the value of the digit by ten, in base 16 it multiplies the value by sixteen. Hence 10 in hexadecimal represents the value sixteen.

Having two bases in which we can work can lead to confusion. Consider, for example, the number 10; as we have seen this can represent either of the values ten or sixteen depending on whether it is being interpreted as a decimal or hexadecimal number. We need a method of specifying whether a number is decimal or hexadecimal. Normally we do this by prefixing hexadecimal numbers with an ampersand (&), e.g.

```
&B1
```

The 'B' has the value 16*11 because it is in the second column to the left, and the '1' represents 1 unit; the number therefore has the decimal value 176 +1 = 177.

&123

The '1' is in the third column to the left, so it has the value 16*16*1, the '2' has the value 16*2 and the '3' has the value 3. Adding these together produces
256 + 32 + 3 = 291

There is no real need to learn how to convert between hexadecimal and decimal because the computer can do it for you, as shown below.

Converting hexadecimal to decimal

To print out the decimal value of a hexadecimal number, such as &123, type

```
PRINT &123
```

The answer, 291, is printed out.

Converting decimal to hexadecimal

To print, in hexadecimal, the value of a decimal number, type
```
PRINT ~123
```

The answer, 7B, is printed out. The number printed will be in hexadecimal notation, but note that the computer doesn't use the symbol '&' when it is printing hexadecimal numbers. In this case it is obvious that the answer is a hexadecimal number but for an answer such as 79 you would need to know which base you requested the computer to use to be able to interpret the result correctly.

The symbol twiddle or, more accurately, tilde ~ means 'print in hexadecimal'; thus writing

```
PRINT~&123
```

will print 123.

1.2 Binary notation and bits

Although the computer can accept numbers in either decimal or hexadecimal notation, it uses neither of these two systems for storing the numbers in its memory. The computer's memory consists of electronic circuits that can be put into one of two different states. The two states are normally represented as 0 and 1, but they are often referred to by different terms as listed below:

0	1
zero	one
low	high
clear	set
off	on
false	true

The circuits are said to be in a 'bistable state', i.e. they are always in one of two possible states. When the digits 0 and 1 are used to refer to these two states they are termed 'binary digits', or 'bits' for brevity.

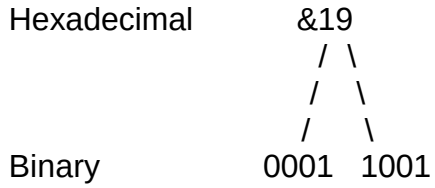
With two bits, e.g. M and N, four different states can be represented:

M	N
0	0
0	1
1	0
1	1

With a 'nibble', which is four bits, 16 different values can be represented (16 = 2^4). This means that a hexadecimal digit can be represented by a four-bit binary number. The hexadecimal digits and their binary equivalents are shown in the following table:

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

Any hexadecimal number can be converted into its binary representation by the simple procedure of converting each hexadecimal digit into the corresponding four bits, for example



Thus the binary equivalent of &19 is 00011001, (or leaving out the leading zeros which are irrelevant, 11001).

1.3 Memory locations and bytes

The computer's memory is made up of a number of 'locations', each capable of holding a value. The size of each memory location is normally referred to as a 'byte'. Each byte can hold an eight-bit number, which means that it can store any one of 256 (2^8) different values; 0... 255.

We have seen already that each hexadecimal digit requires four bits to specify it. A byte, since it contains eight bits, can therefore represent any hexadecimal number between 0 and &FF.

The bits in a byte are usually numbered for convenience, as follows:

bit number	7	6	5	4	3	2	1	0
byte	0	0	0	1	1	0	0	1

Bit 0 is often referred to as the 'low-order bit' or 'least-significant bit', and bit 7 as the 'high-order bit' or most-significant bit'.

1.4 More about memory locations

Somehow it must be possible to distinguish between one location and another. Houses in a town are distinguished by each of them having a unique address. Even when the occupants of a house change, the address of the house remains the same. Similarly, each location in a computer has a unique 'address' consisting of a number which remains unchanged even when the contents of the memory location are altered. Thus we can speak of the 'contents of location 100' as being the number found in the location whose address is 100. The memory locations start from address 0 and could look something like this:

Decimal value of the number being stored:	27	35	6	91
Address:	0	1	2	3

An address can be one or two bytes long. This means that addresses can cover the range 0 to &FFFF. For a detailed look at which part of the memory each address corresponds to see the memory maps in Appendix A.

Examining memory locations

We can look at the contents of some memory locations in the computer using the query (?) operator. The reference '?X' means use the value of X as the address of the location under consideration. Hence the reference '?&FFEE' means that we are concerned with the location whose address is &FFEE. To look at this location type

```
PRINT ?&FFEE
```

This prints out the value found at the location specified, which in this case should be the number 108. Any memory location can be examined in this way and all of them will contain a number between 0 and 255.

It is often convenient to look at several memory locations in a row; for example, to list the contents of the 32 memory locations from &70 upwards, type

```
FOR N = 0 TO 31 : PRINT ?(N+&70); : NEXT N
```

An alternative way of writing this is

```
FOR N=0 TO 31 : PRINT N?&70; : NEXT N
```

This method is tidier than the other and gives identical results; i.e. for each of the values of N between 0 and 31, N is added to the number &70 to give the address of the location whose contents are to be printed out. This should result in the contents of 32 memory locations being listed on the screen.

Changing memory locations

It is possible to change the number stored at a particular memory location by assigning a new value to it. As an example try changing the contents of &70. First, print the contents of this address; the value there will be whatever was in the memory when the computer was switched on since the computer does not use this location for storing any of the variables it is working with. To change the contents to 7, type

```
?&70=7
```

To verify the change, type

```
PRINT ?&70
```

Try setting the contents of this memory location to other numbers. Setting the contents to a number greater than 255 or &FF will result in the number entered modulo 256 being stored there, for example

```
?&70=600
PRINT ?&70
```

This will print out

(600 MOD 256)

A word of warning: Before you change the contents of any other memory locations be sure that you know what you are doing. Although it is quite safe to look at almost any memory location in the computer, care must be exercised when changing any of them. The example given here uses a specific location which is not used by the computer; if you change any other location you may lose any program you have in memory or confuse the computer to such an extent that it proves necessary to reset it by pressing BREAK to make it accept any further commands.

1.5 Negative numbers - two's complement

Although the values stored in the memory locations are between 0 and 255 these can be used to represent both positive and negative numbers. To do this two's complement representation is used. To represent a number using this system we first have to consider what its positive counterpart is in binary notation. For example to find out how -5 would be stored consider the number

+5 = 00000101

We then find the complement of this, i.e. change each 0 into a 1 and each I into a 0, e.g.

complement of +5 = 1111010

Finally we add one: 11111010
1 +
11111011

This gives us the two's complement representation of -5.

We can now try adding together +5 and -5 to see if they give us 0.

```
      00000101
      11111011
(1)   00000000
```

Ignoring the 1 which has overflowed gives us the result, zero, which we were expecting.

Note that when representing numbers using two's complement notation a single byte can represent any number between -128 and +127. The left-hand bit is 1 if the number is negative and 0 otherwise. Zero is classed as a non-negative number.

1.6 Storing text

If locations can only hold numbers between 0 and 255, how is text stored in the computer's memory? The answer is that numbers are used to represent the different characters. Hence text is stored simply as a sequence of numbers in successive memory locations. The computer does not become confused about whether a number is representing an actual number or a character since the context will always make it clear how it should be interpreted.

The unique number corresponding to each character is given by its ASCII code (American Standard Code for Information Interchange). To find the ASCII code of a given character the ASC function can be used, for example type

```
PRINT ASC "A"
```

and the number 65 will be printed out. This means that the character 'A' is represented internally by the number 65. If you try repeating this process for B C D

you will notice that there is a certain regularity. The same is true for a b c ~... and the sequence 1 2 3 4

A full table of the ASCII codes used to represent all the characters is given in Appendix A.

2. CARRYING OUT INSTRUCTIONS

The previous chapter showed how characters and numbers are represented in the computer's memory, i.e. how the computer deals with data storage. However, data on its own is useless to a computer, it also needs instructions telling it what to do with the data. This chapter looks at how the computer handles instructions and explains some of the simpler assembler instructions which it can use. The instructions listed refer only to the 6502 processor so if you have any other sort of processor connected to your machine, e.g. a Z-80 second processor, this will have to be disabled before attempting any of the routines given in this and subsequent chapters.

2.1 The CPU, the computer's brain.

The Central Processing Unit or CPU is the computer's brain. It is the most active part of the computer; although areas of memory can remain unchanged for hours on end when a computer is being used, the CPU is working all the time the machine is switched on. The CPU's job is to read a sequence of instructions from memory and carry out the operations specified by those instructions.

The instructions which the CPU acts on are just values stored in memory locations. The CPU takes a byte and interprets it as an instruction, e.g. &18 will be interpreted to mean 'clear carry flag'*;* this will be explained later in this chapter. It then performs the operation as instructed and goes on to collect the next byte.

The first byte of all instructions is the operation code, or 'op-code'. Some instructions, such as the example above, consist of just the op-code; other instructions require data on which they must operate. These instructions therefore consist of two or three bytes, the first one being the op-code and the other one or two consisting of data. For example the value &E6 is translated into the instruction 'increase the contents of the memory location with the following one-byte address by one'. Hence the CPU then takes the next byte from the memory and interprets this, not as an instruction, but as the address of the location whose contents are to be incremented. It then adds one to the number stored in that location. Having executed this instruction, the CPU then goes on to the next byte which is taken to represent the next instruction it must perform.

2.2 Machine code assembler

The above few paragraphs should have given you the idea that everything the CPU acts upon is a number between 0 and &FF (255 decimal); each number being interpreted by the CPU as an instruction or some data which an instruction must use. The list of numbers which are being used are referred to as machine code. It is possible for us to talk to the computer in its own language, i.e. program in machine code, but this would mean that we would have to know which instructions all the op-codes stand for. Programming in assembler alleviates the need for learning all these translations. In assembler each op-code is represented by a three letter mnemonic, e.g. CLC is used instead of &18 to give the instruction 'clear carry'. The computer then converts all the mnemonics into the corresponding op-codes.

This process is carried out by an assembler and hence is known as 'assembling'. The program that the assembler takes as its input is known as the source code, and the machine code output is referred to as the object code.

2.3 The accumulator and the carry flag

The accumulator is just a temporary location inside the CPU which plays a part in many of the operations performed by the CPU. For example, to add two numbers together you have to load the first number into the accumulator from the memory, add in the second number from memory, and then store the result somewhere. To do this the following assembler instructions will be needed:

Mnemonic	Description	Symbol
LDA	load accumulator from memory	A=M
STA	store accumulator in memory	M=A
ADC	add memory to accumulator with carry	A=A+M+C
CLC	clear carry	C=0

The carry is needed to allow numbers greater than one byte (255 or &FF) to be generated. When an eight-bit value is added to another eight-bit value the result could be too great to be represented by eight bits, e.g. 140 +160 = 300 (>255).

In order to allow for this, the CPU will use the carry as the ninth bit of the accumulator, and thus the carry will contain the extra bit. In the above example, when the numbers 140 and 160 are added together and the result stored in a memory location, this location will contain the value 44 (300 MOD 256). By using the carry flag you will have a record of whether the result of the addition was actually the value 44 or if it was 300. Hence, to avoid confusion, clear the carry before performing any additions.

2.4 Writing an assembler program

Enter the following assembler program:

```
10        DIM P% 100
20[
30        LDA &80
40        CLC
50        ADC &81
60        STA &82
70        RTS
80]
90        END
```

The meaning of each line in this assembler program is as follows:

10 The DIM statement is not an assembler mnemonic; it is a BASIC instruction to tell the assembler where to put the assembled machine code by DIMensioning off an area of memory for it. The DIM statement is followed by a number (not in brackets) and the statement reserves this number of bytes for the machine code which will be generated. As a rough guide to the amount of room needed count the number of assembler instructions used, treble it and reserve at least this number of bytes.

The BASIC variable P% is used by the assembler as a location counter to specify the next free address. Hence the statement sets P% to the lowest address of the reserved block of memory and then as each byte of machine code is generated, P% increases by one byte so that it always points to the next free location.

20 The '[' symbol is an 'assembler delimiter' which has to be used immediately before the first assembler statement to tell the BASIC interpreter that the following statements will be in assembler rather than BASIC.

30 Load the accumulator with the contents of the memory location whose address is &80. (The contents of the memory location are not changed.)

40 Clear the carry flag.

50 Add the contents of location &81 to the accumulator with the carry. (Location &81 is not changed by this operation.)

60 Store the contents of the accumulator to location &82. (The accumulator is not changed by this operation.)

70 The RTS instruction will usually be the last instruction of any program; it causes a return to BASIC from the machine-code program. The mnemonic stands for 'return from subroutine'.

80 The ']' symbol is an assembler delimiter which has to be used after the last assembler instruction to tell the interpreter that the following statements will be in BASIC.

90 The END statement is not an assembler mnemonic; it just denotes the end of the program.

Now type RUN and the assembler program will be assembled; the assembled code being inserted directly in memory at the address specified by P%.
An 'assembler listing' will be printed out to show the machine code the assembler has generated to the left of the corresponding assembler mnemonics:

```
>RUN
OE5D
OE5D    A5    80    LDA    &80
OE5F    18          CLC
0E60    65    81    ADC    &81
0E62    85    82    STA    &82
0E64    60          RTS
```

operand
mnemonic statement
instruction data/address
instruction op code
location counter statement

The program has been assembled in memory starting at &0E5D, immediately after the program text. This address may be different when you enter the example program if you have inserted extra spaces into the program or if you have filing systems other than cassette in your machine, but that will not affect any other part of the listing. All the numbers in the listing are in hexadecimal; thus &18 is the op-code for the CLC instruction, and &A5 is the op-code for LDA when the number being loaded is not given directly but is obtained by looking in the memory location whose one-byte address is given. Hence this LDA instruction consists of two bytes; the first byte is the op-code, and the second byte is the address; &80 in this case.

Another method of finding out where the machine code is, is to find out where 'TOP' is by typing

```
PRINT  ~TOP
```

This value gives the address of the memory location immediately after the program text. Since the machine code follows on straight after the text this address is the one corresponding to the first instruction, &A5. Thus the machine code is stored in memory as follows:

A5 80 18 65 81 85 82 60
^
TOP

When 'RUN' was typed this assembled the assembler program and put the machine code produced into the computer's memory, however it did not execute the program. The method for doing this is described below.

2.5 Executing a machine-code program

To execute the machine-code program at TOP, type

CALL TOP

Nothing obvious will happen except for the '>' prompt being printed again on the screen. This indicates that the computer has finished executing the program and hence the contents of locations &80 and &81 will have been added together and the

results placed in &82.

You can verify this by setting the contents of &80 and &81 to certain values by typing, for example

```
?&80=7 : ?&81=9
```

If you wish you can also set the contents of &82 to 0. Now type

```
CALL TOP
```

and then look at the contents of &82 by typing

```
PRINT ?&82
```

The result is 16 (in decimal); the computer has just added 7 and 9 and obtained 16.

2.6 Adding two-byte numbers

Try executing the program for different numbers in &80 and &81. You might like to try the following:

```
?&80=140 : ?&81=160 : CALL TOP
```

We saw earlier in this chapter that if an addition generates a number greater than 255 then the result stored in the memory location specified will be that number modulo 256. Hence the result in this case will be 44 rather than 300. Here is the calculation in hexadecimal:

160	&A0
140	&8C
300	&12C

Only two hex digits can fit in one byte, so the '1' of &12C is lost, and only the &2C is retained. Luckily the '1' carry is retained for us in the carry flag as was mentioned earlier, though we didn't see then how to use this. The example below shows how the two numbers can be treated as being two-byte numbers and added together using the carry to produce a two-byte number which is the complete answer. This method can be extended to any number of bytes since the carry flag makes it a simple matter to add together two numbers as large as we please. Modify the program already in memory by retyping lines 50 to 120, if you wish (leaving out the comments to the right of the assembler text). Here is the modified program:

```
10 DIM P% 100
20[
30       LDA   &80      Low byte of one number
40       CLC           Clear carry flag
50       ADC   &82      low byte of other number
60       STA   &84      low byte of result
70       LDA   &81      high byte of one number
```

```
80       ADC   &83     high byte of other number
90       STA   &85     high byte of result
100      RTS
110]
123      END
```

Assemble the program:

```
>RUN
OE6E
     OE6E A5   80   LDA  &80
     0E70 18        CLC
     0E71 65   82   ADC  &82
     0E73 85   84   STA  &84
     0E75 A5   81   LDA  &81
     0E77 65   83   ADC  &83
     0E79 85   85   STA  &85
     OE7B 60        RTS
```

Now set up the two numbers as follows:

```
?&81=&8C : ?&81=&00
?&82=&A0 : ?&83=&00
```

Finally, execute the program by typing

```
CALL TOP
```

and look at the result, printing it in hexadecimal this time for convenience:

```
PRINT ~?&84,~?&85
```

The low byte of the result is &2C, as was obtained before using the one-byte addition program, but this time the high byte of the result, &1, has been correctly obtained. The carry generated by the first addition was added into the second addition, giving

0+ 0 + carry = 1

Try some other two-byte additions using the new program.

2.7 Subtraction

The subtract instruction is just like the add instruction, except that there is a 'borrow' if the carry flag is zero. Therefore to perform a single-byte subtraction the carry flag should first be set with the SEC instruction.

Mnemonic		
SEC	set carry flag	C=1
SBC	subtract memory from A with carry	A=A-M-(1-C)

Example

```
10 DIM P% 100
20[
30      LDA       &80     Low byte of first number
40      SEC               Initialise carry flag
50      SBC       &82     Low byte of other number
60      STA       &84     Low byte of result
70      LDA       &81     Now do high bytes
80      SBC       &83
90      STA       &85
100     RTS               Return
110]
120 END
```

Note that the above program is very similar in structure to the addition example in section 2.6.

