A Book on C

R.E. Berry,
B.A.E. Meekings
and M.D. Soren

Second Edition

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For
Marion, Judy and Paul,
Toby, Tim, Lucy, and Ben,
Patrick

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Preface to the Second Edition

When we originally wrote this book, it was with the intention of providing an introduction to a powerful and complex programming language. Its power is amply demonstrated by its use to code a significant portion of the Unix operating system, its complexity by the necessity for books like Feuer's *The C Puzzle Book*. We deliberately omitted some of the more complex features of the language, believing that their description would easily warrant another entire book.

Since the first edition was published, Bob Berry died tragically. He was what I like to call a true 'software practitioner', well versed in every aspect of computer software – from research to education to practical application. He was loved and respected by his students, colleagues and friends alike, and is sorely missed.

Mike Soren is (among other things) a veteran C programmer and has stepped into the breach to make possible the other difference between this edition and the first – the expansion of the text to include all the features of C that were previously left out. This does not represent a change of intent – it is still our belief that no single book can teach anyone to program effectively. That comes only with experience.

At least you now will have the tools to become not just a good, but a great, programmer.

December 1987 Brian Meekings

Acknowledgements

Producing and collecting the material for a book is a time-consuming activity even when shared. The help of others in the activity is always greatly appreciated. It is our pleasure to record sincere thanks to those people whose help has been especially valuable, notably Peter Hurley, Chi Yip, and Jerry Hall. While many of their helpful comments and suggestions have found their way into the text and supporting software, the responsibility for the accuracy and integrity of the text rests solely with the authors.

March 1984

Bob Berry
Brian Meekings

Introduction

Programming is communication. In attempting to teach a programming language we are trying to provide the learner with a means of communication, a means of expressing himself. At first sight it will appear that the communication will be one way, between the program writer and the machine on which his program is processed. This view is too simplistic, for the communication occurs on a number of different levels.

Certainly it is important that a programmer is sufficiently familiar with the language he selects to write his program to produce concise and efficient code, but it should not be forgotten that, after successful development, a program may need to communicate with its user while executing. This aspect of communication is now, justifiably, receiving considerable attention. It is no longer satisfactory that a program produces the correct results – it should also be easy to use, and should be 'bulletproof', which is to say that, no matter how inaccurate the user's input, the program should always provide a sensible and intelligible response. In the jargon, the program should be 'user friendly'.

A further level of communication, all too often neglected, is that between program writer and program reader. Program writers frequently assume that the only readers of the program will be themselves and a computer. The consequence of this assumption is that the program may be tedious and difficult to assimilate by anyone given the task of modifying, or simply reading, the original. Like everything else of man's creation, software will not be perfect, and should be written with the knowledge that it will need to be maintained. This means taking all reasonable steps to ensure that the program logic is lucidly expressed by the text, and the layout and presentation of a program help considerably in this. Unfortunately, there are constraints imposed by some language implementations that inhibit good presentation. Thus when using a BASIC interpreter with access to a limited amount of memory, there will be pressure on a programmer to omit comments and to discard unnecessary spaces. We recognise the pressures, but regret their effect on the intelligibility of programs.

The concept of 'program style' encompasses the presentation, layout and readability of computer programs. The principles apply to any programming language, whether high level or low level. The factors that contribute to program style are undoubtedly highly subjective, and thus contentious. Our contribution to the debate is to enumerate what we consider to constitute a reasonable set of metrics, whose application can be automated, and to associate with each of the program examples within the text a 'style score'. At the foot of every non-trivial program you will see this style score enclosed in square brackets. For small examples the style score can be sensitive to small changes in presentation, for example, the addition of a blank line. Nonetheless, we give it so that the reader can judge its usefulness. A small C program is illustrated in example I.1 to give a hint of what is to follow. The derivation of the style score is detailed in appendix 3. Suffice it to say here that the score is a percentage, and that the higher the score, the more 'elegant' the program.

The programming language C is a powerful language, and deserves its increasing popularity as one of the most important systems programming languages currently available. Without wishing to over-stress program style and the importance of good program design, we feel that it is necessary to point out that no programming language is, as yet, so powerful as to conceal flaws in program logic or to make its clear exposition unnecessary. Sound program logic is achieved by design, and in recent years considerable attention has been given to program design methods. The National Computing Centre has produced an excellent publication on the subject (Bleazard, 1976) which neatly summarises a wide variety of views. A further useful summary is the article by Weems (1978). Whether a structured program is achieved after the design stage will depend on the person or persons who translate the design into a program in an appropriate programming language – a not inconsiderable task. The book by Dahl *et al.* (1972), and the state of the art report (Bates, 1976) are both worthy of the reader's attention.

Programs can become such complex artefacts that many professionals in the computing field speak of software being 'engineered'. With this in mind, it is not surprising to find 'software tools' produced to assist in this engineering. The software tools philosophy espoused in Kernighan and Plauger (1976) and realised in UNIX* is an impressive demonstration of the importance of this approach. We believe that UNIX and C have significantly expanded our own computing horizons, and thoroughly recommend the experience to others.

Example I.1

```
main()

     /* to resort the letters of a word into alphabetical
        order - e.g. the basis of an anagram dictionary */

     { char word[20], min;
       int  i, j, pos, len;

       printf("Gimme a word ... ");
       scanf ("%s", word);
```

*UNIX is a Trademark of Bell Laboratories.

```
        len = strlen(word);
        for (i=0; i<len; i++)
            {
             min = '~'; pos = 0;
             for (j=0; j<len; j++)
                 if (word[j]<min) { min=word[j]; pos=j; }

             printf("%c", min);
             word[pos] = '~';
            }

        printf("\n");
       }

[ style 51.7 ]
```

There are a small but growing number of texts that describe UNIX and C. That by Bourne (1982) we have found particularly useful. Kernighan and Ritchie's (1978) book remains the definitive C reference, while the experienced C user might better himself by reading Feuer (1982).

In this book, the first chapter describes the structure of C programs. Chapter 2 introduces functions, contrasting them with macros. Chapter 3 deals with input and output, emphasising the importance of the interface between the program and its environment.

Chapters 4 and 5 explain the two features of any programming language that give it its power – the control constructs of conditional branching and looping. Operators are introduced in chapter 6, while chapter 7 illustrates the use of arrays and strings.

This is the point at which all the 'basic' features of C have been covered. The remaining chapters describe what we consider to be 'advanced' features – derived data types in chapter 8, data structures in chapter 9 and the C preprocessor in chapter 10. The final chapter presents some guidance on program 'style', which we could define loosely as that enigmatic quality that distinguishes adequate programs from superlative ones.

In learning any programming language we have found that examples which, as well as illustrating language features, stimulate the reader's interest are of particular importance. We have tried to present an interesting variety of examples. It is easy, however, to be left with the impression that all programs are small. To redress this imbalance we have presented a rather larger example which we refer to as RatC. RatC is a C program that accepts as input a program written in a subset of C and produces as output an intermediate code version of the program. In addition to making many references to RatC as a source of examples, we provide the user with sufficient information to implement his own small C compiler.

Above all, C is a language to enjoy. The kind of thing you always wanted to be able to do in other programming languages becomes possible in C – but be warned that its power, as well as getting you out of trouble quickly, can get you into trouble just as quickly.

We hope that learning C gives the same lift to your programming experience as it has done to ours.

1 Program Structure

In the introduction we attempted to show that programming must be undertaken in a disciplined and organised manner. If the resulting program is to display the benefit of this approach then the programmer must be thoroughly familiar with the program structure dictated by the programming language that he, or she, is to use.

FUNCTIONS

A C program consists of one or more functions. One of these functions must have the name *main*. A program is executed when the underlying Operating System causes control to be passed to the function *main* of the user's program. The function *main* differs from the other functions in a program in that it may not be called from within the program, and the parameters to *main*, if they exist, are provided by the Operating System. It is usual, but not essential, for *main* to be the first function of the program text.

Viewed simply, a function name is nothing more than a collective name for a group of declarations and statements enclosed in curly brackets or braces { }. The function *useless* below is of little value since it contains no executable statements. Its only purpose is to illustrate the appearance of a minimal function.

```
useless()
{
}
```

The parentheses following the function name are essential, and will later be shown to be more useful than the present example suggests.

If we assume that *main* is the first function defined in a C program text then, because no function may contain the definition of another function, the definitions of the subsidiary functions of the program text will follow. There may be only two or three such functions, in which case their purposes will be easy to determine, or there may be many, as in RatC. There is no special ordering of the functions dictated by the programming language C (in contrast to Pascal which, despite advocating the structured approach to problem solving, precludes its effective use by insisting that all functions be defined before they are used). However, after emphasising the value of a program as a means of communication, it would be foolish to suggest that an arbitrary order for the functions would be as good as an order with some rationale. The function definitions could be arranged in alphabetical order, or they could be grouped according to their purpose. This latter ordering is not so easy to achieve but can frequently be more helpful. It is this ordering that we adopted for the functions that comprise RatC. Note, however, that even for a program of this size, if utilities are available to number the lines of the source program and provide a list of function names, together with the line numbers on which the definitions start, then it is easy to locate individual function definitions whatever their order of appearance.

IDENTIFIERS

An identifier in C, whether it represents a function name or a variable, consists of any sequence of the characters [a-z, A-Z, 0-9, _], of which usually only the first eight are significant. The first character of an identifier must not be a digit. Upper and lower case letters are distinct, so that, for example, the identifiers 'count', 'Count' and 'COUNT' represent three different quantities. Identifiers are characterised by the two attributes 'type' and 'storage class'. The type of an identifier determines the type of object that it will be used to represent; so, for example, *int*, *float* and *char* qualify an identifier as representing an integer, a real (or floating point) number and a single character respectively. The full list of available types is given in appendix 5. An identifier's storage class determines the way in which it can be accessed from other parts of the program.

FILES AND THE STORAGE CLASS *external*

A program of the size of RatC should prompt questions concerning whether it resides entirely in one file or whether the text is spread over several files. To illustrate the effect of file structure on C programs and the symbols or names used within them, consider the examples given below, in which items within the same file are enclosed by a box.

Example 1.1

file1.c

```
main()
{

}

function1()
{

}
```

file2.c

```
function2()
{

}

function3()
{

}
```

In example 1.1, if we ignore *main*, any of the three functions could legitimately contain references to each of the remaining two. *main* may call any of the other three functions. This is possible because all function names belong to the storage class *external*. Any symbol name from this storage class may be referenced across files.

A function may also contain a call of itself. This is known as a recursive call, and an example of such a call will be found in the number printing function *prnum* given as an example in appendix 1.

STORAGE CLASS *automatic*

In order that the functions we define can perform some useful role they will need to manipulate data. As in most programming languages the name and type of every data item must be declared. A declaration does not necessarily reserve storage to be associated with the identifier, but rather establishes the type and storage class of the declared identifier. In the example below 'size' is declared to be an integer and its storage class is *automatic*.

```
main()
{
    int size;
}
```

The identifier 'size' is local to the function *main* and may only be used within *main*. If the name 'size' is used in any other function in the program it is not then connected in any way with the data item of the same name in function *main*. The storage class is known as *automatic* because, for any identifier in the class, storage space is allocated when the function is entered and given up when exit is made from the function. This is the default storage class for any identifier declared within a function. While this form of storage is economical, in that it is needed only when a function is being executed, it does not meet all our requirements.

STORAGE CLASS *static*

Imagine that, as part of a check upon the operation of a program, it is necessary to count the number of times that a function was executed. The count should be local or private to the function but the associated storage should be preserved from one call of the function to the next in order that the count may be accumulated. An identifier with storage class *automatic* is clearly inappropriate, since its value would be lost between successive calls of the function. Consider example 1.2: the identifier 'count' has been defined as type integer with storage class *static*. It could be used to accumulate the number of calls of *function1*.

Example 1.2

```
file1.c

main()
{
}
function1()
{
    static int count;
}
```

```
file2.c

function2()
{
}
function3()
{
}
```

As another example, suppose that two or more functions are used to manipulate the contents of a table. Each function will require to access the table and its associated pointers. It might also be desirable to protect the table from corruption by ensuring that no other function of the program gains access to the table. Both requirements can be met by using data items belonging to the *static* storage class within the same file.

Example 1.3

```
file1.c

main()
{
    int size;
}
function1()
{
    int i;
}
```

```
file2.c

static int ptr;
function2()
{
}
function3()
{
    int i;
}
```

In example 1.3, the identifier 'size' can only be used in *main*. The identifier 'i' of *function1* has no logical connection with the identifier 'i' of *function3*. The second file contains the declaration of 'ptr'. Both *function2* and *function3* may use the identifier 'ptr', as may any other function defined in that file. The storage class of 'ptr' is not *automatic* but *static*. Identifier 'ptr' is not accessible to a function in any other file. Note that it is not only function names that belong to the storage class *external*. We can declare the names of other data items so that they belong to this class. These names too may be referenced across files. If we change file1 of our example by adding the line

```
extern int ptr;
```

and remove the word *static* from file2, as shown in example 1.4, then the function *main* can now reference the item 'ptr' defined in file2.

Example 1.4

file1.c

```
main()
{
    extern int ptr;
    int size;
}

function1()
{
    int i;
}
```

file2.c

```
int ptr;

function2()
{

}

function3()
{
    int i;
}
```

If, however, the ***extern*** statement were to appear as the first line in file 1 then all functions in that file could refer to 'ptr', and this would be the same object declared in file2. In distributing a program text across files in this fashion we would need to ensure that for each identifier name in the external storage class, other than function names, there was one declaration of this name that did not include the word ***extern***. This is called the definition of the identifier. The prefix ***static*** must be omitted in this definition.

The discussion on files assumes that it is sensible and convenient to divide a program text in this manner and also that the names of the two or more files are passed to the C compiler for processing. There are circumstances, however, in which it might be convenient to divide our program physically between files but to treat it logically as a large program text in one file. This facility is made available by the C preprocessor.

THE C PREPROCESSOR

Preprocessing is, as its name suggests, undertaken prior to compilation and provides two important facilities; the ability to 'include' files and the ability to 'define' text for macro replacement. These are extremely convenient facilities and, since frequent use is made of them, they are introduced at this early stage.

#include

Example 1.5 differs from example 1.1 in the addition of one line at the end of file1. This is sufficient to change the organisation of the program in a small but significant way. The 'include file' request must appear at the left margin and is treated as a request to replace the line itself by the contents of the file given, in this case file2.c. Under the UNIX operating system, if the file name appears in double quote marks it is assumed to be in the current directory; if the file name is included instead in angle brackets, a special directory is assumed to be the location of the file. In either case the contents of the file replace the *include* directive and the combined text is passed on to the C compiler which treats it logically as one file of program text. Several files may be coalesced by use of suitable *include* directives. Included files may themselves contain *include* directives. While this is a legitimate use of the included file facility, an included file more usually contains *define* directives. A file containing *define* directives is known as a header file and, by convention, has a filename ending in '.h'. Any file containing C program text has a name which ends with '.c'.

Example 1.5

file1.c

```
main()
{
}
function1()
{
}
#include "file2.c"
```

file2.c

```
function2()
{
}
function3()
{
}
```

#define

The *define* directive provides the user with a macro replacement facility. The C preprocessor in this context is a macro processor, although this is not always appreciated by newcomers to this facility. The most common use of the *define* directive is of the form

```
#define  DAYSINWEEK  7
```

The preprocessor will thereafter replace the text string 'DAYSINWEEK' throughout the entire text by the text string '7'. In one sense this facility can be likened to the *const* section of a Pascal program in that it provides a means of removing all explicit constants from a program text and enables the user to use symbolic names instead. We think that it is good practice to gather all such definitions at the head of the program text file. However the *define* directive is not restricted to use in the manner described above for program constants. It is, in general, much more powerful and useful, since it replaces one text string by another and will, as we shall see later, also deal with parameters.

SIMPLE C CONSTRUCTS

In order that we may use examples to illustrate the points made in the text, we need, as has already become obvious, some programming language constructs. Even the simple examples need to demonstrate that they work by printing something. We therefore introduce the *printf* function.

```
printf("The answer is 42");
```

printf, print formatted, is perhaps the most commonly used output function. Whatever text appears within the double quote marks is, with a few important exceptions, printed on the user's output device. Input and output statements are not an integral part of the C language, but are usually provided within a commonly accessible library of such routines, which will be made available to the program via an *include* file. Under UNIX, for example, use of

```
#include        <stdio.h>
```

at the head of a program is a convenient way of obtaining access to some commonly used definitions. These definitions include several of the simpler input/output functions. We shall assume for convenience that the user is using a visual display unit (VDU) to a multi-user or microcomputer system on which C is available.

```
printf("\nThe answer is 42\n");
```

This variant of the first *printf* statement prints a newline character, represented by the character pair \n, before and after printing the string itself. All statements in C are terminated by a semi-colon. There may be more than one statement per line. An assignment statement is exemplified by

```
answer=42;      /* 42 is a decimal constant */
answer=052;     /* leading 0 indicates an octal constant */
answer=0x2a;    /* leading 0x or 0X indicates a hex constant */
```

where we assume that 'answer' has been declared to be an integer. Lastly, let us note at this point that the braces { } may be used to enclose one or more C statements

```
{ question=99; answer=42; }
```

The collective name for statements enclosed in this way is a compound statement. It will become obvious from the examples that in C a comment is any text string enclosed by /* and */.

Further examples of the use of the *define* directive can now be given by using the *printf* function. The definition

```
#define  STARS  printf("**********")
```

will cause the symbol 'STARS' to be replaced by the call of the function *printf*. When viewed in the context of the example given below it will be appreciated that the *define* facility could save us some tedious typing.

```
#define  STARS  printf("**********")

main()
{
        STARS;
        printf("\nThe answer is 42\n");
        STARS;
}
```

'*defining*' VDU CHARACTERISTICS

We can use the *define* directive in another more useful way to improve the quality, and thus the user friendliness, of the output produced by any program. Most VDUs in common use have facilities to home the cursor, clear the screen, and so on. Invariably to use these features means sending a special character sequence to the terminal. The character sequence is not easy to remember unless one uses it constantly; it varies from one manufacturer's product to another and frequently between different models from the same manufacturer. What we suggest is that these codes are set up once and for all using *define* directives. For a Lear Siegler ADM5 we would have

```
#define  CLEAR  printf("\033Y")
#define  HOME   printf("\036")
```

Recall that the backslash followed by n was used to denote a newline character. Backslash followed by a number can be used in *printf* and elsewhere in a C program, to denote the character defined by the ASCII code in octal which follows the backslash. A table of the ASCII characters with their octal representations is given in appendix 5. To clear the screen of this particular terminal we can send the escape character (ESC) followed by the letter Y. Since this clears from the cursor to the end of the screen, the HOME command should precede the CLEAR. This form of CLEAR command is given because ESC followed by a character sequence is a common way of expressing VDU directives.

The number of special features available on a VDU varies considerably. A VT100 terminal, for example, will offer cursor addressing, blinking, highlighting, reverse video and other features all of which are selected by a special character sequence beginning ESC[. For any VDU these special features should be noted and appropriate *define* directives set up as illustrated in the examples. Thereafter all the *define* directives for one terminal should be collected together in a suitably named file. Any C program wishing to use these facilities need then only *include* this file at the head of the program and all the commands defined for that VDU become available. The contents of two such *include* files are given in appendix 4.

SUMMARY

In this chapter we have described the structure of C programs. We have illustrated the convenient and versatile mechanisms that are easily available to the programmer to help produce a well-organised and a well-structured program. We shall endeavour to reinforce these ideas through the examples that we present. Our presentation may not be perfect and may seem for the smaller examples to dominate the examples themselves. Effort spent on organisation, structure and layout of a program is worth while and we hope that this point is adequately demonstrated by RatC. Considerable effort has gone into the organisation and presentation of this the largest example in the book. If you find it easy to assimilate and find your way round, then use some of the same strategy on your programs. If on the other hand you feel the presentation or organisation could be improved, then learn from our failings and produce well-structured programs as a result.

2 Functions

As we have seen in the previous chapter, functions offer an easy way to construct a modular program. Since they are such an essential part of good C programming we shall introduce their facilities at an early stage to encourage familiarity with their use.

In order that our examples may achieve something, even if it is not especially useful, we will make use of the *printf* statement introduced earlier.

Example 2.1

```
#include "adm5.h"
#define  GAP printf("\n\n\n\n")

        /* a program to print large letters */

main()
     {
        HOME; CLEAR; GAP;        /* clear the screen */
        bigH();      GAP;
        bigI();      GAP;
     }

/* bigH prints H as a 7*5 matrix of asterisks */

bigH()
     {
        printf("*   *\n");
        printf("*   *\n");
        printf("*   *\n");
        printf("*****\n");
        printf("*   *\n");
        printf("*   *\n");
        printf("*   *\n");
     }

/* bigI prints I as a 7*5 matrix of asterisks */
```

```
bigI()
    {
      printf("*****\n");
      printf("  *  \n");
      printf("  *  \n");
      printf("  *  \n");
      printf("  *  \n");
      printf("  *  \n");
      printf("*****\n");
    }

[ style 55.6 ]
```

Because the program does not do much, its structure, and the preprocessor facilities that it uses, are easily seen. The *include* file 'adm5.h' contains screen control instructions for a Lear Siegler ADM5.

In the body of the program, after clearing the screen, a call to the function *bigH* is made. When executed this function causes asterisks to be printed representing the character H in a 7 * 5 matrix of characters. Similarly *bigI* causes the character I to be printed. The symbol 'GAP' ensures an appropriate separation between the characters and whatever follows them on the screen.

Anyone choosing to type example 2.1 into their own machine will quickly realise that they are typing identical *printf* statements several times over. Repetition like this should always prompt the question, 'Is there a better way?' The answer is often 'yes', and frequently there is more than one 'better way'. Example 2.2 illustrates that by using the *define* facility of the preprocessor we can save writing and typing of text. Remember that the preprocessor will simply replace the defined symbol by its definition throughout the program text, and so the version of program 2.2 that reaches the compiler will be logically equivalent to program 2.1.

Example 2.2

```
#include "adm5.h"
#define  GAP printf("\n\n\n\n")

     /* allstars prints all stars */
#define allstars printf("*****\n")

     /* endstars prints end stars */
#define endstars printf("*   *\n")
```

```
     /* midstar prints mid star  */
#define midstar printf("   *   \n")

main()
    {
     HOME; CLEAR; GAP;       /* clear the screen */
     bigH();       GAP;
     bigI();       GAP;
    }

bigH()
    {
     endstars; endstars; endstars;
     allstars;
     endstars; endstars; endstars;
    }

bigI()
    {
     allstars;
     midstar; midstar; midstar; midstar; midstar;
     allstars;
    }

[ style 63.1 ]
```

Alternatively, the program can be rewritten using function calls instead of *defines* by declaring *allstars*, *endstars* and *midstar* as functions, as shown in example 2.3. The programs 2.2 and 2.3 are functionally, but not logically, equivalent, in the sense that, although the output from both is the same, in one case it is produced by a program with three functions, and in the other, by a program with six.

Example 2.3

```
#include "adm5.h"
#define  GAP printf("\n\n\n\n")

main()
    {
     HOME; CLEAR; GAP;       /* clear the screen */
     bigH();       GAP;
     bigI();       GAP;
    }
```

```
bigH()
    {
      endstars(); endstars(); endstars();
      allstars();
      endstars(); endstars(); endstars();
    }

bigI()
    {
      allstars();
      midstar(); midstar(); midstar(); midstar(); midstar();
      allstars();
    }

        /* allstars(), endstars(), midstar() */
        /* are now defined as functions      */

allstars()
    { printf("*****\n"); }

endstars()
    { printf("*   *\n"); }

midstar()
    { printf("  *  \n"); }

[ style 47.3 ]
```

MACROS OR FUNCTIONS?

When executing, the program 2.3 produces the same results as the two previous versions of this program. Which is best depends on what criteria are used for the comparison. In example 2.2 the preprocessor replaces all symbols defined in a *define*. The transformed program is passed to the C compiler. When executed, the body of the function *bigH* causes seven *printf* statements to be obeyed. When executing the function *bigH* of 2.3, seven function calls are executed and each call causes a *printf* statement to be obeyed. For examples of this size we are unlikely to notice the difference in compile time or execute time between 2.2 and 2.3. If we were able to measure such times accurately then we would find that 2.2 compiled more slowly than 2.3, but executed more quickly. Our guideline, while approximate, will be that where symbols are replaced by small amounts of text then the symbol will be defined in a *define* statement, otherwise the symbol will be defined as a function. In contrast, if we knew that a function with a small body was called in a part of the program that was heavily used, then we would consider replacing the function definition by a *define* statement for the symbol name. This would save the overhead of the function call at execution time. Decisions like these are reflected in the definition of some of the symbol names used in the RatC compiler.

USING PARAMETERS

Functions are much more useful if we are able to pass information to them. Information can be passed implicitly, by using within the function symbol names that are defined elsewhere, or explicitly, by using parameters. The examples of *printf* used to date have been limited in that they simply print a given string. However, *printf* is a much more versatile function than these early examples suggest. In particular it can be made to print the value of data items that are passed as parameters, thus

```
printf("%c   %c\n" , '*','*');
```

The first parameter must always be the string (in double quotes) that contains characters to be printed, formatting information, and conversion characters. The percent sign % precedes conversion characters in the string. More details of the conversion characters will be given in chapter 3. For the moment it will be enough to know that the letter c after % indicates a character conversion. For each conversion character in the control string a suitable parameter must be provided within *printf* following the control string. Each parameter following the control string must have a corresponding conversion character within the control string. The *printf* statement given above has exactly the same effect as the *printf* statement given in function *endstars* of 2.3. We are now in a position to add a useful parameter to those functions that we have defined.

DEFINING PARAMETERS

Consider the following version of *endstars*

```
endstars(anychar)
char  anychar;
{
    printf("%c   %c\n", anychar, anychar);
}
```

Here the function, *endstars*, is defined as having a parameter. A parameter, such as 'anychar', which is used in the function definition is called a formal parameter. The type of the parameters, if there is one or more, is defined before the brace which marks the start of the function body. The parameter may then be used in a manner consistent with its definition anywhere within the function body. The function *endstars* simply uses 'anychar' as a parameter to *printf*. Hence whatever character is passed to *endstars* through the parameter list in a function call is printed in the manner that should now be familiar.