2.8 Comments

There are two methods of putting comments in assembler programs. The first of these, which is used in previous examples, is to put the comment after an assembler instruction, separated from it by one or more spaces, e.g.

```
60  STA&84   low byte of result
```

Alternatively a statement may start with a backslash (\), in which case the remainder of that statement is ignored, e.g.

```
65  \ Now for the high bytes
```

Note that a colon (:) will end the comment and start a new assembler statement, for example line 60 could be replaced by

```
60  \ Low byte of result : STA &84
```

2.9 Printing a character

The computer contains routines for the basic operations of printing a character to the VDU, and reading a character from the keyboard, and these routines can be called from assembler programs.

Name	*Address*	*Function*
OSWRCH	&FFEE	Puts character in accumulator to output (VDU)
OSRDCH	&FFE0	Reads from input (keyboard) into accumulator

In each case all the other registers are preserved. The names of these routines are

acronyms for ‘operating system write character' and 'operating system read character' respectively. These routines are executed with the instruction JSR (jump to subroutine).

A detailed description of how the JSR instruction works will be left until the following chapter.

The following program outputs the contents of memory location &80 as a character to the VDU, using a call to the subroutine OSWRCH:

```
10 DIM P% 100
20 oswrch=&FFEE
30[
40   LDA &80
50   JSR oswrch
60   RTS
70]
80 END
```

The variable 'oswrch' is used for the address of the OSWRCH routine. Assemble the program, and then set the contents of &80 to &21 by typing

```
?&80=&21
```

Then execute the program using

```
CALL TOP
```

and an exclamation mark will be printed out before returning to the computer's prompt character, because &21 is the code for an exclamation mark. An alternative method of setting the contents of location &80 to &21 is therefore

```
?&80=ASC"!"
```

Try executing the program with different values in &80, with values chosen from the table of ASCII values in Appendix A.

2.10 Immediate addressing

In the previous example the instruction

```
LDA &80
```

loaded the accumulator from the location whose address is &80, this is known as 'absolute' addressing. The location was then set to contain &21, the code for an exclamation mark. If at the time the program was written it was known that an exclamation mark was to be printed in would be more convenient to specify this in the program as the actual data to be loaded into the accumulator. Fortunately an 'immediate' addressing mode is provided which achieves just this. Change the instruction to

```
LDA #&21
```

where the '#' (hash) symbol specifies to the assembler that immediate addressing is required. Assemble the program again, and note that the instruction op-code for 'LDA #&21' is &A9, not &A5 as it was previously for the absolute addressing. The op-code of the instruction specifies to the CPU whether the following byte is the actual data loaded, or the address of the location containing the data.

2.11 Using addresses

So far when a value has been saved, a numerical address has been used to define where it is to be stored, e.g.

```
STA &80
```

A better method of giving an address is to use a variable name, e.g.

```
STA addr
```

In this case 'addr' must be specified at the beginning of the program, e.g.

```
addr = &80
```

This method is better than the previous one since it makes the program easier to understand, i.e. an address can be given a relevant name, e.g. 'xlowbyte' or 'yhighbyte'. In addition, changing the location of a value becomes easier, since only the initial specification need be altered rather than every occurrence of that value throughout the program.

The locations used must be chosen carefully to avoid corrupting operating system or BASIC workspace. The memory map in Appendix A should help to show which locations can be used in different circumstances. Also there are some locations which are always free when using BASIC; these are &70 to &8F.

3. JUMPS, BRANCHES AND LOOPS

When an assembler program has been assembled and is being executed, the address of the next instruction to be executed is kept in a register called the 'program counter'. All the programs met so far have been executed in the order that the instructions were written, so the program counter has just steadily increased until it reached the last instruction. This chapter introduces the jump and branch instructions which can make the program counter jump over instructions or move back to previous ones to execute them again. These instructions make it possible to implement loops and perform different instructions depending on the outcome of previous ones.

3.1 Jumps

Ordinary jumps

Mnemonic	Description
JMP	jump to instruction whose address is given

The JMP instruction is followed by the address of the instruction to be executed next, e.g.

```
JMP &E48   or    JMP addr
```

Instead of describing the address by a number, we can use a 'label' to indicate to the assembler where we want to go. In the assembler, labels are variables prefixed with a full stop (.).

```
10    oswrch =&FFEE
20    DIM P% 100
30[
40.enter
50    LDA #ASC"*"
60.loop
70    JSR oswrch
80    JMP loop
90]
100 END
```

When the program is assembled the address corresponding to the label '.loop' will be inserted in the machine code. When the code is executed the value of the program counter will be set to this address and the CPU will collect its next instruction from the location with that address and will continue executing from there.

The label '.enter' at the start of the program has been included so that this label can be called in order to execute the program. This is a better way of executing a program than calling TOP since TOP doesn't always point to the first machine code instruction. This is true for the above example since TOP will point to the

assignment statement ‘oswrch=&FFEE'.

The program will output an asterisk (*), and then jump back to the previous instruction. The program has become stuck in an endless loop! Compare this program with the following BASIC program:

```
10 A=48
20 VDU A
30 GOTO 20
```

To get out of the BASIC loop you press ESCAPE. This will not automatically halt machine code programs, however. To exit from a machine code loop without losing the program you must press BREAK, and then type 'OLD' to retrieve the original program.

Jumps to subroutines

Mnemonic	Description
JSR	jump to subroutine

Examples of this instruction have been used previously. Like the JMP instruction it is followed by a two-byte address, e.g.

JSR oswrch

In this case the address of the instruction directly following the JSR instruction in the code is noted, and then the value of the program counter is set to the address of 'oswrch'. The CPU will go to this address for its next instruction and start executing the code from there until it meets an RTS. This will set the program counter to the address which was noted earlier so that the CPU can then continue executing the code following the JSR instruction. Subroutines jumped to can either be part of the assembler program or, as in this example, sub-routines which exist in the operating system memory.

3.2 The zero and negative flags

There are several flags in the CPU which can be set or cleared depending on the outcome of certain instructions. The carry flag was introduced in the previous chapter, this is set or cleared as the result of an ADC (add with carry) instruction. Another very useful one is the zero flag, called Z. This is set if the result of the previous operation gave zero, and is cleared otherwise, e.g.

```
LDA &80
```

would set the zero flag if the contents of &80 were zero.

Similarly the negative flag, N, is set if the result of the previous operation was negative in two's complement notation, i.e. if the top bit was set, e.g.

```
LDA &80
```

would set the negative flag if the number stored in location &80 was greater than 127 (01111111).

The conditions of all the flags are stored in a byte called the status register (P), and each flag is represented by one bit: e.g. the top bit of the status register is set if N=1 and the bottom bit is set if C=1.

3.3 Conditional branches

Conditional branches enable the program to act on the outcome of an operation. There are eight different branch instructions, six of which are introduced.

Mnemonic	Description	Status
BEQ	branch if equal to zero	(ie Z=1)
BNE	branch if not equal to zero	(ie Z=0)
BCC	branch if carry clear	(ie C=0)
BCS	branch if carry set	(ie C=1)
BPL	branch if plus	(ie N=0)
BMI	branch if minus	(ie N=1)

The conditional branch instructions test the state of the various condition flags, e.g. the zero flag and negative flag. If the condition is not satisfied then it carries on executing, but if the condition is satisfied then the computer goes to the place indicated by the byte following the branch op-code. This byte is stored as a relative address, thus if you say

```
BCS notzero
```

the assembler works out the difference (in bytes) between the current instruction and the place where the label '.notzero' is, and puts this value after the op-code. This means that the value of this byte is used, in conjunction with the address of the current instruction, to tell the CPU where to go next.

Because only a single byte is allowed in this relative addressing mode, the branch instructions can only point to one of 255 nearby bytes. The two's complement representation of numbers is used to give the offset relative to the current address. Branches which point forwards are restricted to 0-127 bytes beyond the current location. The value of the byte following the op-code for these is then 0-127. Branches which point backwards to places at lower addresses in memory require a negative value to be added to the current location. These use the numbers 128-255 to represent the values -128 to -1.

The JMP instruction does not use relative addressing; it is followed by two bytes which specify the absolute address which will be the destination. Hence the branch instruction is shorter than the jump instruction, the jump being three bytes long (op-code and two-byte address) and the branch being two bytes long (op-code and one-byte offset). This difference is automatically looked after by the assembler.

The following simple program will print an

exclamation mark if 'character' contains zero, and a star if it does not. The comments to the right of the assembler statements may be omitted when you enter the program.

```
10      DIM P% 100
20      character=&80
30      oswrch = &FFEE
40[
50.enter
60      LDA     character
70      BEQ     exclamation     If zero print '!'
80      LDA     #ASC"*"         Star
90      JSR     oswrch          Print it
100     RTS                     Return
110.exclamation
120     LDA     #ASC"!"         Exclamation mark
130     JSR     oswrch          Print it
140     RTS                     Return
150]
160 END
```

Note that the above program can be made shorter, by replacing the instructions

```
JSR oswrch
RTS
```

with the single instruction

```
JMP oswrch
```

Replacing JSR and RTS instructions by a JMP to a subroutine reduces the size of both a source program and the object code it produces, and hence increases execution speed.

Now assemble the program by typing RUN. You should get the message:

```
No such variable at line 70
```

This is because the assembler processes the mnemonic instructions in the order in which they are listed in the program. Therefore when it encounters 'BEQ exclamation' it has not yet found the label exclamation' so it cannot work out the offset which is required in the following byte. This is known as the forward-reference problem, and is easily overcome using the method of two-pass assembly which is explained below.

3.4 Two-pass assembly

When a program contains forward references it needs to be assembled twice. During the first pass of the assembler the addresses of all the labels are noted so

that during the second pass the offsets of the branch instructions can be included. And the assembler must be told not to worry when, during the first pass, it comes across errors of the sort indicated above.

This can be done using the OPT statement, an assembler directive which has a single parameter for which the following values are possible:

OPT 0 No error messages, and no listing
OPT 1 No error messages, and listing
OPT 2 Error messages reported, and no listing
OPT 3 Error messages reported, and listing (Default)

Thus to suppress messages and a listing on the first pass, and to restore them on the second pass, we need to use OPT 0 and OPT 3 respectively. This can be effected by placing the directive inside a FOR NEXT loop, which goes from 0 to 3 in steps of 3. Then

The value of the control variable is used as the parameter of the OPT statement. So, to alter the program which was given above, simply enter these lines:

```
10 DIM code 100
23 FOR pass = 0 TO 3 STEP 3
26 P% = code
30[ OPT pass
145 NEXT pass
```

This time the error message will not be produced and the correct offset will be calculated for the branch instruction.

Note lines 10 and 26, which replace the old 'DIM P% 100' statement. P% must be reset to the starting value each time that the code is assembled.

Now execute the program by typing

```
CALL enter
```

and verify that the program behaves as it should for different values in &80.

3.5 X and Y registers

The CPU contains two registers, called the X and Y registers, in addition to the accumulator. As with the accumulator, there are instructions to load and store the X and Y registers:

Mnemonic	*Description*	*Symbol*
LDX	load X register from memory	X=M
LDY	load Y register from memory	Y=M
STX	store X register to memory	M=X
STY	store Y register to memory	M=Y

However, unlike the accumulator, the X and Y registers cannot be used as one of the operands in arithmetic instructions; they have their own special uses which will be outlined later.

The X and Y registers are particularly useful as the control variables in iterative loops, because four special instructions exist which will either increment (add 1 to) or decrement (subtract 1 from) their values.

Mnemonic	*Description*	*Symbol*
INX	increment X register	X=X+1
INY	increment Y register	Y=Y+1
DEX	decrement X register	X=X-1
DEY	decrement Y register	Y=Y-1

Note that these instructions do not affect the carry flag: incrementing &FF will give &00 without changing the carry bit. The zero and negative flags are, however, affected by these instructions.

3.6 Iterative loops

The iterative loop enables the same set of instructions to be executed a fixed number of times, e.g.

```
10 DIM P% 100
20 oswrch = &FFEE
30[
40.enter
50        LDX  #8         Initialise X
60        LDA  #ASC"*"    Code for star
70. Loop
80        JSR  oswrch     Output star
90        DEX               Count it
100       BNE               Loop all done?
110       RTS]
120       END
```

Assemble the program by typing RUN. This program prints out a star, decrements the X register, and then branches back if the result after decrementing the X register is not zero. Consider what value X will have on successive trips around the loop and predict how many stars will be printed out; then execute the program with 'CALL enter' and see if your prediction was correct. (If you were wrong, try thinking about the case where X was initially set to 1 instead of 8 in line 50.)

How many stars are printed if you change the instruction on line 50 to 'LDX #0'?

3.7 Comparing values

In the previous example the condition X=0 was used to terminate the loop. Sometimes we might want to count up from 0 and terminate on some other specified value. The compare instruction can be used to compare the contents of a register with a value in memory; if the two are the same, the zero flag will be set. If they are not the same, the zero flag will be cleared. The compare instruction also affects the carry flag by setting it to 1 if the register is greater than or equal to the value in memory, and 0 otherwise.

Mnemonic	*Description*	*Symbol*
CMP	compare accumulator with memory	A-M
CPX	compare X register with memory	X-M
CPY	compare Y register with memory	Y-M

Note that the compare instruction does not affect its two operands, it just changes the flags as a result of the comparison.

The next example again prints eight stars, but this time it uses X as a counter to count upwards from 0 to 8.

```
10 DIM P% 100
20 oswrch=&FFEE
30[
40.enter
50    LDX   #0       Start at zero
60.loop
70    LDA   #ASC"*"  Code for star
80    JSR   oswrch   Output star
 90   INX            Next X
100   CPX   #8       ALL done?
110   BNE   loop     If not then repeat
120   RTS            Else return
130]
140 END
```

In this program X takes the values 0, 1, 2, 3, 4, 5, 6, and 7. The last time around the loop X is incremented to 8, and the loop terminates. Try drawing a flowchart for this program.

3.8 Using the control variable

In the previous two examples X was simply used as a counter, and so it made no difference whether we counted up or down. However, it is often useful to use the value of the control variable in the program. For example, we could print out the character in the X register each time around the loop. The order in which we want

the characters would then determine whether we count up or down. We therefore need a way of transferring the value in the X register to the accumulator so that it can be printed out by the OSWRCH routine. One way would be to execute:

STX tempaddr
LDA tempaddr

where 'tempaddr' is not being used for any other purpose. However, there is a more convenient way, using one of four new instructions:

Mnemonic	*Description*	*Symbol*
TAX	transfer accumulator to X register	X=A
TAY	transfer accumulator to Y register	Y=A
TXA	transfer X register to accumulator	A=X
TYA	transfer Y register to accumulator	A=Y

Note that the transfer instructions only affect the register being transferred to.

The following example prints out the alphabet by making X cover the range A to Z.

```
10 DIM P% 100
20 oswrch = &FFEE
30[
40.enter
50   LDX #ASC"A"    Start with the Letter A
60.loop
70   TXA            Put it in the accumulator
80   JSR oswrch     Print it
90   INX            Next one
100  CPX #(ASC"Z"+1)Finished ?
110  BNE loop       If so - continue
120  RTS            Else return
130]
140 END
```

All these examples could have used Y as the control variable instead of X in exactly the same way.

3.9 Conditional assembly

Assembler source text can contain tests, and assemble different statements depending on the outcome of these tests. This is especially useful where slightly Different versions of a program are needed for many different purposes. Rather than creating a different source file for each different version, a single variable can determine the changes using conditional assembly, eg:

```
10 DIM CODE%100
20 char=&70
30 oswrch=&FFEE
40 osrdch=&FFE0
50 bell=7                      Beep = VDU 7
60 prompt=ASC":"
70 INPUT"bell",bell$           Input 'bell$'
80 bellflag=INSTR("Yy",bell$) 'bellflag' is true if
90 FOR pass=0 TO 3 STEP 3      bell$ = 'y' or 'Y'
100 P%=CODE%
110[ OPTpass
120.enter
130]
140 IF bellflag THEN [OPT pass:LDA #bell :JSR oswrch:]
150[OPT pass
160  LDA #prompt               Load A with ':' prompt
170  JSR oswrch                Print from A
180  JSR osrdch                Read in a character
190  STA char                  store it at char and
200  JSR oswrch                print it out
210  RTS
220]
230  NEXT pass
```

When this program is run it asks if you want the computer to bleep or not and sets 'bellflag' accordingly. Then when the machine code is executed it inputs a character from the keyboard, bleeping if 'bellflag' is set to remind you that an input is required, and prints out a character corresponding to the first key pressed. This character is also saved at the address 'char'.

4. LOGICAL OPERATIONS, SHIFTS AND ROTATES

We have seen previously that each byte or memory location is made up of eight bits, each of which can be set to the value 0 or 1. Although the operations we have considered so far have treated the whole byte as the smallest quantity being dealt with, many operations in the computer's instruction set are best considered as operations which act on eight separate bits. Some of these perform such important tasks as changing the case of characters, or multiplying and dividing.

4.1 Logical operations

Logical operations are performed between the individual bits of two operands; one of the operands is always the accumulator and the other is a memory location or immediate value. In this section three such operations are introduced; AND, OR and EOR. A truth table is used to give a compact description of each operation. This takes two single bit inputs which, for convenience, we call A and B, and shows the bit which is produced as a result of ANDing, ORing or EORing them together. This is known as Boolean logic after its inventor, George Boole.

AND

Mnemonic	*Description*	*Symbol*
AND	AND accumulator with memory	A=A AND M

Truth table:

A	B	out
0	0	0
0	1	0
1	0	0
1	1	1

The AND operation sets a bit of the result to a 1 only if the corresponding bit of one operand is a 1 AND the corresponding bit of the other operand is a 1; otherwise the bit in the result is a zero, e.g.

	Hexadecimal	*Binary*
operand 1	A9	10101001
operand 2	E5	11100101
result of AND	Al	10100001

One way of thinking of the AND operation is that one operand acts as a 'mask', and only where there are ones in the mask do the corresponding bits in the other operand 'show through'; otherwise, the bits are zero.