Example 2.4

```
#include "adm5.h"
#define  GAP printf("\n\n\n\n")

main()
    {
      HOME; CLEAR; GAP;       /* clear screen */
      bigH('H');   GAP;       /* use H to construct letter H */
      bigI('I');   GAP;       /* use I to construct letter I */
    }

bigH(ch)
    char ch;
    {
      endstars(ch); endstars(ch); endstars(ch);
      allstars(ch);
      endstars(ch); endstars(ch); endstars(ch);
    }

bigI(ch)
    char ch;
    {
      allstars(ch);
      midstar(ch); midstar(ch);
      midstar(ch); midstar(ch); midstar(ch);
      allstars(ch);
    }

        /* allstars(), endstars(), midstar()   */
        /* are now defined as functions,       */
        /* each has one parameter of type char */

allstars(ch)
    char ch;
    { printf("%c%c%c%c%c\n", ch, ch, ch, ch, ch); }
```

```
endstars(ch)
    char ch;
    { printf("%c   %c\n", ch, ch); }

midstar(ch)
    char ch;
    { printf("  %c  \n", ch); }

[ style 61.1 ]
```

If all the functions of the example 2.3 are parameterised in this fashion, and the corresponding calls are suitably amended, then we obtain a program such as 2.4. This program is more versatile than the others in the series in that by changing the character that is the actual parameter to *bigH*, or to *bigI*, we can change the output produced. Using parameters in this way will usually help to make quite clear what must be passed from the caller to the function. If communication between a caller and a function is done implicitly by use of symbols to which both have access, the communication is not so obvious to the reader. For this reason early examples within the book will use the parameter list. Later examples will not be restricted in this way.

A further example of a function with parameters is one that enables us to move the cursor on the VDU screen to any position. For the ADM5 this function definition might appear as

```
    /* to move the cursor to `row', `pos' */

cursor(row, pos)
int  row, pos ;
{
    int us = 31;     /* initialise for ADM5 */
    printf("\033=%c%c", us+row, us+pos);
}
```

The call

```
cursor(1, 1);
```

would move the cursor to the ‘home’ position, while the call

```
cursor(12, 40);
```

would move the cursor to the middle of the screen. However, all of our other screen control directives are gathered together in an *include* file. The logical place for *cursor* is within that file too. But *cursor* needs parameters and so far none of the symbols in a *define* directive has used parameters. Recall that replacement of defined symbols is undertaken by a macroprocessor and, fortunately, this offers us parameter replacement. Hence the addition to our file of the following definition

```
#define  CURSOR(r, p) printf("\033=%c%c", 31+r, 31+p)
```

will perform exactly the same role as the function of the same name. We will therefore extend both screen control files to contain the same cursor movement feature, but note that it is implemented in quite a different way for the VT100 (see appendix 4).

USING *return*

As well as passing information to a function, we must be able to pass information back to the caller from the function. This may be done in one of three ways: by using a *return* statement to pass a value via the function name, by passing one or more values back through the parameter list, or by changing the values of symbols to which both the function and the caller have access. For the reason given earlier this last form of communication will not yet be used.

The function *surface* in example 2.5 computes the surface area of a rectangular box having dimensions that can be expressed as integers. The value computed is communicated to the caller by the *return* statement and can be thought of as being associated with the function name. The function call can, in consequence, be used in expressions. In particular the call may appear in a *printf* statement, as indicated in example 2.5.

Example 2.5

```
main()
    { int length, width, depth;

      length = 10 ; width = 16 ; depth = 4;

      printf("surface area = ");

      printf("%d\n", surface(length, width, depth));
    }

    /********************************/

    /* to compute the surface area */

    /*     of a rectangular box    */

    /********************************/

surface(len, wid, dep)
    int len, wid, dep;
    {
      return(2*(len*wid + wid*dep + dep*len));
    }

[ style 53.8 ]
```

Even such an apparently simple example raises several new points. The conversion character following the percent sign is d to indicate a decimal integer. In other respects the *printf* statement is little different from those already seen. The function definition has three formal parameters of integer type (*int*). The function call has three actual parameters of integer type. The formal parameters and actual parameters correspond in order, number and type. The function body consists simply of a *return* statement which computes the surface area. So that no confusion arises in these early examples, the formal parameters have been given names that are different from the names of the actual parameters. The names leave no doubt as to which formal parameter corresponds to which actual parameter.

The *return* statement passes a single value from the function to the caller. The type of this value is determined by the form of the expression in the *return* statement and the type of the operands. If the returned value is of type integer or character (*char*) then the function definition is as given in example 2.5. However if the parameters to the function were of type *float* then the program should appear as in example 2.6.

Example 2.6

```
main()
    { float length, width, depth;

      float surface();       /* NB  this is needed */

      length = 20.0; width = 26.0; depth = 4.0;
      printf("surface area = ");
      printf("%f\n", surface(length,width,depth));
    }

        /* this version of surface returns */
        /* a result of type float          */

float surface(len, wid, dep)
    float len, wid, dep;
    { return(2*(len*wid + wid*dep + dep*len)); }

[ style 51.9 ]
```

The type of the actual parameters and the formal parameters has been changed to *float*. The function must now return a value that is also of type *float*. The type of result returned by the function is signalled by preceding the function name in the function definition by the type of value to be returned. There is a further consequence of this action. A function is assumed by default to have the type *int*. If it is our intention to use a function that violates this assumption then we must signal this intention. This is done by including, in the functions or files that call this function, a declaration of the function. It is for this reason that an additional line appears

```
float surface() ;
```

Another example of a function that only has a *return* statement for a body is the function *numeric* in RatC. This function returns a character value.

RETURNING VALUES VIA THE PARAMETER LIST

As well as receiving data values through the parameter list it is also reasonable to expect that we can communicate data values back to the caller through one or more parameters. In order to understand the mechanism by which this is achieved, let us observe that in C all parameters are value parameters. That is, the values of the actual parameters are copied into temporary storage in the function work space upon entering the function. Thereafter, the function only makes reference to these local values. If assignment is made within the function body to one of the parameters, it will be the local copy that is changed, not the original. At first sight this seems to inhibit communication from the function to the caller via the parameter list. For C the way out is to use the address of the relevant data item.

ADDRESSES AND POINTERS

Address	Contents
&i	i
ptr	*ptr

In a high-level language it is not usually necessary to know or care about the address in memory of the data values that we wish to manipulate. As a consequence, in some languages we have to resort to subterfuge in order to access specific memory locations. Pascal is one such language. At the other extreme, if it is too easy to access and modify memory locations then a program exploiting this facility can become unreadable. Thus a BASIC program which makes too much use of 'peek' and 'poke' instructions is not easily intelligible. In C an easy and convenient way of obtaining the address of a data item is provided. Correspondingly, given the address of a data item, we can easily obtain its value. As might be expected in C the mechanism is short and simple. We obtain the address of an item by prefixing it with ampersand: thus &x is the address of x. In order that we can manipulate addresses we need to be able to define items that have pointers or addresses as their values. This is done as follows

```
int i ;       /* i represents a value of type integer */
int *ptr;     /* ptr holds the address of a data item */
              /*     of type integer.                  */

              /* an alternative declaration with the  */
              /* same effect follows                  */
int i, *ptr;
```

This notation can now be used to enable a function to communicate with its caller. For if the caller passes to the function the address of a data item, it is the address that is stored in the local storage area of the function. The function cannot change the address of the item, but it can change the contents of the address which is, after all, what we wish to happen. Example 2.5 may now be rewritten as example 2.7.

Example 2.7

```
main()
    { int length, width, depth, area;

      length = 10; width = 16; depth = 4;
      surface(length, width, depth, &area);
      printf("surface area = %f\n", area);
    }

      /* the fourth parameter is an address */
      /* we refer to its contents as *addr  */

surface(len, wid, dep, addr)
    int len, wid, dep, *addr ;

    { *addr = 2 * (len*wid + wid*dep + dep*len); }


[ style 45.8 ]
```

The differences between this example and the two previous examples need to be highlighted. In the function *surface* the formal parameter 'addr' is used to communicate the computed surface area back to the caller. In order that this may happen the content of 'addr', *addr, is typed as an integer which means that 'addr' is an address. The caller must therefore provide the address of an integer type variable as the fourth parameter. In the example it is the address of 'area', &area, that is provided. Since a ***return*** statement is not used within the function no value is associated with the function name. Accordingly the function call is a statement in the main segment of the example.

When a function has only one value to communicate to the caller it will usually be convenient to use a *return* statement to pass the value via the function name. If more than one value is to be communicated to the caller, then we can use both the return mechanism and the parameter list, or we can use the parameter list alone. Functions exhibiting these features will be used later in the book when further language constructs have been introduced.

SUMMARY

In this chapter, we have introduced two methods of abbreviating the number of statements that a programmer must write to produce a program: *defines* and functions. Choosing between the two is largely a matter of personal taste, subject to the guidelines that we have laid down.

Functions represent a major aid both to the modular development of a program and to its subsequent readability. The length of a function is again a matter of taste; ideally, a function should perform a single task, and should rarely, if ever, exceed a printed page in size.

We have discussed the various methods by which the functions of a program can communicate with each other. Suitable use of parameters not only generalises the use of a function, but also assists in an understanding of its purpose and the extent to which different parts of a program fit together.

The RatC compiler is a good example of the judicious use of each of these features.

3 Output and Input

OUTPUT

Our use of the output function *printf* has so far been straightforward. We have seen that, as well as printing text strings, it can easily be made to convert the internal form of our data items into a suitable form for printing. The general form of the *printf* function call can be expressed as

```
printf(control_string [, argument_list])
```

(The square brackets enclose an item that is optional.) The control string may contain characters to be printed, control characters preceded by backslash, and conversion specifiers.

CONVERSION SPECIFIERS

For each conversion specifier there must be a corresponding argument in the argument list. The minimal form of a conversion specifier is a percent sign followed by one of a limited set of characters. Examples of conversion specifiers are given in table 3.1.

The general form of the conversion specifier can be written

```
%[-][fw][.][pp]C
```

where C is the conversion character or character pair.

- \- is used to indicate that the output is to be left justified in the field (the output is right justified by default).

- fw is a digit string giving the minimum field width – the total number of print positions occupied. Excess places in the field are by default filled with blanks. If the first digit of the field width is zero, the field is zero filled. A data value that is too large for the field specified is printed in its entirety.
(An asterisk used instead of the digit string signifies that the field width

is given by an integer (constant or variable) in the appropriate position in the argument list.)

separates fw from pp.

pp is a digit string which for a data item of type *float* or *double* specifies the number of digits to be printed after the decimal point. For a string it specifies the number of characters from the string to be printed.

Table 3.1

Conversion characters	Argument type	Comment
c	char	Single character
d	int	Signed (if –ve) decimal
ld or D	long	Signed (if –ve) decimal
u	int	Unsigned decimal
lu or U	long	Unsigned decimal
o	int	Unsigned octal, zs
lo or O	long	Unsigned octal, zs
x	int	Unsigned hexadecimal, zs
lx or X	long	Unsigned hexadecimal, zs (zs . . . zero suppressed)
f	float or double	Decimal notation
e	float or double	Scientific notation
g	float or double	Shortest of %e, %f
s	string	

Any invalid conversion character is printed!

The examples in the text so far have used none of the option facilities listed above. If our programs are to produce acceptable output then we must be able to take full advantage of the facilities offered by *printf*. Much the best way to obtain the necessary familiarity is to use, and experiment with, different conversion specifiers. To help in this a list of examples is given in table 3.2.

BACKSLASH

Within the control string we have used the backslash character preceding n to force the printing of a newline. There are other characters which have special significance when preceded by the backslash. The full list is given in table 3.3.

Table 3.2

Value	Control	: Output :
360	%10d	`:       360:`
−1	%10ld	`:        -1:`
360	%−10d	`:360       :`
−1	%10u	`:     65535:`
−1	%10lu	`:4294967295:`
360	%10o	`:       550:`
−1	%10lo	`:37777777777:`
360	%010o	`:0000000550:`
360	%−10x	`:168       :`
−1	%−10lx	`:ffffffff  :`
360	%−010x	`:1680000000:`
3.14159265	%10f	`:  3.141593:`
3.14159265	%10.3f	`:     3.142:`
3.14159265	%−10.3f	`:3.142     :`
3.14159265	%10.0f	`:         3:`
3.14159265	%10g	`:   3.14159:`
3.14159265	%10e	`:3.141593e+00:`
3.14159265	%10.2e	`:  3.14e+00:`
programmer	%10s	`:programmer:`
programmers	%10s	`:programmers:`
programmer	%10.7s	`:   program:`
programmer	%−10.7s	`:program   :`
programmer	%10.4s	`:      prog:`
programmer	%10.0s	`:programmer:`
programmer	%.3s	`:pro:`

Table 3.3

\b	backspace
\f	form feed
\n	newline (line feed)
\r	carriage return
\t	tab
\ddd	ascii character code in octal
\‘	‘
\\	\

The features of the *printf* statement that have been itemised are sufficient to provide the user with good control over the output generated. Remembering also that through the control string itself we can separate one field from another, we appear to have everything that we need. It is now easy to modify example 2.1 so that it will print its large letters in the middle of the screen instead of on the left-hand side. All that is necessary is to ensure that, say, thirty-six leading spaces are printed before every string that is printed. This could be done by changing the first %c of each control string to %37c. If this proved unsatisfactory for some reason we would need to change each occurrence of 37 to something new. It will be much more convenient to use a *define* directive of the form

```
#define indent printf("%36c", ' ')
```

which will give us 36 leading spaces, and place the statement

```
indent;
```

before each of the relevant *printf* calls. A change in the number of leading spaces is now conveniently obtained by changing the value of one numeric constant.

INPUT

So far our primary concern has been the organisation of our output. We must also be able to supply our program with data when it is executing. Corresponding to the output function *printf* is the input function *scanf* which has a similar philosophy. If we continue with the assumption that input and output are done through a VDU then a call to *scanf* of the form

```
scanf("%d %d %d", &length, &width, &depth);
```

could have been used in example 2.5 to give values to the identifiers. The user would then need to type three integers as input when the program started to execute. Notice that because *scanf* must be able to communicate the input values to the caller, the caller must provide the address of the symbols to which the values are to be assigned. The general form of *scanf* is

```
scanf(control_string [, argument_list])
```

Within the control string blanks, tabs or newlines (collectively known as 'white space') are ignored. If any characters, apart from those needed in the conversion specifiers, appear in the control string, it is assumed that they are to match the next non-white-space character of the input stream. In particular, if any such characters appear as the first items in the control string then *scanf*, whenever it is called, will expect to find just these characters as the next to be read from the input stream.

CONVERSION SPECIFIERS

For *scanf* the conversion specifier has the following general form

```
%[*][dd]C
```

where C is the conversion character, * is an optional assignment suppression character, and dd represents a digit string giving the maximum field width. The character or character pairs admissible as conversion characters are given in table 3.4.

Table 3.4

Conversion characters	Argument type
c	Pointer to char
h	Pointer to short
d	Pointer to int
ld or D	Pointer to long
o	Pointer to int
lo or O	Pointer to long
x	Pointer to int
lx or X	Pointer to long
f	Pointer to float
lf or F	Pointer to double
e	Pointer to float
le or E	Pointer to double
s	Pointer to array of char
[.....]	Pointer to array of char

Consider the following simple example

```
scanf ("%d",&fw);              /* read an integer `fw'  */
printf("%*c\n", fw, '+');      /* print a plus sign in  */
                               /* a field width of `fw' */
```

An input field is normally delimited by white space characters, and hence for our first example of the use of *scanf* the three integers required for input could have been typed on a line separated by one or more spaces, or they could have been typed one per line. Either form, or a mixture of the two, would be acceptable. Be warned that this means that *scanf* will read across input lines to find the next item of data. If the conversion specifier includes the assignment suppression character, no assignment is made; in other words the corresponding input field is matched and skipped. Should the length of the input field exceed the fieldwidth specified, then the data item is assumed to consist of the first 'fieldwidth' characters. Example 3.1 will perhaps help to clarify some of these points.

Example 3.1

```
char  ch;
char  string[20];
int   i, j, number, extension;
float x;

    /* assume the input string         PHONE65201X4133          */

scanf("PHONE %ld %c %d", &number, &ch, &extension);
    /* yields number = 65201, ch = 'X', extension = 4133        */

scanf("PHON %c %f %*c %d", &ch, &x, &ch, &extension);
    /* yields ch = 'E', x = 65201.0, extension = 4133           */

scanf("PHONE %2d %3d %c %2f", &i, &j, &ch, &x);
    /* yields i = 65, j = 201, ch = 'X', x = 41.0               */

scanf("%[^X] %c %d", string, &ch, &extension);
    /* yields string = "PHONE65201", ch = 'X', extension = 4133 */

scanf("PHONE %[0123456789] %c %d", string, &ch, &extension);
    /* yields string = "65201", ch = 'X', extension = 4133      */
```

Note that in the third example *scanf* has not read the last two characters (33) of the input stream. The next call to *scanf* would scan from the first of these characters. If the input stream contains nothing to match the current item of the control string, *scanf* terminates. Termination also occurs when all elements of the control string have been satisfied.

A variation on the string conversion specification is introduced in the last two examples, where the string is not delimited by white space characters. The specifier % [. . .] indicates a string containing any of the characters within the square brackets (and delimited by any that is not), while the specifier %[^ . . .] indicates a string delimited by the character set within brackets.

scanf returns to the caller the number of data items that were matched and assigned. A value of zero is returned when the next character of the input stream does not match the first item in the control string, and the value EOF (conventionally defined in stdio.h) is returned when end of file is encountered. Thus if the call to *scanf* in the third example appeared instead as

```
items = scanf("PHONE %2d %3d %c %2f", &i, &j, &ch, &x);
```

then 'items' would be assigned the value 4.

The input stream searched by *scanf* is the standard input stream 'stdin'. The output produced by *printf* is directed to the standard output 'stdout'. It will frequently be necessary to scan other data sources and to direct output to other destinations. This can easily be achieved by using variants of *scanf* and *printf*. One of these variants allows us to deal with strings.

STRINGS

In C a string constant is a sequence of characters enclosed in double quotes. Like other data items strings may be read in, stored, manipulated and printed. Strings are stored in arrays of characters (this topic is covered in detail in chapter 7) and are referenced by the address of the first character, a pointer to array of char. The general form of the version of *scanf* that processes strings is

```
sscanf(data_string, control_string [, argument_list])
```

sscanf scans the string data_string attempting to match the data items specified in the control string. Successful matches are, when appropriate, assigned to the arguments in the argument list. Correspondingly

```
sprintf(data_string, control_string [, argument_list])
```

writes the arguments specified in the argument list into the data string in the manner determined by the control string. Since we can refer to strings only by means of a pointer to an array of char, it is obvious that the first argument to *sprintf* is the address of the data item that is to be changed.

I/O FUNCTION LIBRARY

The definition of the language C does not include the definition of input and output facilities. Instead, it is assumed that in every environment in which C programs are processed there will exist a library of functions to perform various input/output tasks. We assume that *printf* and *scanf* will be in this library. In passing we note that RatC uses neither *printf* nor *scanf*. The only functions that it uses are those that will read or print characters. The rationale for this is easy to appreciate as RatC is meant to be able to compile itself. In order to do this the RatC compiler must be able to process correctly all function calls that appear in the text being processed.

Functions that are used but not defined are assumed to belong to the runtime library available on the host machine. It will be relatively easy to provide, as part of this library, functions that read a character or print a character, whereas *printf* and *scanf* will necessarily be much more complex. Hence RatC assumes that they are not in the runtime library. The functions *getchar* and *putchar* should be part of any C library and, as their names imply, they communicate single characters from and to the VDU which we are assuming to be our input/output device. For example

```
ch = getchar();          /* get next character */
putchar(ch);             /* print it           */
```

or, equivalently

```
putchar(ch = getchar());
```

since, in C, an assignment is an expression that yields the value assigned as its result.

The input/output functions that will usually form part of any runtime library are listed in table 3.5. Any function not appearing and thought to be important or useful can be added to such a library by the user. There is no suggestion that the list gives all, and only, those functions that should appear in the library. When viewed collectively the functions listed in table 3.5 leave one wondering why

(1) the names *putc*, *getc* are not *fputc*, *fgetc* to indicate that they communicate with files, and

(2) the file_pointer argument of *putc*, *fputs*, *fgets* does not appear as the first argument as it does in *fprintf*, *fscanf*.

The following definitions might help the user whose sense of order is offended.

```
#define fputc(f, a)             putc(a, f)
#define fgetc(f)                getc(f)
#define fputstring(f, a)        fputs(a, f)
#define fgetstring(f, a1, a2)   fgets(a1, a2, f)
```

FILE I/O

We have explicitly assumed so far that our input or output takes place from or to the user's terminal. While this will suffice for much initial work, we will wish, ultimately, to be able to read from and write to files. There are three files that are always available to any program. These are 'stdin', 'stdout', and 'stderr', the files for standard input, standard output and standard error messages. In practice these three files are always linked to the user's terminal. These files are opened at pro-

Table 3.5 Functions commonly appearing in the I/O library

printf(control_string [, argument_list])
scanf(control_string [, argument_list])
putchar(argument)
getchar( )
sprintf(data_string, control_string [, argument_list])
sscanf(data_string, control_string [, argument_list])
fprintf(file_pointer, control_string [, argument_list])
fscanf(file_pointer, control_string [, argument_list])
putc(argument, file_pointer)
getc(file_pointer)
fputs(argument, file_pointer)
fgets(argument1, argument2, file_pointer)

gram entry and closed at program exit. A user wishing to use other files must perform the opening and closing himself. Functions are provided to simplify this work. Opening a file involves passing a file name together with other information to the function *fopen* which returns a pointer to a file. Input/output functions using this pointer may write to a file or read from a file. The functions *fprintf* and *fscanf* are, apart from the fact that they communicate with a file, identical in action to their counterparts *printf* and *scanf*. The general form of their calls is given in table 3.5.

CLOSING A FILE

As part of the housekeeping associated with our program, a file should be closed when it is no longer needed. This is done by a call to the function *fclose* which has a general form

```
fclose(file_pointer)
```

When a program terminates normally, all open files are closed automatically.

OPENING A FILE

The operating system under which a C program executes may impose a limit on the number of files that the program may have open at one time. You should establish whether such a limit exists for your system and ascertain its value. If this limit is inadvertently exceeded, a warning should be given when opening the file that causes the limit to be passed. Since other problems also could arise in opening a file, such as 'file does not exist', 'file is write protected', and so on, it is worth having a closer look at the details of opening a file.

A file pointer points to a data item that we have not so far encountered, an object of type FILE. This is not a simple data item such as one with type *char* or *int* that we have used previously, but is more complex. We need not know what data items the type FILE embraces. On UNIX systems, and other systems too, a file of standard definitions of items essential to the input/output functions is kept in the include file 'stdio.h'. By including this file in our program, we define such symbols as FILE, EOF and NULL. For local use within the program we need a file pointer, which we will call 'fptr', and we need to use *fopen* to open the required file. The general form of a call to *fopen* is

```
fopen(file_name, file_mode)
```

This function returns a file pointer to the file that has been opened. Since the function is therefore not returning a value of the default type (*int* or *char*), it must be declared within the function, or file, that is to use it. This is the reason for the line

```
FILE *fptr, *fopen();
```

in our modified program of example 3.2.

Example 3.2

```
#include "adm5.h"
#include <stdio.h>
#define GAP fprintf(fptr, "\n\n\n\n")

#define allstars fprintf(fptr, "*****\n")
#define endstars fprintf(fptr, "*   *\n")
#define midstar fprintf(fptr, "  *  \n")

FILE *fptr, *fopen();

main()
    {
     fptr = fopen("results.text", "w");
     if ( fptr == NULL )
         {
          printf(" error in opening file\n");
         }
```

```
        else
            {
              HOME; CLEAR; GAP;
              bigH();     GAP;
              bigI();     GAP;
              fclose(fptr);
            }
    }

bigH()
    {
      endstars; endstars; endstars;
      allstars;
      endstars; endstars; endstars;
    }

bigI()
    {
      allstars;
      midstar; midstar; midstar; midstar; midstar;
      allstars;
    }

[ style 67.5 ]
```

The file_name argument to *fopen* must be a string giving the name of the file to be opened. The file_mode argument must also be a string which specifies the type of access required. Possible file modes are

"r" read access

"w" write access

"a" append access

An attempt to open a file that does not exist for writing or appending will result in the file being created. If a non-existent file is opened for reading, then *fopen* will return the value NULL. Other errors will also result in the NULL value being returned by *fopen*. As a result, if the file is opened by a statement such as

```
fptr = fopen("results.text", "w");
```

we must immediately check that the file pointer 'fptr' is not NULL. This is done using a conditional statement, and while this has not yet formally been introduced, it should be clear from the example that a NULL return from *fopen* will cause our program to print an error message. A non-NULL return from *fopen* will cause our program to continue execution normally.

There are some specific comments worth making about the example 3.2. HOME and CLEAR have not been modified and so send their character sequences to the VDU and not to the results file. The FILE declaration must not be within a function since *main*, *bigH*, and *bigI* all need to refer to 'fptr'. *printf* has been changed to *fprintf* in the *define* directives and 'fptr' has been added as the first parameter. The standard input/output definitions in 'stdio.h' have been included.

SUMMARY

Output and input provide the interface between the program and its environment. A number of contemporary languages recognise that the environment is usually so implementation dependent that it is difficult to include these facilities within the language definition itself, and opt instead to provide them as library routines. The input/output facilities that we have discussed in this chapter are generally accepted as a *de facto* standard, but your local implementation should be checked before assuming that you can use the functions we have specified: your implementation may have either more or less than ours.

Since the principal function of all programs is to communicate, whether it be with other programs, devices, or the human user, as much thought should be given to the design of this interface as to the problem solution. It is not sufficient that a program produces the correct results, if those results, by virtue of poor presentation, are difficult to interpret; nor is it sufficient that a program assumes the integrity of its input, for this is usually the one factor over which the programmer has no control.

4 Decisions

A programming language that only offered the possibility of moving from one instruction to the next instruction in sequence would be extremely limiting. To be useful, we must be provided with the facility to choose different courses of action under different circumstances. There are two distinct ways that this may be done in C. We can use either the conditional statement or the *switch* statement.

CONDITIONAL STATEMENT

Two forms of the conditional statement are available in C

```
if (expression) statement1
if (expression) statement1 else statement2
```

An example of the latter form appears in example 3.2 to test that a file has been opened satisfactorily.

If the conditional statement currently under discussion is included, the kind of statements used so far in the text include

- an assignment statement,
- a function call,
- a conditional statement,
- a return statement, and
- a compound statement.

(Recall that a compound statement is a group of statements enclosed by braces { }). Any of the statement types listed can be used as indicated by the general form of the conditional statement. Other forms of statement, defined later, can also be used. With the exception of the compound statement in the list above, all statements are terminated by a semi-colon. Anyone familiar with Pascal will find that the form of the conditional statement which uses *else* can, in certain circumstances, look strange. Different forms of the conditional statement are shown in example 4.1.