OR

Mnemonic	*Description*	*Symbol*
ORA	OR accumulator with memory	A=A OR M

Truth table:

A	B	out
0	0	0
0	1	1
1	0	1
1	1	1

The OR operation sets a bit of the result to a 1 if the corresponding bit of one operand is a 1 OR the corresponding bit of the other operand is a 1, or indeed, if they are both ones; otherwise the bit in the result is zero, e.g.

	hexadecimal	Binary
operand 1	A9	10101001
operand 2	E5	11100101
Result of OR	ED	11101101

Exclusive OR

Mnemonic	*Description*	*Symbol*
EOR	Exclusive-OR accumulator with memory	A=A EOR M

Truth table:

A	B	out
0	0	0
0	1	1
1	0	1
1	1	0

The Exclusive-OR operation is like the OR operation, except that a bit in the result is set to 1 only if the corresponding bit of one operand is a 1, or if the corresponding bit of the other operand is a 1, but not if they are both ones, e.g.

	hexadecimal	Binary
operand 1	A9	10101001
operand 2	E5	11100101
result of EOR	4C	01001100

Another way of thinking of the Exclusive-OR operation is that a bit of the result is 1 if and only if the corresponding bits in the operands are different.

Example - converting lower to upper case
The following example converts all characters entered in lower case to upper case. See Appendix A for the ASCII character set.

```
.loop
     JSR osrdch Get character
     AND #&DF   Make case bit zero
     JSR oswrch Print it
     JMP loop   And do it again
```

Try altering this using the 'ORA' instruction to convert all characters to lower case. When you have succeeded in doing this try writing a routine to swap case.

4.2 The BIT instruction

This instruction is available to test whether individual bits of a number are set or not.

Mnemonic	*Description*
BIT	Compare memory bits with accumulator

The instruction AND's the bits of the accumulator and the memory. The zero and negative flags are set or cleared as a result of this operation; Z=1 if the result was 0 and N = top bit, V = bit 6 of contents of location.

Hence BIT may be used to test any bit of the memory by loading the accumulator with a value containing a 1 in the relevant position and 0's everywhere else. Then the values 0 and 1 for Z show whether the bit was or was not set respectively, e.g.

```
LDA #4      4=00000100
BIT addr
BEQ bit-not-set
```

If addr contained, for example, &43 (01000011) then the branch would occur. If, however, addr contained &44 (01000100) then the branch would not take place. Bit differs from the AND instruction in that it does not corrupt the accumulator.

4.3 Rotates and shifts

The rotate and shift operations move the bits in a byte either left or right.

Mnemonic	*Description*
ASL	arithmetic shift left
ROL	rotate left
LSR	logical shift right
ROR	rotate right

The ASL instruction moves all the bits one place to the left; what was the high-order bit is put into the carry flag, and a zero is put into the low-order bit of the byte. The ROL instruction is identical except that the previous value of the carry flag is put into the low-order bit instead of zero.

The right shift and rotate right instructions work in a similar way except that the bits are shifted to the right.

ASL – Arithmetic shift Left one bit

ROL - Rotate Left one bit

LSR - Logical shift right one bit

Example - multiplying by two

The most efficient way to multiply a two-byte number, stored in 'addr' and 'addr+1, by two, is to shift the contents of the two bytes one place to the left. Where 'addr' and 'addr+1' are the addresses of the locations storing the low and high bytes of the number being doubled, use the following two statements:

```
ASL addr
ROL addr+1
```

This works by using the carry to hold the bit that falls off the end of 'addr', and then using the ROL statement, which puts the carry into the correct place in the high-order byte.

5. ADDRESSING MODES

So far we have met two addressing modes. One of these is absolute addressing as in

```
LDA addr
```

which, when executed, loads the accumulator with the contents of the location whose address is 'addr'. The other is immediate addressing as in

```
LDA #&81
```

which, when executed, loads the accumulator with the actual value &81.

However, other addressing modes exist and one of the most important, 'indexed addressing', is introduced here prior to a summary exposition of all the addressing modes available to the 6502 processor.

5.1 Indexed addressing

In this addressing mode one of the index registers (X or Y) is added to the address as an offset which gives the precise location for the stored data. For example, we can write:

```
LDA addr, X
```

If X contains zero this instruction will behave just like 'LDA addr'. However, if X contains 1 it will load the accumulator with the contents of 'one location further on from addr'. Since X can contain any value from 0 to 255, the instruction 'LDA addr,X' gives you access to 256 different memory locations. If you are familiar with BASIC's byte vectors you can think of 'addr' as the base of a vector, and of X as containing the subscript, e.g.

```
addr?7 = 12
```

is equivalent to

```
LDA #12
LDX #7
STA addr, X
```

5.2 String types

Two examples of the use of indexed addressing are given below, both involving strings. There are two string types available for use in BASIC and assembler; ATOM strings and Microsoft strings. An ATOM string is a string of characters terminated by a RETURN character. The name which identifies the string is preceded by a dollar ($) sign and the strings can be easily set up in BASIC, e.g.

```
$name = "Fred"
```

ATOM strings must have an area of memory set aside for them. This can be done, as in the examples, by using a DIM statement. The characters making up the string are then stored in the location identified by the name of the string. This is very useful as the address of each character is then also known.

A Microsoft string is a string of characters preceded by a byte which gives the length of the string. In this case, the name of the string has a dollar ($) sign *after* it. It is more flexible than the ATOM string because it can contain RETURN characters. Its disadvantage is that all the characters making up the string are stored in locations chosen by BASIC, hence the addresses of these are not known.

Example - print inverted-case string

The following program uses indexed addressing to print out a string of characters terminated by a carriage return (which is represented in the memory by &D), swapping case as it prints out each character.

```
10 DIM string 256, code 100
20 oswrch = &FFEE
30 FOR pass = 0 TO 3
40 P% = code
50[OPT pass
60.enter
70   LDX #0              Set index to zero
80.loop
90   LDA string,X        Get characters from string
100  CMP #&D             Is it end of string?
110  BEQ return          If so, end
120  EOR #&20            Else invert case bit
130  JSR oswrch          Print it
140  INX                 Increment index
150  BNE Loop            If string longer than 256
160.return
170  RTS                 then end anyway
180]
190 NEXT pass
200 END
```

Assemble the program by typing RUN, and then try the program by entering:

```
$string = "Test String" : CALL enter
```

Example - index subroutine

Another useful operation, easily performed in a machine-code routine, is looking up a character in a string and returning its position in that string. The following subroutine reads in a character, using a call to the OSRDCH read-character routine, and saves in '? found' the position of the first occurrence of that character in

'$target'. This is exactly the same as the BASIC '?found =INSTR ("ABCDEFGH", GET$)'.

```
0 REM Index Routine
10 DIM target 25,P% 100
20 osrdch=&FFE0 : $target="ABCDEFGH" : found= &70
30[
40.enter
50   JSR osrdch               Get character
60   LDX#(LEN($target)-1)     Length of string
70.loop
80   CMP target,X             Compare character
90   BEQ match                Got a match
100  DEX                      Try again
110  CPX#255                  Until end of string
120  BNE loop
130.match
140  INX                      The position in the
150  STX found                String is stored
160  RTS                      Return
170]
180 END
```

The routine is entered at '.enter', and as it stands it looks for one of the letters A to H.

5.3 Summary of addressing modes

The following sections summarise all addressing modes that are available on the 6502, some of which have been met already.

Immediate addressing

Use immediate addressing when the data for an instruction is known at the time of writing the program. In this mode the second byte of the instruction contains the actual eight-bit data to be used by the instruction. The '#' symbol denotes an immediate operand.

Examples:
```
LDA #value
CPY #flag+2
```

Absolute addressing

Use absolute addressing when the effective address, to be used by the instruction, is known at the time the program is being written. In this mode the two bytes following the op-code contain the 16-bit effective address to be used by the instruction, the low byte being given first, followed by the high byte.

Example: LDA address

Zero page addressing

Zero page addressing is a subset of absolute addressing. They are similar in that the instruction specifies the effective address to be used; the difference between them is that in absolute addressing the address used can be anywhere, whereas in zero page addressing the address is in zero page, i.e. from &0000 to &OOFF. Hence this address is only one byte rather than two. The assembler will automatically produce zero-page instructions.

Examples:
```
JSR loop
ASL &9A
```

Indexed addressing

Indexed addressing is used to access a table of memory locations by specifying them in terms of an offset from a base address. The base address is known at the time that the program is written; the offset, which is provided in one of the index registers, can be calculated by the program.

In all indexed addressing modes one of the eight-bit index registers, X and Y, is used in order to calculate the effective address to be used by the instruction. Five different indexed addressing modes are available, and are listed below.

Absolute indexed addressing

The simplest indexed addressing mode is absolute indexed addressing. In this mode the two bytes following the instruction specify a 16-bit address which is to be added to one of the index registers to form the effective address to be used by the instruction.

Examples:
```
LDA table,X
LDX palette,Y
INC score,X
```

Zero,X indexed addressing

Here, the second byte of the instruction specifies an eight-bit address, which is added to the X-register to give a zero-page address to be used by the instruction.

Note that in the case of the LDX instruction a ‘zero,Y' addressing mode is provided instead of the ‘zero,X' mode.

Examples:
```
LSR &80,X
LDX addr,Y
```
(where addr+Y is in zero page)

Indirect addressing

It is sometimes necessary to use an address which is actually computed when the

program runs, rather than being an offset from a base address or a constant address. In this case indirect addressing is used.

Indirect addressing is distinct from direct addressing (i.e. absolute, indexed, etc) in that the address specified after the mnemonic is used to refer to a location where the final address will be found. Thus the machine does not go directly to the address, but instead it goes indirectly, via the address given.

The indirect mode of addressing is available for the JMP instruction. Thus control can be transferred to an address calculated at the time the program is run.

Examples:
```
JMP (&2800)
JMP (addr)
```

For the dual-operand instructions ADC, AND, CMP, EOR, LDA, ORA, SBC and STA, two different modes of indirect addressing are provided: pre-indexed indirect, and post-indexed indirect. Pure indirect addressing can be obtained, using either mode, by first setting the respective index register to zero.

Pre-indexed indirect addressing

Examples:
```
STA (zerotable,X)
EOR (&60,X)
```

This mode of addressing is used when a table of effective addresses is provided in zero page; the X index register is used as a pointer to select one of these addresses from the table.

In pre-indexed indirect addressing the second byte of the instruction is added to the X register to give an address in zero page. The two bytes at this zero-page address are then used as the effective address for the instruction.

Post-indexed indirect addressing

This indexed addressing mode is like the absolute,X or absolute,Y indexed addressing modes, except that in this case the base address of the table is provided in zero page, rather than in the bytes following the instruction.

In post-indexed indirect addressing the second byte of the instruction specifies a zero-page address. The two bytes at this address are added to the Y index register to give a 16-bit address which is then used as the effective address for the instruction.

Examples:
```
ADC (&66),Y
CMP (pointer),Y
```

This last addressing mode is very useful. An example of its use is given in the program below, which will only work on a machine without a second processor attached. It clears the screen.

```
10 DIM MC% 100
20 addr=&70
30 FOR pass=0 TO 2 STEP 2
40 P%=MC%
50[OPT pass
60.cls
70   LDA #&58       High byte of start address
80   STA addr+1
90   LDY #0         Low byte of address,
100  STY addr       and value to write to screen
110  TYA            Put zero (black) into A
120.clsloop
130  STA (addr),Y   store zero
140  INY
150  BNE clsloop    do 256 times
160  INC addr+1     Increment hi byte of address
170  LDX addr+1     Set status register to addr
180  BPL clsloop    Compare with top of RAM
190  RTS
200]
210 NEXT pass
220 MODE 4
230 COLOUR 129
240 CLS             White out screen
250 A=GET           Wait for a key
260 CALL cls        Black out screen
270 COLOUR 128
280 END
```

6. THE STACK

The 6502 processor supports a hardware stack. This is an important part of the computer which can be used both by the CPU and the programmer. This chapter looks at how the stack can be used and how it performs its task.

6.1 Using the stack

A hardware stack is simply a set of memory locations (&100 to &1FF) which are reserved by the processor. These locations can be used as temporary storage locations. Up until now, when we have wanted to store a value, we might have used.

```
STA tempaddr
```

And to recall the value which was in the accumulator at that time, the instruction

```
LDA tempaddr
```

Loading the accumulator with the value from 'tempaddr' does not alter the value stored in 'tempaddr'. Hence the number may be recalled several times. When storing a value on the stack, however, the situation is different. The value to be stored is 'pushed' onto the stack and when it is wanted again, it is 'pulled' off into a register - a one-time only operation.

The stack is a LIFO structure, these initials stand for 'last-in, first-out', which means that the first item put on the stack will be at the bottom and so will be the least readily available, whereas the last item on the stack will be at the top and will be the first one to be pulled off it.

The four instructions which a programmer can use to access the stack are:

Mnemonic	*Description*
PHA	push the contents of A onto the stack
PLA	pull a value off the stack and store it in A
PHP	push the contents of the status register P
PLP	pull a value off the stack and store it in P

'Last-in, first-out': the stack forbids the use of any item other than in that order.

A stack pointer is used to manage the stack. This is a register which contains the address of the top location being used. For example, on encountering a PLA instruction, the accumulator is loaded from the memory location pointed to by the stack pointer and then the stack pointer is automatically moved back one location. Whenever a PHA instruction is executed, the accumulator is stored in the memory location pointed to by the stack pointer and then the stack pointer is moved on to the next location.

Example
The following series of pushes and pulls leaves the stack in a state which is shown below:

```
LDA #78
PHA
LDA #79
PHA
PLA
LDA #80
PHA
```

	Stack pointer points to next free space
80	Last value pushed onto the stack
78	Previous value pushed onto the stack

Note that the value 79 which was pushed onto the stack and then pulled off it again no longer occupies a location on the stack.

To see why the stack is used as a temporary storage place in preference to a memory location such as ‘tempaddr', consider the two alternative sections of assembler below:

```
PHA        STA tempaddr
LDA addr   LDA addr
CLC        CLC
ADC #12    ADC #12
STA addr   STA addr
PLA        LDA tempaddr
```

These both produce the same result when executed but the one on the left will produce less code. This is because the LDA and STA instructions consist of either two or three bytes, one for the op-code and one or two for the address. The PHA and PLA instructions, however, just consist of an op-code.

Note that if more than one value is stored on the stack at once, care must be taken when these values are retrieved. Because it is a LIFO structure, the values must be taken off the stack in the opposite order to how they were placed on it, e.g.

PHA save accumulator
TXA prepare to save X
PHA save X
PLA restore value
TAX transfer to X the last value pushed
PLA restore accumulator

When using the stack it is very important to pull as many values as you push. Otherwise confusion can arise as we will see below.

6.2 How the CPU stores addresses

The stack is used by the CPU as well as by the programmer. On encountering a JSR instruction, the address of the instruction following the JSR is stored so that the CPU knows where to start executing from when it comes to the end of the subroutine. This is done by pushing the two bytes of the address onto the stack so that they can be retrieved when the RTS is reached. Thus a routine which is entered with a JSR and finishes with RTS should always pull the same number of bytes as are pushed otherwise the value obtained from the top of the stack by the RTS will not be the correct return address, e.g.

```
.entersubroutine
PHA
LDA addr
CLC
ADC #12
RTS
```

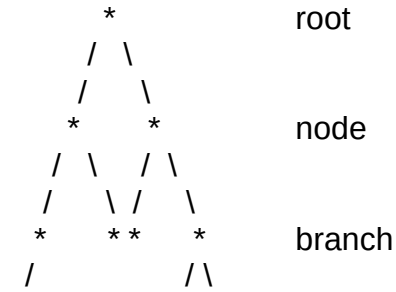
When the RTS is reached the CPU will pull two values off the stack, and put them into the program counter. However, as one of these values is the value pushed with the 'PHA', the program counter will almost certainly contain the wrong address. This will mean that the CPU will start trying to execute instructions at the wrong address and do something undefined by the designers of the 6502.

6.3 Recursion

One of the most important reasons for using a stack to hold the addresses of subroutine returns is that recursion is then automatically supported.

A recursive subroutine is one which calls itself. This can be a very powerful feature and enables a programmer to implement tree structures as shown below.

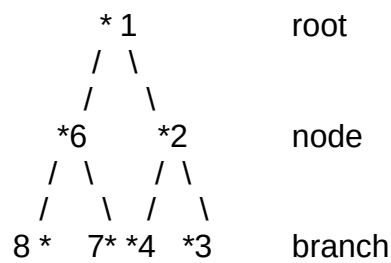
Using trees
A tree in computing is normally pictured as follows:



Note that it is usually drawn with the 'root' at the top.

In order to print out all the elements (root and nodes) in the tree, you must write a routine which prints out an element and then goes down a branch to the element beneath it. If there isn't an element below, then it goes back up one level and sees if there is an alternative branch from there. For the above tree the order that the elements would be visited, assuming that the routine shows a preference for right-

hand branches, is:



A BASIC routine to do this is as follows:

```
DEFPROCtree(element)
PRINT value(element)
IF right(element) THEN PROCtree(right(element))
IF left(element) THEN PROCtree(left(element))
ENDPROC
```

This assumes that each element has three things known about it: its value, the element that its right branch leads to (FALSE if no branch) and the element that its left branch leads to (FALSE if no branch). These should be stored in three arrays whose names are 'value', 'right' and 'left'.

The routine can be called using

```
PROCtree(0)
```

The assembler version of this is:

```
.enter
     LDX #0              Start at root (zeroth element)
.tree
     LDA value,X         Get value of element
     JSR printnumber     See section 13.1 for details
     LDA right,X         Is there a right branch?
     BEQ tryleft         If not, try a left one
     TAX
     JSR tree            Else take that branch
.tryleft
     LDA left,X          Is there a left branch?
     BEQ backup          If not, go back up one level
     TAX
     JSR tree            Else take that branch
     RTS                 Return
```

In this case the block of memory locations starting with the address 'value' should contain the values of each element in turn: those starting at 'right' should contain the element to which each one's right-hand branch leads, and 'left' the element to which each one's left-hand branch leads.

7. MACROS

If an assembler programmer wants to use a block of instructions several times during a single program then this block only needs to be entered once. There are then two methods of using this block when it is needed. The first is to put a label before it and an RTS instruction at the end, and reference it as a subroutine using the JSR instruction which was described earlier. In this case the CPU will 'jump' to the label when it reaches the JSR and 'jump' back again when it reaches the RTS at the end of the subroutine.

The alternative method is to turn the block of instructions into a macro, the method for doing this will be explained later. Essentially what this does is to give this block of instructions a name and, when the assembler comes across this name, it inserts the instructions of the macro into the object code which it is producing so that the CPU does not have to perform any jumps when it is executing the code.

Hence the main difference between macros and subroutines is that subroutines are called at run-time and macros are called at assembly time.

The advantage of macros is that they are faster than subroutines since no jumps are needed during execution. The disadvantage is that if the macro is to be used several times, the resulting machine code program will have to contain multiple copies of the instructions represented by the macro, and thus be long. Using a subroutine would only require one copy of the instructions. Macros can be more useful than just an aid to save typing however, and this chapter explains some of their other features. Further examples can be found in section 12.5 (General purpose macros).

7.1 Generating and calling a macro

Consider the sequence of instructions:

```
ROR A : ROR A : ROR A : ROR A
```

This simply shifts the upper nibble of the accumulator into the lower nibble. A macro with the name 'FNrotateacc' containing this sequence can be set up outside the assembler program as follows:

```
DEF FNrotateacc
[OPT pass
ROR A : ROR A   ROR A : ROR A
] :=pass
```

This macro can then be called from inside the assembler with the statement
OPT FNrotateacc

The OPT statement is being used here as a dummy statement, simply to call FNrotateacc and have no other effect. We therefore arrange for the value of the

function to be 'pass', which should be the value used in the initial OPT statement. Therefore on reaching this statement the assembler will generate the machine code corresponding to the assembler instructions of the macro, and place this in the object code. Then it will move on to the next instruction of the assembler program.

The flow of control when the program is being typed will look something like this:

```
LDA addr
FNrotateacc
STA addr
```

The flow of control when the program is being assembled will look something like this:

```
LDA addr
DEFFNrotateacc
ROR A
ROR A
ROR A
ROR A
:=pass
STA addr
```

The machine code produced will be as follows:

```
     A5   81   LDA addr
     6A        ROR A
     6A        ROR A
     6A        ROR A
     6A        ROR A
     85   81   STA addr
```

7.2 Macro parameters

Macros can take parameters, thus the previous example could be rewritten in such a way that it could rotate the accumulator any number of times (as long as this number is greater than 0):

```
DEF FNrotateacc(rotate)
FOR number=1 TO rotate
[OPT pass
ROR A
]
NEXT number
= pass
```

So, to rotate the bits in any memory location any number of times to the right, simply set up a macro as follows:

```
DEF FNrotate(address, rotate)
FOR number = 1 TO rotate
```

```
[OPT pass
ROR address
]
NEXT number
= pass
```

A typical call might be

```
OPT FNrotate(&3000, 4)
```

This would generate machine code to rotate right four times the bits in location &3000.

7.3 Conditional assembly in macros

Macros can also be constructed to contain conditional instructions, so that they will assemble different pieces of code according to the parameters passed. For example, the following macro works out the shortest way of rotating the accumulator left:

```
DEF FNoptimumrotate(rotate)
IF rotate < 1 THEN = pass
IF rotate < 5 THEN FOR number=1 TO rotate
[OPT pass : ROL A:]:Next number
ELSE FOR number = 1 TO (9-rotate):
[OPT pass : ROR A:]:Next number
= pass
```

7.4 Labels in macros

Labels cannot be used in the normal way inside macros. Consider, for example, the macro given below:

```
DEFFNstar
[OPT pass
LDX addr
BEQ exclamation
LDA #ASC"*"
JSR oswrch
.exclamation
LDA #ASC”!”
JSR oswrch
] : =pass
```

When the assembler reaches the 'BEQ exclamation' loop instruction on the second pass, it will give the offset the same address of the label which was set up the first time around. If forward referencing is not used then this problem will not occur, but it is still undesirable to use label names time and again. The program becomes very difficult to follow and to debug.

To use labels in macros that are called from more than one place, it is necessary to set up tables of labels. Thus if the label 'start' is used in a macro, an array called 'start' would have to be DIMensioned at the beginning of the program together with as many elements as the number of times the macro is called. If the macro with 'start' in it was called three times from within the program, the statement 'DIM start(2)' would have to be inserted before the first call to that macro took place. Also, each call to the macro would have to pass a parameter which contained a number (0,1 or 2) so that the correct label would be used. To illustrate:

```
DEF FNmacro(fred,jim,no)
[OPT pass
LDA fred
LDY jim
.start(no)
JSR oswrch
DEY
BNE start(no)
]
=pass
```

The above macro will print the contents of 'fred' as an ASCII character, 'jim' times. By convention the label number is always passed as the last parameter, and it is also a good idea to have all the macros using the same variable to hold the number (in this case 'no').

A typical call to the above macro might be

```
OPT FNmacro(addr, 45, 1)
```

This would use the label 'start(1)'.

8. BASIC I, BASIC II AND ELECTRON BASIC

There are, at the time of writing, two versions of BBC BASIC available for the BBC Microcomputer, known officially as BASIC and BASIC II. In this book, however, they are referred to as BASIC I and BASIC II respectively, and the name BASIC is used as a general term to cover either. This chapter looks at the differences between the two which affect the assembler programmer and provides BASIC I versions of the new directives and keyword.

The BASIC provided on the Electron can be assumed to be BASIC II. The BASIC routines given elsewhere in this book will all work on machines containing BASIC II and can be adapted to work with BASIC I as well.

8.1 Distinguishing BASIC I from BASIC II

To find out if you have BASIC I or BASIC II press BREAK and then type REPORT. BASIC II will give the message:

```
(C)1982 Acorn
```

Whereas BASIC I will produce:

```
(C)1981  Acorn
```

8.2 The main differences between BASIC I and BASIC II

The main differences between the two BASICs which concern assembler programmers are:

OPT
In BASIC I only the lowest two bits in the OPT statement are significant; if the lowest bit is set then the machine code is listed and if the next bit is set error messages are reported. The other bits are ignored. However, in BASIC II the third bit is significant as well; it is used to produce code which will execute somewhere other than the assembled position. If the third bit is set (OPTs 4 to 7) then the code is assembled at the value of O% (the code origin), not at P%. However, all the JMP's etc. will be set up as if it is going to execute at P%, and so it is an easy matter to relocate the code. This is particularly useful if, for example, you had written a routine which had to work in ROM, or some other space which is not normally accessible. Note that if this option is used then as the code is produced both O% and P% are incremented, otherwise just P% is incremented.

EQUB, EQUW, EQUD and EQUS
Four assembler directives have been introduced in BASIC II which are not present in BASIC I. These new directives are EQUB, EQUW, EQUD and EQUS which stand for 'equate byte', 'equate word' (2 bytes), 'equate double word' (4 bytes) and 'equate string' (0 - 255 bytes). These each take a single argument, and put its value into the assembly code at P% (also incrementing P% by the correct amount), e.g.

`EQUB &FE`	Put '&FE' at P%
`EQUW oswrch`	Put contents of 'oswrch' at P% and P%+1
`EQUD 0`	Set the next four bytes to zero
`EQUS "Fred"+CHR$(13)`	Put 'Fred'+Carriage Return in memory starting at P%

OSCLI

A new keyword, OSCLI, has been introduced which takes as its argument an expression, which it then passes to the operating system command line interpreter. This is not directly useful in assembler source code, but is useful when saving or loading variable amounts of data, or when sending variable FX commands. For example the following routine sets up soft key 0 to contain the string 'LIST+ERL+[RETURN]':

```
PROCkey (0, "LIST "+STR$ERL+"|M")
*
*
DEFPROCkey(number, A$)
OSCLI("KEY " + STR$number + " " + A$)
ENDPROC
```

Another example is to SAVE a BASIC program by typing

```
OSCLI("SAVE <filename> " STR$~PAGE + " " + STR$~TOP)
```

Note: this is exactly the same as the BASIC command SAVE <filename>. Note also the use of 'STR$~' here to convert a hexadecimal number to a string.

8.3 BASIC I versions of EQUB, EQUW, EQUD and EQUS

Macros can be set up in BASIC I to emulate these directives:

EQUB

```
DEF FNequb(byte)
?P% = byte
P% = P% + 1
= pass
```

EQUW

```
DEF FNequw(word)
?P% = word AND &FF
P%?1 = word DIV &100
P% = P% + 2
= pass
```

EQUD

```
DEF FNequd(doubleword)
!P% = doubleword
P% = P% + 4
= pass
```

EQUS

```
DEF FNequs(string$)
$P% = string$
P% = P% + LEN(string$)
= pass
```

Note that 'FNequs' will put the string into memory from ‘P%’ on, and will also set the byte following the string to a &D byte (RETURN character), although the next mnemonic assembled will overwrite this. In the event that this is a problem, 'FNequs' could be rewritten so that only the string is put into memory, and nothing more. This is left as an exercise for the reader.

8.4 BASIC I version of OSCLI

The following routine can be used in exactly the same way as OSCLI is used in BASIC II, e.g.

PROCoscli("SAVE <filename> " + STR$~PAGE + “ ” + STR$~TOP)

Note that 'cli' is an ATOM string which should be DIMensioned at the start of the program, e.g. DIM cli 64

```
DEFPROCoscli ($cli)
LOCAL X%, Y%
X% = cli AND &FF
Y% = (cli AND &FF00) DIV &100
CALL oscli                          oscli is at &FFF7
ENDPROC
```

9. OS ROUTINES AND SPECIAL EFFECTS

A whole book would be needed to describe all the features of the operating system and the routines it contains. This chapter briefly introduces two operating system calls, 'OSBYTE' and 'OSWORD'. Between them, they perform a wide variety of tasks. It then shows how operating system routines can be intercepted and replaced by user defined ones. Finally it takes a look at some of the special effects which can be obtained using either the operating system commands or specialised hardware provided by the BBC Microcomputer and Acorn Electron.

9.1 OSBYTE and OSWORD

OSBYTE - &FFF4

OSBYTE calls can be used to access several operating system routines. The particular routine is selected by the number passed in the accumulator. The X and Y registers are used to pass any parameters needed to the routine and to pass back any results which may be produced as a result of the call, e.g.

```
LDA #12
LDX #10
JSR osbyte
```

will call OSBYTE 12 which sets the keyboard auto repeat rate, in this case to 10 centiseconds.

```
LDA #129
LDX #&9D
LDY #&FF
JSR osbyte
```

will call OSBYTE 129 which performs the INKEY function, in this case it is being called with a negative value (&9D = -99) and performs a keyboard scan to see if the key with this value, the Space bar, is being pressed.

On exit, X and Y contain &FF if the key being scanned was pressed and 0 otherwise.

*FX calls are used to access OSBYTE calls from BASIC. In this case the values of the registers are passed in the following way:

```
*FX 12,10
```

This will have the same effect as the first example.

However *FX calls do not return results so it is not appropriate to replace the second example given by a *FX call.

OSWORD - &FFF1
OSWORD routines are similar to OSBYTE routines, the difference being that parameters are not passed in the X and Y registers, instead they are passed in a parameter block, and the X and Y registers are used to contain the address of this block, e.g.

```
LDA #2
LDX #&80
LDY #&00
JSR osword
```

This calls OSWORD 2 which sets the value of the system clock to the five byte value which is stored in memory starting at the address &0080.

```
LDA #1
LDX #&80
LDY #&00
JSR osword
```

This calls OSWORD 1 which reads the system clock, the five byte value being returned in memory starting at the address &0080.

9.2 Revectoring operating system routines

Many of the operating system routines are not entered directly by jumping to their position in the ROM, instead they are entered via addresses stored in the RAM.

For example, to use the operating system write character routine (OSWRCH) (the instruction which has been used in previous examples is JSR &FFEE). Location &FFEE, however, contains not the start of the routine, but the instruction JMP (&20E), since the address of the code for OSWRCH is stored in locations &20E and &20F in RAM. These locations are known as the 'vector' for this routine.

Accessing routines indirectly, via vectors in the RAM has several advantages. In different operating systems the entry position of the routine may alter, but this will not affect the user since the instructions JSR &FFEE or JMP (&20E) will still access it. The difference will be dealt with by the operating system which will store the correct addresses in locations &20E and &20F.

In addition the user can intercept any of the routines by 'revectoring' them. For example he could change the contents of &20E and &20F so that they contained the address of a user defined routine. One use of this is shown below.

Pretty Printer – prettyprint

When printing text to the screen it is often difficult to ensure that words will not be broken at the end of the line. The following routine achieves this. When linked in, it will buffer characters up to a space or carriage return character, and then only output the characters on the same line if there is room without splitting them. Note that the routine does not deal with control characters (codes less than 32) that have

trailing characters. The routine should be linked into the OSWRCH vector at &20E - &20F, by typing !&20E = !&20E AND &FFFF0000 OR prettyprint

Notice that the variable 'linelength' is set to the length of the line (19, 39 or 79, depending on the screen mode selected). On entry A holds the character to be printed. X and Y are irrelevant. A typical call would be any call to OSWRCH. On exit all registers have been preserved.

An example of the output of this is: (40 column screen)

```
This text is Prettily Printed This text is Prettily Printed This text
Is Prettily Printed This text is Prettily Printed This text is
Prettily Printed this text is prettily Printed
```

```
.prettyprint
     PHA
     STX savedx          Save X register
     LDX pointer         Get line pointer
     CMP #ASC" "         Is it a space ?
     BEQ isspace
     STA buffer,X        Store character
     INX                 Increment pointer
     CPX # linelength    Is buffer full ?
     BNE exit            If not, get next character
     STX pointer         Update pointer
     BEQ newline         Branch always
.isspace
     CPX #0
     BEQ exit
     JSR getpos
     LDX #0              set X to zero for printbuffer
     LDA pos             get cursor position( x-coord)
     CLC
     ADC pointer         get cursor x+pointer
     CMP # linelength    If >= linelength
     BCS newline         print buffer
     LDA pos             If cursor is at beginning
     BEQ printbuffer     of a line print the buffer
     LDA #ASC " "        else print a space
     JSR printchar
     JMP printbuffer     and print the buffer
.newline
     LDA #13
     JSR printchar
     LDA #10
     JSR printchar
.printbuffer
     LDA buffer,X        get characters
     JSR printchar       print characters
     INX                 increment pointer
     CPX pointer         if line pointer<> line end
     BNE printbuffer     then get next character
```

```
     LDX #0
.exit
     STX pointer          save pointer
     LDX savedx           restore X register
     PLA                  restore A
     RTS                  Return
.getpos
     TYA                  save Y
     PHA                  push to stack
     LDA #&86             osbyte 86 is read cursor position
     JSR osbyte           return pos and vpos in X and Y
     STX pos              X holds x pos of cursor
     PLA                  restore Y
     TAY
     RTS
.printchar
     JMP (oldoswrch)      old oswrch holds original contents
                          of &20E and &20F
```

9.3 Screen Scrolling

On both the BBC Microcomputer and the Acorn Electron, there are two screen-scrolling methods known as software scrolling and hardware scrolling. Software scrolling is often slow. If you define a text window to cover the whole screen (VDU 28,0,24,39,0 in MODES 6 or 7 only) and then scroll and screen (by moving the cursor off the bottom of the screen), you will notice the scrolling slowing down as it attempts to move all the screen memory up a line. An alternative and faster method of scrolling has been incorporated in the hardware.

A section of each computer incorporates a register designed to hold the start of screen memory. In the BBC machine it is the 6845 CRTC (Cathode Ray Tube Controller), and in the Electron it is a section of the ULA (Uncommitted Logic Array). To employ this screen-scrolling method, it is only necessary to change the number in the register. On the next vertical sync, the new screen will be displayed starting at that number. To scroll the screen up on the BBC machine, simply type:

```
MODE 6
VDU 23; 12, &0C; 0; 0; 0; : VDU 23; 13, &28; 0; 0; 0;
```

and on the Electron

```
MODE 6
?&FE02 = &A0 : ?&FE03 = &30
```

To explain: on the BBC machine there are in fact two registers which control hardware scroll. These are registers 12 and 13. Register 12 contains the high byte of the start address, and register 13 contains the low byte. Things are not quite this simple however, as the start address held in the two registers is only to the nearest 8 bytes (1 character cell in the MODEs 0 to 6), and so the number put into the registers is the start address, DIV 8. In the above example, the new address is

&6000 + 40 * 8 (=&6140) DIV 8, which is &C28, and so we put &C in register 12 and &28 in register 13.

On the Electron things are not quite the same. The address held in the hardware is not to the nearest 8 bytes, but to the nearest 64 bytes.

The value to put into the Electron's ULA is the address of the top of the screen, divided by 2. The two registers are at &FE02 and &FE03 (low byte and high byte). The address, &6140, is written there by working out &6140 DIV 2 (=&30A0), and then writing the low and high bytes of the new value into the registers.