Example 4.1

```
if ( n<0 )  printf("n is negative\n");
if ( n==0 ) printf("n is zero\n");
if ( n>0 )  printf("n is positive\n");

/*  since  the  three statements above are  */
/*  distinct  conditional  statements, all  */
/*  tests are always performed. In contrast */
/*  consider the following alternative:     */

if ( n<0 ) printf("n is negative\n");
else if ( n==0 ) printf("n is zero\n");
else printf("n is positive\n");
```

What follows the comments in example 4.1 is a single conditional statement. The first *if* has a corresponding *else*, and what follows the *else* is a conditional statement. This way of expressing a condition may at first seem strange, but it will usually permit an elegant expression of our logic. In addition it is economical, in that, when one of the tests within the statement is satisfied and the corresponding action undertaken, execution of the conditional statement terminates.

The use of braces to signify a compound statement adds considerably to the expressive power of the conditional statement, in that the execution of groups of statements can be made dependent on a specific condition. This can perhaps be appreciated in example 3.2 where the main part of the program is executed only if the output file is opened satisfactorily.

Perhaps the part of the conditional statement that it is most important to understand is the condition itself. The general form of the statement showed this to be an expression enclosed by parentheses. Expressions will be considered in greater detail in chapter 6. For the present we can use the comparison of simple data items as an example of the form of expression required. An expression such as

$$n > 7$$

can be evaluated as soon as n is known. We expect the result 'true' if n is greater than 7 and 'false' otherwise. Convention dictates that we regard the value zero as 'false' and non-zero as 'true'. Thus, if the parenthesised expression following *if* yields a non-zero or 'true' value the statement that immediately follows is executed, and the *else* part, if it exists, is ignored. However, if the parenthesised expression yields a zero or 'false' value, the statement that follows *else* is executed. This property is exploited in the following function

```
        /* to determine whether `ch' is */
        /* the letter 'y', or 'Y' .     */

    affirmative(ch)
        char ch;
        {
            if ( ch=='y' ) return(1);
            else if ( ch=='Y' ) return(1); else return(0);
        }
```

If the character passed to *affirmative* is an upper case or lower case 'y' the value 1 is returned, otherwise 0 is returned. Such a function can significantly help the readability of our program. For, after prompting the user for a single character reply 'reply' to a question, we could then write

```
    if ( affirmative(reply) ) printf("reply is yes\n");
```

Note that it is not necessary to compare the value returned by *affirmative* with zero or anything else. Indeed to do so would detract from the readability of the resulting statement. We could of course exploit the same principle by writing

```
    if ( n ) printf("n is non-zero\n");
```

but we would argue that this is not good practice as n represents numeric values rather than the 'true' or 'false' values that *affirmative* represents.

(For illustrative purposes, the body of *affirmative* is more verbose than it need be. This function would normally be written in C as

```
    affirmative(ch)
        char ch;
        { return(ch=='y' || ch=='Y') }
```

where || is the 'or' operator.)

TRAPS FOR THE UNWARY

Consider the two statements

```
    if ( ch='Y' ) return(1);
    if ( ch=='Y' ) return(1);
```

and ask whether you can clearly state what each does. They differ only in that the first has one less 'equals' sign than the second. There is, nonetheless, a significant difference in their actions. The second statement tests whether 'ch' has the value 'Y', returns 1 if it does and continues with the next statement in sequence if it does not. In contrast the first statement assigns the value 'Y' to 'ch' then, because an assignment is an expression that yields as its result the value assigned, the *return* statement is executed, since the parenthesised expression yields a non-zero value. This difference in action can be extremely important. Its advantage is that an assignment and a test of the assigned value are neatly combined. Its disadvantage is that if you intended comparison (= =) rather than assignment (=) your program is logically incorrect but syntactically correct. Those people moving to C from a language in which the single 'equals' sign is used for comparison are advised to check their conditional statements carefully.

In RatC there are several functions that use conditional statements in a simple but effective way. The functions *an*, to determine whether a character is alphanumeric, and *alpha*, to test for an alphabetic character, are useful examples.

MULTIPLE CONDITIONS

Let us assume that we are given an integer, which is an examination mark, and that we are to translate this mark into a grade. An A grade is obtained for a mark in the range 80 to 99, B for a mark in the range 60 to 79, and so on. The character NULL is returned for a mark outside the range 0 to 99. There is, as usual, more than one way to achieve this end, but a look at several methods will help to contrast the use of different facilities in C.

Example 4.2

```
grade(mark)
     int mark;
     {
       char g;

       if ( mark<0 ) g=NULL;
       else if ( mark<20 ) g='E';
       else if ( mark<40 ) g='D';
       else if ( mark<60 ) g='C';
       else if ( mark<80 ) g='B';
       else if ( mark<100 ) g='A';
       else g=NULL;

       return(g);
     }

[ style 49.3 ]
```

While the logic of the statement is simple and economical, it is lengthy. What is needed to deal with the problem of example 4.2 is a construct that offers a multiple choice of actions in contrast to the binary choice offered by the conditional statement. The *switch* statement is just such a construct.

THE *switch* STATEMENT

The general form of the switch statement is

switch (expression) statement

The value yielded by the expression must be of type *int* (or *char* since the conversion to *int* is automatic) and will be used to select which of several statements to execute. The statement that follows the selecting expression will, if the switch is to serve any useful purpose, contain one or more statements preceded by

case constant_expression:

The constant expression can be thought of as labelling the statement that it prefixes. This statement is executed if the selecting expression yields a value that matches the constant expression. Within any *switch* statement the constant expression that labels a statement must be unique. A rewritten version of the mark grading example should make clear the form and logic of the *switch* statement.

Example 4.3

```
grade(mark)
     int mark;
     {
       char g;

       switch (mark/20)
            {
              case 0: g='E'; break;
              case 1: g='D'; break;
              case 2: g='C'; break;
              case 3: g='B'; break;
              case 4: g='A'; break;
            }

       return(g);
     }

[ style 40.5 ]
```

The unexpected feature of this example is, perhaps, the *break* statement. When it is encountered it causes exit from the *switch*. If in the example 4.3 the first *break* were omitted, then having assigned 'E' to 'g' the next statement, which assigns 'D' to 'g', is executed. In other circumstances, as we shall see, we might wish to exploit this course of action. It is not appropriate to do so in this example – all the *break* statements, with the exception of the last, are essential.

Example 4.3 is logically similar to example 4.2. It is not identical in its action, as NULL is not returned if 'mark' is outside the expected range. A statement prefixed by *default* is executed if the value produced by the switching expression does not match any of the constants following *case* within the switch statement. In example 4.3 when none of the *case* constants is matched exit is made from the *switch* statement. We can ensure that marks which are out of range are satisfactorily processed by including the statement

```
default: g=NULL; break;
```

anywhere within the *switch* statement of example 4.3. Finally we note that no ordering of the *case* or *default* prefixes is necessary or implied. The example 4.4 should make these points clear.

Example 4.4

```
        /* to determine whether a given character */
        /* is a vowel. Zero is returned for non-   */
        /* vowels. An integer in the range 1 to 5 */
        /* is returned for a vowel.                */

vowel(ch)
        char ch;
        {
          switch (ch)
                {
                  default: return(0);
                  case 'u': case 'U': return(5);
                  case 'a': case 'A': return(1);
                  case 'e': case 'E': return(2);
                  case 'i': case 'I': return(3);
                  case 'o': case 'O': return(4);
                }
        }
```

[style 49.2]

This example exploits the fact that a *case* which is not followed by a *break* causes the following statement to be executed. In this way we can easily deal with both upper and lower case versions of the characters. The statement prefixed by *default* could as easily be the last statement of the switch as the first. Another feature exploited is the use of *return* rather than a *break* statement. *return* causes exit from the *switch* statement and from the function.

The RatC compiler does not support a *switch* statement and therefore none is used in the RatC program. The function *statement* within RatC has the task of determining what kind of statement is about to be processed. It uses a conditional statement of the form illustrated in example 4.2. An integer indicating which kind of statement was detected is returned to the caller.

SUMMARY

In this chapter we have discussed two of the constructs that give programming its flexibility - the two-way and multi-way branch. Strictly, from the point of view of the logic of a program, one of the constructs is unnecessary, since either can be expressed in terms of the other. Careful use of the appropriate construct can, however, considerably enhance the intelligibility of a program.

A two-way branch will almost always be implemented with a conditional statement; a multi-way branch can be implemented either by nested conditionals or by a *switch* statement. As a general rule, we can say that nested conditional statements should be used whenever we are testing a series of conditions in decreasing order of expected frequency; when all the conditions are equally likely to occur, a *switch* statement should be used.

5 Loops

The conditional statements of the previous chapter freed our programs from the straitjacket of the sequential execution of instructions without branching, but it is the ability to loop, or repeat the execution of one or more instructions, that brings power to programming. It brings economy too, for a modest number of programming language statements can be responsible for a significant amount of computing time.

C offers at least three ways in which we can construct loops. We can use a *while* statement, a *do* statement, or a *for* statement. Of these, the *while* statement is the most important, because it can be used to do anything that the other two loop constructs can do. The other two forms of loop construct are available because, in certain circumstances, they offer a more appropriate means of expressing our logic. The RatC processor only offers the *while* statement as a looping construct and thus that is the only form of loop used throughout RatC.

THE *while* STATEMENT

The *while* statement has the general form

while (expression) statement

The list of statements given at the start of chapter 4 must now be extended to include the *while* statement. Any one of this extended list of statements is admissible as the statement part of the general form of the *while* statement given above. The expression in parentheses has the same role as the parenthesised expression of the conditional statement – that is, it is evaluated and tested. If it produces a non-zero or 'true' result, the statement that follows is executed. The expression is then tested again and, if 'true', the statement following is executed once more. This sequence is repeated until the evaluation of the expression yields a 'false' result, and then the statement that follows the *while* statement is executed.

There is, of course, an implicit assumption that something occurs within the *while* loop which causes the value produced by the controlling expression to change at some time. The statement

```
while (1) i=0;
```

causes an infinite loop, setting 'i' to zero interminably. Care must be taken to ensure that loops do terminate!

In example 5.1 we introduce two new operators, !=, and ++. The first tests for inequality; the second is the increment operator, which when used as in

```
count++;
```

causes 'count' to be incremented by one. Suppose our task is to count the number of characters on a line. Assuming that the input stream is positioned at the start of a line, the following statements perform the count

```
count=0;
ch=getchar();

while ( ch!='\n' )
     {
       count++;
       ch=getchar();
     }
```

But these statements do not exploit some of the features that we have already seen. In particular, the test that controls the *while* statement could easily be modified to include the assignment to 'ch'. The modified version uses this feature and is presented as a function.

Example 5.1

```
counter()
     { char ch;
       int count=0;

       while ( (ch=getchar()) != '\n') count++;
       return(count);
     }

[ style 46.6 ]
```

Example 5.1 also capitalises upon the ability, in C, to initialise variables as part of their definition. A closer look at the function *counter* should prompt the realisation that 'ch' is used only in the expression that controls the *while* loop. If this is so, then we should dispense with 'ch' altogether and rewrite the function as in example 5.2.

Example 5.2

```
counter()
    { int count=0;

      while ( getchar() != '\n') count++;

      return(count);
    }
```

```
[ style 48.4 ]
```

In this, and other ways, C offers many aids to writing 'economical' (some would say terse) programs. The reader is encouraged to exploit these features but to bear in mind that simplicity and clarity of expression should not be sacrificed in order to produce 'smart', but not easily readable, programs.

ESCAPING FROM LOOPS

The *break* statement, which was used to escape from the *switch* statement, will also force exit from a *while* statement. Following the execution of *break*, the statement that follows the *while* statement is executed. A *return* statement also may be used to escape from a *while* loop. However, as might be expected, this not only causes immediate exit from the *while* statement, but also forces exit from the function that contains the *while* statement. The function *doasm* of RatC uses the *break* statement to escape from a *while* loop. *doasm* is invoked when the directive indicating that 'assembly language statements follow' is discovered. All lines of input that contain assembly language statements are simply copied to the output file until either 'end of file' or the terminating directive is discovered.

The *while* statement can also be exploited when attempting to make the user interface of a program more robust. If a program directs a query to its user which requires a simple 'yes' or 'no' answer, for example

Do you wish to continue (Y or N) ?

then only the response indicated should be accepted. Consider example 5.3.

Example 5.3

```
#define BELL '\7'

replyisyes()
    { char ch;

      while (1)
```

```
            {
              ch=getchar();
              switch (ch)
                   {
                     default: putchar(BELL); break;
                     case 'y': case 'Y': return(1);
                     case 'n': case 'N': return(0);
                   }
            }
    }
```

```
[ style 61.3 ]
```

Exit is only made from the function when 'Y' or 'N' of either upper or lower case is received. Receipt of any other character causes the VDU to 'beep' and, although exit is made from the *switch* statement, the *while* statement remains active.

This last example provides the opportunity to state again that a program's interface with its user is extremely important. If a question is directed to the user, ensure that the acceptable responses are made known, and write the program logic in such a way that only valid responses are accepted.

Further details of the input/output philosophy of the underlying Operating System will need to be clarified before example 5.3 can be used conveniently. Usually, for example, a user is required to provide 'line at a time' input. That is, a character followed by 'newline' would be expected. Example 5.3 would 'beep' at any 'newline' character that it encountered. It is usually possible to arrange 'character at a time' input, but the mechanism for achieving this will be environment dependent and thus outside the scope of this book.

The *while* loop is important because, as is evident from its structure, the controlling condition is tested before entering the loop. In contrast, the expression that controls the *do* loop is tested only at the end of the loop, and therefore the statement controlled by the loop is always executed at least once.

THE *do* STATEMENT

The general form of the *do* loop is

do statement while (expression)

Our list of statements must now be extended to include the *do* statement. Any one of the resulting list of statements is suitable as the statement used in the general form given above.

As an illustrative example, let us assume that we have access to a file containing one word per line. Our task is to sum, for each such word, the number of times that we find a vowel preceded by a consonant. The sum produced is a good approximation to the number of syllables in the word. We assume a file pointer 'fptr', and a function *consonant* which returns a non-zero (true) value if the character passed as a parameter is a consonant. The function *vowel* was given as example 4.4.

Example 5.4

```
syllables()
    { char ch;
      int changes=0, previousvowel=0;

      do
          {
            ch=getc(fptr);
            if ( vowel(ch) )
                {
                  if ( !previousvowel ) changes++;
                  previousvowel=1;
                }
            else if ( consonant(ch) ) previousvowel=0;
          }
      while ( ch != '\n' );
      return(changes);
    }

[ style 52.7 ]
```

(As a syllable counter, the function of example 5.4 is limited in that there are special cases that it does not handle. Thus 'by' would be credited with having no syllables, and 'ale' with two. For most words, however, it is a good first approximation.)

THE *for* STATEMENT

The *for* statement proves convenient to use when it is necessary to execute a loop a given number of times. While this could also be done by either of the other two loop constructs, we should select the statement that is most appropriate for the task. Counting through a loop requires three 'housekeeping' activities: initialising the counter, incrementing the counter, and testing whether the terminating value has been reached. It is helpful to both the reader and the writer of a program if these three housekeeping activities are collected together. This is economically achieved in the *for* statement which has the general form

for (expression1; expression2; expression3) statement where

expression1	initialises the counter,
expression2	gives the continuing condition, and
expression3	increments the counter.

Thus to compute the sum of the first N natural numbers we could write

```
sum=0;
for ( i=1; i<=N; i++ ) sum=sum+i;
```

or, if it is more suitable to count down

```
sum=0;
for ( i=N; i>=1; i-- ) sum=sum+i;
```

In C, the statement controlled by the *for* statement in these examples can be more concisely written as

```
sum+=i;
```

THE *continue* STATEMENT

We have seen that *break* will cause immediate exit from a *switch* or *while* statement. It will also cause immediate exit from a *do* statement or *for* statement. The loop statements (*while*, *do*, and *for*) can also use a *continue* statement. The *continue* statement is less drastic than the *break* statement because it only causes termination of the present iteration. If *continue* is encountered in the execution of *while* or *do* loops, it causes a branch to the loop control test to be made. In a *for* statement a *continue* causes execution of the 'increment' expression prior to testing whether another iteration of the loop is appropriate.

Imagine that a file contains a collection of marks, except that the very first number in the file gives the number of marks that follow. Using the function *grade* of example 4.2, we are to compute the number of pass grades in the mark list (example 5.5).

Example 5.5

```
        /* n.b. fscanf may return EOF or zero;   */
        /*      grade returns NULL if the        */
        /*             mark is out of range;     */
        /*      only an E grade does not pass.   */

passes()
```

```
{ char g;
  int  listsize, mark, m, psum=0;

  if ( fscanf(fptr, "%d", &listsize) < 1 ) return(-1);

  for ( m=1; m<=listsize; m++)
      {
        if (fscanf(fptr, "%d", &mark) > 0 )
            {
              if ((g=grade(mark)) == NULL) continue;
              if (g=='E') continue;
              psum++;
            }
        else return(-1);
      }
  return(psum);
}
```

[style 65.9]

DYNAMIC CHANGE OF INCREMENT

The *for* statement in C is implemented in a manner that enables it to be used in some rather surprising ways. For example

```
for ( ; ; ) k=0;
```

represents an infinite loop. The assumption is made that, if the second expression, which is the controlling condition, is omitted, the value 'true' is to be used. The most significant way that the *for* statement differs from the *for* statement as defined in, say Pascal, is that both the terminating condition and the increment expression are re-evaluated for every iteration. This means that if the identifiers used in computing these values are changed within the *for* loop, then either the terminating condition, or the step size, or both, can be constantly changed from within the loop. Consider, for example

```
for ( p=1; p<=4096; p=2*p) printf("%4d\n", p);
```

which prints a small list of powers of two. It achieves this by multiplying the 'increment' by two each time through the loop.

The loop terminating condition need not involve the 'counter', although it usually will. The loop of example 5.2 could be rewritten, using a *for* statement, in the following form

```
for ( count=0; getchar() != '\n'; count++ );
```

Here the *for* statement has an empty statement part, because all the necessary work is done within the controlling expressions. Note that the terminating condition is independent of 'count'. Changing the loop terminating condition from within the loop should be done carefully, if at all. There is a danger that it may be changed in such a way as to ensure that the loop never terminates at all.

A final example on *for* statements is used to show that they, or any of the other looping constructs, may be nested to create a loop within a loop. Example 5.6 computes 'perfect' numbers. If we exclude the number itself from a list of its factors, then a perfect number is the same as the sum of its factors, so that the first perfect number is 6, because the factors of 6 are 1, 2 and 3, and 1+2+3 = 6. It is only necessary to examine even numbers for perfection, because, although it remains to be formally proved, it is surmised that odd numbers cannot be perfect.

Example 5.6

```
#define LO   6          /* first perfect number */
#define HI   1000       /* limit of search      */

main()
    { int num, sum, factor;

      printf(" Perfect numbers \n");
      for ( num=LO; num<=HI; num+=2 )
          {
            sum=1;
            for ( factor=2; factor<num; factor++ )
                if ( num%factor == 0 ) sum+=factor;
            if ( sum == num ) printf("%4d\n", num);
          }
    }

[ style 63.8 ]
```

The modulus operator, %, is described in more detail in chapter 6. It gives, in this case, the remainder when 'num' is divided by 'factor'.

THE *goto* STATEMENT

The loop structures introduced so far, if used properly, should mean that the user rarely, if ever, needs to use a *goto* statement. In particular, a *goto* need never be used to construct loops. However, in certain error situations, a *goto* may enable a cleaner program termination to take place. A statement may be labelled by prefixing it by an identifier followed by a colon. The *goto* statement may then use this label as its destination, thus

```
goto abort;
    ....
    ....
abort: printf(" abnormal termination \n");
```

SUMMARY

C's looping constructs correspond to those found in many other high-level languages. Usually, a determinate loop, where the number of iterations is known in advance, is most appropriately implemented by a *for* statement, while an indeterminate loop, where termination depends on some condition being satisfied, is better implemented as a *while* or a *do* statement. These are general rules, however and, as has already been demonstrated, C's *for* statement is powerful enough to enable it to be effectively used to control an indeterminate loop under certain circumstances. This being so, it is wise to consider carefully which particular statement is likely to yield the most natural expression of the loop's intent.

6 Operators

In preceding chapters we have used identifiers with type *char*, *int*, and *float*. Data types *char* and *int* must be available in any C implementation. When the size of a C language processor has to be reduced, it will be the data type *float* that will be sacrificed. RatC does not support the type *float*. On larger machines offering a 'full' implementation of C we might also expect to have access to the types double length floating point (abbreviated to *double*), double length integer (abbreviated to *long*) and perhaps short integers (*short*). We suggest that you look at the implementation notes for C on your system to discover what is on offer. This information is needed only when it is necessary to mix types in an expression, for then we need to know the type of the result.

TYPE CONVERSION

The type names introduced above can conveniently be listed in order as follows

    char, short, int, long, float, double

Apart from the *long/float* boundary, this list is in order of increasing storage size. By storage size we mean the amount of storage needed for a data item of the given type. With this list in mind the implicit type conversion rules given below can readily be understood.

For an expression involving one of the binary operators (one with two operands), such as

    a + b

the type of the result is determined by the type of the operands according to the following rules. *char* and *short* are converted to *int*, and *float* is converted to *double*. If, as a result, either operand ('a' or 'b') is of type *double*, the other is converted to *double*. As a result of this conversion either both operands are *double*, in which case the result is *double*, or one or both of them is *int* or *long*. If either operand is *long* the other is converted to *long* and the result is *long*, or they are both *int* and the result is *int*. The implicit conversion is therefore always from the 'smaller' object to the 'larger'. The results of type conversion are summarised in table 6.1. An explicit type conversion can be obtained by using a 'cast'.

Table 6.1

a	b	Result
char short int	char short int	int
char short int	long	long
char short int	float double	double
long	long	long
long	float double	double
float double	float double	double

CAST

By prefixing an expression with one of the type names used earlier enclosed in parentheses, we force the expression to yield a result of the type indicated so that

```
(long) 2+3
```

produces the result 5 which has type *long*. A cast can also be useful in forcing an actual parameter to have the type of the corresponding formal parameter. The functions *exp*, *log*, and *sqrt*, which are to be found in the library of mathematical functions, expect a parameter of type *double*, and produce a result of type *double*. If we wish to obtain the natural logarithm of 'x', which has type *float*, then we can write

```
log( (double) x )
```

The assignment operator is treated in a different way to most of the other operators. The type of the expression of the right-hand side (rhs) is changed to the type of the identifier on the left-hand side. In appropriate circumstances, therefore, a rhs of type *double* is rounded to *float*, a rhs with type *float* is truncated to *int*, and an *int* is converted to *char* by ignoring excess high order bits.

ASSIGNMENT OPERATORS

We have introduced a limited number of these operators at suitable places in the text. For example, the operator += was used to enable us to write

```
sum+=i;
```

rather than

```
sum=sum+i;
```

An assignment in C is treated like any other operator in that, having made the assignment the value assigned is available for other use. Thus

```
(sum+=i) > max
```

adds 'i' to sum and compares the assigned value with 'max'. The validity of a 'multiple assignment' should therefore be apparent.

```
sum=total=start=0;
```

The full list of assignment operators is

```
 +=          -=
 *=          /=
 %=          >>=
<<=          &=
 ^=          |=
```

The meanings of the various assignments will become obvious as we consider the different groups of operators.

ARITHMETIC OPERATORS

We will introduce operators in the various groups by using them in simple expressions. While this may not be strictly necessary for the more familiar operators, it should help to clarify the action of the less familiar ones.

```
  - 5    -5   (unary minus)
7 + 5    12    add
7 - 5     2    subtract
7 * 5    35    multiply
7 / 5     1    divide
7 % 5     2    modulus
```

With the exception of the modulus operator, the type of the result from such expressions will, in general, be determined by the conversion rules given earlier. In the examples above, all results are of type *int*. When two items of type *int* are divided, the fractional part of the result is truncated to produce a result of type *int*. The modulus operator produces the remainder after division of one integer by another. The result is of type *int*. Operands of type *double* or *float* may not be used with this operator.

A small example which uses most of the operators above is a function to evaluate Zeller's Congruence (Uspensky and Heaslet, 1939), shown in example 6.1. This function, when given a day, month, and year (full form), produces a result in the range 0 to 6. With Sunday as day 0, this number represents the day of the week on which the given date fell. It can be used, for example, to determine birthdays.

Example 6.1

```
/* zeller returns a number in the range  */
/* 0..6 representing the day of the week */
/* on which the given date falls.        */
/* Sunday is day 0.                      */

zeller(day,month,year)
    int day, month, year;
    { int temp, yr1, yr2;

      if (month<3) { month+=10; year-=1; }
      else month-=2;

      yr1=year/100; yr2=year%100;
      temp=(26*month-1)/10;

      return((day+temp+yr2+yr2/4+yr1/4-2*yr1+49)%7);
    }

[ style 51.3 ]
```

BITWISE OPERATORS

C enjoys well-deserved popularity as an 'implementation' language. This is in large measure due to the ease with which the user can access and manipulate bit patterns in memory. The following operators are available

<table>
<tr><td>7 << 5</td><td>224 (0xE0)</td><td></td><td>left shift</td></tr>
<tr><td>7 >> 5</td><td>0</td><td>*</td><td>right shift</td></tr>
<tr><td>7 | 5</td><td>7</td><td></td><td>inclusive or</td></tr>
<tr><td>7 ^ 5</td><td>2</td><td></td><td>exclusive or</td></tr>
<tr><td>7 & 5</td><td>5</td><td></td><td>and</td></tr>
<tr><td>~05</td><td>0177772</td><td></td><td>one's complement</td></tr>
<tr><td></td><td></td><td>*</td><td>beware sign propogation</td></tr>
</table>

Note the use of hexadecimal and octal constants above – hexadecimal constants are written with a leading *0x* or *0X*, and may use digits *0* through *9* and letters *A* through *F* (or *a* through *f*); octal constants are written with a leading *0*, and may use digits *0* through *7*. The last example, of the one's complement operator, assumes that the length of an *int* is 16 bits.

Bit manipulation, usually the preserve of assembly language programmers, is necessary, for example, when checking the bits of a status register and in masking data to be received or transmitted. An example to illustrate use of these operators need not be drawn from such a machine specific area. The 'feedback shift register' technique for generating pseudo-random numbers is easily expressed using the bitwise operators as example 6.2 shows.

Example 6.2

```
#define MAXINT 32767
#define PSHIFT 4
#define QSHIFT 11

random(range)
    int range;
    { static int n=1;

      n=n^n>>PSHIFT;
      n=(n^n<<QSHIFT)&MAXINT;
      return(n%(range+1));
    }

/* the function is dependent upon */
/* the word length of the host     */
/* machine. The seed `n' should    */
/* be capable of easier change     */
/* than is possible here.          */

[ style 64.1 ]
```

The rationale behind this algorithm, which is a good source of random numbers, is given in Lewis (1975). A Pascal version, which makes an interesting comparison, is given in Meekings (1978). Remember too that since C makes it easy to print the value of a variable in either octal or hexadecimal, the results of bitwise operations can usually be displayed in an easily assimilated form.