You will have noticed that the hardware scroll operation is not exactly the same as that of the operating system scroll, in that the top line is filled not with spaces but with what was on the bottom line when the process began. This is because the memory map will 'wrap round', as in the following diagram;

		0	1	2	3		37	38	39
0		&6140	&6148	&6150	…..	…..	&6268	&6270	&6278
1		&6141	&6149	&6151	…..	…..	&6269	&6271	&6279
2		&6142	&614A	&6152	…..	….	&626A	&6273	&627B
3		&6143	&614B	&6153	…..	…..	&626B	&6273	&627C
4		&6144	&614C	&6154	…..	…..	&626C	&6274	&627C
5		&6145	&614D	&6155	…..	….	&626D	&6275	&627D
6		&6146	&614E	&6156	…..	…..	&626E	&6277	&6?7E
7		&6147	&614F	&6157	…..	….	&626F	&6277	&627F
8		&6280	&6288	&6290	…..	…..	&64E8	&64F0	&64F8
		…..	…..	…..	…..	…..	…..	…..	…..
24*8+6		&7F46	&7F4E	&7F56	….		&606E	&6076	&607E
24*8+7		&7F47	&7F4F	&7F57	….		&606F	&6077	&607F

9.4 Palette handling

Both the BBC Microcomputer and the Acorn Electron provide a palette facility in the 'soft' screen modes. On the Electron all modes are 'soft' screen modes, but on the BBC machine Teletext (MODE 7) has no palette facility. The idea is that each mode can display a certain number of colours at any one time (16 in MODE 2, 4 in MODE 5 and so on).

Essentially the palette provides a mapping between the screen memory and what appears on the screen. The screen memory contains logical colours, and these are represented by the palette as physical colours which you see displayed on the screen. Thus in MODE 1, where there are four logical colours, each can be represented as any of the sixteen physical colours which these computers are capable of producing. Use the VDU19 statement to tell the computer how to represent a particular logical colour as a particular physical colour, i.e.

VDU 19, logical colour, physical colour ; 0 ;

For example:

```
VDU 19,1,3;0;
```

This tells the computer to display all occurrences of logical colour 1 in its memory as physical colour 3 (Yellow). Think of the palette as a mapping of physical colours onto logical colours, where all that the VDU 19 statement does is to simply change the mapping. The illustration below should make this clear:

Colour Mode	*Logical Physical number*	*colour*
0,3,4,6	0	black
	1	white
1,5	0	black
	1	red
	2	Green
	3	Yellow
	4	Blue
	5	Magenta
	6	Cyan
	7	White
	8	F(lashing) black / white
	9	F red / cyan
	10	F green / magenta
	11	F yellow / blue
	12	F blue / yellow
	13	F magenta / green
	14	F cyan / red
	15	F white / black

Another way of changing the palette is to call OSWORD with A set to 12. In this you simply set up a block of 5 bytes to this format:

paletteblock	logical colour
paletteblock+1	Physical colour
paletteblock+2	0
paletteblock+3	0
paletteblock+4	0

Then OSWORD is called in the normal manner (with X and Y pointing to the parameter block, 'paletteblock' in this case). This has precisely the same effect as VDU 19, except that it is faster and also may be called from an interrupt or event routine (See Interrupts below).

OSWORD 12 is not available on BBC machines with OS 0.10.

9.5 Interrupts, events and BREAK interrupts

Both the BBC Microcomputer, and the Acorn Electron run under interrupts. Interrupts allow the machine to update its own internal variables, without the user even realising that their program is not in complete control.

On the 6502 there is an interrupt request pin (IRQ) which, when a signal hits it, tells the processor that an interrupt request has occurred. The 6502 then has the option of ignoring the interrupt. This decision is made by the state of an interrupt flag. If the flag is set, then the interrupt will be ignored, otherwise the operating system will deal with it.

The interrupt flag can be altered with the two assembler instructions:

Mnemonic	*Description*
SEI	set interrupt disable flag
CLI	clear interrupt disable flag (Default state)

Note that the interrupt flag should not really be altered, as then all interrupt driven devices (keyboard, flashing colours, sound, etc.) would stop working.

There are two interrupt vectors provided by the operating system. These are IRQ1V (at &204), through which all interrupt requests are passed, and IRQ2V (at &206), through which any unrecognised interrupts are passed. Normally, IRQ2V would be used, but if you want to update your own device before the operating system can act, then you should use IRQ1V. The routine must first handle the interrupt, then disable the device that caused the interrupt, and finally, it must perform a 'JMP (oldIRQIV)' (where 'oIdIRQ1V' is the old contents of IRQ1V). This should only be used if there is no other way of achieving the desired effect.

One way to set up interrupts on the BBC Microcomputer is by the User 6522 VIA (Versatile Interface Adapter). This has two timers, which can be set to count down from any particular 16-bit value, and to cause an interrupt request on reaching zero. Also, it will be necessary to write a routine to handle this, and to put the address of the entry point of the routine in the correct vector (in this case IRQ2V). Note that the routine must perform an 'RTI' in order to transfer control back to the operating system. RTI stands for return from interrupt.

All this might seem a bit messy, and so a second kind of interrupt peculiar to the BBC microcomputer and Electron has been implemented. This second kind of interrupt is called an Event. (It is not implemented on BBC Microcomputers with OS 0.1).

Events

These operate in a similar way to interrupts in that they are totally transparent (undetectable by the user program) and are indirect, via a vector (at &220).

Certain occurrences within the machine have events associated with them, and these events can be trapped by the user. These are:

0 Buffer empty, where X gives buffer identity
1 Buffer full, where X gives buffer identity and Y holds character that could not be stored.
2 Keyboard interrupt
3 ADC conversion complete
4 Start of TV field pulse (vertical sync)
5 Interval timer crossing zero
6 Escape condition detected
7 RS423 receive error
8 Remote procedure call detected (on Econet)

Events can be selectively disabled and enabled with OSBYTEs 13 and 14, where X specifies the event. Note that the default state is all events disabled.

Example event handler:

```
10   REM Event handler
20
30   vsynccounter=&70
40   DIM code 100
50   FOR pass = 0 TO 2 STEP 2
60   P%=code
70[ OPT pass
80.event
90     PHP                    preserve status
100    CMP #4                 is this the event we want
110    BNE notvsync           if not return
120    INC vsynccounter       increment event counter
130.notvsync
140    PLP                    restore status
15']   RTS                    return
16O]
170  NEXT pass
180
190  eventvec = &220
200  ?eventvec = FNlo(event)
210  eventvec?1= FNhi(event)
220   *FX 14 4
230  END
240
250  DEF FNlo(value) = value AND &FF
260
270  DEF FNhi(value) = (value AND &FF00)DIV 256
```

BRKs

The 6502 supports a BRK instruction. This generates a software interrupt, which is similar to the interrupt request described earlier, except that it cannot be disabled. BASIC and the operating system use BRKs for flagging errors. This means that the

BRK handler will print an error message. The standard format of the BRK error message is;

BRK instruction (op-code is &00)
Fault number (one byte)
Fault message (string of characters terminated by a zero byte)

Thus it is possible to put error messages in a program, and have them printed out by the BRK handler (which, incidentally, is normally handled by the language). This can be useful for debugging purposes. A useful macro for this is:

```
DEF FNerror(err,error$)
[OPT pass
BRK             Cause BREAK
EQUB err        Fault number
EQUS error$     Error message
EQUB 0          Message terminator
.pass
```

A typical call to this would be:

```
OPT FNerror(60, "Hello")
```

where '60' is the fault number, and 'Hello' is the message to be printed when that BRK is activated.

It is, of course, possible to write your own BRK handler, by simply putting the start address of a suitable routine in the BRK vector (&202). For example, the following routine prints out all registers at a BRK:

```
0REM BREAK Handler
10
20 oswrch = &FFEE
30 osnewl = &FFE7
40 stringptr=&70
50 exit=stringptr
60 temp=stringptr+2
70 exit = !&202
80 DIM code 200
90 FOR pass = 0 TO 2 STEP 2
100 P% = code
110[ OPT pass
120.header
130  EQUS " A  X  Y  PC  N  V  U  B  D  I  Z  C"+ CHR$10 +
CHR$ 13
140.break
150  TYA            X and Y
160  PHA            push all registers so they may be printed
170  TXA
180  PHA
```

```
190  LDA &FC             Get accumulator
200  PHA
210  JSR osnewl          go onto a new line
220  LDX #FNlo(header    Print "A  X  Y  PC..
230  LDY #FNhi(header)
240  JSR atomstring
250  PLA                 Get accumulator
260  JSR hexandspace     print it and a space
270  PLA                 Get X register
280  JSR hexandspace     Print it and a space
290  PLA                 Get Y register
300  JSR hexandspace     print it and a space
310  LDA &FE             FE an FD hold the
320  JSR printhex        program counter where
330  LDA &FD             the break occured
340  JSR hexandspace
350  PLA                 Status register
360  JSR printbinary     Print P in binary
370  JMP exit            return to old error
380
390. hexandspace
400  JSR printhex        Print A in hexadecimal
410  LDA #ASC" "         load a space
420  JMP oswrch          print it
430
450  PHA                 Save accumulator
460  LSR A               get
470  LSR A               top
480  LSR A               nibble
490  LSR A
500  JSR print           print top hex digit
510  PLA                 get bottom nibble
520  AND #&0F
530.print                print bottom hex digit
540  CMP #&0A
550  BCC notalpha        if not 0 - 9 get char
560  ADC #6              carry is set here (add 7)
570.notalpha
580  ADC #&30            convert to ASCII
590  JMP oswrch          print and return
600
610.printbinary
620  LDX #8              eight bits per byte
630.binaryloop
640  ASL A               get a bit
650  STA temp            print either 0 or 1
660  LDA #ASC"0"
670  BCC printzero
680  LDA #ASC"1"
690.printzero
700  JSR oswrch          print 0 or 1
```

```
710  LDA #ASC" "         followed by a space
720  JSR oswrch
730  LDA temp
740  DEX
750  BNE binaryloop      Get next bit
760  RTS                 return
770
780.atomstring
790  STX stringptr       Address of string
800  STY stringptr+1     is given in X and Y
810  LDY #&100           Y is pointer along string
820.atomstringloop
830  LDA (stringptr),Y   get next character
840  JSR oswrch          print it
850  INY                 increment pointer
860  CMP #13             is it a return
870  BNE atomstringloop  if not repeat loop
880  RTS                 return
890
900]
910 NEXT pass
920 !&202=!&202 AND &FFFF0000 OR break
930[OPT 2
940.test
950  LDA #&01
960  LDX #&23
970  LDY #&45
980  SED
990  CLC
1000 BRK
1010 EQUB 75
1020 EQUS "HELLO"
1030 EQUB 0
1040]
1050 CALL test
1060
1070 DEF FNlo(value)=value AND &FF
1080
1090 DEF FNhi(value)=(value AND &FF00) DIV &100


>RUN

 A  X  Y  PC  N V U B D I Z C
01 23 45 1BB6 0 0 1 1 1 0 0 0
HELLO at line 1050
```

10. LARGE ASSEMBLER PROGRAMS

When writing substantial assembler programs it soon becomes evident that even 32K of memory is insufficient to hold both the assembler source text and the object code produced. This difficulty is heightened still further if the graphics modes are used. The problem can be overcome by breaking the source text into smaller modules or files and this chapter looks at how to set these up and how to use them.

10.1 Source files and the 'master compiler' program

A source module is a program which acts like a subroutine but has assembly code inside it. The master 'compiler' program reads in each source text module and assembles it. This program is shown below. (Note that anything enclosed within < > (angled brackets) is not to be typed in, but is to be replaced with the value for your application.)

```
0    REM Compile program
10   origin = <start of area for machine-code>
20   file$ = "ABC"
30   PROCrun("I",<page for source files>)
40   PROCrun("M",<page for macro file> (optional))
50   FOR pass = 0 TO 2 STEP 2
60   P% = origin
70   FOR files = 1 TO LENfile$
80   PROCrun(MID$(file$,files,1),<page for source files>)
90      NEXT files
100       NEXT pass
110     PRINT '"Object code from &";~origin;" to &";~P%
120     END
130
140  DEFPROCrun(name$,start)
150  PRINT name$;
160  OSCLI "LOAD SOURCE"+name$+" "+STR$~start
170       PAGE = start
180  GOSUB 0
190  ENDPROC
```

The files are assumed to be called SOURCEA, SOURCEB, ... i.e. the word 'SOURCE' followed by a single letter. The string 'file$' holds the letters which identify them and hence in this example it contains 'ABC'. Since single letters are used, the length of 'file$' gives the number of source programs. Note that in this example 'I' and 'M' should not be used for naming source files since they have their own special uses.

The program starts by reading in and assembling SOURCEI which is the initialisation file to be described later in this chapter. Then the macro file (if one exists) will be treated similarly; again this will be explained later. The main loop takes each of the source files in turn, loads it into the area you have defined as reserved for the source files, and then assembles it. For the first source file the object code starts at the value of the variable 'origin', and P% is used by the

assembler as a pointer to the next free byte. Hence this allows subsequent source files to be assembled so that their code follows on directly after that produced by the previous one.

A typical source file would be of the following format:

```
0 REM SOURCEX
10
20[OPT pass
30
…(Assembler text)
…
…
…
900
910] : RETURN
```

A typical memory map might look like this:

Start of BASIC	Screen - Smallest MODE possible (MODE 7)
	Variables shared by all source files
	COMPILE program
	Macro source file
	Source files
Origin	Object Code

Note that if you are using a 6502 second processor then the screen mode selected will not make any difference.

This method has been designed for use with disc based systems, but can also be used on cassettes if the tape is rewound between the two passes. To remind you of this you should place a 'Rewind Tape' message, together with a 'dummy=GET' statement (to wait for a key to be pressed as an indication that the tape is in the correct position), between the two NEXT statements.

10.2 Saving source files

One routine which is useful when using discs and the above method is a PROCsave routine;

```
DEF PROCsave:OSCLI("SAVE <filename>+ STR$~PAGE +" "+STR$~TOP)
ENDPROC
```

Note: this routine will not work on BASIC I. See chapter 9 (BASIC 1, BASIC II and Electron BASIC) for a description of OSCLI and the equivalent BASIC I routine.

The routine should be inserted at the ends of all the source files, and called whenever you wish to save the source file that is in memory at the time.

Thus to SAVE the program all that is needed is to type 'PROCsave'. The reason this is so useful is that when editing large numbers of source files which all look alike, it is very easy to overwrite an existing file by typing the wrong name.

An alternative to this, which works on all versions of BASIC, is to type, in immediate mode, 'SAVE $(PAGE+6)'. This looks at the first line of the program to find the filename. So, each program should start with

```
0    REM <filename>
100  <program>
200  ....
```

Default soft keys

Another useful idea is to employ the machine's soft keys. This is best done by having a default soft keys program, which can be loaded at the beginning of the session.

```
10   REM Default Soft Keys
20
30   *KEY 0 |LLIST|N|M
40   *KEY 1 RUN|M
50   *KEY 2 LOAD"SOURCE
60   *KEY 3 CALL enter|M
70   *KEY 5 PROCsave|M
80   *KEY 6 PROCfind("
90   *KEY 7 MODE7|MPAGE=&600|MLOAD"COMPILE"|M
100  *KEY 9 |L*CAT|M
```

Note that line 80 has a reference to PROCfind. This procedure is to be used from immediate mode to find all occurrences of strings in the current source module. (PROCfind is defined in section 12.6.) This procedure should be at the end of every source file.

10.3 Macro source files

If source files are to be used then calling macros can be a problem. To understand why, some knowledge of how BASIC works is required. When BASIC first comes across a reference to a function or procedure its search for the function or procedure definition starts from PAGE. Once it has found the definition it stores the address of the start of the function or procedure in memory, so that the next time it finds a reference to that particular function or procedure it doesn't have to waste time searching through the whole program again.

In the simplest case, when just one source file references a given macro, the macro

can be added to the end of that source file, and the file treated normally. Consider, however, what would happen if two source files both had a reference to a macro called 'FNfred', and this macro was put at the end of each of them. Since they would almost certainly be different sizes the definition of 'FNfred' would, in each case, start at different addresses. Moreover, when the first source file was assembled the address of the macro in this file would be stored for use by all later references to the macro. Thus, when the second source file tried to use the macro, no searching through would occur. Instead the assembler would jump straight to the address which was stored by the first file and be unlikely to find 'DEFFNfred' starting there.

To avoid this problem a macro file is set up containing all the macros referenced in any of the assembler source files. This is present in the memory all the time, though in a different area of memory to the other files. Each of the macros must be called before the source files are assembled, however, so that the addresses where their definitions may be found are available to the compiler. Otherwise the first time that the compiler comes across a reference to a macro, e.g. FNfred, it will start searching for 'DEFFNfred', starting at PAGE, look through to the end of the source file, not find the definition, conclude that the macro doesn't exist and report 'No such FN/PROC'. So, set PAGE to the bottom of the macro file and call each macro once.

Thus a typical macro source file looks like this:

```
0    REM Macro file
10
20   pass=-1:REM Dummy compilation
30   A% = FNmacro1(0,0)+FNmacro2(0,0,0,0)..
40   RETURN
50
60   DEF FNmacro(temp,no)
70   IF pass <0 THEN =TRUE
80[OPT pass
90  ...
```

Line 20 sets 'pass' to a value that the assembler will not use, so that the first time the macro is referenced it will not generate any code. Note that every macro in the file must have a test to see if it is being referenced for the first time (as at line 70).

Since the macro file needs to be resident in memory during the compilation a space will have to be assigned for it. This is usually between the top of the normal source files and the bottom of the COMPILE program.

10.4 Initialisation file

The initial file mentioned in COMPILE (line 30) is the file that sets up all variables to be used in the later source files. This is normally in the form:

```
0  REM SOURCEI
10
20 REM variables
30
------------------------------------------------------------
This is where all the variables that will be accessed by all
the source files are defined. Note that all the variables are
defined to be resident in memory one after the other. Thus to
move the block of variables around in memory, all you have to
do is to simply change the value of 'P%' in line 40.
------------------------------------------------------------
40 P% = <start of memory to put variables>
50[OPT2 \ Report any errors, but don't list
60.<first variable> EQUB 0 \ Reserves one byte
70.<second variable> EQUW 0  \Reserves two bytes
30.<third variable> EQUS STRING$(20,CHR$(0))
90 etc.

200]
------------------------------------------------------------
This section sets up any constants that may be used in the
program. The use of constants in any program is very
important as is explained in chapter 12 (Program structure).
------------------------------------------------------------
210
220 REM Constants
230
240 limit = 45
250 numberofshapes = 12
260 oswrch = &FFEE
270 etc.
------------------------------------------------------------
This section reserves memory for the data tables.
------------------------------------------------------------
300
310 REM Main Memory Allocations
320
330 P%=<start of memory allocated for tables>
340[OPT2
350.jim
360 OPT FNspace(80)
370.fred
380 OPT FNspace(300)          See section 12.5
390.lenqth                    for FNspace
400 OPT FNspace(100)
```

```
410 etc
-------------------------------------------------------------
This section fills the data tables.
-------------------------------------------------------------
600
610  REM fill data tables
620
630  FOR offset = 0 TO numberofshapes
640  READ offset?length, offset?width, offset?type
650  NEXT offset
660
670  DATA 20,12,3,36,24,1,etc.
680  etc
999  RETURN
```

11. PROGRAM STRUCTURE

The aim of this chapter is to help you write a large assembler program. It gives several tips how to produce structured and readable code which can be debugged easily.

11.1 Where to start

There are two entirely different approaches which can be used when producing a structured program. The first is to work out what the program is going to do and what it is going to look like before you start writing any code. Then you can start by writing the main loop which, for a game, could look something like this:

```
.enter
     JSR initialise
.restart
     JSR setupscreen
.main
     JSR plotshapes
     JSR checkcollisions
     JSR keyboardscan
     JSR updatecoordinates
     JSR checkifdead
     BNE mainloop
     DEC lives
     BNE restart
     RTS
```

Although, at this stage, the subroutines have not been defined, it is obvious from their names what they are meant to do. The next task is to write these subroutines, again breaking them down into simpler routines if this is possible.

Since the main loop is the top level in the overall structure, this method is known as 'top-down' approach. Its advantage is that you know what you are aiming at right from the start. You shouldn't need any 'fixes' in the subroutines to make up for the fact that when you wrote them you didn't make them apply to all cases eventually required.

The alternative method is to start by writing the individual routines and then to add the code which joins them together into the final program. The advantage of this method is that all routines can be tested individually before very much effort has gone into the program. Consider how much time would be wasted if you used the first method and completed the whole program except for one routine which proved impossible to write in such a way that it performed satisfactorily.

In practice most people use a mixture of the two methods, so that any demanding routines are written first; then the top-level is written, followed by the rest of the program.

11.2 Self-documenting code

Long, directly referential variable names are a good idea when writing a program as they make the program more intelligible, e.g. 'JSR updatecoordinates' is better than 'JSR label2'. These may make the source code longer, but the problem can be overcome by splitting up the code into separate sections and compiling these individually as described in chapter 10 (Large assembler programs). Note that the fewer JMP's there are, the easier it is to follow the flow of control. Hence, using macros rather than subroutines also helps to increase the clarity of the code.

11.3 Parameters

Parameter passing is also recommended in assembler, for precisely the same reasons as it is in BASIC, viz. It enables a single block of code to be used for more than one purpose. However, the method of achieving this is somewhat different. Parameters are usually passed in the three registers A, X and Y, or alternatively the X and Y registers are used to specify an address of an information block, and the A register then holds some other information. A third method is to pass parameters in specified locations, so enabling an arbitrary number of parameters to be passed. This method doesn't support nesting or recursion, however.

The CALL statement

This statement, which is used to transfer control from a BASIC program to a machine code program, can also pass parameters. When it is used, the bottom bytes of the BASIC variables A%, X% and Y% are transferred to the A, X and Y registers respectively. Also the lowest bit of C% is transferred to the carry flag.

Control is passed to the address given after the CALL statement and any parameters following this address are put into the parameter block starting at &600. The parameter block is of the following format:

&600 Number of parameters
&601 Parameter address (low byte)
&602 Parameter address (high byte)
&603 Parameter type
&604 Parameter address (low byte)

The parameter types are as follows:

Type 0 8-bit byte
Type 4 32-bit word
Type 5 40-bit floating point string
Type 128 ATOM string
Type 129 Microsoft string

In the case of a string parameter the address given points to a 'string information block', which contains the following:

Start address of the string

Number of bytes allocated
Current length of string

An example of a CALL statement is

```
CALL enter,fred,A$
```

This would cause the machine code from 'enter' to be executed and the parameters 'fred' and 'A$' would be described in the parameter block as follows:

```
I 02 I C7 I 0E I 05 I DO | 0E | 81 I ?? I ?? I ?? I
 0600 0601  0602 0603 0604 0605 0606 0607 0608 0609
```

The USR function

Another way of transferring control to a machine code routine is via the USR function. The differences between CALL and USR are that USR returns a result, a four-byte number consisting of the Status, Y, X and A registers (most significant byte to least significant byte), and takes only one parameter which is the address to which control is transferred.

11.4 Size of routines

All routines, whether in BASIC or assembler, should be as small as possible, so that they can be seen easily in their entirety. This is another real help when debugging. Debugging is often overlooked when estimating the time needed to write a program, and yet it is probably true to say that at least 50% of the time taken to write a program is taken up with debugging.

11.5 Conditional assembly as an aid to debugging

Conditional assembly can be used to insert extra instructions which print out intermediate values during debugging: these statements can be removed when the program is finally assembled. To do this a logical variable ('flag' in the following example) is given the value FALSE during debugging and TRUE otherwise. In the following example, if 'flag' is FALSE a routine to print the value of the accumulator in hexadecimal notation is assembled, and calls to this routine is inserted at two relevant points in the test program.

```
10 REM print hex digits
20 DIM code 100
30 oswrch = &FFEE
40 FOR pass = 0 TO 3 STEP 3
50 P% = code
60 [OPT pass
70 .enter CLC :ADC #&40 :]
80 IF flag = FALSE  [OPT pass : JSR debug:]
90 [OPT pass
100 BEQ exit :SBC :#&10:]
110 IF flag = FALSE [OPT pass  : JSR debug:]
```

```
120[OPT pass
130 .exit RTS:]
140 IF flag THEN 360
150 [OPT pass
160  \ print hex digits
170.print
180 AND #&0F        get bottom four bits
190 CMP #&0A        if less then 10 then miss
200 BCC P% + 4 the next instruction
210 ADC #&06        Add 7 (6 + carry)
220 ADC #ASC"0"     Add ADC (0)
230 JMP oswrch Write the character
240 \ print A in hex
250.debug
260 PHA
270 PHA
280 LSR A           exchange top four bits
290 LSR A           for bottom four bits
300 LSR A
310 LSR A
320 JSR print       print first hex char
330 PLA
340 JSR print       print second hex char
350 PLA             restore original value of A
360 RTS             return
370]
380 NEXT pass
```

The program works by finding out whether or not the four bits corresponding to each hex digit represent a number less than ten. If it is less than ten then the value ASC ("0") is added and the character, which will be a number 0... 9 will be printed. If it is greater than or equal to ten then a number equivalent to ASC ("A-10") is added so that ten will be printed as A, eleven as B etc.

For debugging purposes this program is assembled by typing

```
15 flag=FALSE
RUN
```

The program can then be executed for various values of A% by typing

```
A%=&12:CALL enter
```

The final version of the program is assembled, without the debugging aids, by typing

```
15 flag=TRUE
RUN
```

11.6 Lower case variable names

As a convention, lower case is used for variable names. Most people consider this to make the code more readable. It also means that there is no chance of using variable names that conflict with BASIC's keywords e.g. 'print' can be used as a variable name, even though PRINT cannot).

11.7 Constants

Constants are used to give names to numbers which will be used several times throughout a program. They help to make the code easier to understand, e.g.

```
LDX#initial-lives
```

explains far better what is happening than

```
LDX#3
```

Using constants has another advantage - if a value needs to be changed and constants have been used, only the definition of the constant would need to be altered, rather than every occurrence of that value.

Some languages support constants and variables as totally different data types, and make it impossible to change the value of the constant. BASIC does not treat variables and constants differently (except for it's own constants, e.g. PI) and so it is up to the programmer to make sure that any constants defined retain their value. One convention used for this is to prefix all constants with a pound (£) sign as a reminder.

11.8 Lookup tables

Lookup tables are useful when converting one value to another. As an example consider the following:

```
LDY index
LDA table,Y
```

In this example the value of A is dependent upon the value of Y. The example consists of a table of values, starting at 'table'.

Note that the above assembler is directly equivalent to the BASIC 'A=table?index'.

The values in 'table' could be the values of a palette, for example

```
.table
     EQUB &3   \Colour 0 is yellow
     EQUB &1   \Colour 1 is red (default)
     EQUB &6   \Colour 2 is cyan
etc.
```

Thus lookup tables should be used wherever it is necessary to produce a value from another value, but only when there is no simple relationship between the two.

11.9 Use of absolute addresses

A mark of a good assembler program is that it will contain no absolute addresses in the assembler source code. Thus, if a data table starts at location &30F6, a constant should be set up initially to have the value &30F6, and the constant used in the assembler code, not the number &30F6. This follows on from the above points, and also makes the code easier to read and alter.

12. UTILITIES FOR ASSEMBLER PROGRAMS

This chapter consists of a number of routines which are designed to be used in any assembler program. Typical calls are given for each, as are the values to be passed to the routines in the registers, and those values to be returned by them.

Note that these routines are not meant to be complete programs and cannot be run without additional code being added, e.g. assignment of values to any addresses being used and all the necessary assembler directives. If you wish to use any of these routines inside your own programs then the comments to the right of the assembler statements may be omitted. If the routines contain any BASIC commands then any comments to the right of these must be left out or preceded by REM statements.

12.1 Input/Output

Print BCD number – printnumber

The 6502 microprocessor can perform arithmetic in two ways. These are binary (normal addition), and binary coded decimal (BCD). In the second method, each byte is split up into two nibbles, each of which can hold a decimal digit (0 to 9). Thus the largest number that can be held in one byte using this method is 99. The advantage of this method is that it is easier to output a binary coded decimal number in decimal than it is to output a straight binary number in decimal.

The following routine takes a BCD number in the accumulator and prints it, with leading zero suppression, at the current cursor position.

On entry, A contains the number to be printed, Y contains the leading zero flag (0 for no suppression, else suppress zeros), and X contains the ASCII code of the character to be printed in place of leading zeros.

A typical call to print out a two-byte BCD number, with leading zeros being replaced by spaces, would be:

```
     LDX#ASC" "          Set leading zero character to space
     LDY#&FF             Set leading zero flag
     LDA highbyte        Get top byte of number
     JSR printnumber     Print it
     LDA lowbyte         Get bottom byte of number
     JSR printnumber     Print it
```

On exit X has been preserved and A and Y will have been corrupted.

```
.printnumber
     PHA                 Save number
     OPT FNrotateacc(4)  Get top digit (See section 8.2)
     JSR printit         Print it
     PLA                 Restore number
     AND#&0F             Get bottom digit
```

```
 .printit                Fall through
     BNE validchar       if non-zero print
     TYA                 Check zero flag
     BNE leadingzero     if set must be leading zero
.validchar               digit ok
     LDY#&00             clear zero flag
     ORA#ASC"0"          add in ASCII zero
     JMP oswrch          print and return
.leadingzero
     TXA                 Get leading zero character
     JMP oswrch          print and return
```

Keyboard scan – inkey

This routine can be called to detect if a key is being held down at a particular instant; it uses INKEY of negative numbers.

On entry, X specifies the key to be tested. For details of the values for each key, see the table of INKEY negative numbers in Appendix A.

A typical call would be:

```
LDX#firstkey
JSR inkey
BNE keypressed
```

On exit, the zero flag is set or cleared depending upon the key's position at the time of testing. This routine does NOT go via the keyboard buffer. A and Y will have been preserved.

```
.inkey
     PHA                 Save A
     TYA                 Save Y
     PHA
     LDY#&FF             Negative numbers
     LDA#&81             osbyte &81 is INKEY
     JSR osbyte          Do it
     PLA                 Restore Y
     TAY
     PLA                 Restore A
     CPX                 Adjust zero flag
     RTS                 and return
```

Sound

Sound routines are always useful in games programs. The routine below works by using a table to hold all the sounds that it is to play, and, on entry, the number of the sound to be played is given. To set up the table, the following could be used:

```
FOR offset = 0 TO <number  of  sounds>*8 STEP  2
READ sndbuff!offset
NEXT offset
DATA 1,-15,200,20
DATA 3,1,150,10
DATA etc.
```

Where 'sndbuff' is the table to be filled with sounds, on entry, A holds the number of the sound to be played. X and Y are irrelevant.

A typical call would be:

```
LDA#firingsound
JSR sound
```

On exit, all registers will have been corrupted.

```
.sound
     ASL A               multiply soundbuffer by 8
     ASL A
     ASL A
     ADC#FNlo(sndbuff)   add in address of sound table
     TAX                 put low byte of address in X
     LDY#FNhi(sndbuff)   Get hi byte in Y
     BCC nohibyte        If carry then X and Y correct

     INY                 else increment hi byte
.nohibyte
     LDA#&07             OSWORD 7 is sound
     JMP osword
```

Print strings

ATOM style string - atomstring

ATOM strings are defined as being groups of characters terminated by a RETURN character (&0D). On entry, X and Y hold the start address in memory of the string to be printed (X holds low byte, and Y holds high byte). A is irrelevant.

A typical call would be:

```
     LDX#FNlo(hiscorestring)
     LDY#FNhi(hiscorestring)
     JSR atomstring
```

On exit, all registers will have been corrupted.

```
.atomstring
     STX stringptr            Address of string to be printed
```

```
      STY stringptr + 1       is given in X and Y
      LDY #&00                Y is pointer along the string
.atomstringloop
     LDA (stringptr),Y        Get next character from string
     JSR oswrch               print it
     INY                      increment pointer
     CMP#&0D                  is character return
     BNE atomstringloop       no? go back to start of loop
     RTS                      return
```

Microsoft style strings – microsoftstring

Microsoft strings are defined as being groups of characters, preceded by a byte giving the length of the string. A Microsoft string can be set up as follows:

```
.fredstring
EQUB LEN(fred$)
EQUS fred$
```

On entry, X and Y hold the start address of the string (X holds low byte, Y high byte). A is irrelevant.

A typical call might be:

```
LDX#FNlo(fredstring)
LDY#FNhi(fredstring)
JSR microsoftstring
```

On exit, all registers will have been corrupted.

```
.microsoftstring
     STX stringptr       Address of string to be printed
     STY stringptr + 1   is given in X and Y
     LDY#&00             Set pointer to length byte
     LDA(stringptr),Y    Get length of string
     STA len             Save length
.stringloop
     INY                 loop counter
     LDA (stringptr),Y   get next char from string
     JSR oswrch          print it
     CPY len             printed all chars?
     BNE stringloop      no ? go back to start of loop
     RTS
```

Centre a string - centre

This routine will centre up Microsoft strings on the current line of the cursor. The reason that only Microsoft strings can be centred using this routine is that their length is far more accessible than the length of an atom string, although the routine could be adapted for atom strings.

The BASIC equivalent of the routine given below is:

```
PRINT SPC((screenwidth-LEN(A$)) DIV 2);A$
```

On entry, X and Y point to the string to be centred, and A is irrelevant.

A typical call would be:

```
LDX#FNlo(string)          Point to string
LDY#FNhi(string)
JSR centre                Centre it
```

On exit, all registers will have been corrupted.

```
.centre
     STX stringptr        Save Low byte of start address
     STY stringptr+1      Save high byte of start address
     LDY#&00              Prepare to get  Length byte
     LDA#screenwidth      Get screen width
     SEC
     SBC (stringptr),Y    Subtract  length
     LSR A                Divide by 2
     TAX                  And transfer it to X
     LDA#ASC" "           Stand by to print X spaces
.centreloop
     JSR oswrch           Print a space
     DEX                  Decrement counter
     BNE centreloop       and loop until counter is zero
     LDX stringptr        Restore string pointers
     LDY stringptr+1
     JMP microsoftstring  And print the string
```

Move cursor to X, Y – printtab

This is a very simple routine to move the text cursor to X, Y. It simulates BASIC's 'PRINT TAB(X,Y)'.

On entry, X and Y hold the X and Y coordinates of the position that the text cursor is to be moved to, A is irrelevant.

A typical call might be:

```
LDX#xcoord
LDY#ycoord
JSR printtab
```

On exit, X and Y will be preserved, and A will have been corrupted.

```
.printtab
     LDA#31          VDU 31 (move textcursor to X,Y
     JSR oswrch
     TXA             send X coordinate
     JSR oswrch
     TYA             send coordinate
     JMP oswrch      do it and return
```

Double height characters - double

This next routine will only work in Teletext mode, and is thus only suitable for the BBC microcomputer.

The BASIC equivalent of this routine is:

```
DEF PROCdouble(A$)
vpos%=VPOS : pos%=POS
FOR string% = 0 TO 1
PRINT TAB(pos%,vpos%+string%);CHR$&8D;A$;CHR$&8C;
NEXT string%
ENDPROC
```

On entry, X and Y point to the string that is to be printed in double height, A is irrelevant.

A typical call would be:

```
LDX#FNlo(string)
LDY#FNhi(string)
JSR double
```

On exit, all registers will have been corrupted.

```
.double
```

```
     STX stringptr       Save start address of string
     STY stringptr +1
     LDA#&86             Read text cursor position
     JSR osbyte
     STX pos             and store it
     STY vpos
     LDX#&02             Print string twice
     STX count
.doubleloop
     LDX pos             Move cursor to X,Y
     LDY vpos
     JSR printtab
     LDA#&8D             Teletext code for Double height
     JSR oswrch
     LDX stringptr       Restore string start address
     LDY stringptr+1     Either  'microsoft' or 'atom'
     JSR string          To centre string JSR centre
     LDA#&8C             Teletext Normal height code
     JSR oswrch
     INC vpos            Move down a  line
     DEC count           Done it twice yet
     BNE doubleloop      If not then do it again
     RTS                 Else return
```

Palette handling - ospalette

This routine performs VDU 19, Y, A, 0, 0, 0. On entry, Y contains the logical colour to be defined, A contains the physical colour to change Y to. (See section 9.4 for details of palette handling.) X is irrelevant.