LOGICAL OPERATORS

These operators are usually used to combine one or more comparisons in the controlling expressions of conditional statements, *while* statements, and the other loop constructs.

```
7 && 5    1     logical and
7 || 0    1     logical or
   ! 0    1     logical not
```

The important point that distinguishes these operators from the bitwise operators is that any non-zero operand is treated as 1 (true). A zero operand is treated as false. The result of the operation is 0 or 1 according to the normal rules for logical connectives. Expressions using && and || are evaluated left to right and evaluation should terminate once the truth or falsity of the expression is determined. None of these operators is used in RatC, and none is processed by RatC. In consequence some of the expressions that would normally be written using the logical connectives are written using several conditional statements to obtain the required termination as soon as possible. The group of functions in RatC that deal with expression processing, *hier1* to *hier11*, contains several examples of such constructions. For illustrative purposes, imagine that we wish to compute the mean rainfall given the total rainfall 'train' over a number of days 'days'. We might write

```
if (days>0)
    if ( (mean=train/days) > 5.0) print("%d\n", mean);
```

assuming that we wished to avoid division by zero. But consider

```
if ( (days>0) && ((mean=train/days) > 5.0))
```

as an alternative test. It is only a useful alternative if, when 'days' is zero, the expression in which 'days' is a divisor is not evaluated. C guarantees that when the truth or falsity of an expression is known, as it is above when (days > 0) evaluates to zero (false), evaluation of the expression immediately terminates.

RELATIONAL OPERATORS

Examples of some of these operators have appeared at several places in the text so far. The operators are

```
>    greater than
>=   greater than or equal to
==   equal
!=   not equal
<=   less than or equal
<    less than
```

The test for a digit is a simple example of the use of two relational operators and a logical operator

```
digit = ( ch >= '0') && ( ch <= '9' );
```

INCREMENT AND DECREMENT

The usefulness of the increment operator should by now have become apparent. The decrement operator is used in an entirely similar fashion, so that

```
countdown--;
```

decrements countdown by one. What has not been emphasised so far is that both the increment operator and the decrement operator may be used either as a prefix or postfix to an operand. We may therefore write

```
++count;            --countdown;
```

Such simple usage as this does not make clear what difference there might be between the prefixed or postfixed operator. The difference can be illustrated by the following example

```
up=0;
printf("%2d\n", up++);     /* prints 0 */
printf("%2d\n", ++up);     /* prints 2 */
```

The first statement after the initialisation will print zero and then increment 'up'. In the second print statement the value of 'up' will be incremented (to two) and then printed. The prefixed form means increment (or decrement) and use, while the postfixed form means use and then increment (or decrement). The difference is important, as we will see, when dealing with array subscripts.

CONDITIONAL OPERATOR

The conditional operator affords an easy and compact way to express a value which depends on a test. In the following example, the absolute value of x is computed.

```
if (x < 0)
        xabs = -x;
else
        xabs = x;
```

C gives us a more concise way to write such things, so their meaning becomes more apparent. The conditional operator takes three expressions and is used in the following format

expression-1 ? expression-2 : expression-3

Expression-1 is evaluated and then tested. Based upon the results of this test, either one (but not both) of expression-2 and expression-3 will then be evaluated and that value will become the result of the whole conditional expression. If the value of expression-1 is true (non-zero), expression-2 is evaluated; otherwise, expression-3 is evaluated. Thus, we can write the absolute value computation as

```
xabs = (x<0) ? x : -x;
```

Printing a heading only after a certain number of lines suddenly becomes easy to write

```
#define HEADING      "\n\n\n      - Treasure Island -\n\n\n"


printf ("%s", (no_lines % 60 == 0) ? HEADING : "");
```

Standard conversion rules will be used to bring the constituent values of the conditional expression to a common type to produce the result. So, in the following example, if x is of type float when it is substituted by the preprocessor, the resulting type of the whole conditional expression is a float.

```
#define min_1(x)       (x>1 ? x : 1)
```

COMMA OPERATOR

The comma operator is syntactic sugar: it need not be provided since there are other facilities in the C language which can accomplish the same function; its use is more a question of style than of functionality. Expressions connected by a comma operator are executed in sequence. One use might be to initialise several quantities in a for statement. The following code might be used to scramble the letters in a word five successive times

```
for (count = 0, j = word; count++ < 5; j = scramble (j))
        ;
```

First the expression on the left of the comma is evaluated and the result discarded; then the expression on the right of the comma is evaluated and used as the resulting value. The type of the result is the type of the operand on the right of the comma.

Ambiguity can arise in the cases where the comma can also be interpreted as a character separating items in a list (that is, arguments and initialisers). In those circumstances, the comma operator can only be used inside parentheses

```
my_func (arg1, (c = C_INIT, (c + 1)*10), arg3);
```

PRECEDENCE OF OPERATORS

Whatever programming language you use it is important to write expressions in a way that makes sense to you, the writer. (Bear in mind too that others will wish to read and understand your program.) In order to do this, and still produce programs that are syntactically and logically correct, it is necessary to understand how expressions are written and how they are interpreted. Operands must be separated by operators, and evaluation usually proceeds from left to right. Thus, in an expression such as

```
a + b * c
```

it can be seen that the operators separate the operands, but we are accustomed to the multiplication of 'b' and 'c' being carried out before the addition of 'a'. Formally we say that multiplication has a higher priority or precedence than addition. Parentheses can always be used to enforce the required priority. In C, however, there are occasions on which even this rule may not be as easy to apply as we would wish. Another possible source of confusion is that some operators, for example * and &, have more than one role. Consider for example

```
*pint++
```

which is not part of a multiplication. It might mean increment the pointer (address) 'pint' by one and retrieve the contents, or it might mean that the value '*pint' is to be increased by one. In fact unary operators are evaluated from right to left and so the expression increments the pointer 'pint' and not what it points to. The latter effect is achieved by

```
(*pint)++
```

It is therefore important to know the order of precedence of operators and the direction of association. A table of this information is given in table 6.2. Operators are listed in decreasing priority, with operators in the same section having equal priority.

SUMMARY

C has a well-deserved popularity among high-level and low-level programmers alike. Such popularity is, in large part, attributable to the richness of its set of operators, which allows a clear and natural expression of the program logic, with the additional bonus of an efficient translation into the underlying machine instructions. It is the large variety of operators that characterise the language, and possibly pose the greatest hurdle for the novice C programmer.

Time spent initially in learning how to use the full set of operators will be amply rewarded by clear, concise and efficient programs.

Table 6.2

Operator	Name	Associativity
( )	parentheses	left to right
[ ]	brackets	
–>	pointer	
.	dot	
++	increment	right to left
--	decrement	
(type)	cast	
*	contents of	
&	address of	
-	unary minus	
~	one's complement	
!	logical NOT	
sizeof	size of	
*	multiply	left to right
/	divide	
%	modulus	
+	plus	left to right
-	minus	
>>	shift right	left to right
<<	shift left	
>	greater than	left to right
>=	greater than or equal	

Operator	Name	Associativity
<=	less than or equal	
<	less than	
==	equal	left to right
!=	not equal	
&	bitwise AND	left to right
^	bitwise exclusive OR	left to right
|	bitwise inclusive OR	left to right
&&	logical AND	left to right
||	logical OR	left to right
?:	conditional	right to left
=	equals	right to left
+=	plus equals	
-=	minus equals	
*=	multiply equals	
/=	divide equals	
%=	modulus equals	
>>=	shift right equals	
<<=	shift left equals	
&=	and equals	
^=	exclusive or equals	
|=	inclusive or equals	
,	comma	left to right

7 Arrays

In the examples used so far each data item that we wished to manipulate has been given a name, or identifier. Each identifier has associated with it a type, and a storage class. This association is made explicit through the declaration. But so far any identifier has represented a numeric value of one type or another, or a character. Consider again example 4.3 in which we produced a grade for a given mark. If we now change the specification of the problem, to ask that we produce the number of times that each grade was achieved, the statements in example 7.1 could appear in a suitable loop.

Example 7.1

```
/* assume a=b=c=d=e=f=0; prior to loop entry */

switch (mark/20)
    {
     case  0: e++; break;
     case  1: d++; break;
     case  2: c++; break;
     case  3: b++; break;
     case  4: a++; break;
     default: f++;
    }
```

While we can contemplate writing this when only five grades are involved, we would, if twenty-five grades were involved, look for a 'better way'.

ARRAY DECLARATIONS

Instead of having individual identifiers for each grade total, which causes difficulty when dealing with them collectively, what would be much more useful would be a collective name for the grade totals together with a method of accessing each grade total. A street name is a collective name for several houses. The house number uniquely identifies each house of the street. An array name is a collective name for several data items of the same type. Each item has a unique reference number known as an index or subscript. If 'grades' is the collective name for the five grade totals it could be declared as

```
int grades[5];
```

In C array subscripts start at zero. The five grades can therefore be referred to as

grades [0] , grades [1] , grades [2] , grades [3] , grades [4]

POINTERS AND ARRAYS

Another method of referring to the individual elements of an array is available to us in C. The array name, 'grades' in this case, is always treated as a pointer, or address. It points to the first element of the array. If, for example, we make a copy of the pointer, then we can increment and decrement the pointer value in order to refer to different elements of the array. Consider example 7.2.

Example 7.2

```
int grades[5], *gptr;
gptr=grades;     /* gptr points to grades[0] */
gptr++;          /* gptr points to grades[1] */
gptr++;          /* gptr points to grades[2] */
```

A subscript within square brackets is the more usual way to refer to elements within an array. Use of a pointer, while initially not so familiar, can become more convenient and is usually more economical in implementations of C. We shall move towards use of pointers for array access.

With an array to help us, we can now write example 7.1 in the following way

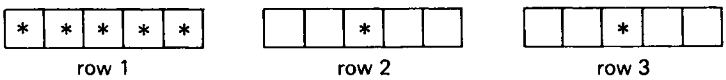
```
int grades[5], *gptr, s;

    /* initialise array elements */

    gptr=grades;
    for (s=0; s<5; s++) *gptr++=0;

    /* assume a function  getmark' which */
    /* returns either the next mark or   */
    /* -1 to indicate the end            */

    while ((mark=getmark()) != -1)
        {
          s=mark/20;
          if ( (s>=0) && (s<5) ) grades[s]++;
        }
```

There are several points of interest in this example. First note that the explicit constant 5, the number of elements in the array, appears three times in the program text. A symbolic name should be 'defined' to have this value, thus making a change in array size easy to accommodate. Secondly, note that the array elements are zeroised using the pointer 'gptr', and finally note that the increment operator can be used on an array element just as on any other variable.

ARRAYS OF MORE THAN ONE DIMENSION

C allows us to use arrays of more than one dimension. Imagine that instead of simply printing letters in a 7*5 grid, as we did in the early examples of chapter 2, we wish to store these representations of characters in a 7*5 array, that is, an array with 7 rows and 5 columns. If we wish to access these elements using a pointer, then it is essential to appreciate that in C arrays are stored by row.

first three rows of big I



This means that the rightmost of the two subscripts changes more quickly because elements are accessed in the order that they are stored. A two-dimensional array can easily be visualised as a table, and therefore we shall initially use subscripts, rather than a pointer, to access the elements (example 7.3). We shall later rethink this approach.

Example 7.3

```
#define ROWMAX 7
#define COLMAX 5

char letter[ROWMAX][COLMAX];
int  col;

    /* fill array with spaces */

for (row=0; row<ROWMAX; row++)
    for (col=0; col<COLMAX; col++) letter[row][col]=' ';

    /* alternatively we could write .. */

for (row=0; row<ROWMAX; row++)
    for (col=0; col<COLMAX; letter[row][col++]=' ');
```

Observe that each subscript is enclosed by square brackets and that the final *for* statement does not have a statement to control. This is because each element of 'letter' can be set to a space in such a way that the column subscript is incremented after it has been used to access the array element. This is an occasion where use of

++col rather than col++

would not have the required effect.

ARRAYS AS PARAMETERS

Pursuing our example a little further, for those upper case letters of the alphabet that can be constructed from horizontal and vertical lines only, it would be convenient to have functions that fill a row, or a column, with a given character. The functions of example 7.4 fulfil this task.

Example 7.4

```
/*                NB                    */
/* the following defines are assumed */

#define ROWMAX 7
#define COLMAX 5

fillrow(row, matrix)
    int row;
    char matrix[ROWMAX][COLMAX];
    { int c;

      for (c=0; c<COLMAX; matrix[row][c++]='*');
    }

fillcol(col, matrix)
    int col;
    char matrix[][COLMAX];
    { int r;

      for (r=0; r<ROWMAX; matrix[r++][col]='*');
    }

[ style 53.5 ]
```

Each of the functions must change the contents of the array and, as we saw in chapter 2, must therefore have access to the address of the data item to be changed.

But since the array name is the address of the first element, it can be used without modification as a parameter to a function. The functions of example 7.4 will access the contents of the array that is the actual parameter, and it should therefore be obvious that the purpose of the line

```
char matrix[ROWMAX][COLMAX];
```

in each function is simply to establish the type of the formal parameter 'matrix'. No storage allocation is performed. It may not be necessary, but it is not wrong, to give the size of each dimension. Given that arrays are stored in row-major order, the size in the first dimension may be omitted, as it has been in the function *fillcol* of example 7.4.

It should be apparent that the functions of 7.4 also make use of what we called implicit parameters in chapter 2. *fillrow* uses 'COLMAX' which, although its definition is a *define* statement, could as easily have been, say, a static variable of the file containing the functions. The functions are not 'self-contained' in the sense that the identifiers that they use do not all derive from either the parameter list or the local variable declarations. This is a common occurrence but worth emphasising. Assuming the definitions of 7.3 and 7.4 we can write

```
makeH(mat)
    char mat[ROWMAX][COLMAX];
    {
      fillcol(0, mat);
      fillcol(COLMAX, mat);
      fillrow(3, mat);
    }
```

and thereafter write

```
makeH(letter);
```

STRINGS

In the preceding section we used an array of characters and, because of the particular example chosen, all elements of the array were always used. But when we wish to deal with strings, which are stored as an array of characters, it is inefficient to assume that the string will occupy all elements of the array in which it is stored. We must expect that either the length of the string is stored along with it, or that the end of a string is denoted by a special character. C adopts the convention that the end of a string is denoted by the NULL character '\0'.

Example 7.5

```
#define WIDTH 80

char mess[WIDTH], *m;

mess[0]='h';
mess[1]='e';
mess[2]='l';
mess[3]='l';
mess[4]='o';
mess[5]='\0';
```

The rather laboured statements of example 7.5 cause six characters to be stored in 'mess'. Since the last character is NULL we can say that the array 'mess' holds a string. The string may be printed by any of the following statements.

```
    /* assume the assignment m=mess */
    /*      for each alternative     */

while (*m != NULL) putchar(*m++);

while ( ((m-mess) < WIDTH) && (*m != NULL)) putchar(*m++);

printf("%s\n", m);
```

The tedious parts of the above examples are those that deal with individual characters. While this may sometimes be necessary, we more usually wish to process the string as a whole. We have been accustomed to writing a string as a sequence of characters between double quotes thus

```
" C-ing is believing "
```

It is therefore not unreasonable to expect that we may assign a string to an identifier without the necessity of doing it character by character. We achieve this as follows

```
char *sptr;
    sptr=" C-ing is believing ";
```

From its declaration 'sptr' is a pointer to a character. In particular, after assignment, 'sptr' points to the first character of the string. It is important to note that the assignment does not copy the character string. The declaration of 'sptr' offers no storage space for characters. The string is stored somewhere, we know not where, except that we have in 'sptr' a pointer to the first character. This is usually sufficient. If, for some reason, it is necessary to copy the string into local storage, then this must be done with a function such as *strcpy* which copies a string from one storage place to another. In example 7.5 when storing one character at a time in 'mess' we were responsible for ensuring that a NULL character followed the last useful character. When, as above, a string is assigned to a pointer, a NULL is automatically appended to the character sequence. Use of pointers to refer to a string is much the most common and convenient way of dealing with strings in C. Any functions provided by a C implementation to help process strings, compare strings, find the length of a string, find a character within a string, will require the user to pass pointers as parameters.

Those functions in RatC that access and use the symbol tables of necessity process strings. *addglb*, *addloc*, and *addmac*, are responsible for adding global symbols, local symbols, and macro symbols, respectively, to the appropriate tables. The organisation of the tables is simple rather than efficient and the functions *findglb*, *findloc*, and *findmac*, find symbols in the respective tables by means of a linear scan through all names in the table. The functions *streq*, *astreq*, *match*, and *amatch*, also deal with strings. String comparison is done by *streq*, and *match*, while the variants *astreq*, and *amatch* compare strings over a given number of characters.

ARRAYS OF POINTERS

A program that was designed to report a variety of error messages to its user might use the approach given in example 7.6.

Example 7.6

```
char *error[30];

/* error is an array of 30 pointers to char */

error[0]="not enough arguments";
error[1]="too many arguments";
error[2]="invalid argument";

/* etc., etc. */

/* to report error number `i' */

printf("*** %s ***\n", error[i]);
```

The patterns of asterisks held in 7*5 arrays of characters, while not especially useful, are easily visualised. Imagine therefore, that we wish to construct, and store in this form, representations of all upper case letters of the alphabet. If lptr[$i-1$] is to point to the representation of the ith letter, then we need the declaration

```
char (*lptr[26])[7][5];
```

This declaration says that 'lptr' is a 26 element array of pointers. The pointers point to 7*5 arrays of characters. If we wish to associate the eighth pointer with the eighth letter of the alphabet, H, we could do this easily by the statement

```
makeH(lptr[7]);
```

The preceding examples should have helped to clarify the way in which two-dimensional arrays can be used in C. But a moment's reflection will reveal that in order to store our upper case characters in this manner we would need storage space for 26*7*5 characters. Furthermore, each character needs to be placed in the correct element. This is certainly not making best use of the facilities available in C. Even in our earliest examples we recognised that it was worth having functions or *define* statements to deal with five stars, a middle star, and two end stars (example 2.3). Following this course we could set up strings as follows

```
char *allstars, *endstars, *midstars;

     allstars="*****";
     endstars="*   *";
     midstars="  *  ";
```

An array of seven elements, where each element is a pointer such as 'allstars', can now be used to represent a character composed of asterisks. Thus the character H can now be represented by seven pointers, six of which point to the same object.

```
makeH(sptr)
     char *sptr[ROWMAX];

     {
       sptr++=sptr++=sptr++=endstars;
       sptr++=allstars;
       sptr++=sptr++=sptr=endstars;
     }
```

We now need an array of 26 pointers in which each pointer points to an array of seven pointers which point to strings. This is obtained with the declaration

```
char (*lptr[ROWMAX])[26];
```

The call to our new version of *makeH* defined above would be

```
makeH(lptr[7]);
```

The advantage of rethinking our example, or rather the way to express it in C, has been that we have eliminated the need to assign characters to individual array elements. We now assign strings to pointers. Further, our storage requirement is considerably reduced as we store only one copy of each string (row) of characters. Each 'big' character can be represented by seven pointers and we need twenty-six such characters. We therefore save ourselves writing effort, storage space, and run time, by thinking about our task in a way which enables us to take full advantage of the facilities offered by C.

It is important, and useful, to be thoroughly familiar with the handling of strings and pointers in C. The next example, which is complete, should help to consolidate the work on strings.

Example 7.7

```
/* Soundex code generator: to transform a string */
/* into a code that tends to bring together all  */
/* variants of the sàme name (usually surname).  */
/*     -  (Knuth, 1973)                          */

main()
    { char    str[20];

      printf("\nCharacter string ? ");         /* ask user ..      */
      scanf("%s",str);                         /* for a string     */

      encode(str);                             /* encode all but   */
                                               /* the first char   */

      dumpdups(str);                           /* erase adjacent   */
                                               /* duplicate codes  */

      dumpzeros(str);                          /* erase zero codes */

      fixup(str);                              /* pad or truncate  */
                                               /* to four digits   */

      printf("\nSoundex code is  : %s\n",str);       /* tell user */
    }


encode(s)
    char    *s;
    { static char code[]="01230120022455012623010202";

      while (*++s) *s=code[*s-'a'];
    }
```

```
dumpdups(s)
    char    *s;
    { char    *t;

      while (*s)
          if (*s==*(s+1))
              { t=s+1; while (*t= *(t+1)) t++; }
          else s++;
    }

dumpzeros(s)
    char    *s;
    { char    *t;

      while (*s)
          if (*s=='0')
              { t=s; while (*t= *(t+1)) t++; }
          else s++;
    }

fixup(s)
    char    *s;
    { int     i;

      for (i=1; *++s && i<4; i++);
      for ( ; i<4; i++) *s++ ='0';
      *s=(char)0;
    }

[ style 55.7 ]
```

In example 7.7 only one copy of the string exists. The functions are given a pointer to this copy and may modify the string. The string is obtained from a call to *scanf* which we have not so far used in the examples on strings. Note that *encode* initialises the array 'code' at its declaration with one digit for each letter of the alphabet. Both *dumpdups* and *dumpzeros* use the expression *t=*(t+1) in a *while* statement to eliminate adjacent identical characters, while *fixup* capitalises upon the flexibility of the *for* statement.

SUMMARY

The availability of arrays has clearly made a significant difference to the ease with which we can express our tasks in C. Pointers, together with arrays, provide us with easy-to-use and economical programming aids. C does not limit us to arrays as a way of storing data items with a collective name. We are also able to use structures, which enable us to group together data items of differing types – this is the subject of the next chaper. Pointers too have a wider role to play than we have thus far indicated, and we will return to them in a later chapter.

The elements of C that we have covered so far constitute a 'basic set'. It is perfectly possible to write meaningful C programs armed with only that knowledge – indeed, the RatC compiler is written using just those features. The remaining chapters deal with more advanced topics, without which your C armoury would be incomplete.

8 More Data Types

So far, all data types of identifiers have been simple: they consist of one elementary type. The elementary types are

(char)	characters
(int)	integers
(float)	floating point

Chars and *ints* can be either signed or unsigned, and *ints* and *floats* can have modifiers short or long. A 'long float' is referred to as a 'double'. Unless otherwise explicitly stated in a declaration, the default type is *int*.

If these were the only data types the C language could represent, many problems would be much more difficult to express than they should be. Part of the great flexibility of C is that the language provides a way to combine elementary types together into new derived types called structures and unions.

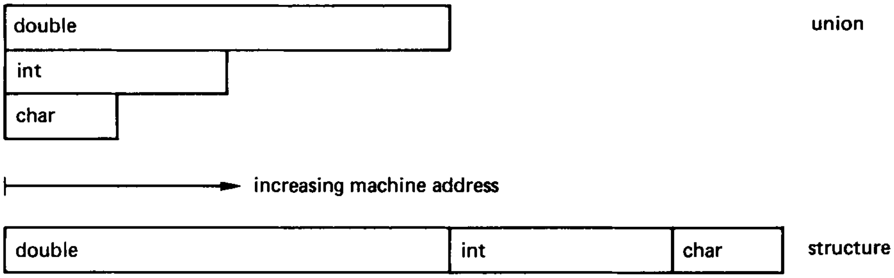
STRUCTURES AND UNIONS

When we combine types, we can do it in one of two ways: we can either lay them end to end so that none of them overlaps and each of them contains independent values, or we can overlay them on top of each other, so that they all start at the same machine storage location and overlap.

If we lay the types next to each other so that none of them overlaps, we create a structure – a type which is the concatenation of the individual member elementary types. Each of the variables starts at a different storage location, one after the other in a series. Therefore, the length of a structure is at least as much as the sum of the lengths of its members. Some compilers insert space in between members of a structure in order to enforce data type address alignment restrictions of the hardware. As a result, the length of a structure may be more than the sum of the lengths of its members because of 'holes' in the structure form.

If we overlay types on top of each other, we create a union – a type which is the union of the individual member elementary types. The same memory storage area is accessed by all of the variables within the union. Since each of the variables starts at the same location, the length of the union is the length of the longest member.

Pictorially, we can represent the distinction between structures and unions as



If we assume that the size of a char is 1 byte, of an int is 2 bytes, and of a double is 4 bytes, then the size of the union is 4 bytes, while the size of the structure is 7 bytes.

Structures are used to group together related data so that it becomes more manageable. Consider, as an example, a date. We can represent the date by three numbers: the month of the year, the day of the month, and the year. By grouping these together, we can create a new type

```
struct date_type {
    short int month;        /* Month of year - 1 --> 12 */
    short int day;          /* Day of month - 1 --> 31 */
    short int year;         /* Year */
};
```

The above statement declares a derived type (*struct* date_type) and its form, that is, what its members are. The identifier date_type is called the structure tag or template name; the compiler will know what a '*struct* date_type' is at any point after this declaration.

No storage is allocated by the above statement, however. The template name before the left curly bracket is used only to identify the form of the structure so that it can be referenced more easily afterwards. To create an instance of this new type to hold a birth date, an identifier is placed after the right curly bracket

```
struct date_type {
    short int month;
    short int day;
    short int year;
} birth;                        /* Date of birth */
```

or better still

```
struct date_type birth;        /* Date of birth */
```

assuming that the template declaration has already been made.

Structures and unions nest; that is, they can be embedded within other structures and unions. Arrays can also be put inside structures or unions. So, if we were interested in storing information about a person, we might create a structure

```
struct person_type {
    char name[NAMESIZE];        /* Name of person */
    struct date_type birth;     /* Date of birth */
    struct date_type death;     /* Date of death */
};
```

We can even create arrays of structures, so that this information about everyone in a group could be stored by declaring

```
struct person_type brits[UK_POPULATION];
```

Unions of all types can be created in a similar fashion. This facility to group data into a new type makes it easier to manage, and thus reduces the complexity of the programming task.

As an example of a union, consider a piece of storage which will sometimes hold an *int*, and at other times a *double*. The declaration for such a union would be written

```
union int_double {
    int i;
    double d;
};
```

ACCESSING STRUCTURES AND UNIONS

Only two things can be done with structures and unions: a member can be accessed, or the address can be taken with the & operator. For the previously declared structure *birth*

```
birth.day
```

represents the member identified by day, and

```
&birth
```

represents the address of that structure. If *pbirth* is declared as a pointer to a date_type structure and then initialised

```
struct date_type *pbirth = &birth;
```

then the day member from such a pointer is accessed with the pointer operator

```
pbirth->day
```

When accessing a member of a structure directly, the dot operator is used; for indirect access from a pointer to a structure, the pointer operator is used.

The name of the person in the first element of the array of structures *brits* declared above is accessed

```
brits[0].name
```

which is an array of characters holding the person's name. Note that this is distinct from the first character of the name, which would be accessed as

```
brits[0].name[0]
```

To give a structure initial values at compile time, it can be declared with them

```
struct person_type henry_viii = {
    "Henry VIII",           /* Name */
    { 6, 28, 1491 },        /* Born June 28, 1491 */
    { 1, 28, 1547 }         /* Died January 28, 1547 */
};
```

Using the dot and pointer operators to access members works with nested structures, so that

```
henry_viii.birth.year
```

would have the value 1491.