A typical call might be:

```
LDY#logicalcolour
LDA#physicalcolour
JSR ospalette
```

On exit, Y and X have been preserved, A has been set to zero.

```
.ospalette
     PHA            Save physical colour
     LDA#19         VDU 19
     JSR oswrch
     TYA            Get logical colour
     JSR oswrch     VDU it
     PLA            Get physical colour
     JSR oswrch     VDU it
     LDA#&00        Pad out with zeroes
     JSR oswrch
     JSR oswrch
     JMP oswrch     and return
```

Another routine for those of you with Electrons or BBC micros with 1.0 or 1.2 Operating Systems is to change the palette with OSWORD 12. This has the advantage of being able to be called from an interrupt routine.

```
.ospalette
STY paletteblock          Same format as VDU 19
STA paletteblock
LDX#FNlo(paletteblock)
LDY#FNhi(paletteblock)    Note that all registers are
LDA#12                    corrupted
JMP osword
```

This is called in the same manner as before. Note that the 'paletteblock' must contain zeros in the last three locations before the routine is called.

Wait for flyback - vsync

The next routine is a must for animation. It will wait for the electron beam inside the VDU (Visual Display Unit) to reach the top of the screen in BBC Microcomputers or the bottom of the screen in Acorn Electrons, and will then return. This is when all shapes should be updated to avoid flickering.

On entry, all registers are irrelevant. A typical call would be:

```
JSR vsync
```

On exit, all registers will have been corrupted.

```
.vsync
     LDA#19          Osbyte 19 is wait for vsync
     JMP osbyte      (vertical synchronisation)
```

or

```
. vsync              This routine is only for Issue 0.10
     LDA#&02         Operating Systems on the BBC micro
     STA viaier      This is at &FE4E
.vloop
     BIT viaifr      viaifr stands for Versatile Interface
     BEQ vloop       Adapter Interrupt flag
     LDA #&82        Register, which is at &FE4D
     STA viaier
     RTS
```

12.2 Analogue to digital routines

Analogue to digital value - adval

This routine reads any A to D channel.

On entry, X holds channel to be read. Y and A are irrelevant.

A typical call might be:

```
     LDX#1               Get value of channel
     JSR adval
```

On exit, the value is returned in Y and X (Low byte and high byte respectively).

```
.adval
     LDY #0              Get ADVAL(X)
     LDA #&80
     JMP osbyte
```

Joystick handler -joystick

This routine reads either of the two joysticks connected to the A to D converter. Note that the sensitivity of the reading is dependant upon the value of the constant 'joyrange' (0 - insensitive to 127 - very sensitive). The variables 'xcoord' and 'ycoord' are user variables.

On entry, X holds the number of the joystick to be read (1 or 3). A and Y are irrelevant.

A typical call might be:

```
     LDX #1              Get readings of first joystick
     JSR joystick
```

On exit, all registers will have been corrupted.

```
.joystick
     STX temp            Preserve joystick number
     JSR adval           Get horizontal reading
     LDX temp            Restore joystick number
     CPY #joyrange       Is reading within Limit ?
     BCS tryleft         See if within other limit
.right
     INC xcoord          Go right
.tryleft
     CPY #256-joyrange   Is reading within limit ?
     BCC getotherpot     no? try vertical component
.left
```

```
     DEC xcoord          go left
.getotherpot             get vertical component
     INX                 Get adval (joystick + 1)
     STX temp            preserve as before
     JSR adval           get reading
     LDX temp            restore joystick number
     CPY#joystick        all this is as above
.down                    except that y coordinate
     DEC  ycoord         is being adjusted
.tryup
     CPY#256-joyrange
     BCC tryfire
.up
     INC ycoord
.tryfire                 Get fire button
     TXA                 Halve X (for fire button
     LSR A               mask)
     STA temp            (ADVAL(0) AND X DIV 2)
     LDX#0               Get ADVAL(0)
     JSR adval
     TXA                 X holds fire button status
     AND temp            AND with mask
     BEQ exit            Not held down, then exit
.fire
     JSR firebullet      Else do something exit
.exit
     RTS                 Return
```

Oscilloscope

The program displays the four A to D channels as four different colours (colours 1 to 4). This program will only work on the BBC Microcomputer Model B, as it uses MODE 2, the Analogue to Digital converter, and Hardware scroll. The program also only reads the top eight bits of each channel, as the graphics vertical resolution is only 256. Sampling of the channels takes places every 1/50 of a second.

Some of the ideas in this program can be adapted to other programs. Note the modular construction, with each module as small as possible, so that it could be debugged easily during development.

```
10   REM Oscilloscope V1
20   DIM code 512            set aside area for code
30   PROCassemble            assemble code
40   MODE 2                  set up screen mode
50   CALL oscilloscope       call machine code
60   END
70
80   DEF PROCassemble
90   osbyte = &FFF4          set up variables
100  oswrch = &FFEE          constants
```

```
110  top = &80                        zero page location
120  screen = top + 2
130  temp = screen + 2
140  DIM colour 3, sidebuffer 255     define vectors
150  !colour = &030C0F30              fill colour vector
16O  FOR pass = 0 TO 2 STEP 2
170  P% = code
18O[OPT pass
190.oscilloscope                      entry point
200  JSR clearsidebuffer
210  JSR readchannels
220  JSR vsync
230  JSR scrollscreen
240  JSR writeside
250  JMP oscilloscope
260
270.clearsidebuffer
280  LDA#0                            set buffer to 0
290  TAY                              buffer is a page long
300.clearloop
310  STA sidebuffer,Y
320  DEY
330  BNE clearloop
340  RTS
350
360.readchannels
370  LDX#4                            get four channels
380.loop JSR adval
390  LDA colour-1, X                  get channel colour
400  STA sidebuffer, Y                put reading in buffer
410  DEX                              get next channel
420  BNE loop
430  RTS
440
450.vsync
460  LDA#19                           see section 12.1 for
470  jmp osbyte                       OS 0.10 vsync routine
480
490.scrollscreen
500  LDA top                          top = 16 bit address
510  STA temp
520  LDA top+1                        store top DIV 8 in the
530  LSR A                            6845 CRTC chip, see
540  ROR temp                         section 9.3 for
550  LSR A                            details of screen
560  ROR temp                         scrolling
570  LSR A
580  ROR temp
590  LDX#12                           register 12 & 13
600  JSR os6845                       hold start address of
610  LDX#13                           memory to be displayed
```

```
620  LDA temp
630  JSR os6845
640  # Now increment top
650  CLC                    adjust variable that
660  LDA top                holds start address
670  ADC#8
680  STA top
690  LDA top+1
700  ADC #0
710  BPL validaddress
720  SEC                    allow for wraparound at
730  SBC#&50                &3000 / &8000 barrier
740.validaddress
750  STA top+1
760  RTS
770
780.writeside               dump buffer to screen
790  LDX#&FF                start at top of buffer
800  LDY#0                  set offset to zero
810  LDA top                add &270 to top
820  CLC                    to right hand side of
830  ADC#&70                the screen
840  STA screen
850  LDA top+1
860  ADC#2
870  BPL validaddress2
880  SEC                    again allow for
90   SBC#&50                wraparound
900.validaddress2
910  STA screen+1
920.outerloop
930  LDA sidebuffer,X       get next byte from buffer
940  STA (screen),Y         store to screen
950  DEX                    adjust buffer pointer
960  INY                    every 8 bytes down
970  CPY#8                  the program must add in
980  BNE outerloop          &280 to the address ,in
990  LDY#0                  order to move to the next
1000 LDA screen             line
1010 CLC
1020 ADC#&80
1030 STA screen
1040 LDA screen + 1
1050 ADC#2
1060 BPL validaddress3
1070 SEC
1080 SBC#&50
1090.validaddress3
1100 STA screen + 1
1110 CPX#&FF                buffer all transferred to
1120 BNE outerloop          screen ?
```

```
1130 RTS
1140
1150.adval
1160 TXA                     preserve channel pointer
1170 PHA
1180 LDY#0                   get adval(X)
1190 LDA#&80
1200 JSR osbyte
1210 PLA                     restore channel pointer
1220 TAX
1230 RTS
1240
1250.os6845
1260 PHA                     perform
1270 LDA#23                  VDU23;X,A,0;0;0;
1280 JSR oswrch              to put A into 6845
1290 LDA#0                   register X
1300 JSR oswrch
1310 TXA
1320 JSR oswrch
1330 PLA
1340 JSR oswrch
1350 LDX#6
1360 LDA#0
1370.pad
1380 JSR oswrch
1390 DEX
1400 BNE pad
1410 RTS
1420]
1430 NEXT pass
1440 ENDPROC
```

12.3 Numerical routines

MOD – mod

This routine can be useful when rounding numbers down, or when the remainder of a value is wanted, and the AND instruction cannot be used (e.g. value MOD 3). Note that this method is not one to be recommended for anything other than single byte operations, as the method of repeated subtraction would then be too slow. Also, there is no error checking procedure, so setting Y to 0 would cause the routine to loop forever.
On entry, A holds dividend, and Y holds the divisor. X is irrelevant.

A typical call might be:

```
LDA#dividend
LDY#divisor
JSR mod
```

On exit, A holds the remainder, X and Y are preserved.

```
.mod                    Performs A = A MOD Y
     STY temp SEC       Store divisor in temporary  location
.modloop
     SBC temp           Set carry (for subtraction)
     BCS modloop        Repeatedly subtract Y from A
     ADC temp           until A becomes less than zero
     RTS                Add divisor (Note carry clear) and
return
```

Random number generator – rnd

A routine which is always useful for games programs is a random-number generator. The following routine generates a pseudo-random number in A. The seed for the random number is three bytes long. This seed can be initialised before using the routine, in order to generate a fixed sequence of numbers. Note that the seed should never contain zero in all three bytes as then the routine will continually give zero.

On entry, all registers are irrelevant. A typical call would be:

```
JSR rnd
```

On exit, A holds the next pseudo-random number. X and Y are preserved.

```
     LDA seed           Get low byte of shift register
     AND#&48
     ADC#&38
     ASL A
     ASL A
     ROL seed+2
     ROL seed+1
     ROL seed
     LDA seed
     RTS
```

12.4 Miscellaneous

Cyclic redundancy check - CRC

Cyclic redundancy checks can be useful for error detection when comparing blocks of data. Using the program below you can give any block of memory a 'unique' two-byte signature. Thus you can check that two copies of a program are identical, by seeing if they have the same signature. This method is very secure, as it is very unlikely that two different blocks of memory would give the same signature.

```
0 REM CRC calculator
10
20 signature = &70
30 addr = signature + 2
40 endaddr = addr + 2
50 DIM code 200
60 FOR pass = 0 TO 2 STEP 2
70 P%=code
8O [OPT pass
90.crc
100  LDA#0                    initialise signature
110  STA signature
120  STA signature+1
130.mainloop
140  JSR crcbyte              get crc for each byte
150  INC addr                 16 bit increment
160  BNE nohibyte
170  INC addr+1
180.nohibyte
190  LDA addr                 if at last address
200  CMP endaddr              then end
210  BNE mainloop             else do another byte
220  LDA addr+1
230  CMP endaddr+1
240  BNE mainloop
250  RTS
260
270.crcbyte
280  LDY #0
290  LDA (addr),Y             get byte
300  LDX #8                   8 bits in a byte
310.loop
320  LSR A                    do crc
330  ROL signature
340  ROL signature+1
350  BCC nextbit
360  PHA
370  LDA signature
380  EOR #&2D
390  STA signature
```

```
400  PLA
410.nextbit
420  DEX                    get new bit in byte
430  BNE loop
440  RTS
450]
460 NEXT pass
470 INPUT"Start address &"start$
480 !addr = EVAL ("&"+start$)
490 INPUT"Length &"length$
500 !endaddr  EVAL("&" + length$ + "+&" + start$)
510 CALL crc
520 PRINT"Signature = "&";~!signature AND &FFFF
```

12.5 General purpose macros

Get low byte - FNlo

```
DEF FNlo(value) : =value AND &FF
```

An example call is

```
LDA#FNlo(table)
```

Get hi byte – FNhi

```
DEF FNhi(value): =(value AND &FF00) DIV &100
```

An example call is

```
LDY#FNhi(string)
```

Reserve space - FNspace

```
DEF FNspace(amount)
P% = P%+amount
O% = O%+amount           this line is only relevant
= pass                   on BASIC II or electron
```

An example call is

```
.table
OPT FNspace(500)
```

16 bit addition – FNadc

Provides 16 bit addition.

A typical call might be:

```
OPT FNadc(&3000,&2000,&2004)
```

This would add the contents of &2000 (low byte) and &2001 (high byte) to the contents of &3000 (low byte) and &3001 (high byte) and store the result in locations &2004 and &2005.

```
DEF FNadc(operand1,operand2,result)
[OPT pass
LDA operand1
CLC
ADC operand2
STA result
LDA operand1+1
ADC operand1+1
STA result+1
]
= pass
```

16 bit subtraction - FNsbc

Provides 16 bit subtraction. A typical call would be:

```
OPT FNsbc(&3000,&2000,&2004)
```

This would subtract the contents of &2000 (low byte) and &2000 (high byte) from the contents of &3000 (low byte) and &3001 (high byte) and store the result in locations &2004 and &2005.

```
DEF FNsbc(operand1, operand2,result)
[OPT pass
LDA operand1
SEC
SBC operand2
STA result
LDA operand1+1
SBC operand2+1
STA result+1
]
=pass
```

Debugging macro - FNdebug

This can be inserted anywhere in the sources code to provide an indication of which path the processor has taken through the program. When executed, the routine will make a 'Bleep' sound and wait for a key to be pressed before continuing. All registers are preserved.

A typical call would be

```
OPT FNdebug
```

```
DEF FNdebug
[OPT pass
PHP             Save all registers
PHA
TYA
PHA
TXA
PHA
LDA#7           Make 'Bleep' sound
JSR oswrch
LDX#1           Flush keyboard buffer
LDA#15
JSR osbyte
JSR osrdch      Wait for a key
PLA             Restore all registers
TAX
PLA
TAY
PLA
PLP
]
= pass
```

16 bit rotation – FNshift

This provides a 16-bit shift instruction.

A typical call might be

```
OPT FNshift(&2034,TRUE,2)
```

which would shift locations &2034 and &2035 right twice.

```
DEF FNshift(addr,right,number)
LOCAL shift
FOR shift=1 TO number
IF right [OPT pass:LSR addr+1:ROR addr:]
ELSE [OPT pass:ASL addr:ROL addr+1:]
NEXT shift
= pass
```

12.6 BASIC routines for use with assembler

Double height - PROCdouble

The next two routines can be used to produce double height characters in MODEs 0,1,2,4 and 5. MODEs 3 and 6 (and 7 on the Acorn Electron) have gaps between lines which make it impossible to do double height. To centre the string, type

```
PRINT TAB((screenwidth DIV 2)-LEN(A$) DIV 2,VPOS);
```

after 'LOCAL I%'. Note that 'block' is a global array which should be DIMensioned at the start of the program, using, for example, DIM block 9. Note also that 'char' is the character to be defined, in this case it is always 224. The routine currently prints out the characters as it redefines them, although it is possible to suppress this.

```
DEFPROCdouble(A$)
LOCAL I%
FOR I% = 1 TO LEN(A$)
PROCchar(ASC(MID$(A$,I%,1)),224)
NEXT I%
ENDPROC

DEFPROCchar(C%,char)
LOCAL A%,X%,Y%,J%,I%
?block = C%
A%=10
X%=FNlo(block)
Y%=FNhi(block)
CALL osword                    osword is at &FFF1
FOR J%=0 TO 1
VDU 23,char
FOR I%=2 TO 9
VDU block?(J%*4 + I% DIV 2)
NEXT I%
VDU char,10,8
NEXT J%
VDU 11,11,9
ENDPROC
```

Find string in program - PROCfind

This next routine will find all occurrences of a specified string in the BASIC program, and print out the line numbers in which the string occurs. In its present form, the routine will not find BASIC keywords (FOR, REPEAT, PROC, etc). To allow for this it will be necessary to store the string as a line of BASIC, which could then be used as the target string in the search. So type PROCfind ($(PACE + 4)). This will find the string specified in the first line of the program, which should be line 0 to avoid the routine searching for the wrong string. The first line of the routine can now be changed to 'DEFPROCfind', as the parameter is now in line 0. Note that the first IF statement is only needed in BASIC I.

```
DEFPROCfind(A$)
LOCAL Z%,A%
Z% = PAGE
REPEAT A%=Z%+4
IF LEN($A%)>=LEN(A$) IF INSTR($A%,A$)
PRINT Z%?1*256 + Z%?2 ;  Z%=Z%+Z%?3 UNTIL Z%?1>&7F
ENDPROC
```

13. GRAPHICS

This chapter is all about fast shape drawing. Like everything else, shapes such as space invaders are stored as a series of numbers in the computer's memory This chapter consists of two main sections. The first contains a routine which is designed to be used independent of any other program. It allows a shape to be designed, and produces the relevant numbers representing that shape. The second contains two routines which are meant to be included as part of an assembler program. While the program is running, these routines convert the numbers in the memory back into the original shape and plot this shape on the screen at a stated position. These routines have been highly optimised for fast animation.

Some knowledge of graphics is assumed, up to User Guide level. Those of you without this knowledge are recommended to read the Acornsoft book, Creative Graphics, which gives a clear illustration of the graphics facilities available on the BBC Microcomputer and Acorn Electron.

13.1 Shape designer – DESIGN

The BASIC program below can be used to design shapes which can be plotted on the screen using the routines described later in this chapter. Remember that smaller shapes are plotted faster so if you wish to move several shapes on the screen at once it is better not to make them too large. The program is only suitable for a BBC Model B, or Electron.