Newer compilers understand structure arguments and assignments. That is, structures can be passed as arguments to functions, and are valid as return values from functions. In addition, structure assignment allows the programmer to assign structures of the same type, so that all members are copied in one expression.

ENUMERATIONS

Still another method for creating new types is available with the C language. In an enumerated type, a variable can take on one of a finite set of values which are listed at the place where the type is declared. If we create a type to model the five flavours of ice cream available at a certain store, we could say

```
enum flavour_type {
    CHOCOLATE,
    VANILLA,
    STRAWBERRY,
    COFFEE,
    RASPBERRY
};
```

Thereafter, a variable of type *flavour_type* can take on any of the values enumerated. The values are treated like constants and can be used anywhere constants can be used. Thus

```
enum flavour_type flavour = CHOCOLATE;
```

would create a variable named *flavour*, and give it an initial value of CHOCOLATE.

In our previous example, we could modify the person_type structure to include information about the sex of a person. Since the sex of most people is only one of two possible values, we can define an enumerated type to represent it

```
struct person_type {
    char name[NAMESIZE];          /* Name of person */
    enum sex_type {
        MALE,
        FEMALE
    } sex;                        /* Sex */
    struct date_type birth;       /* Date of birth */
    struct date_type death;       /* Date of death */
};
```

To demonstrate the use of *enum* types, we could write a routine which would recognise an argument of a string of characters as being either 'MALE' or 'FEMALE', and then return the appropriate *enum* value

```
enum sex_type
get_sex (str)
char *str;
{
        return (strcmp (str, "MALE") ? FEMALE : MALE);
}
```

The above routine uses the C library function *strcmp,* which compares two character arrays, and returns an integer which is less than, equal to, or greater than 0 according to whether the first argument is lexicographically less than, equal to, or greater than the second.

BIT FIELDS

There are times when it becomes necessary to pack several pieces of information into the storage that would normally be occupied by a single variable. Such circumstances can occur when manipulating huge amounts of data, or when dealing with boolean values or flags. For these occasions, C provides us with a way to indicate how many bits should be assigned for each variable. When we access one of these fields, the compiler will isolate the correct bits and allow us to manipulate the field as though it was stored as a separate variable. For example, if we wanted to save space and squeeze the date structure so it occupied as little machine storage as possible, we could define it as

```
struct {
    unsigned month : 4;
    unsigned day : 5;
    unsigned year : 11;
} short_date;
```

Since the month of the year can only be a number between 1 and 12, we need only 4 bits to represent it; the day can only be between 1 and 31 (5 bits required), and we can let the year be represented by 11 bits (allows us up to the year 2047). Thus, short_date occupies only 20 bits, instead of the 48 bits it would take if the month, day, and year were each 16 bits (*int*).

There are several restrictions on the use of bit fields – all variables are necessarily unsigned, and there are no arrays of fields. Also, because they might not begin on a byte or word boundary, they have no address, so the & operator cannot be applied to them.

As the cost of memory continues to decline, it seems that bit fields will be most useful in those cases when compact representation of data is paramount.

VOID

An additional type, 'void', is available to describe those objects which have no value. This is useful for declaring functions that return no value, or casting expressions which generate values that are to be discarded. As an example, the function *exit*, which does not return to the calling routine after it is invoked, could be declared

```
void exit ();
```

A void expression denotes a non-existent value and, as such, can only be used as an expression statement, or as the left operand of a comma expression.

TYPEDEF

In C, it is possible to use a short-hand notation to describe fundamental or derived types. A declaration using *typedef* defines synonyms for the indicated type. For example, we could define the data_type structure previously mentioned in this chapter as a *typedef* called DATE in the following manner

```
typedef struct {
    short int month;        /* Month of year - 1 -> 12 */
    short int day;          /* Day of month - 1 -> 31 */
    short int year;         /* Year */
} DATE;
```

After this declaration, the compiler will understand the use of DATE as a reference to the above structure template. It is important to note that no new types are generated; the use of *typedef* is just a short-hand for an existing type. The semantics are exactly the same for *typedef* variables as for variables whose definitions are written out the long way. *Typedefs* can be used to declare synonyms for unions, enums and fundamental data types in exactly the same way.

Arrays, functions and pointers can be used in *typedef* declarations as well. The declaration

```
typedef int ARRAY_DATE[3];
```

allows the definition of a variable

```
ARRAY_DATE date;
```

which is an array of three *ints*. If we wanted to have a synonym for a pointer to a DATE structure, we could write

```
typedef DATE *PDATE;
```

Thus, PDATE would be a pointer to a DATE structure.

SUMMARY

The object of the game in programming is to reduce the complexity of problems to a form where the solution is readily understandable to both the writer and the reader. Derived data types afford us the luxury of defining arbitrarily complex aggregates so that we can group variables together in some logical fashion, where it is sensible to do so. This principle of data abstraction allows us to concentrate on the fundamental ideas of the problem, rather than on the details of its implementation. Without derived data types, it would be impossible to implement the data structures that are required to solve complicated problems. The next chapter deals with the development of these data structures.

9 Pointers Revisited

Our use of pointers so far has been largely restricted to the processing of character strings. In this chapter we will explore much more imaginative uses of this very powerful feature of C. In particular, we will need pointers to simplify the handling of the data structures that are typical of more complex programs.

The data structures used by RatC are of necessity very simple – RatC does not support derived data types (such as structures) which would make the task of the compiler writer so much easier.

Choosing the right data structure to contain the data that the program will manipulate is at least as important as choosing the right algorithm and, in many cases, a poor choice of data structure will lead to a clumsy program.

POINTERS TO STRUCTURES

Given an array of structures of the kind

```
typedef struct {
        int a;
        char b;
        float c;
} STRUCT;

STRUCT array[10];
```

we have two methods of stepping through the array, examining the individual elements. One way we are already familiar with – using subscripts, so that *array[i]* refers to the (i+1)th element (because the first element is subscript 0). The other way is to use a pointer

```
STRUCT *p;
for (i = 0, p = array; i < 10; i++, p++)
    printf ("array[%d] %d %c %f\n", i, p->a, p->b, p->c);
```

Note that when we say 'i++' we mean 'add 1 to i', but when we say 'p++' we mean 'add enough to p to make it point to the next element', and this is precisely what C does. Pointer arithmetic takes account of the underlying type, so that 'p++' means something different if p is a pointer to *char* – in that case, since the underlying type is one byte, p is actually incremented by 1.

It is for this reason that the expressions A[I] and *(A+I) are functionally equivalent, regardless of the type of A.

ALLOCATION OF STORAGE

If we wanted to read lines of text from a file and store them internally for subsequent processing, one way that we could do it is to declare an array of fifty 132-character lines, and read the data into it. The problem with this is that we do not know how many lines there will be, or how long they are. As long as the lines are less than 132 characters, and as long as there are less than 50 lines, then the program will work, even though we may have reserved much more space than we actually need (suppose we only have two 10-character lines!).

We can use space much more economically, and eliminate the restriction on the number of lines we can read in, by allocating space dynamically, as shown in example 9.1.

Example 9.1

```
/* Maximum length of input line */

#define        LINESIZE        132

/* Error handling macro */

#define ERROR(msg)    { fprintf (stderr, "%s\n", msg); exit(1); }

/* Linked list structure */

typedef struct list {
    char text[LINESIZE];
    struct list *next;
} LIST;

LIST *lines = NULL,            /* Pointer to the head of the list */
     *this_line = NULL,        /* Pointer to the current element */
```

```
    *new_line;                    /* Pointer to a new element */

int eof = 0;                      /* End of file flag */

while (!eof)
   {
     /* Allocate space for a new line */

     if (!(new_line = (LIST *) malloc (sizeof(LIST))))
         ERROR ("Memory exhausted");
/* Initialise next pointer */

new_line->next = (LIST *) NULL;

/* Read in the next line */

if (!gets (new_line->text))
    eof = 1;
else

/* If this is the first line, set head and current pointer to it */

if (!lines)
    lines = this_line = new_line;

/* Otherwise, link current line to new one and advance current line */

else
    this_line = this_line->next = new_line;
}
```

[style 78.0]

Here we have generated a 'linked list' data structure, where each element in the structure, as well as containing the data, has a pointer to the next element in the list. Thus, we finish up with exactly as many elements as there are lines in the input – no more, no less. We could print out the text afterwards by

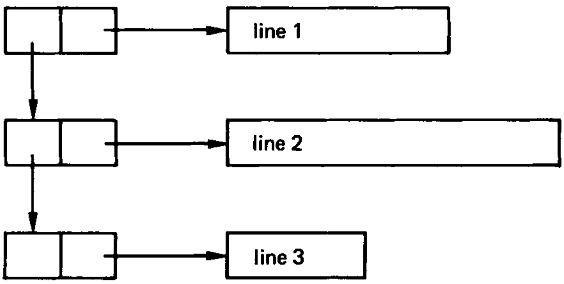
```
for (this_line = lines; this_line; this_line = this_line->next)
    printf ("%s\n" , this_line->text);
```

When allocating space dynamically in this way, it is important to remember that we need to de-allocate, or free, the space at some time. This will be done automatically when the program exits, but if space limitations require that you free the space before then (if, for example, you wish to re-use the space for other purposes), it can be freed by

```
LIST *next_line;

while (lines)
    {
      next_line = lines->next;
      free (lines);
      lines = next_line;
    }
```

and this will leave the variable *lines* set to a NULL value, so that, if used inadvertently, it will not pick up garbage data.

Of course, we have still potentially allocated more space than we need, since each line reserves 132 characters, regardless of its actual length. A better structure would be one that looked like



which would be declared as

```
typedef struct list {
        char *text;
        struct list *next;
} LIST;
```

and we would have to allocate storage for both the list element and for the data, as shown in example 9.2.

Example 9.2

```
/* Maximum line size */

#define BUFSIZE 2048

char data[BUFSIZE];

while (!eof)
    {
      if (!(new_line = (LIST *) malloc (sizeof(LIST))))
          ERROR ("Memory exhausted");

      new_line->next = (LIST *) NULL;
      if (!gets (data))
          eof = 1;
      else
          {

            /* Allocate enough space for this line */

            if (!(new_line->text = (char *) malloc (strlen(data)+1)))
                ERROR ("Memory exhausted");

            /* Copy the line read in */
```

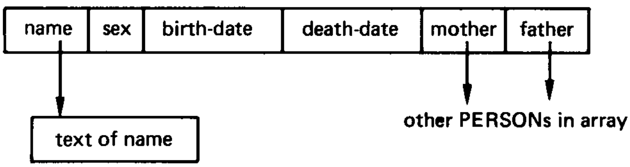
```
strcpy (new_line->text, data);


if (!lines)
                lines = this_line = new_line;
            else
                this_line = this_line->next = new_line;
          }
    }



[ style 64.8 ]
```

Now we are allocating exactly the amount of storage required. Note also that the limit on line length is only that it be less than 2048 characters!

COMPLEX DATA STRUCTURES

As an example of a more complex data structure, consider the program of example 9.3, together with its header file in example 9.4. This program constructs a family tree from input data, and prints out the pedigree chart of a named individual.

The principal data structure is an array of elements of type PERSON, which looks like



The dates of birth and death are themselves structures, nested within the PERSON structure.

Example 9.3

```
#include <stdio.h>
#include "family.h"

/* Maximum number of people in input data */

#define MAXPEOPLE     64

/* Error handling macro */
```

```
#define ERROR(msg,data)        \
  { fprintf (stderr,"%s%s\n",msg, data); exit (1); }

/* Array for data structure */

static PERSON people[MAXPEOPLE+1];

/* Pointer to output image area */
static char *space;

/* Months of year */

static char *month[MONTHS] =
    { "JANUARY",   "FEBRUARY",  "MARCH",     "APRIL",
      "MAY",       "JUNE",      "JULY",      "AUGUST",
      "SEPTEMBER", "OCTOBER",   "NOVEMBER",  "DECEMBER" };

/* Global variables */

static int curr_level = 0;
static int max_level = 0;
static int totrows, totcols;

main (argc, argv)
int argc;
char *argv[];
    { char line[LINESIZE];        /* Input line */
      register int i;             /* General purpose counter */
      register PERSON *p;         /* Pointer to data structure */

      /* Arguments can be passed in on the command line as :
                command arg1 arg2 ...
         where argc is the argument count (including the command
         name), and argv[i] are the arguments (argv[0] is the
         command itself, argv[1] is the first argument, etc.) */

      if (argc != 2)
          ERROR ("Usage: ftree <name>", "");

      /* Initialise the data structure */

      for (i = 0; i <= MAXPEOPLE; people[i++].name = NULL)
          ;

/* Input lines consist of fields separated by "tokens"
   from SEPSTRING. Read in each line, extracting the
   fields and entering them into the data structure.
   Ignore lines beginning with "*" (comments). */

while (gets (line))
    {
      if (line[0] == '*')
          continue;
      p = get_name (strtok (line, SEPSTRING));
      p->sex = get_sex (strtok (NULL, SEPSTRING));
      p->birth = get_date (strtok (NULL, SEPSTRING));
      p->death = get_date (strtok (NULL, SEPSTRING));
      p->father = get_name (strtok (NULL, SEPSTRING));
      p->mother = get_name (strtok (NULL, SEPSTRING));
    }

/* Find out how big the tree will be .. */

get_level (p = get_name (argv[1]));
totrows = (5 * power (2, max_level) - 1);
totcols = (max_level + 1) * COLPLEV;
```

```
      /* ... and allocate space for the output */

      if (!(space = malloc ((unsigned) (totrows * totcols))))
          ERROR ("Memory exhausted", "");

      /* Initialise the output area with spaces using the library
         function memset */

      memset (space, (int) ' ', totrows * totcols);

      /* Generate the output image ... */

      drawtree (p, 0, 1);
      vlines ();

      /* ... print it ... */

      printtree ();

      /* ... and exit */

      exit (0);
    }

/**
 *  Find the person indicated by the supplied name in the
 *  'people' array. If the person is currently non-existent,
 *  insert them into the array. Return a pointer to the person
 *  if successful, otherwise terminate with an error message.
**/

PERSON *
get_name (str)
register char *str;             /* Name of person */
    { register PERSON *p;       /* Data structure pointer */
      static DATE zero_date = { 0, 0, 0 }; /* Date */
     /* '-' means unknown */

     if (!strcmp (str, "-"))
         return (PERSON * ) 0;

     /* Search the array for a matching name */

     for (p = people; p->name && strcmp (p->name, str); p++)
         ;

     /* If found, return the pointer ... */

     if (p->name)
         return p;

     /* ... otherwise make sure there's enough room ... */

     if (p >= &people[MAXPEOPLE])
         ERROR ("Too many people", "");

     /* ... add them to the end ... */

     if (!(p->name = malloc ((unsigned) strlen (str) + 1)))
         ERROR ("Memory exhausted", "");
     strcpy (p->name, str);
     p->birth = p->death = zero_date;
     p->father = p->mother = (PERSON * ) 0;

     /* ... and return the pointer */
```

```
        return p;
      }

/**
 *  Determine sex.
**/

enum sex_type
get_sex (str)
register char *str;           /* Sex from input line */
      {
        /* Convert to upper case */

        strupcase (str, str);

        /* Should be either MALE or FEMALE */

        return (strcmp (str, "MALE") ? FEMALE : MALE);
      }

/**
 *  Convert src to upper case in dest (toupper is a library
 *  function that converts [a-z] to [A-Z], and leaves all other
 *  characters untouched).
**/

strupcase (dest, src)
register char *dest, *src;   /* Destination and source strings */
      {
        while (*dest++ = toupper (*src++))
            ;
      }
/**
 *  Generate the family tree in the output image by drawing this
 *  person, and then the family trees of their mother and father.
 *  The recursion stops when we run out of parents.
**/

drawtree (p, level, offset)
PERSON *p;
int level, offset;
      { PERSON * mom, *dad;

        /* Draw this person */

        drawperson (p, rowloc (level, offset), level * COLPLEV + 1);

        /* Draw father's family tree */

        for (dad = people; dad->name && dad != p->father; dad++)
            ;
        if (dad->name)
            drawtree (dad, level + 1, offset * 2 - 1);

        /* Draw mother's family tree */

        for (mom = people; mom->name && mom != p->mother; mom++)
            ;
        if (mom->name)
            drawtree (mom, level + 1, offset * 2);
      }

/**
 *  Print date.
**/

 char    *
put_date (date)
DATE date;                   /* Date to be printed */
```

```
    { static char words[25];    /* Buffer for date in words */

      sprintf (words, "%s %d, %d", month[date.month - 1],
        date.day, date.year);
      return words;
    }

/**
 *  Draw a person in the output image, complete with name and dates
 *  of birth and death.
**/

drawperson (p, row, col)
PERSON *p;                          /* Person to be drawn */
int row, col;                       /* Where to draw */
    { char *d;                      /* Date buffer */

      /* Copy in name (memcpy is a library function which copies
         data from its second parameter to its first for a length
         in bytes of its third parameter) ... */

      memcpy (pixel(row, col + 1), p->name, strlen (p->name));
      memcpy (pixel(row + 1, col), NAMELINE,
        sizeof(NAMELINE) - 1);
      /* ... and birth date, if it exists ... */
      if (p->birth.year)
          {
            memcpy (pixel(row + 2, col), " Born", 5);
            d = put_date (p->birth);
            memcpy (pixel(row + 2, col + 6), d, strlen (d));
          }

      /* ... and date of death */

      if (p->death.year)
          {
            memcpy (pixel(row + 3, col), " Died", 5);
            d = put_date (p->death);
            memcpy (pixel(row + 3, col + 6), d, strlen (d));
          }
    }

/**
 *  Print the output image.
**/

printtree ()
    { int i;

      for (i = 0; i < totrows; i++)
          printf ("%.*s\n", totcols, pixel(i + 1, 1));
    }

/**
 *  Put vertical lines into output image.
**/

vlines ()
    { register int i, j, k;

      for (i = 1; i <= max_level; i++)
          for (j = 1; j < power (2, i); j += 2)
              for (k = rowloc (i, j) + 1;
                k <= rowloc (i, j + 1) + 1; k++)
                  *(pixel(k, i * COLPLEV + 1)) = '|';
    }
```

```
/**
 *  Convert str to a date. Terminate with a message on error.
**/

DATE
get_date (str)
register char *str;            /* Date from input line */
    { char *ptr;               /* String pointer */
      register int i;          /* Month counter */
      DATE date;               /* Converted date */

      /* '-' means unknown */

      if (!strcmp (str, "-"))
          date.month = date.day = date.year = 0;

      /* Convert str to DATE format */

      else
          {
            strupcase (str, str);
            for (i = 0; i < MONTHS; i++)
                if (!strncmp (str, month[i], strlen (month[i])))
                    break;
            if (i >= MONTHS)
                ERROR ("Invalid date ", str);
            date.month = i + 1;

            /* strtol is a library function that returns the long
               integer corresponding to the string in the first
               argument according to the number base in the third
               argument.  Leading white space is ignored. If the
               second argument is not NULL, it will contain the
               address of the first non-digit character which
               terminates the conversion. */

            date.day = (short int)
              strtol (str + strlen (month[i]), &ptr, 10);
            date.year = (short int)
              strtol (ptr + 1, (char **) 0, 10);
          }
      return date;
    }

/**
 *  Find out how many generations have to be printed.  This
 *  function operates recursively by determining the number of
 *  generations above this one on both the mother's and father's
 *  side - the number of generations to be printed is the maximum
 *  of these numbers.
**/

get_level (p)
PERSON *p;                     /* Name of person */
    { PERSON * dad, *mom;      /* Pointer to mother & father */

      /* Find father */

      for (dad = people; dad->name && dad != p->father; dad++)
          ;

      /* Find out how many generations above him */

      if (dad->name)
          {
            curr_level++;
```

```
            max_level = max(max_level, curr_level);
            get_level (dad);
            curr_level--;
          }

      /* Find mother */

      for (mom = people; mom->name && mom != p->mother; mom++)
          ;

      /* Find out how many generations above her */

      if (mom->name)
          {
            curr_level++;
            max_level = max(max_level, curr_level);
            get_level (mom);
            curr_level--;
          }
    }

/**
 *  C does not have an exponentiation operator - this function
 *  simulates it.
**/

power (base, exp)
register int base, exp;
    { register int i, result;

      result = 1;
      for (i = 0; i < exp; i++)
          result *= base;
      return result;
    }

/**
 *  Find the row position in the output image for this generation.
**/

rowloc (level, offset)
int level, offset;
    {
      if (level == max_level)
          return (offset * 5 - 4);
      if (level == max_level - 1)
          return (offset * 10 - 6);
      return (rowloc (level + 1, offset * 2) +
              rowloc (level + 1, offset * 2 - 1)) / 2;
    }

      /* ... and birth date, if it exists ... */
      if (p->birth.year)
          {
            memcpy (pixel(row + 2, col), " Born", 5);
            d = put_date (p->birth);
            memcpy (pixel(row + 2, col + 6), d, strlen (d));
          }

      /* ... and date of death */

      if (p->death.year)
          {
            memcpy (pixel(row + 3, col), " Died", 5);
            d = put_date (p->death);
            memcpy (pixel(row + 3, col + 6), d, strlen (d));
```

```
            }
        }

/**
 *  Print the output image.
**/

printtree ()
    { int i;

      for (i = 0; i < totrows; i++)
          printf ("%.*s\n", totcols, pixel(i + 1, 1));
    }

/**
 *  Put vertical lines into output image.
**/

vlines ()
    { register int i, j, k;

      for (i = 1; i <= max_level; i++)
          for (j = 1; j < power (2, i); j += 2)
              for (k = rowloc (i, j) + 1;
                k <= rowloc (i, j + 1) + 1; k++)
                  *(pixel(k, i * COLPLEV + 1)) = '|';
    }


[ style 83.8 ]
```

Example 9.4

```
typedef struct {
    short int month;              /* Month of year: 1 -> 12   */
    short int day;                /* Day of month: 1 -> 31    */
    short int year;               /* Year: 1 -> 1987          */
} DATE;

typedef struct person {
    char *name;                   /* Name of person           */
    enum sex_type {
        MALE,
        FEMALE
    } sex;                        /* Sex                      */
    DATE birth;                   /* Date of birth            */
    DATE death;                   /* Date of death
                                     (0 year ==> still alive) */
    struct person *mother;        /* Pointer to mother        */
    struct person *father;        /* Pointer to father        */
} PERSON;

/* Maximum length of an input line */
#define LINESIZE      128

/* Valid separators between fields in input line */
#define SEPSTRING     ":\n"

/* Width of one output column */
#define COLPLEV               25

/* Months in a year */
#define MONTHS                12
```

```
/* Maximum width of a name */
#define NAMELINE       "-------------------------"

/* Define NULL if it isn't defined already */
#ifndef NULL
#define NULL           ((char *) 0)
#endif

/* Maximum value of x and y */
#define max(x,y)       ((x) > (y) ? (x) : (y))

/* Position in output array of row r column c */
#define pixel(r,c)     (space + ((r) - 1) * totcols + (c) - 1)

/* Function calls - since all functions not declared are assumed
   to return int, we must declare those that don't */
void exit ();
char *strtok (), *malloc (), *strcpy (), *memset (), *memcpy ();
long strtol ();
PERSON *get_name ();
DATE get_date ();
enum sex_type get_sex ();
```

Input to the program might look like

```
* Input for ftree.c program
* Family tree of Michael Soren
Michael Soren:male:August 18, 1958:-:Howard Soren:Toni Grossman
Toni Grossman:female:September 10, 1932:-:Abraham Grossman:Erna Salzberg
Howard Soren:male:May 11, 1930:-:Charles Sorkowitz:Minnie Sorkowitz
Abraham Grossman:male:February 24, 1894:April 14, 1966:Arie Zev Grossman:Mindl Weiser
Erna Salzberg:female:September 13, 1896:February 12, 1970:Jonah Mendel Salzberg:Chaya ?
Charles Sorkowitz:male:May 1, 1895:April 14, 1980:Harris Sorkowitz:Goldie Eglewitz
Minnie Sorkowitz:female:December 1, 1898:September 24, 1966:Nathan Sorkowitz:Etka Rachel Cohen
```

in which case the output for the pedigree chart of Michael Soren would look like

```
                                                                            Harris Sorkowitz
                                                                           |--------------------
                                                                           |
                                                   Charles Sorkowitz       |
                                                  |------------------------|
                                                  |Born MAY 1, 1895        |Goldie Eglewitz
                                                  |Died APRIL 14, 1980     |--------------------
                                                  |
                          Howard Soren            |
                         |------------------------|
                         |Born MAY 11, 1930       |                         Nathan Sorkowitz
                         |                        |                        |--------------------
                         |                        |                        |
                         |                        |Minnie Sorkowitz        |
                         |                        |------------------------|
                         |                         Born DECEMBER 1, 1898   |Etka Rachel Cohen
                         |                         Died SEPTEMBER 24, 1966 |--------------------
                         |
 Michael Soren           |
-------------------------|
 Born AUGUST 18, 1958    |                                                  Arie Zev Grossman
                         |                                                 |--------------------
                         |                                                 |
                         |                         Abraham Grossman        |
                         |                        |------------------------|
                         |                        |Born FEBRUARY 24, 1894  |Mindl Weiser
                         |                        |Died APRIL 14, 1966     |--------------------
                         |                        |
                         |Toni Grossman           |
                         |------------------------|
                          Born SEPTEMBER 10, 1932 |                         Jonah Mendel Salzberg
                                                  |                        |--------------------
                                                  |                        |
                                                  |Erna Salzberg           |
                                                  |------------------------|
                                                   Born SEPTEMBER 13, 1896 |Chaya ?
                                                   Died FEBRUARY 12, 1970  |--------------------
```

The program is commented well enough to be self-explanatory, but there are a number of features which are worthy of further explanation. Firstly, there are some 'standard' functions used, such as *memset* and *strtok*, which are part of a run-time library whose contents will depend on the particular installation (see appendix 5). The ones we have used are standard on Unix, but may be different in other implementations. In any case, the functions are mostly straightforward to duplicate.

Secondly, the mechanism for passing arguments into the program from the command line is demonstrated. In order that a program be as flexible as possible, it is important to parameterise it in the same way that you would parameterise any other function. In this case, the parameter is the name of the person whose pedigree chart is to be printed.

Thirdly, notice that the functions *get_level* and *drawtree* are recursive, which is a common feature of programs which manipulate data structures. Any one person's family tree consists of two sub-trees – the family trees of both person's mother and father. *Drawtree* utilises this fact to draw the person's family tree by drawing first the person, and then the family trees of the person's mother and father; *get_level* determines the number of generations to be printed, which is simply one more than the maximum of the number of generations in either the mother's or father's tree.

And finally, note how provision is made for the input data to contain comment lines – this simple feature allows commentary to be included within data files to explain, for example, what the data is, or how it is to be used.

SUMMARY

The theory and practice of data structures is a complicated topic, and one which is largely beyond the scope of this book. What we have presented is the basic tools – pointers, structures and dynamically allocated storage – which will allow you to generate arbitrarily complex data structures.

The thing to remember is that pointers are the equivalent in data structures of gotos in control structures. It is as easy to finish up with unruly data structures as it is to generate 'spaghetti code', and both are usually indicative of lack of forethought. The representation of data requires as much thought as the algorithm which manipulates it, and often the two are inextricably linked, in the sense that a poor design of either may cause the other to be unnecessarily complex and clumsy. The book *Algorithms + Data Structures = Programs* by Wirth (1976) is an excellent illustration of the way in which algorithms and data structures interact.

10 The C Preprocessor

We have already introduced the C preprocessor directives *#include* and *#define* for file inclusion and symbol definition capabilities. In this chapter, we expand the discussion to include the *#undef* directive, and the use of the conditional compilation directives *#if*, *#ifdef*, *#ifndef*, *#else* and *#endif*. In addition, parameters for the *#define* directive are introduced to yield a more powerful macro facility.

Note that the C preprocessor is not part of the compiler; it is a macro processor which is used prior to compilation to perform textual substitutions and file inclusion. It has no knowledge of C syntax, and could equally well be used to process text in any language, including natural language. The results of the processed text are passed to the C compiler for subsequent translation.

#define

#define is used to associate a symbol with a value

```
#define  ENTRIES  100
```

If the value changes, we need only change it in the place where it is declared. A definition may refer to previously defined symbols, as in

```
#define  ARRAYSIZE  (ENTRIES+1)
```

The parentheses surrounding the substitution string are not mere formality; if ARRAYSIZE is used in the following context

```
char array[ARRAYSIZE*4];
```

then omitting the parentheses would allocate an array of 104 bytes (100 + 1 * 4) instead of the intended 404 ((100 + 1) * 4).

In chapters 1 and 2, when we discussed the use of the *#define* directive to define constant text, we gave the example

```
#define  CLEAR  printf("\033Y")
```

to define the sequence necessary to clear the screen on a Lear Siegler ADM5.

#undef

To make the preprocessor forget its definition of CLEAR, we can write

```
#undef  CLEAR
```

and thereafter the preprocessor will leave all occurrences of CLEAR alone, passing it unsubstituted to the compiler.

CONDITIONAL COMPILATION

When we write programs, it is advantageous to try to write them in such a way so they are portable; that is, they can be moved to another machine of differing architecture or operating system without changing the source code. They should perform the same function on the new machine as they did on the old one, even though the underlying code and implementation may be different. This increases programmer efficiency so that it is no longer necessary to re-code existing functions for a new machine. The preprocessor makes this task easier with the availability of conditional compilation.

Consider the example of clearing a terminal screen. If all terminals in the world were Lear Siegler ADM5s, the definition of CLEAR would be the same in all cases. However, because different terminals use different sequences to accomplish the same function, this definition must be modified. On a DEC VT100, the statement would have to be

```
#define  CLEAR  printf("\033[2J")
```

The conditional compilation statements allow us to include certain sections of code based upon specified conditions. Thus, we can combine the two CLEAR definitions so that the desired one is defined for either situation. We can write

```
#ifdef  VT100
#define  CLEAR  printf("\033[2J")
#else
#define  CLEAR  printf("\033Y")
#endif
```

The above construction says that if the symbol VT100 is defined to the preprocessor, use the first definition of CLEAR; otherwise, use the second. Conditional compilation proceeds until the *#endif* directive is encountered. Now, all that is needed in order to use this program for a VT100 is to include a line at the top of the program which defines the symbol VT100

```
#define  VT100  1
```

If we wanted to, we could define the sequence for all other available terminals so that the same source code would run unchanged.

We can make similar constructions to define symbols only if they are not already defined, as in the following

```
#ifndef  NULL
#define  NULL  ((char *) 0)
#endif
```

This construction defines the symbol NULL only if it was not previously defined.

We can make the condition for compilation more complex by using the *#if* directive. With the *#if* directive, the condition must be a non-zero constant at compile time in order for the lines through *#endif* to be passed to the compiler. Making programs machine independent then becomes a matter of defining a symbol and testing for it to indicate the target processor. Then, definitions are made on the basis of which type machine the program is compiled for

```
#if mc68k | i286 | i386
      .
      /* Set definitions for the Motorola 68000 based
         or Intel 80286 or 80386 processor */
      .
#endif
#if u3b2 | u3b5 | u3b15 | u3b20
      .
      /* Set definitions for the AT&T 3b processors */
      .
#endif
#if uts | u370
      .
      /* Set definitions for the Amdahl and IBM processors */
      .
#endif
```

Although the examples presented above show only preprocessor directives (*#define*, *#undef*) used within the conditional compilation directives, C source code can be placed there as well to perform different functions under different circumstances.

MACRO PARAMETERS

The *#define* directive is useful in its ability to substitute arbitrary text for a symbol. Here, we see how that capability can be expanded by providing arguments with a macro definition. As an example, consider a macro useful for debugging which prints out a trace message when a function is entered

```
#define  DB_ENTER  printf("Entering a function\n")
```

We could place this statement at the beginning of each function

```
my_function ()
{
    DB_ENTER;
    .
    .
    .
```

This macro, in itself, is not very useful, since it does not say which function is being entered, and the flow of logic may not be easy to understand. Fortunately, we can provide an argument (the function name) with the macro invocation if we define the macro as

```
#define  DB_ENTER(x)  printf("Entering function %s\n", x)
```

Then, the statement at the beginning of each function could look like

```
my_function ()
{
    DB_ENTER("myfunction");
    .
    .
    .
```

After the DB_ENTER macro is substituted, the printf will arrange to print out "Entering function my_function\n", which can be useful in examining the flow of control.

Similarly, we could define a macro to tell us when control is leaving a function, and the returning value. We could define

```
#define  DB_RETURN(x)  {printf("Returning value = %d\n", x); return(x);
```

so that if the above function were written as

```
my_function ()
{
    DB_ENTER("myfunction");
    .
    .
    .
    DB_RETURN(69);
}
```

the output would look like

```
Entering function my_function
Returning value = 69
```

This type of information can be very useful when trying to trace what is happening inside a program.

We could combine this with conditional compilation directives so that output would only be printed if a certain symbol, such as DEBUG, were defined

```
#ifdef DEBUG
#define  DB_ENTER(x)  printf("Entering function %s\n", x)
#define  DB_RETURN(x)  {printf("Returning value = %d\n", x); return(x)
#else
#define  DB_ENTER(x)
#define  DB_RETURN(x)  return(x)
#endif
```

The second definition of DB_ENTER specifies that the DB_ENTER(x) text should be substituted by nothing. Then, the program could be coded as before, but would only produce trace output if it was compiled with the symbol DEBUG defined. If the symbol DEBUG were not defined, no extra code would be generated into the program.

Macro parameters can also be used to simplify complex expressions or structure references. In example 9.4 where a PERSON structure was declared, we could define a macro to access the name of a person's paternal grandfather easily

```
#define GRANDPA(p) (p->father->father.name)
```

SUMMARY

There are many reasons to utilise the C preprocessor's capabilities to perform text substitution within a program. Among them are

- #define'd constants and macros can be declared in one place and used throughout the code; subsequent changes can be made once at the declaration, without having to search for every instance.
- Complexity can be hidden from the programmer without sacrificing efficiency or functionality so that program logic is not obscured by detail.
- Conditional compilation can be used to eliminate machine and other dependencies.
- Using names for constants improves the intelligibility of the code.

11 Programming Style

Programming in any language is a skill acquired largely by experience and by observing the example of others. This is one of the reasons that the compiler listing for RatC, a substantial program, is included as an appendix (the other principal reasons are that, firstly, it is feasible for the interested reader to implement a minimal C system on his own machine, if he does not already have access to the language; and that, secondly, since we have spent the previous chapters discussing the input that is acceptable to the compiler, we thought you might be curious to see the type of C program that processes your C programs).

The way in which your programs are presented is a matter for personal taste. It is often a trade-off between brevity and intelligibility. Although programming 'style' is often considered to be unquantifiable and assessable only in subjective terms, we have made an attempt, in another appendix, to identify those features of program layout and organisation that tend to make it more visually appealing and more easily comprehensible.

It is now realised that the lifetime of a program, and the cost of program maintenance, frequently done by someone other than the author, make considerations of clarity of expression often of equal importance with those of efficiency. It is to the usually conflicting aims of clarity, conciseness and efficiency that we address our attention in this final chapter.

CLARITY

The clarity of a program is influenced by two principal factors: the way in which the program is presented visually, and the way in which the programming language constructs are used. The 'style score' that we have associated with all the programming examples throughout the book is a measure of the former. Appendix 3 gives a suite of programs (not all of which are written in C, although all of them could be) to perform a style analysis on a C program according to certain criteria which we believe contribute directly to a program's readability. You may not agree entirely with the criteria that we have chosen, or with the importance that we attach to each criterion, but you will almost certainly agree that the version of the program 'detab' presented in appendix 3 (which replaces all the tab characters in a file by the appropriate number of spaces), is very much more intelligible than that presented in example 11.1.

Example 11.1

```
#include        <stdio.h>

main()
{ int c,i,tabs[132],col=1;
  settabs(tabs);
  while ((c=getchar())!=EOF)
       if (c=='\t')
            do {putchar(' ');col++;} while (!tabpos(col,tabs));
       else if (c=='\n') {putchar('\n'); col=1;}
             else {putchar(c); col++;}
}
settabs(tabs)
int tabs[132];
{ int i;
  for (i=1;i<=132;i++)
       if ((i%8)==1) tabs[i]=1;else tabs[i]=0;
}
tabpos(col,tabs)
int col,tabs[132];
{
  if (col>132) return(1);else return(tabs[col]);
}


[ style 24.6 ]
```

The programs are equivalent, in the sense that they contain identical executable statements differently laid out. The 'bad' program could, of course, be very much worse, but then it would not be so typical of the kind of program that it is very tempting to write in a language that encourages brevity. In the authors' experience, programs written like this, with the intention of subsequent cosmetic improvement, tend to remain in their original format – there is little incentive to modify (even superficially) a working program. Automatic aids to 'beautifying' a program by introducing indentation, blank lines, etc. to reflect the program's structure are no substitute for a program thoughtfully written.

The criteria that we have chosen to use in the style analysis of our own programs are shown, in decreasing order of importance, in table 11.1.

Table 11.1

Criterion	Weighting	Ideal range	
Module length	15%	10–25	non-blank lines
Identifier length	14%	5–10	characters
% comment lines	12%	15–25%	
% indentation	12%	24–48%	
% blank lines	11%	15-30%	
Characters per line	9%	12–25	non-blank characters
Spaces per line	8%	4–10	spaces
% #defines	8%	15-25%	of all identifiers
Reserved word usage	6%	16–30	of available words
Include files	5%	3	included files

The relative weights and ideal ranges are not arbitrarily chosen, but rather are the result of careful tuning after analysis of programs that we recognised intuitively as 'good' or 'bad'. They may need modification to cater for individual preferences, or to reflect a particular 'house style'. With the exception of RatC, all examples for which a style score is given are small in size. Style scores for a number of large programs from the UNIX system are given in Berry and Meekings (1985).

The style analysis suite does not pretend to measure, in anything more than the most rudimentary sense, the second factor contributing to clarity: the use of the language itself. As in so many things, in programming there is no 'right' answer – just a number of alternative ways of achieving the same ends. Invariably, some of those ways will be clumsy or obscure. This will most often be the result of either inexperience or poor design – experience of using a language brings with it a number of benefits: for example, being able to 'think in the language' avoids the clumsy type of construct that arises from the direct transliteration of an algorithm derived by a programmer more familiar with another language, and also being able to use effectively the programming 'tricks' that exist within any language (for example, in C, using

```
while (*str1++ = *str2++);
```

to copy a string); and poor initial design, failure to derive a complete solution before coding, is bound to yield a program that is a functional mess, badly structured and with poor lines of communication.

CONCISENESS

There is a point, not always easy to identify, at which 'concise' becomes 'obscure'. Compare, for example, the random number generator program of chapter 6 with the functionally equivalent program of example 11.2. The gain in execution speed would have to be considerable to justify the inclusion of such a complex (but perfectly legal) statement in any program.

Example 11.2

```
#define maxint 32767
#define pshift 4
#define qshift 11

random(range)
    int range;
    {
    static int n=1;

    return((n=((n=n^n>>pshift)^n<<qshift)&maxint)%(range+1));
    }

[ style 49.3 ]
```

As a further example of a program that is concise to the point of obscurity, study the program of example 11.3, and try to determine its effect.

Example 11.3

```
#define LO 2
#define HI 1000

main()
    { int i,j;

      for (i=LO; i<=HI; i++)
          {
            j=sum(i);
            if (j==i) printf("%d\n",i);
            else if (sum(j)==i) printf("%d %d\n",i,j);
          }
    }

sum(n)
```

```
     int n;
     { int s, f;

       s=1;
       for (f=2; f<n; f++)
           if (n%f==0) s+=f;
       return(s);
     }

[ style 49.9 ]
```

Even with explanation, the program is very much more difficult to understand than is the equivalent program of example 11.4 which differs only by using more meaningful identifier names and having a helpful user interface. The program is in fact a generalisation of the perfect number program of chapter 5. Perfect numbers are a special case of 'amicable' numbers, which are pairs of numbers, each of whose sum of factors yields the other number; so that, for example, the sum of the factors of 220 is 284, while the sum of the factors of 284 is 220: 220 and 284 are amicable numbers.

Example 11.4

```
#define LO 2
#define HI 1000

main()
     { int number, sum;

       for (number=LO; number<=HI; number++)
           {
             sum=factorsum(number);
             if (sum==number) printf("%d is perfect\n",number);
             else if (factorsum(sum)==number)
                  printf("%d and %d are amicable\n",number,sum);
           }
     }

factorsum(num)
     int num;
     { int fsum, factor;
```

```
        fsum=1;
        for (factor=2; factor<num; factor++)
            if (num%factor==0) fsum+=factor;
        return(fsum);
    }
```

```
[ style 63.4 ]
```

C is undoubtedly a concise language, and encourages the terse representation of complex ideas. Such power should be judiciously used.

EFFICIENCY

The price that is paid for writing programs in any high-level language is in program size and execution time. Unless either of these is particularly critical, the advantages, in terms of productivity and maintenance costs, far outweigh the disadvantages.

C has a number of features that are more usually found in a lower-level language, to the extent that the correspondence between a C program and the machine code to which it compiles is often very close. The effect of this is to reduce the overheads resulting from the translation process very much more than for other contemporary languages. Some C compilers will offer the user an optional optimisation phase, but an alert and informed user is usually the best optimiser of a program. C provides some help in this: for example, the type specifiers *int* or *char* may be preceded by the storage class specifier *register*, thus

```
register int  n;
register char *sptr;
```

This is interpreted by the compiler as an indication that these identifiers will be heavily used and should, if possible, have storage space in registers. If the compiler is able to do this, then shorter, faster programs should result.

Nevertheless, the program has not yet been written that could not be written better, or executed faster. This was our experience with the RatC compiler. RatC is a descendant, via two generations, of Small-C (Cain, 1980a). For us, Small-C begat HotC, which was a version largely the same structurally as the original, but with considerable modification in the interests of efficiency; and HotC begat RatC which, apart from using a different, two-stage, method of code generation, represented a major restructuring of the program in the interests of style.

The transition from Small-C to HotC was made with the aid of one of the software tools available on the UNIX operating system, under which the programs were developed. This provides the facility of producing an 'execution profile' of a program, in terms of, for each function, the number of times that it was called, and the percentage of total execution time that it accounted for. This is of obvious benefit, since there is relatively little return from devoting time to improving the efficiency either of functions that are infrequently called, or of those that occupy only a small percentage of the execution time. We were able to concentrate on those areas where our efforts would be most rewarded, with the result of reducing the time taken for the compiler to recompile itself to a quarter of its original value.

As an illustration of the kind of improvements that were made, using the compiler recompiling itself as a yardstick, the top of the 'league table' of the execution profile for the original Small-C was

Function	*Number of calls*	*% of execution time*
alpha	382,521	10.1
findmac	3,594	10.0
astreq	334,421	8.6
numeric	381,794	6.4
an	379,550	5.6

In other words, the three functions *alpha*, *numeric* and *an* (which simply check a character parameter to see whether it is alphabetic, numeric and alphanumeric, respectively) accounted for a quarter of the execution time, and *findmac* (which is essentially a table look-up to determine whether a symbol has been previously defined as a macro) also made a significant contribution. When it is known that the compiler consists of only about 50,000 characters, the number of calls of *alpha*, *numeric* and *an* should cause concern.

Example 11.5

```
/* test if a given character is alphabetic */
alpha(c)
    char c;
    {
      c=c&127;    /* strip off the parity bit */
      return( ((c>='a') & (c<='z')) |
              ( (c>='A') & (c<='Z')) |
                (c=='_') );
    }


/* test if a given character is numeric */
numeric(c)
    char c;
    {
      c=c&127;
      return( (c>='0') & (c<='9') );
    }
```

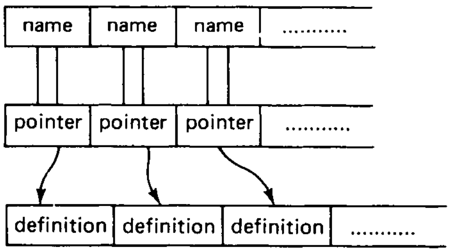
```
/* test if a given character is alphanumeric */
an(c)
    char c;
    {
      return( (alpha(c)) | (numeric(c)) );
    }


[ style 42.0 ]
```

The character checking functions were originally defined as shown in example 11.5. Two significant changes were made: firstly, the parity bit was stripped off once and for all on input by the function *preprocess*, to avoid unnecessary repetition; and secondly, the function *an* was made to check explicitly for the requisite characters, avoiding the overheads incurred by the two function calls. In RatC, these three functions account for less than 5 per cent of the execution time.

The way in which macro definitions were stored was changed from a simple table of the form

name	definition	name	definition	name	definition	....

to a more complex one of the form



in order to speed up the time taken to perform a linear search for a particular name. This is very important in view of the fact that the majority of searches will be unsuccessful, requiring a search through the entire table. The execution time for *findmac* was thus reduced to a quarter of its original value, at the expense of a little extra memory.

Two points should be mentioned here: firstly, that *findmac* could still be improved, but we believe that the simplicity/efficiency trade-off is about right; and secondly, that the pointer array should strictly be declared as

```
char *macp[mactsize]
```

but, owing to Small-C's inability to handle more than one modifier per declaration, has to be declared (potentially dangerously) as

```
int macp[mactsize]
```

Improving the efficiency of a program is not always an easy, or even desirable, task. For a small program, the effects may not be noticeable; for a large program, run infrequently, the time invested may not be worth while. For a heavily utilised program, such as a compiler, however, attention to the time-critical, bottleneck areas can give a significant improvement in performance.

DEFENSIVE PROGRAMMING

Throughout the book we have attempted to emphasise the importance of the interface between the program and its environment. Any program should take every possible precaution to ensure that it does not fail, and that, if it does, the failure is 'graceful', which is to say that it should provide the naive user with sufficient information to correct, or work around, the problem.

This section is concerned with 'bulletproofing' a program, and consists for the most part of a series of suggestions which you should bear in mind whenever writing programs – they are often the result of painfully acquired experience! If you follow our advice, you are certain to avoid at least some of the common pitfalls of porting programs from one machine to another, which, contrary to popular opinion, is not nearly as simple as it is supposed to be.

(a) Use lint. 'Lint' is a Unix utility which is commonly available on a variety of other systems. It performs a much more rigorous check than does the compiler on such things as type consistency, use of uninitialised variables, and correspondence between actual and dummy function arguments. If we had only one piece of advice to give you, it would be this.
(b) Check input data. At the end of chapter 3, we mentioned that input data is nearly always beyond the control of the programmer. You should check the integrity of all data which is derived from outside the program to make sure that it is within prescribed values. If you do not know what the prescribed values are, at least check that the value will not cause a run-time error – zero values used for division are an obvious example.
(c) Check function arguments. By a similar reasoning to the previous point, if you assume that function arguments are always sane, you will be caught unawares when, at some time in the future, you 'steal' the code to put in some other program where you have not been quite so careful.
(d) Check return values from functions. If a function (either yours or a system-provided one) returns a value, check it before continuing. Nearly all system-provided functions return values, and it is good practice to make yours do so too. Never assume that a function will always be successful – it always will be, except when you do not check it!
(e) Make sure variables are unique. Some C implementations only discriminate

identifiers based on the first 8 characters. If all your identifiers are unique over the first 8 characters, you should have no problem porting your code to a different machine.

(f) Do not rely on uninitialised variables. Variables of storage class *static* can be safely assumed to start with zero value; variables of storage class *automatic* start with garbage values. While this may be true, if you do not explicitly initialise them, the time will come when you change the storage class of one of your variables without changing the program logic, and wonder why it does not work anymore.

(g) Do not exploit implementation-dependent features. On some systems, a pointer occupies the same storage space as an integer. If you use that fact, your program probably will not work on another, dissimilar, machine. Structure-to-structure assignment is available on many systems, but is not yet standard, and should be avoided.

A slightly more insidious example arises from something we said at the end of chapter 6 – 'no ordering is implied among operators with the same priority'. Parentheses in an expression control precedence and associativity, but not order of evaluation, which is to say that the expression '*a* + *b* + *c*' could be evaluated by adding *a* to *b*, and adding the result to *c*, or by adding *b* to *c*, and the result to *a*. Normally this causes no problem, but consider the expression

```
y = x++ + x;
```

If *x* initially has the value 1, what value does *y* have after the assignment? 2? 4? The answer is that it is impossible to say – of course, on any particular implementation, it will always be evaluated the same way, but this is not true of the same program running on a different machine.

The assignment should have been written as

```
x++; y = x + x;
```

or

```
y = x + x; x++;
```

depending on what you intend.

(h) Do not use side effects in macro calls. The seemingly innocuous macro

```
#define MAX(a,b)  (a < b ? b : a)
```

when invoked by

```
z = MAX (x++, y);
```

leaves *x* with a different result depending on whether it is greater or less than *y*, because the preprocessor only performs textual substitution so that, in practice, the macro expands to

```
z = (x++ < y ? y : x++);
```

(i) Use parentheses in expressions. If you are unsure of operator precedence, or if the expression you are formulating is complex, do not be afraid to use parentheses to make it clearer. It adds nothing to the execution time, but a great deal to the comprehensibility.

(j) Do not corrupt C with the preprocessor. It is very easy, using the preprocessor, to make C look like some other language. If you are fond of Pascal, you might be tempted to write

```
#define BEGIN    {
#define END      }
          .
          .
```

but the result will be a confusion of neither one language nor the other.

(k) Use the right type of variable. Do not use an *int* when a *char* will do – for example, with a truth value; or an *int* where you mean a pointer. You not only save space, you give a program like 'lint' a much better chance of detecting potential problems.

(l) Exit gracefully. A program should never fail inexplicably – provide the user with sufficient information as to the cause of the failure that he understands what has gone wrong and what he can do to correct it.

(m) Do not rely on defaults. Often a system-provided function will offer default values for some of its arguments. If you take advantage of that you run the risk of your program no longer working should those defaults ever change.

(n) And lastly, beware of the difference between = and = =. If you are used to a language which uses the same operator for assignment and equivalence, sometime you will fall into the trap. It sounds easy to remember, but we have all forgotten it!

SUMMARY

Programming style and program efficiency are contentious issues: some will maintain that 'style' is so personal that it is impossible to lay down more than vague guidelines, others that it is the business of compilers and optimisers to worry about efficiency. What should never be forgotten is that, as we said in the introduction, programming is communication, and the communication operates at different levels: between the program and the computer, between the program and the user, and between the program and its maintainer.

It is all too tempting in a language like C to sacrifice clarity for conciseness and efficiency. There are relatively few occasions on which careful consideration of the method by which a program achieves its results (as in the RatC macro table organisation, above) would not yield the desired effect, without the need to resort to tricky obscure code.

The power of C, used properly, can be exploited to produce programs that are elegant, concise and, above all, intelligible.

Appendix 1: RatC

RatC ('rationalised Small-C') is a descendant, via two generations, of Ron Cain's Small-C (Cain, 1980a). Small-C is a compiler for a subset of the full C language, designed originally to generate code for Intel's 8080 microprocessor.

There are obvious reasons why it is advantageous to be able to develop microprocessor programs in a high-level language rather than assembly language, but, in the compiler, this objective inevitably leads to a trade-off between the language features implemented and the compiler size. While Small-C implements only those features of C considered essential to microprocessor applications, the language is rich enough to enable the compiler to recompile itself, so that it is quite possible to contemplate extending the compiler to accommodate any missing features. Modifications and extensions to the original Small-C can be found in Hendrix (1982).

There are three principal reasons for the inclusion of the RatC compiler listing within this book: firstly, because it has been a useful source of programming examples throughout the book; secondly, because any new programming language, in our experience, is most effectively learnt by example rather than by instruction, and the compiler is a good example of a substantial program; and, thirdly, because it is a useful piece of software in its own right.

THE DEVELOPMENT OF RatC

The language actually processed by RatC is identical to that of Small-C: the difference is one of approach and implementation, rather than of end product. Where Small-C generates code suitable for input to an 8080 assembler, RatC generates an intermediate language of its own, closely modelled on a subset of the 8080 instruction set. The resultant code can be executed in one of three ways: it can be interpreted, by a program resident on the target machine; it can be microcoded, effectively changing the target machine's native instruction set (the interested reader is referred to Hall (1982) for an example of a microcoded architecture for a Pascal system); or it can be translated into the specific code for a 'target' machine. We have chosen the last alternative in our implementations.

Whichever method is chosen, the compiler is no longer processor-specific, and it is usually a straightforward task to implement RatC on any particular processor.

THE HYPOTHETICAL MACHINE

The underlying hypothetical machine on which the intermediate instruction set is based is 8080-like, consisting of four registers:

PC	the program counter;
SP	the stack pointer;
P	the primary register; and
S	the secondary register.

The stack, as in most hardware implementations on the older microprocessors, grows downwards. The primary and secondary registers provide a useful extension to purely stack-oriented hypothetical machines: acknowledging the existence of working registers reduces the number of memory accesses required to emulate the machine, while more than two such registers introduce problems of optimal register allocation.