The keys used by this program are:

0,1….. E,F	Colours 0 to 15
V and H	Vertical and horizontal reflections
L and S	Load and Save shapes
Cursor keys	For moving the cursor around
SY%	Height of 'pixels' in large shape.
shape	Byte vector to hold shape.
cursor X	X co-ordinate of cursor in 'pixels'.
cursor Y	Y co-ordinate of cursor in 'pixels'.
command$	String containing commands.
	String containing keys for colours.
colour$	Colours are specified by pressing key corresponding to Hexadecimal digit. Note state of CAPS LOCK or SHIFT keys is irrelevant.
key$	Holds key pressed.
length	Holds length of shape data.
C%	Zero if command, else holds colour key plus one.

```
0 REM Design Program
10
--------------------------------------------------------------------------
Top Level. Note that FNinitialise returns the mode
as MODEs cannot be defined in FNs or PROCs
--------------------------------------------------------------------------
20 MODE FNinitialise
30 PROCmainloop
40
--------------------------------------------------------------------------
Set up global variables, especially those that are
relevant to the screen mode selected.
--------------------------------------------------------------------------
50    DEF FNinitialise
60    lenshape 300
70    DIM shape lenshape
80    REPEAT
90    INPUT "Mode (0 - 2) ?"mode
100   UNTIL mode>0 AND mode<=2
110   RESTORE 230
120   FOR I%=0 TO mode
130     READ pixbits
140   NEXT I%
150   RESTORE 240
160   FOR I%=0 TO mode
170     READ W%
180   NEXT I%
190   RESTORE 250
200   FOR I%=0 TO mode
210     READ pixelperbyte
220   NEXT I%
230   DATA 1, 2, 4
240   DATA 2, 4, 8
250   DATA 8, 4, 2
260   INPUT "Width in X-direction:" NX%
270   INPUT "Width in Y-direction:" NY%
280   byteNX%=NX% DlV pixelperbyte
290   byteNY%=NY%-1
300   SX%=(1024 DIV NX%) AND &FFF0
310   SY%=(1024 DIV NY%) AND &FFF8
320   PROCclear
330   cursorX=0:cursorY=0
340   *FX 4 1
350   command$="VvHhLlSs"+CHR$&88+CHR$&89+CHR$&8A+CHR$&8B
360   colour$ ="001!2""3#4$5%6&7'8(9)AaBbCcDdEeFf"
370   Length = NX%*NY%*pixbits DIV 8
380   = mode
390
--------------------------------------------------------------------------
Main loop. Get a key, and then test to see if it is legal. If the key is
legal, then pass it on to the rest of the routine, which then calls the
relevant routine(s).
--------------------------------------------------------------------------
400   DEF PROCmainloop
410   PROCcursor
420   REPEAT
430     REPEAT
440        key$ = GETS
450     UNTILINSTR(colour$,key$) OR INSTR(command$,key$)
460     C% = (INSTR(colour$,key$)+1)  DIV 2
470     IF C% THEN PROCcolour(C%-1) ELSE ON
```

```
      INSTR(command$,key$) GOSUB 670, 670, 780, 780,
      630, 630, 650, 650, 510, 540, 570,  600
480   UNTIL FALSE
490   ENDPROC
500
--------------------------------------------------------------------------
Handle cursor control keys, making sure that the cursor does not go off
the side of the screen.
--------------------------------------------------------------------------
510   IF  cursorX>0 THEN PROCdocursor(-1,0)
520   RETURN
530
540   IF  cursorX<NX%-1 THEN PROCdocursor(1,0)
550   RETURN
560
570   IF cursorY>0 THEN PROCdocursor(0,-1)
580   RETURN
590
600   IF  cursorY<NY%-1 THEN PROCdocursor(0,1)
610   RETURN
620
-------------------------------------------
Handle saving/loading of shapes
-------------------------------------------
630   PROCload:VDU 22,mode:PROCshape(FALSE,byteNX%,byteNY%): PROCdisplay
      :RETURN 640
650   PROCsave:VDU 22,mode:PROCshape(FALSE,byteNX%,byteNY%): PROCdisplay
      :RETURN
660
-----------------------------------------------------
Reflect the shape in Y-maximum Y/2
-----------------------------------------------------
670   FORI%=0 TO NX%-1
680   FORJ%=0 TO (NY%-1)DIV2
690   temp=FNpoint(I%,J%)
700   PROCplot(I%,J%,FNpoint(I%,NY%-1-J%))
710   PROCplot(I%,NY%-1-J%,temp)
720   NEXT J%
730   NEXT I%
740   PROCshape(TRUE,byteNX%,byteNY%)
750   PROCdisplay
760   RETURN
770
-----------------------------------------------------
Reflect the shape in X maximum X/2
-----------------------------------------------------
780   FORJ%=0 TO NY%-1
790   FORI%=0 TO (NX%-1)DIV2
800   temp=FNpoint(I%,J%)
810   PROCplot(I%,J%,FNpoint(NX%-1-I%,J%))
820   PROCplot (NX%-1-I%,J%,temp)
830   NEXT I%
840   NEXT J%
850   PROCshape(TRUE,byteNX%,byteNY%)
860   PROCdisplay
870   RETURN
880
890   DEF  PROCplot(X,Y,col)
900   GCOL 0,col
910   PLOT 69,X*W%+1024,Y*4+640
920   ENDPROC
```

```
930
940   DEF FNpoint(X,Y)
950   = POINT(X*W%+1024,Y*4+640)
960
------------------------------------------------------------------------
Plot a large square at the cursor position, looking
at the final size version at the side of the screen
to find the color
------------------------------------------------------------------------
970   DEF PROCsq(X,Y)
980   GCOL 0,FNpoint(X,Y)
990   MOVE X*SX%, Y*SY%
1000  PLOT 0,SX%-4,0
1010  PLOT 81,4-SX%,SY%-4
1020  PLOT 81,SX%-4,0
1030  ENDPROC
1040
------------------------------------------------------------------
Display whole shape
------------------------------------------------------------------
1050  DEF PROCdisplay
1060  LOCAL X,Y
1070  FOR X = 0 TO NX%-1
1080   FOR Y = 0 TO NY%-1
1090    PROCsa(X,Y)
1100   NEXT Y
1110  NEXT X
1120  PROCcursor
1130  ENDPROC
1140
------------------------------------------------------------------
plot the box cursor at the cursor position
------------------------------------------------------------------
1150  DEF PROCcursor
1160  VDU 5
1170  GCOL 3,3
1180  MOVE SX%*(cursorX+0.25), SY%*(cursorY+0.25)
1190  PLOT 1,SX% DIV 2 - 4,0
1200  PLOT 1,0, SY% DIV 2 - 4
1210  PLOT 1,4-SX% DIV 2,0
1220  PLOT 1,0, 4-SY% DIV 2
1230  ENDPROC
1240
--------------------------------------------------------------------
get a shape from the filing system
--------------------------------------------------------------
1250  DEF PROCload
1260  LOCAL I%,channel
1270  PROCshape(TRUE, byteNX%, byte NY%)
1280  channel = FNopen(TRUE)
1290  IF channel = FALSE ENDPROC
1300  PROCclear
1310  FOR I%=0 TO (byteNX%*NY%)-1
1320  shape?I%=BGET#channel
1330  NEXT I%
1340  CLOSE#channel
1350  ENDPROC
1360
----------------------------------------------------------------
write a shape to the filing system
----------------------------------------------------------
```

```
1370  DEF PROCsave
1380  LOCAL I%,channel
1390  PROCshape(TRUE,byteNX%,byteNY%)
1400  channel=FNopen(FALSE)
1410  IF channel=FALSE ENDPROC
1420  FOR I%=0 TO (byteNX%*NY%)-1
1430  BPUT#channel,shape?I%
1440  NEXT I%
1450  CLOSE#channel
1460  ENDPROC
1470
------------------------------------------------------------------------
utility used by procload and procsave to open a file
------------------------------------------------------------------------
1480  DEF FNopen(in)
1490  LOCAL W$
1500  VDU 22,7
1510  INPUT "file name ?"W$
1520  IF W$ = "" FALSE
1530  IF in THEN OPENIN(W$) ELSE OPENOUT(W$)
1540
------------------------------------------------------------------------
plot point on final size shape and also plot square on main screen
------------------------------------------------------------------------
1550  DEF PROCcolour(colour)
1560  PROCcursor
1570  PROCplot(cursorX,cursorY,colour)
1580  PROCsq(cursorX,cursorY)
1590  PROCcursor
1600  ENDPROC
1610
------------------------------------------------------------------------
Wipe previous cursor from screen update cursor's X and Y coordinates, and
then plot the cursor at new coordinates
------------------------------------------------------------------------
1620  DEF PROCdocursor(X,Y)
1630  PROCcursor
1640  cursorX = cursorX+X
1650  cursorY = cursorY+Y
1660  PROCcursor
1670  ENDPROC
1680
------------------------------------------------------------------------
clear the array used to hold the shape
------------------------------------------------------------------------
1690  DEF PROCclear
1700  LOCAL clear
1710  FOR clear=0 TO lenshape-4 STEP 4
1720  clear!shape=0
1730  NEXT clear
1740  ENDPROC
1750
------------------------------------------------------------------------
either write final size shape from shape array or put final size shape
into shape array
------------------------------------------------------------------------
1760  DEFPROCshape(flag,X,Y)
1770  LOCAL I%, J%, tempx, tempy
1780  FOR I%=0 TO X
1790  FOR J%=0 TO Y
1800  tempx=I%+1024 DIV 16
```

```
1810  tempy=((J%+640 DIV 4)EOR&FF)DIV8
1820  PROCaccess(flag,(tempy*&280+tempx*8+((J% AND 7)EOR
      7)+&3000),Y+1,J%,I%)
1830  NEXT J%
1840  NEXT I%
1850  ENDPROC
1860
-------------------------------------------------------------------------
Get/put byte from/to final shape.
-------------------------------------------------------------------------
1870  DEF PROCaccess(flag,addr,Y,J%,I%)
1880  IF flag THEN shape/(I%*Y+(Y-J%-1))=?addr ELSE
      ?addr=shape?(I%*Y+(Y-J%-1))
1890   ENDPROC
```

Variables Used:

lenshape	Maximum length of shape (in bytes).
mode	Holds graphics modeselected.
I%	generral loop control variable.
J%	general loop control variable.
pixbits	Number of bits per pixel.
pixelperbyte	holds number of pixels per byte.
W%	Width of pixels in graphics co-ordinates
NX%	Width of shape
NY%	height of shape
byteNX%	Width of shape (in bytes)
byteNY%	height of shape (in bytes)
SX%	Width of pixels in large shape
SY%	height of pixels in large shape.
shape	Byte vector to hold shape.
cursorX	X co-ordinate of cursor in pixels.
cursorY	Y co-ordinate of cursor in 'pixels'.
command$	String containing commands.
colour$	String containing keys for colours

Colours are specified by pressing key corresponding to Hexadecimal digit. Note state of CAPS LOCK or SHIFT keys is irrelevant.

key$	Holds key pressed.
length	Holds length of shape data.
C%	Zero if command, else holds colour key plus one.

13.2 Plotting a shape on the screen

To plot a shape on the screen at a specified position it is necessary to have two routines; one to convert the X and Y coordinates to a memory location on the screen, and another routine to plot a shape at that address.

Two routines are given below which perform these tasks. The method chosen can only be used for plotting shapes to a resolution of 80 by 256 in MODEs 0, 1 and 2. The routines work by Exclusive ORing the shape onto the screen. This has two main advantages over other methods (such as writing the shape on the screen or

ORing the shape with the screen memory). The first advantage is that the detail under the shape is not lost when the shape is unplotted, the second is that the same routine can be used for both plotting and unplotting.

Convert X, Y coordinate to screen address – getaddr

This routine doesn't write anything to the screen, all that it does is generate an address where a shape might then be written to the screen, or read from the screen. It will generate an address for MODEs 0, 1 and 2, allowing for hardware scroll. The algorithm used is given at the end of the listing so that the code can be adapted for MODEs 4 and 5.

On entry, X holds the X coordinate (0 79), Y holds the Y coordinate (0 - 255), and A is irrelevant.

A typical call might be:

```
LDX xcoord
LDY ycoord
JSR getaddr
```

On exit, X will be preserved, Y and A will have been corrupted. The resultant address is left in 'addr' and 'addr+1' (low byte, high byte) which must be in zero page. Other locations used are 'temp' (1 byte) and 'top' (2 bytes). For speed, these locations should also be in zero page.

```
.getaddr
     LDA#&00             set hi byte of address
     STA addr+1          to zero
     TYA
     EOR#&FF             invert Y coordinate
     PHA
     OPT FNrotateacc(3)  divide Y coordinate by 8
     TAY                 and leave in Y
     LSR A               adjust carry for * &280
     STA temp            save Y/16 in temp
     LDA#&00             set bottom byte of address to 0
     ROR A               put carry into top bit
     ADC top             and add in top of screen
     PHP                 save carry flag
     STA addr            store result in addr
     TYA                 get y/8
     ASL A               double it for top byte
     ADC temp            of addr, add in Y/16
     PLP                 restore carry
     ADC top+1           and add in top of screen
     STA addr+1
     LDA#&00             set temp to zero
     STA temp
     TXA                 get x coordinate
```

```
     ASL A                perform two byte multiply
     ROL temp             by 8 because of memory
     ASL A                map
     ROL temp
     ASL A
     ROL temp
     ADC addr             add in rest of result so
     STA addr             far, and store it
     LDA temp
     ADC addr+1
     BPL ok               check for hardware scroll
     SEC                  if over 3000 - 8000 boundary
     SBC#&50              then correct address
.ok
     STA addr+1           And store it
     PLA                  Restore inverted Y coord
     AND#&07              Get row number in computed
     ORA addr             column, and add it in
     STA addr
     RTS                  Return
```

Some words of explanation:

The algorithm used to calculate the screen memory address is:

```
addr=X*8+((Y EOR &FF)AND 7)+&280*((Y EOR &FF)DIV 8)+top
```

where X and Y are the coordinates. The reason Y is inverted is so that the bottom of the screen is treated as 0, even though the memory map is the other way round. There are 640 bytes per character line on the display, which is &280 in hex. The variable 'top' is normally set to &3000, except when hardware scroll is taking place. In most applications this will be irrelevant, and so 'top' may be set up at the beginning of the program and then forgotten about. The Y AND 7 and Y DIV 8 operations are performed because of the memory map of the screen, DIV 8 is performed to get to the start of the current character cell, and AND 7 to get to the current byte in the character cell:

```
top    +&00  +&08  +&10  +&18  +&20  +&28
+0     +-------+-------+-------+-------+-------+-------
+1     +-------+-------+-------+-------+-------+-------
+2     +-------+-------+-------+-------+-------+-------
+3     +-------+-------+-------+-------+-------+-------
+4     +-------+-------+-------+-------+-------+-------
+5     +-------+-------+-------+-------+-------+-------
+6     +-------+-------+-------+-------+-------+-------
+7     +-------+-------+-------+-------+-------+-------
+&280 +-------+-------+-------+-------+-------+-------
+&281 +-------+-------+-------+-------+-------+-------
```

Plotting a shape at a given screen coordinate - doplot

This routine works in conjunction with the above routine for plotting a shape at a given X,Y screen coordinate.

On entry, all registers are irrelevant. The parameters passed are:

counter - holds width of shape in bytes
addr - holds screen address to put shape
depth - holds height of shape
shape - start address of shape in memory

('shape' must be in zero page.)

On exit, all registers may have been corrupted, but all parameters will have been preserved.

```
.doplot
     LDY#&00                  set shape offset to zero
     LDA addr+1               push screen address onto
     PHA                      stack for later use
     LDA addr
     PHA
     LDA depth                get depth of shape
     STA rowcounter
     LDA addr                 put offset in character
     AND#&07                  cell into Y
     STA offset
     LDA addr                 adjust address accordingly
     AND#&F8                  goto top of character cell
     STA addr
     STY temp
.innerloop
     LDY temp
     LDA (shape),Y            get byte from shape
     INY
     STY temp
     LDY offset
     EOR (addr),Y
     STA (addr),Y
     INY                      Y holds offset on screen
     CPY#&08                  bottom of character cell
     BEQ block                if so then go down a line
.nobIock
     STY offset
     DEC rowcounter
     BNE innerloop
.nextblock
     LDA shape
     CLC
```

```
     ADC depth
     STA shape
     BCC nohi
     INC shape+1
.nohi
     CLC                    go to the top of the next
column
     PLA                    by resetting address to top
     ADC#&08                of current column, and
     STA addr               moving to next character
     PLA                    cell
     ADC#&00
     BPL nobound1
     SEC
     SBC#&50
.nobound1
     STA addr+1
     DEC counter            easier to DEC counter in
     BNE doplot             two places and test
     RTS
.block
     LDY#&00                go down a line
     LDA addr               addr=(addr+&280)
     CLC
     ADC#&80
     STA addr
     LDA addr+1
     ADC#&02
     BPL noboundary         if the contents of addr are
     SEC                    greater than &8000 then
     SBC#&50                subtract &5000
.noboundary
     STA addr+1
     BNE nolock                  always jump
```

Interfacing getaddr and doplot - plotshape

The number of parameters may be cut down by having a 'front end' attached to the start of the doplot routine which would make interfacing easier.
On entry to 'plotshape' A would hold the number of the shape to be plotted and X and Y would hold the X and Y coordinates at which the shape is to be plotted.

A typical call to 'plotshape' would be:

```
     LDY#0              Get  first  shape
     TYA
     PHA                preserve shape number
     LDA xcoord,Y       get x coordinate
     TAX
     LDA ycoord,Y       get y coordinate
```

```
     TAY
     PLA                 get shape number back
     JSR plotshape       plot shape
```

On exit from 'plotshape' all registers may have been corrupted, although all internal parameters ('depth', 'counter', etc.) will have been preserved.

```
.plotshape
     PHA                 Save shape number
     JSR getaddr         Get address
     PLA                 Restore shape
     TAY
     LDA shapeloaddr,Y   Set up parameters
     STA shape           This assumes that
     LDA shapehiaddr,Y   the User has set
     STA shape+1         up the relevent
     LDA shapesize,Y     tables
     STA counter         (shape loaddr,
     LDA shapedepth,Y    shapesize, etc)
     STA depth
```