THE INSTRUCTION SET

The instruction set is designed to be translatable to any target instruction set using simple string processing techniques, such as are found, for example, in a text editor or macroprocessor. This will generally produce assembly language to be processed by the native assembler to resolve symbolic addresses. The instruction set is defined as follows

start		beginning of program – perform processor-specific initialisation and housekeeping
ldir.b	<label>	load the byte at the specified address into the low-order byte of the primary register (P), sign extending to the left
ldir.w	<label>	load the word at the specified address into P
addr	<value>	get effective address (SP + offset) into P
sdir.b	<label>	store the low-order byte from P at the specified address
sdir.w	<label>	store P at the specified address
sind.b		store the low-order byte from P at the address in the secondary register (S)
sind.w		store P at the address in S
lind.b		load byte at address in P into P, sign extending to the left
lind.w		load word at address in P into P
call	<label>	call specified subroutine, return address to stack top (T)
scall		call subroutine at address in T, return address to T
ujump	<label>	unconditional jump to specified location
fjump	<label>	jump to specified location if P is false (zero)
modstk	<value>	modify SP by the specified amount
swap		exchange contents of P and S

limm	<expr>	load the specified value into P
push		push P on to stack
pop		pop top of stack into S
xchange		exchange contents of P and T
return		return from subroutine: address on top of stack
scale	<value>	multiply P by the specified value (for example, to convert an integer offset into a byte offset)
add		add S to P, result in P
sub		subtract P from S, result in P
mult		multiply S by P, result in P
div		divide S by P, quotient in P, remainder in S
mod		divide S by P, remainder in P, quotient in S
or		bitwise inclusive or of P and S, result in P
xor		bitwise exclusive or of P and S, result in P
and		bitwise and of P and S, result in P
asr		arithmetic shift right of S, number of places in P, result in P
asl		arithmetic shift left of S, number of places in P, result in P
neg		two's complement of P, result in P
inc	<value>	increment P by the specified value
dec	<value>	decrement P by the specified value
testeq		set P to one if S = P, otherwise reset P to zero
testne		set P to one if S ! =P, otherwise reset P to zero
testlt		set P to one if S < P, otherwise reset P to zero
testle		set P to one if S < = P, otherwise reset P to zero
testgt		set P to one if S > P, otherwise reset P to zero
testge		set P to one if S > = P, otherwise reset P to zero
testult		set P to one if S < P (unsigned), otherwise reset P to zero
testule		set P to one if S < = P (unsigned), otherwise reset P to zero
testugt		set P to one if S > P (unsigned), otherwise reset P to zero
testuge		set P to one if S > = P (unsigned), otherwise reset P to zero
ds	<value>	reserve specified number of bytes of storage
db	<b1,b2,..>	initialise successive bytes of storage as specified
end		end of program

In the above, <label> is an alphanumeric symbolic location; <value> is a decimal, possibly signed, constant; <expr> is either a <value> or an expression of the form <label> + <value>; and <bi> are decimal byte values.

EXAMPLE PROGRAM

The output of the RatC compiler is illustrated overleaf, using a small program that employs a recursive function to print a number in a specified number base (shown in example A1.1). Source language statements appear as comments in the RatC output and are immediately followed by the code that represents them.

Example A1.1

```
int test, base;

main()               /*  RatC example program   */
    {
      test = 99;
      base = 8;
      prnum(test,base);
      putchar('\n');
    }

prnum(num, base) /* print `num' in base `base' */

    int num, base;
    { int quot,rem;

      if (base<2 | base>10) return;
      if (num<0) { putchar('-'); num= -num; }
      quot=num/base;
      rem=num%base;
      if (quot!=0) prnum(quot,base);
      putchar(rem+'0');
    }

[ style 48.0 ]
```

RatC COMPILER OUTPUT

```
; Lancaster RatC compiler
;int test, base;
;main()              /*  RatC exampl
        start
_main:

;     {
;       test = 99;
        limm    99
        sdir.w  test

           modstk  2
           addr    8
           push
           addr    10
           lind.w
           neg
           pop
           sind.w

;       quot=num/base;
cc4:
```

```
;       base = 8;
        limm    8
        sdir.w  base

;       prnum(test,base);
        ldir.w  test
        push
        ldir.w  base
        push
        call    _prnum
        modstk  4

;       putchar('\n');
        limm    10
        push
        call    _putchar
        modstk  2

;    }
        return

;prnum(num, base) /* print `num' in
_prnum:

;    int num, base;
;    { int quot,rem;

modstk  -2
modstk  -2

if (base<2 | base>10) return;
addr    6
lind.w
push
limm    2
pop
testlt
push
```

```
        addr    2
        push
        addr    10
        lind.w
        push
        addr    10
        lind.w
        pop
        div
        pop
        sind.w

;       rem=num%base;
        addr    0
        push
        addr    10
        lind.w
        push
        addr    10
        lind.w
        pop
        div
        swap
        pop
        sind.w

;       if (quot!=0) prnum(quot,base);
        addr    2
        lind.w
        push
        limm    0
        pop
        testne
        fjump   cc5
        addr    2
        lind.w
        push
```

```
        addr    8
        lind.w
        push
        limm    10
        pop
        testgt
        pop
        or
        fjump   cc3
        modstk  4
        return

;       if (num<0) { putchar('-'); nu
cc3:
        addr    8
        lind.w
        push
        limm    0
        pop
        testlt
        fjump   cc4
        limm    45
        push
        call    _putchar
        addr    8
        lind.w
        push
        call    _prnum
        modstk  4

;       putchar(rem+'0');
cc5:
        addr    0
        lind.w
        push
        limm    48
        pop
        add
        push
        call    _putchar
        modstk  2

;       }
        modstk  4
        return
test:   ds 2
base:   ds 2
        end     start
```

RatC *VERSUS* C

The RatC compiler, being written in precisely that subset of the C language that it processes, is the definitive specification of the subset. Briefly, the features that are *not* supported are

(1) Data types other than character, integer and pointer (no floating point).
(2) Structures, unions and multiple-dimension arrays (single-dimension arrays only).
(3) Type definitions.
(4) The logical operators && and | | (bitwise operators are used instead).
(5) The unary operators ! and ~.
(6) The , operator.
(7) Assignment operators other than = (+=, −=, /=, etc.).
(8) Switch, do-while, for and goto statements.
(9) Input/output (other than via your own runtime library).

The preprocessor directives #include and #define are supported, except that *include* files may not themselves contain #include directives, and constant definitions may not be parameterised. An additional directive pair, #asm–#endasm, is provided, between which native assembly language for the target machine can be inserted (use of this feature, of course, makes a program highly machine-dependent).

RatC IMPLEMENTATION

The RatC hypothetical machine and intermediate language are intended to be easily implementable on any target machine. Inevitably, efficiency is sacrificed for generality, and translation from the intermediate language to the target language will not usually yield optimal code.

What this means in practical terms is that, firstly, it will almost always be possible to produce a more compact and faster program than that produced by RatC either by writing directly in native machine code, or by using a compiler that generates code specifically for the target machine, and can thus exploit features of its instruction set that are unknown to RatC; and, secondly, that there will rarely be a one-to-one correspondence between the RatC instruction set and the native instruction set. The more powerful RatC instructions will often be implemented as calls to a runtime library to avoid the excessive space overheads of including the code inline (the same argument applies here as was presented in chapter 2 in support of the choice between macros and functions).

Thus, for any implementation, a runtime library must be provided, whose extent will depend largely on the power of the instruction set for the particular processor. A part of this library that will be common to all implementations, however, is that dealing with input and output. The routines used by the RatC compiler, which are closely modelled on the C standard I/O package, are

fopen	open a file for reading ("r") or writing ("w"), returning a non-zero integer for success, and NULL (0) for failure
fclose	close a file
getc	read in a character from the specified file
getchar	read in a character from the standard input
gets	read in a character string from the standard input
putc	write a character to the specified file
putchar	write a character to the standard output
puts	write a character string to the specified file

As examples of implementation, presented overleaf are the translations from RatC to, at one end of the scale, the 8080 instruction set, and, at the other, to the VAX. We are greatly indebted to Peter Hurley for the VAX implementation.

EXAMPLE TRANSLATION: RatC to 8080

To implement RatC on the 8080, the implementation-dependent constants 'intwidth' and 'charwidth' at the beginning of the compiler need to be changed to 2 and 1 respectively, and a runtime library must be provided, comprising the following routines (in which the primary register is HL, and the secondary DE)

ccgchar — fetch a single byte from the address in HL and sign extend into HL
ccgint — fetch a 16-bit integer from the address in HL into HL
ccpchar — store a single byte from HL at the address in DE
ccpint — store a 16-bit integer in HL at the address in DE
ccor, ccxor, ccand
: inclusive or, exclusive or, and HL and DE into HL
cceq, ccne, ccgt, ccle, ccge, cclt
: set HL to 1 if DE==HL, DE!=HL, DE>HL, DE<=HL, DE>=HL, DE<HL, and to 0 otherwise
ccuge, ccult, ccugt, ccule
: set HL to 1 if DE >= HL, DE < HL, DE > HL, DE <= HL (all unsigned comparisons), and to 0 otherwise
ccasr, ccasl
: shift DE arithmetically right, left by number of places in HL, and return result in HL
ccsub — subtract HL from DE, and return result in HL
ccneg — form the two's complement of HL
ccmult — multiply DE by HL, and return result in HL
ccdiv — divide DE by HL, and return quotient in HL, remainder in DE

The translation below is largely extracted from the original Small-C compiler (Cain, 1980a): the code for the runtime library appears in Cain (1980b).

ldir.b	<label>	LDA	<label>
ldir.w	<label>	LHLD	<label>
addr	<value>	LXI	H, <value>
		DAD	SP
sdir.b	<label>	MOV	A, L
		STA	<label>
sdir.w	<label>	SHLD	<label>
sind.b		CALL	ccpchar
sind.w		CALL	ccpint
lind.b		CALL	ccgchar
lind.w		CALL	ccgint
call	<label>	CALL	<label>
scall		LXI	H, S+5
		XTHL	
		PCHL	

```
ujump     <label>      JMP    <label>
fjump     <label>      MOV    A, H
                       ORA    L
                       JZ     <label>
modstk    <value>      XCHG
                       LXI    H, <value>
                       DAD    SP
                       SPHL
                       XCHG
swap                   XCHG
limm      <expr>       LXI    H, <expr>
push                   PUSH   H
pop                    POP    D
xchange                XTHL
return                 RET
scale     <value>      XCHG
                       PUSH   H
                       LXI    H, <value>
                       CALL   ccmult
                       POP    D
add                    DAD    D
sub                    CALL   ccsub
mult                   CALL   ccmult
div                    CALL   ccdiv
mod                    CALL   ccdiv
                       XCHG
or                     CALL   ccor
xor                    CALL   ccxor
and                    CALL   ccand
asr                    CALL   ccasr
asl                    CALL   ccasl
neg                    CALL   ccneg
inc       <value>      XCHG
                       PUSH   H
                       LXI    H, <value>
                       DAD    D
                       POP    D
dec       <value>      XCHG
                       PUSH   H
                       LXI    H, -<value>
                       DAD    D
                       POP    D
testeq                 CALL   cceq
testne                 CALL   ccne
```

```
testlt                      CALL  cclt
testle                      CALL  ccle
testgt                      CALL  ccgt
testge                      CALL  ccge
testult                     CALL  ccult
testule                     CALL  ccule
testugt                     CALL  ccugt
testuge                     CALL  ccuge
ds       <value>            DS    <value>
db       <b1,b2,..>         DB    <b1,b2,..>
end                         END
```

EXAMPLE TRANSLATION: RatC to VAX

The VAX being a 32-bit word machine, the implementation-dependent constant 'intwidth' in the RatC compiler needs to have the value 4; the only runtime library needed comprises the input/output routines.

```
start                   .ENTRY  START,^M<>
                        CALLS   #0,INIT_IO
                        JSB     MAIN
                        $EXIT_S

ldir.b  <label>         CVTBL   <label>,R2

ldir.w  <label>         MOVL    <label>,R2

addr    <offset>        ADDL3   #<offset>,SP,R2

sdir.b  <label>         CVTLB   R2,<label>

sdir.w  <label>         MOVL    R2,<label>

sind.b                  MOVB    R2,(R3)

sind.w                  MOVL    R2,(R3)

lind.b                  CVTBL   (R2),R2

lind.w                  MOVL    (R2),R2

call    <label>         JSB     <label>

scall                   JSB     (SP)
```

```
ujump    <label>          JMP     <label>

fjump    <label>          TSTL    R2
                          BNEQ    .+4
                          BRW     <label>

modstk   <value>          ADDL    #<value>,SP

swap                      PUSHL   R2
                          MOVL    R3,R2
                          POPL    R3

limm     <value>          MOVL    #<value>,R2

push                      PUSHL   R2

pop                       POPL    R3

xchange                   POPL    R4
                          PUSHL   R2
                          MOVL    R4,R3

return                    RSB

scale    <value>          MULL    #<value>,R2

add                       ADDL    R3,R2

sub                       SUBL3   R2,R3,R2

mult                      MULL    R3,R2

div                       MOVL    R3,R4
                          BLSS    .+5
                          CLRL    R5
                          BRB     .+8
                          MOVL    #-1,R5
                          EDIV    R2,R4,R2,R3

mod                       MOVL    R3,R4
                          BLSS    .+5
                          CLRL    R5
                          BRB     .+8
                          MOVL    #-1,R5
                          EDIV    R2,R4,R3,R2
```

```
or                      BISL    R3,R2

xor                     XORL    R3,R2

and                     MCOML   R3,R3
                        BICL    R3,R2
                        MCOML   R3,R3

asl                     ASHL    R2,R3,R2

asr                     MNEGL   R2,R2
                        ASHL    R2,R3,R2

neg                     MNEGL   R2,R2

inc     <value>         ADDL    #<value>,R2

dec     <value>         SUBL    #<value>,R2

testeq                  CMPL    R3,R2
                        BEQL    .+5
                        CLRL    R2
                        BRB     .+4
                        MOVL    #1,R2

testne                  CMPL    R3,R2
                        BEQL    .+6
                        MOVL    #1,R2
                        BRB     .+3
                        CLRL    R2

testlt                  CMPL    R3,R2
                        BLSS    .+5
                        CLRL    R2
                        BRB     .+4
                        MOVL    #1,R2

testle                  CMPL    R3,R2
                        BLEQ    .+5
                        CLRL    R2
                        BRB     .+4
                        MOVL    #1,R2
```

```
testgt                      CMPL    R3,R2
                            BGTR    .+5
                            CLRL    R2
                            BRB     .+4
                            MOVL    #1,R2

testge                      CMPL    R3,R2
                            BGEQ    .+5
                            CLRL    R2
                            BRB     .+4
                            MOVL    #1,R2

testult                     CMPL    R3,R2
                            BLSSU   .+5
                            CLRL    R2
                            BRB     .+4
                            MOVL    #1,R2

testule                     CMPL    R3,R2
                            BLEQU   .+5
                            CLRL    R2
                            BRB     .+4
                            MOVL    #1,R2

testugt                     CMPL    R3,R2
                            BGTRU   .+5
                            CLRL    R2
                            BRB     .+4
                            MOVL    #1,R2

testuge                     CMPL    R3,R2
                            BGEQU   .+5
                            CLRL    R2
                            BRB     .+4
                            MOVL    #1,R2

ds      <value>             .BLKB   <value>

db      <b1,b2,...>         .BYTE   <b1,b2,...>

end                         .END
```

Appendix 2: RatC Listing

```
     /****************************************/
     /*                                      */
     /*               RatC                   */
     /*                                      */
     /*      Lancaster implementation        */
     /*               by                     */
     /*    Bob Berry and Brian Meekings      */
     /*             May 1983                 */
     /*                                      */
     /*   (based on Ron Cain's  Small-C)     */
     /*                                      */
     /****************************************/


     /* Implementation dependent definitions */

#include     <stdio.h>        /* UNIX i/o     */
#define      intwidth     2   /* integer size */
#define      charwidth    1   /* char size    */
#define      clearscreen {putchar(30);putchar(27);putchar('Y');}

     /* Ascii codes */

#define      bspch        8
#define      tabch        9
#define      eolch        10
#define      ffch         12
#define      crch         13
#define      quoch        39
#define      bslch        92


     /* Output definitions */

#define      nl           outbyte(eolch)
#define      tab          outbyte(tabch)
#define      colon        outbyte(':')
#define      comma        outbyte(',')
#define      space        outbyte(' ')
#define      comment      outbyte(';')


     /* Define the symbol table parameters */

```

```
#define     symsiz      15
#define     symtbsz     5400
#define     numglbs     300
#define     startglb    symtab
#define     endglb      startglb+numglbs*symsiz
#define     startloc    endglb+symsiz
#define     endloc      symtab+symtbsz-symsiz


     /* Define symbol table entry format */

#define     name        0
#define     ident       10
#define     type        11
#define     storage     12
#define     offset      13

     /* System wide name size (for symbols) */

#define     namesize    10
#define     namemax     9


     /* Define possible entries for "ident" */

#define     variable    1
#define     array       2
#define     pointer     3
#define     function    4


     /* Define possible entries for "type" */

#define     cchar       1
#define     cint        2


     /* Define possible entries for "storage" */

#define     statik      1
#define     stkloc      2


     /* Define the "while" statement queue */

#define     wqtabsz     100
#define     wqsiz       4
#define     wqmax       wq+wqtabsz-wqsiz


     /* Define entry offsets in while queue */

#define     wqsym       0
#define     wqsp        1
#define     wqloop      2
```

```
#define     wqlab       3


    /* Define the literal pool */

#define     litabsz     2500
#define     litmax      litabsz-1


    /* Define the input line */

#define     linesize    80
#define     linemax     linesize-1


    /* Define the macro (define) pool */

#define     macbsize    1500
#define     mactsize    75
#define     macssize    750  /*namesize*mactsize*/


    /* Define statement types (tokens) */

#define     stif        1
#define     stwhile     2
#define     streturn    3
#define     stbreak     4
#define     stcont      5
#define     stasm       6
#define     stexp       7


    /* Now reserve some storage words */

char    symtab[symtbsz];    /* symbol table           */
char    *glbptr,*locptr;    /* ptrs to next entries */
int     wq[wqtabsz];        /* while queue            */
int     *wqptr;             /* ptr to next entry      */

char    litq[litabsz];      /* literal pool           */
int     litptr;             /* ptr to next entry      */

char    macb[macbsize];     /* macro body buffer      */
char    mact[macssize];     /* macro name table       */
char    *macbptr  *mactptr; /* and their indices      */
char    *macbmax;           /* end of body buffer     */
int     macp[mactsize];     /* ptrs into body         */
int     macpmax, *macpptr;  /* macro count            */

char    line[linesize];     /* parsing buffer         */
char    mline[linesize];    /* temp macro buffer      */
char    *ch,*nexch,*chmax,*mptr; /* ptrs into each    */
int     mpmax;              /* limit of mline         */

```

```

    /* Miscellaneous storage */

int     nxtlab,       /* next available label #        */
        litlab,       /* label # assigned to lit pool */
        sp,           /* stack pointer                 */
        argstk,       /* function argument sp          */
        ncmp,         /* # open compound statements    */
        errcnt,       /* # errors in compilation       */
        inscnt,       /* # instructions generated      */
        lncnt,        /* # source lines                */
        eof,          /* non-zero on final input eof   */
        input,        /* iob # for input file          */
        output,       /* iob # for output file         */
        input2,       /* iob # for "include" file      */
        glbflag,      /* non-zero if internal globals */
        mulfile,      /* non-zero for many input files*/
        ctext,        /* non-zero to intermix c-source*/
        cmode,        /* non-zero while parsing c-code*/
                      /* zero when parsing assembly   */
        lastst;       /* last executed statement type */

char    quote[2];     /* literal string for '"'        */
char    *cptr;        /* work ptr to any char buffer   */
int     hasmain;      /* does this file have `main()' */



    /****************************************/
    /*                                      */
    /*    Compiler begins execution here    */
    /*                                      */
    /****************************************/

main()
    {
    glbptr=startglb;          /* clear global symbols */
    locptr=startloc;          /* clear local symbols  */
    chmax =line+linemax;      /* max value of ptr ch  */
    mpmax =mline+linemax;     /* ditto for mline      */
    wqptr=wq;                 /* clear while queue    */

    litptr=                   /* clear literal pool   */
    sp=                       /* stack ptr (relative) */
    eof=                      /* not eof yet          */
    input=                    /* no input file        */
    input2=                   /* or include file      */
    output=                   /* no open units        */
    ncmp=                     /* no open compounds    */
    lastst=                   /* no last stmt yet     */
    0;                        /* ... all set to zero  */

    errcnt=                   /* no errors            */
    inscnt=                   /* no instructions yet  */
    lncnt=                    /* no source lines yet  */
```

```
    hasmain=                    /* no main segment yet   */
    0;                          /* ... all set to zero   */

    mactptr=mact;               /* clear the macro table*/
    macbptr=macb;               /* start of body buffer */
    macpptr=macp;               /* none to start with    */
    macpmax=macp+(mactsize-1)*intwidth;
    macbmax=macb+macbsize-1;

    quote[0]='"';               /* fake a quote literal */
    quote[1]=0;
    cmode=1;                    /* enable preprocessing */

    /************************/
    /*    Compiler body     */
    /************************/

    ask();                      /* get user options      */
    openout();                  /* get an output file    */
    openin();                   /* & initial input file */
    comment;
    outstr(" Lancaster RatC compiler");
    nl;
    parse();                    /* process ALL input     */
    dumplits();                 /* dump literal pool     */
    dumpglbs();                 /* and all static memory*/
    trailer();                  /* follow-up code        */
    closeout();                 /* close the output      */
    errorsummary();             /* summarize errors      */
    return;                     /* then exit to system   */
    }

    /*********************************/
    /*    Process all input text    */
    /*  At this level, only static  */
    /*    declarations, defines,    */
    /*    includes and function     */
    /*    definitions are legal     */
    /*********************************/

parse()
    {
    while (eof==0)          /* do until no more input */
        {
        if (amatch("char",4))
            {declglb(cchar);needsemi();}
        else if (amatch("int",3))
            {declglb(cint);needsemi();}
        else if (match("#asm"))
            doasm();
        else if (match("#include"))
            openinclude();
        else if (match("#define"))
            addmac();
        else newfunc();
```

```
        skipblanks();     /* force eof if pending   */
        }
    }

    /*********************************/
    /*   New function definition    */
    /*********************************/

newfunc()
    {
    char n[namesize], *ptr;
    int  argtop;

    if (symname(n)==0)
        {
        error("illegal function or declaration");
        resetptr();
        return;
        }
    if (ptr=findglb(n))
        {
        if (ptr[ident]!=function) errmulti(n);
        else if (ptr[offset]==function) errmulti(n);
        else ptr[offset]=function;
        }
    else addglb(n,function,cint,function);

    if (match("(")==0)
        error("missing opening parenthesis");
    if (astreq(n+1,"main",4))
        { hasmain=1; header(); }
    outstr("_"); outstr(n); colon; nl;

    locptr=startloc;
    argstk=0;
    while (match(")")==0)
        {
        if (symname(n))
            {
            if (findloc(n)) errmulti(n);
            else
                {
                addloc(n,0,0,argstk);
                argstk=argstk+intwidth;
                }
            }
        else { error("illegal argument name");skipchars(); }
        skipblanks();
        if (streq(ch,")")==0)
            {
            if (match(",")==0) error("expected comma");
            }
        if (needstend()) break;
        }
    sp=0; argtop=argstk;
```

```
    while (argstk)
        {
        if (amatch("char",4))
            { getarg(cchar,argtop); needsemi(); }
        else if (amatch("int",3))
            { getarg(cint,argtop); needsemi(); }
        else { error("wrong number of args"); break; }
        }
    if (statement()!=streturn)
        {
        modstk(0);
        ret();
        }
    sp=0;
    locptr=startloc;
    }

    /*********************************/
    /*   Get function arguments     */
    /*********************************/

getarg(t,argtop)
    int t,argtop;
    {
    int j,legalname,address;
    char n[namesize],c,*argptr;

    while(1)
        {
        if (argstk==0) return;
        if (match("*")) j=pointer; else j=variable;
        if ((legalname=symname(n))==0) errname();
        if (match("["))
            {
            while (inbyte()!=']')
                if (needstend()) break;
            j=pointer;
            }
        if (legalname)
            {
            if (argptr=findloc(n))
                {
                argptr[ident]=j;
                argptr[type]=t;
                address=argtop-((argptr[offset]&255)+
                    ((argptr[offset+1]&255)<<8));
                argptr[offset]=address;
                argptr[offset+1]=address>>8;
                }
            else error("expecting argument name");
        }
        argstk=argstk-intwidth;
        if (needstend()) return;
        if (match(",")==0) error("expected comma");
        }
```

```
	}

	/*********************************/
	/*    Process a statement      */
	/*********************************/

statement()
	{
	if ((*ch==0) & (eof)) return;
	else if (amatch("char",4))
	    { declloc(cchar); needsemi(); }
	else if (amatch("int",3))
	    { declloc(cint); needsemi(); }
	else if (match("{"))
	    compound();
	else if (amatch("if",2))
	    { doif(); lastst=stif; }
	else if (amatch("while",5))
	    { dowhile(); lastst=stwhile; }
	else if (amatch("return",6))
	    { doreturn(); needsemi(); lastst=streturn; }
	else if (amatch("break",5))
	    { dobreak(); needsemi(); lastst=stbreak; }
	else if (amatch("continue",8))
	    { docont(); needsemi(); lastst=stcont; }
	else if (match(";"));
	else if (match("#asm"))
	    { doasm(); lastst=stasm; }
	else    {expression(); needsemi(); lastst=stexp; }
	return lastst;
	}

	/*********************************/
	/*  Process compound statement  */
	/*********************************/

compound()
	{
	++ncmp;
	while (match("}")==0)
	    if (eof) return; else statement();
	--ncmp;
	}

	/*********************************/
	/*    Process IF statement      */
	/*********************************/

doif()
	{
	int flev,fsp,flab1,flab2;

	flev=locptr;
	fsp=sp;
	flab1=getlabel();
```

```
    test(flab1);
    statement();
    sp=modstk(fsp);
    locptr=flev;
    if (amatch("else",4)==0)
        {
        outlabel(flab1); colon; nl;
        return;
        }
    jump(flab2=getlabel());
    outlabel(flab1); colon; nl;
    statement();
    sp=modstk(fsp);
    locptr=flev;
    outlabel(flab2); colon; nl;
    }

    /********************************/
    /*   Process WHILE statement    */
    /********************************/

dowhile()
    {
    int wq[4];

    wq[wqsym]=locptr;
    wq[wqsp]=sp;
    wq[wqloop]=getlabel();
    wq[wqlab]=getlabel();
    addwhile(wq);
    outlabel(wq[wqloop]); colon; nl;
    test(wq[wqlab]);
    statement();
    jump(wq[wqloop]);
    outlabel(wq[wqlab]); colon; nl;
    locptr=wq[wqsym];
    sp=modstk(wq[wqsp]);
    delwhile();
    }

    /********************************/
    /*   Process RETURN statement   */
    /********************************/

doreturn()
    {
    if (needstend()==0) expression();
    modstk(0);
    ret();
    }

    /********************************/
    /*   Process BREAK statement    */
    /********************************/
```

```
dobreak()
     {
     int *ptr;

     if ((ptr=readwhile())==0) return;
     modstk((ptr[wqsp]));
     jump(ptr[wqlab]);
     }

     /*********************************/
     /*  Process CONTINUE statement  */
     /*********************************/

docont()
     {
     int *ptr;

     if ((ptr=readwhile())==0) return;
     modstk((ptr[wqsp]));
     jump(ptr[wqloop]);
     }

     /*********************************/
     /*   Process #asm directive     */
     /*********************************/

doasm()
     {
     cmode=0;
     while(1)
          {
          inline();
          if (match("#endasm")) break;
          if (eof) break;
          outstr(line);
          nl;
          }
     resetptr();
     cmode=1;
     }

     /*********************************/
     /*   Expression evaluation by   */
     /*       recursive descent      */
     /*********************************/

expression()
     {
     int lval[2];

     if (hier1(lval)) rvalue(lval);
     }

hier1(lval)
     int lval[];
```

```
     {
     int k, lval2[2];

     k=hier2(lval);
     if (match("="))
          {
          if (k==0) {errlval();return 0;}
          if (lval[1]) push();
          if (hier1(lval2)) rvalue(lval2);
          store(lval);
          return 0;
          }
     else return k;
     }

hier2(lval)
     int lval[];
     {
     int k, lval2[2];

     k=hier3(lval);
     skipblanks();
     if (*ch!='|') return k;
     if (k) rvalue(lval);
     while(1)
          {
          if (match("|"))
               {
               push();
               if (hier3(lval2)) rvalue(lval2);
               pop();
               or();
               }
          else return 0;
          }
     }

hier3(lval)
     int lval[];
     {
     int k, lval2[2];

     k=hier4(lval);
     skipblanks();
     if (*ch!='^') return k;
     if (k) rvalue(lval);
     while (1)
          {
          if (match("^"))
               {
               push();
               if (hier4(lval2)) rvalue(lval2);
               pop();
               xor();
               }
```

```
            else return 0;
            }
        }

hier4(lval)
        int lval[];
        {
        int k, lval2[2];

        k=hier5(lval);
        skipblanks();
        if (*ch!='&') return k;
        if (k) rvalue(lval);
        while (1)
            {
            if (match("&"))
                {
                push();
                if (hier5(lval2)) rvalue(lval2);
                pop();
                and();
                }
            else return 0;
            }
        }

hier5(lval)
        int lval[];
        {
        int k, lval2[2];

        k=hier6(lval);
        skipblanks();
        /* check for == and !=  */
        if (*nexch != '=') return k;
        if ((*ch != '=') & (*ch != '!')) return k;
        if (k) rvalue(lval);
        while (1)
            {
            if (match("=="))
                {
                push();
                if (hier6(lval2)) rvalue(lval2);
                pop();
                eq();
                }
            else if (match("!="))
                {
                push();
                if (hier6(lval2)) rvalue(lval2);
                pop();
                ne();
                }
            else return 0;
            }
```

```
    }

hier6(lval)
    int lval[];
    {
    int k, lval2[2];

    k=hier7(lval);
    skipblanks();
    /* wish to identify >, <, >=, <=, but reject >>, << */
    if ( ( *ch    != '<') & ( *ch    != '>') ) return k;
    if ( ( *nexch == '<') | ( *nexch == '>') ) return k;
    if (k) rvalue(lval);
    while (1)
        {
        if (match("<="))
            {
            push();
            if (hier7(lval2)) rvalue(lval2);
            pop();
            if (cptr=lval[0])
                if (cptr[ident]==pointer)
                    {
                    ule();
                    continue;
                    }
            if (cptr=lval2[0])
                if (cptr[ident]==pointer)
                    {
                    ule();
                    continue;
                    }
            le();
            }
        else if (match(">="))
            {
            push();
            if (hier7(lval2)) rvalue(lval2);
            pop();
            if (cptr=lval[0])
                if (cptr[ident]==pointer)
                    {
                    uge();
                    continue;
                    }
            if (cptr=lval2[0])
                if (cptr[ident]==pointer)
                    {
                    uge();
                    continue;
                    }
            ge();
            }
        else if ((streq(ch,"<")) & (streq(ch,"<<")==0))
            {
```

```
            inbyte();
            push();
            if (hier7(lval2)) rvalue(lval2);
            pop();
            if (cptr=lval[0])
                if (cptr[ident]==pointer)
                    {
                    ult();
                    continue;
                    }
            if (cptr=lval2[0])
                if (cptr[ident]==pointer)
                    {
                    ult();
                    continue;
                    }
            lt();
            }
        else if ((streq(ch,">")) & (streq(ch,">>")==0))
            {
            inbyte();
            push();
            if (hier7(lval2)) rvalue(lval2);
            pop();
            if (cptr=lval[0])
                if (cptr[ident]==pointer)
                    {
                    ugt();
                    continue;
                    }
            if (cptr=lval2[0])
                if (cptr[ident]==pointer)
                    {
                    ugt();
                    continue;
                    }
            gt();
            }
        else return 0;
        }
    }

hier7(lval)
    int lval[];
    {
    int k, lval2[2];

    k=hier8(lval);
    skipblanks();
    if ((streq(ch,">>")==0) & (streq(ch,"<<")==0)) return k;
    if (k) rvalue(lval);
    while (1)
        {
        if (match(">>"))
            {
```

```
            push();
            if (hier8(lval2)) rvalue(lval2);
            pop();
            asr();
            }
        else if (match("<<"))
            {
            push();
            if (hier8(lval2)) rvalue(lval2);
            pop();
            asl();
            }
        else return 0;
        }
    }

hier8(lval)
    int lval[];
    {
    int k, lval2[2];

    k=hier9(lval);
    skipblanks();
    if ((*ch!='+') & (*ch!='-')) return k;
    if (k) rvalue(lval);
    while (1)
        {
        if (match("+"))
            {
            push();
            if (hier9(lval2)) rvalue(lval2);
            if (cptr=lval[0])
                if ((cptr[ident]==pointer) &
                    (cptr[type]==cint)) scale(intwidth);
            pop();
            add();
            }
        else if (match("-"))
            {
            push();
            if (hier9(lval2)) rvalue(lval2);
            if (cptr=lval[0])
                if ((cptr[ident]==pointer) &
                    (cptr[type]==cint)) scale(intwidth);
            pop();
            sub();
            }
        else return 0;
        }
    }

hier9(lval)
    int lval[];
    {
    int k, lval2[2];
```

```

    k=hier10(lval);
    skipblanks();
    if ((*ch!='*') & (*ch!='/') & (*ch!='%')) return k;
    if (k) rvalue(lval);
    while (1)
        {
        if (match("*"))
            {
            push();
            if (hier9(lval2)) rvalue(lval2);
            pop();
            mult();
            }
        else if (match("/"))
            {
            push();
            if (hier10(lval2)) rvalue(lval2);
            pop();
            div();
            }
        else if (match("%"))
            {
            push();
            if (hier10(lval2)) rvalue(lval2);
            pop();
            mod();
            }
        else return 0;
        }
    }

hier10(lval)
    int lval[];
    {
    int k;
    char *ptr;

    if (match("++"))
        {
        if ((k=hier10(lval))==0) { errlval(); return 0;}
        if (lval[1]) push();
        rvalue(lval);
        ptr=lval[0];
        if ((ptr[ident]==pointer) & (ptr[type]==cint))
             inc(intwidth);
        else inc(charwidth);
        store(lval);
        return 0;
        }
    else if (match("--"))
        {
        if ((k=hier10(lval))==0) { errlval(); return 0;}
        if (lval[1]) push();
        rvalue(lval);
```

```
            ptr=lval[0];
            if ((ptr[ident]==pointer) & (ptr[type]==cint))
                  dec(intwidth);
            else dec(charwidth);
            store(lval);
            return 0;
            }
        else if (match("-"))
            {
            k=hier10(lval);
            if (k) rvalue(lval);
            neg();
            return 0;
            }
        else if (match("*"))
            {
            k=hier10(lval);
            if (k) rvalue(lval);
            lval[1]=cint;
            if (ptr=lval[0]) lval[1]=ptr[type];
            lval[0]=0;
            return 1;
            }
        else if (match("&"))
            {
            k=hier10(lval);
            if (k==0) { error("illegal address"); return 0; }
            else if (lval[1]) return 0;
                  else
                 {
                 immed();
                 outstr(ptr=lval[0]);
                 nl;
                 lval[1]=ptr[type];
                 return 0;
                 }
            }
        else
            {
            k=hier11(lval);
            if (match("++"))
                 {
                 if (k==0) { errlval();return 0; }
                 if (lval[1]) push();
                 rvalue(lval);
                 ptr=lval[0];
                 if ((ptr[ident]==pointer) & (ptr[type]==cint))
                       inc(intwidth);
                 else inc(charwidth);
                 store(lval);
                 if ((ptr[ident]==pointer) & (ptr[type]==cint))
                       dec(intwidth);
                 else dec(charwidth);
                 return 0;
                 }
```

```
        else if (match("--"))
            {
            if (k==0) { errlval(); return 0; }
            if (lval[1]) push();
            rvalue(lval);
            ptr=lval[0];
            if ((ptr[ident]==pointer) & (ptr[type]==cint))
                 dec(intwidth);
            else dec(charwidth);
            store(lval);
            if ((ptr[ident]==pointer) & (ptr[type]==cint))
                 inc(intwidth);
            else inc(charwidth);
            return 0;
            }
        else return k;
        }
    }

hier11(lval)
    int *lval;
    {
    int k;
    char *ptr;

    k=primary(lval);
    ptr=lval[0];
    skipblanks();
    if ((*ch=='[') | (*ch=='('))
        while (1)
            {
            if (match("["))
                {
                if (ptr==0)
                    {
                    error("can't subscript");
                    skipchars();
                    needbrack("]");
                    return 0;
                    }
                else if (ptr[ident]==pointer)
                    rvalue(lval);
                else if (ptr[ident]!=array)
                    {
                    error("can't subscript");
                    k=0;
                    }
                push();
                expression();
                needbrack("]");
                if (ptr[type]==cint) scale(intwidth);
                pop();
                add();
                lval[0]=0;
                lval[1]=ptr[type];
```

```
                k=1;
                }
            else if (match("("))
                {
                if (ptr==0) callfunction(0);
                else if (ptr[ident]!=function)
                    {
                    rvalue(lval);
                    callfunction(0);
                    }
                else callfunction(ptr);
                k=lval[0]=0;
                }
            else return k;
            }
        if (ptr==0) return k;
        if (ptr[ident]==function)
            {
            immed();
            outstr(ptr);
            nl;
            return 0;
            }
        return k;
    }

primary(lval)
    int *lval;
    {
    char *ptr, sname[namesize];
    int num[1];
    int k;

    if (match("("))
        {
        k=hier1(lval);
        needbrack(")");
        return k;
        }
    if (symname(sname))
        {
        if (ptr=findloc(sname))
            {
            getloc(ptr);
            lval[0]=ptr;
            lval[1]=ptr[type];
            if (ptr[ident]==pointer) lval[1]=cint;
            if (ptr[ident]==array) return 0; else return 1;
            }
        if (ptr=findglb(sname)) if (ptr[ident]!=function)
                {
                lval[0]=ptr;
                lval[1]=0;
                if (ptr[ident]!=array) return 1;
                immed();
```

```
                        outstr(ptr);
                        nl;
                        lval[1]=ptr[type];
                        return 0;
                        }
                ptr=addglb(sname,function,cint,0);
                lval[0]=ptr;
                lval[1]=0;
                return 0;
                }
        if (constant(num)) return(lval[0]=lval[1]=0);
        else
                {
                error("invalid expression");
                immed();
                outdec(0);
                nl;
                skipchars();
                return 0;
                }
        }

        /********************************/
        /*   Process function call      */
        /********************************/

callfunction(ptr)
        char *ptr;
        {
        int nargs;

        nargs=0;
        skipblanks();
        if (ptr==0) push();
        while (*ch != ')')
                {
                if (needstend()) break;
                expression();
                if (ptr==0) swapstk();
                push();
                nargs=nargs+intwidth;
                if (match(",")==0) break;
                }
        needbrack(")");
        if (ptr) call(ptr+1);
        else callstk();
        sp=modstk(sp+nargs);
        }

        /********************************/
        /* Declare a static variable -  */
        /* makes an entry in the symbol */
        /* table so that subsequent     */
        /* references can call symbol   */
        /* by name                      */
```

```
    /*********************************/

declglb(typ)
    int typ;
    {
    int k,j; char sname[namesize];

    while(1)
        {
        while(1)
            {
            if (needstend()) return;
            k=1;
            if (match("*")) j=pointer;
            else j=variable;
            if (symname(sname)==0) errname();
            if (findglb(sname)) errmulti(sname);
            if (match("["))
                {
                k=needsub();
                if (k) j=array;
                else j=pointer;
                }
            addglb(sname,j,typ,k);
            break;
            }
        if (match(",")==0) return;
        }
    }

    /*********************************/
    /*   Declare local variables    */
    /*********************************/

declloc(typ)
    int typ;
    {
    int k,j; char sname[namesize];

    while(1)
        {
        while(1)
            {
            if (needstend()) return;
            if (match("*")) j=pointer;
            else j=variable;
            if (symname(sname)==0) errname();
            if (findloc(sname)) errmulti(sname);
            if (match("["))
                {
                k= needsub();
                if (k)
                    {
                    j=array;
                    if (typ==cint) k=k*intwidth;
```

```
                    }
                else
                    {
                    j=pointer;
                    k=intwidth;
                    }
                }
            else
                if ((typ==cchar) & (j!=pointer)) k=charwidth;
                else k=intwidth;
            sp=modstk(sp-k);
            addloc(sname,j,typ,sp);
            break;
            }
        if (match(",")==0) return;
        }
    }

    /********************************/
    /*   Insert new global symbol   */
    /********************************/

addglb(sname,id,typ,value)
    char *sname,id,typ;
    int value;
    {
    char *ptr;

    if (cptr=findglb(sname)) return cptr;
    if (glbptr>=endglb)
        {
        error("global symbol table overflow");
        return 0;
        }
    cptr=ptr=glbptr;
    while (*ptr++ = *sname++);
    cptr[ident]=id;
    cptr[type]=typ;
    cptr[storage]=statik;
    cptr[offset]=value;
    cptr[offset+1]=value>>8;
    glbptr=glbptr+symsiz;
    return cptr;
    }

    /********************************/
    /*  Find a global symbol name   */
    /********************************/

findglb(sname)
    char *sname;
    {
    char *ptr;

    ptr=startglb;
```

```
    while (ptr!=glbptr)
        {
        if (*sname == *ptr)         /* check lengths */
            if (streq(sname,ptr)) return ptr;
        ptr=ptr+symsiz;
        }
    return 0;
    }

    /********************************/
    /*    Insert new local symbol   */
    /********************************/

addloc(sname,id,typ,value)
    char *sname,id,typ;
    int value;
    {
    char *ptr;

    if (cptr=findloc(sname)) return cptr;
    if (locptr>=endloc)
        {
        error("local symbol table overflow");
        return 0;
        }
    cptr=ptr=locptr;
    while (*ptr++ = *sname++);
    cptr[ident]=id;
    cptr[type]=typ;
    cptr[storage]=stkloc;
    cptr[offset]=value;
    cptr[offset+1]=value>>8;
    locptr=locptr+symsiz;
    return cptr;
    }

    /********************************/
    /*  Find a local symbol name    */
    /********************************/

findloc(sname)
    char *sname;
    {
    char *ptr;

    ptr=startloc;
    while (ptr!=locptr)
        {
        if (*sname == *ptr)         /* check lengths */
            if (streq(sname,ptr)) return ptr;
        ptr=ptr+symsiz;
        }
    return 0;
    }
```

```
    /*********************************/
    /*  Put a new macro definition  */
    /*        in the table          */
    /*********************************/

addmac()
    {
    char sname[namesize], *sn, *mn;

    if (symname(sname)==0)
        {
        errname();
        resetptr();
        return;
        }
    sn=sname; mn=mactptr;
    if  (macpmax >= macpptr)
        {               /* add macro to table */
        while (*mn++ = *sn++);
        *macpptr++ = macbptr; mactptr = mactptr + namesize;
        }
    else error("macro count exceeded");
    while (*ch==' ' | *ch==tabch) gch();
    while (*macbptr++ = gch()) /* add macro body to buffer */
        {
        if (macbptr>=macbmax)
            {error("macro table full");break;}
        }
    }

    /*********************************/
    /* Look up possible macro name   */
    /*********************************/

findmac(sname)
    char *sname;
    {
    int *mqp;
    char *mqt;

    mqp=macp; mqt=mact;
    while (mqp<macpptr)
        {
        if (*sname == *mqt)     /* check lengths */
            if (streq(sname,mqt)) return (*mqp);
        mqt=mqt+namesize; mqp++;
        }
    return 0;
    }

    /*********************************/
    /*  WHILE table manipulations    */
    /*********************************/

addwhile(ptr)
```

```
    int ptr[];
    {
    int k;

    if (wqptr==wqmax)
        { error("too many active whiles"); return; }
    k=0;
    while (k<wqsiz)
        { *wqptr++=ptr[k++]; }
    }

delwhile()
    {
    if (readwhile()) wqptr=wqptr-wqsiz;
    }

readwhile()
    {
    if (wqptr==wq)
        { error("no active whiles"); return 0; }
    else return (wqptr-wqsiz);
    }

    /**********************************/
    /*     Generate next label        */
    /**********************************/

getlabel()
    {
    return(++nxtlab);
    }

    /**********************************/
    /*      Read symbol name          */
    /**********************************/

symname(sname)
    char *sname;
    {
    int k;

    skipblanks();
    if (alpha(*ch)==0) return 0;
    k=1;
    while (an(*ch)) sname[k++]=gch();
    sname[k]=0;
    sname[0]=k-1; /* first 'char' is length of symbol */
    return 1;
    }

    /**********************************/
    /* Check for a number in input    */
    /**********************************/

number(val)
```

```
    int val[];
    {
    int k, minus;
    char c;

    k=minus=1;
    while (k)
        {
        k=0;
        if (match("+")) k=1;
        if (match("-")) { minus=(-minus); k=1; }
        }
    if (numeric(*ch)==0) return 0;
    while (numeric(*ch))
        {
        c=inbyte();
        k=k*10+(c-'0');
        }
    if (minus<0) k=(-k);
    val[0]=k;
    return 1;
    }

    /*********************************/
    /*       Load a constant        */
    /*********************************/

constant(val)
    int val[];
    {
    if (number(val)) immed();
    else if (getqchar(val)) immed();
        else if (getqstring(val))
                {
                immed();
                outlabel(litlab);
                outbyte('+');
                }
             else return 0;
    outdec(val[0]);
    nl;
    return 1;
    }

    /*********************************/
    /*  Get one or two characters   */
    /*     from input stream        */
    /*********************************/

getqchar(val)
    int val[];
    {
    int k;
    char c;

```

```
    k=0;
    if (match("'")==0) return 0;
    if ( (c=gch())==bslch )     /* escape sequence? */
        {
        if ( (c=gch())=='n') k=eolch;  /* newline   */
        else if (c=='t') k=tabch;      /* tab       */
        else if (c=='b') k=bspch;      /* backspace */
        else if (c=='r') k=crch;       /* return    */
        else if (c=='f') k=ffch;       /* form feed */
        else if (c=='\\') k=bslch;     /* backslash */
        else if (c=='0') k=0;          /* null      */
        else k=c;
        }
    else k=c;
    if (match("'")==0) return 0;
    val[0]=k;
    return 1;
    }

    /*********************************/
    /* Get string from input stream */
    /*********************************/

getqstring(val)
    int val[];
    {
    char c;

    if (match(quote)==0) return 0;
    val[0]=litptr;
    while ( *ch!='"' )
        {
        if ( *ch==0 ) break;
        if (litptr >= litmax)
            {
            error("string space exhausted");
            while (match(quote)==0) if (gch()==0) break;
            return 1;
            }
        litq[litptr++]=gch();
        }
    gch();
    litq[litptr++]=0;
    return 1;
    }

    /*********************************/
    /*       String compare         */
    /*********************************/

streq(str1, str2)
    char *str1, *str2;
    {
    int k;

```

```
    k=0;
    while (*str2)
        {
        if ((*str1)!=(*str2)) return 0;
        k++; str1++; str2++;
        }
    return k;
    }

    /*******************************/
    /*  String compare over `len'  */
    /*        characters           */
    /*******************************/

astreq(str1, str2, len)
    char *str1, *str2;
    int  len;
    {
    int k;

    k=0;
    while (k<len)
        {
        if ((*str1)!=(*str2)) break;
        if (*str1==0) break;
        if (*str2==0) break;
        k++; str1++; str2++;
        }
    if (an(*str1)) return 0;
    if (an(*str2)) return 0;
    return k;
    }

    /*******************************/
    /*  Compare literal with line  */
    /*  buffer contents, advancing */
    /*   buffer pointer if found   */
    /*******************************/

match(lit)
    char *lit;
    {
    int k;

    skipblanks();
    if (k=streq(ch,lit))
        { ch=ch+k; nexch=ch+1; return 1; }
    return 0;
    }

    /*******************************/
    /*  As `match', but over `len' */
    /*        characters           */
    /*******************************/
```

```
amatch(lit, len)
    char *lit;
    int len;
    {
    int k;

    skipblanks();
    if (k=astreq(ch,lit,len))
        {
        ch=ch+k; nexch=ch+1;
        while (an(*ch)) inbyte();
        return 1;
        }
    return 0;
    }

    /********************************/
    /*     Get array bounds         */
    /********************************/

needsub()
    {
    int   num[1];

    if (match("]")) return 0;
    if (number(num)==0)
        {
        error("must be constant");
        num[0]=1;
        }
    if (num[0]<0)
        {
        error("negative size illegal");
        num[0]=(-num[0]);
        }
    needbrack("]");
    return num[0];
    }

    /********************************/
    /*    Check for semicolon       */
    /********************************/

needsemi()
    {
    if (match(";")==0) error("missing semicolon");
    }

    /********************************/
    /*  Check for end of statement  */
    /********************************/

needstend()
    {
    skipblanks();
```

```
    return ((streq(ch,";") | (*ch==0)));
    }

needbrack(str)
    char *str;
    {
    if (match(str)==0)
        {
        error("missing bracket");
        comment; outstr(str); nl;
        }
    }

    /*********************************/
    /*  Skip white space in input    */
    /*********************************/

skipblanks()
    {
    while (1)
        {
        while (*ch==0)
            {
            inline();
            preprocess();
            if (eof) break;
            }
        if (*ch==' ') gch();
        else if (*ch==tabch) gch(); else return;
        }
    }

    /*********************************/
    /*   Skip this token and all     */
    /*   succeeding white space      */
    /*********************************/

skipchars()
    {
    if (an(inbyte())) while (an(*ch)) gch();
    else while (an(*ch)==0)
        { if (*ch==0) break; gch(); }
    skipblanks();
    }

    /*********************************/
    /*     Test input character      */
    /*********************************/

alpha(c)
    char c;
    {
    if ( (c >= 'a')&(c <= 'z') ) return 1;
    if ( (c >= 'A')&(c <= 'Z') ) return 1;
    return  (c=='_') ;
```

```
        }

numeric(c)
        char c;
        {
        return((c>='0')&(c<='9'));
        }

an(c)
        char c;
        {
        if ( (c >= '0')&(c <= '9') ) return 1;
        if ( (c >= 'a')&(c <= 'z') ) return 1;
        if ( (c >= 'A')&(c <= 'Z') ) return 1;
        return  (c=='_') ;
        }

        /*********************************/
        /* Get a character - read in a  */
        /* line and preprocess if you   */
        /*          have to             */
        /*********************************/

inbyte()
        {
        while (*ch==0)
            {
            if (eof) return 0;
            inline();
            preprocess();
            }
        return gch();
        }

        /*********************************/
        /* Get a character - read in a  */
        /*   line if you have to, but   */
        /* don't preprocess (since this */
        /* is called from preprocessor!)*/
        /*********************************/

inchar()
        {
        if (*ch==0) inline();
        if (eof) return 0;
        return (gch());
        }

        /*********************************/
        /*       Read in a line         */
        /*********************************/

inline()
        {
        int k,unit;
```

```

     while(1)
         {
         if (input==0)
             if ( mulfile) openin(); else eof=1;
         if (eof) return;
         if ((unit=input2)==0) unit=input;
         resetptr();
         while ((k=getc(unit))>0)
             {
             if ((k==eolch) | (ch>=chmax))
                 { lncnt++; break; }
             *ch++=k;
             }
         *ch=0;
         if (k<=0)
             {
             fclose(unit);
             if (input2) input2=0; else input=0;
             }
         if (ch>line)
             {
             if ((ctext)&(cmode))
                 {
                 comment;
                 outstr(line);
                 nl;
                 }
             ch=line; nexch=ch+1;
             return;
             }
         }
     }

     /*********************************/
     /*  Preprocess a line - expand  */
     /* macros and remove redundant  */
     /*      tabs and spaces          */
     /*********************************/

preprocess()
     {
     int k;
     char c,sname[namesize],*mq;

     if (cmode==0) return;
     mptr=mline; ch=line; nexch=ch+1;
     while (*ch)
         {
         if ((*ch==' ') | (*ch==tabch))
             {
             keepch(' ');
             while ((*ch==' ') | (*ch==tabch)) gch();
             }
         else if (*ch=='"')
```

```
            {
            keepch(*ch);
            gch();
            while (*ch!='"')
                {
                if (*ch==0)
                    {error("missing quote");break;}
                keepch(gch());
                }
            gch();
            keepch('"');
            }
        else if (*ch==quoch)
            {
            keepch(quoch);
            gch();
            while (*ch!=quoch)
                {
                if (*ch==0)
                    {error("missing apostrophe");break;}
                keepch(gch());
                }
            gch();
            keepch(quoch);
            }
        else if ((*ch=='/') & (*nexch=='*'))
            {
            inchar(); inchar();
            while (((*ch=='*') & (*nexch=='/'))==0)
                {
                if (*ch==0) inline(); else inchar();
                if (eof) break;
                }
            inchar(); inchar();
            }
        else if (an(*ch))
            {
            k=1;
            while (an(*ch))
                {
                if (k<namemax) sname[k++]= *ch;
                gch();
                }
            sname[k]=0; sname[0]=k-1;
            if (mq=findmac(sname))
                while (c= *mq++) keepch(c);
            else
                {
                k=1;
                while (c=sname[k++]) keepch(c);
                }
            }
        else keepch(gch());
        }
    keepch(0);
```

```
    if (mptr>=mpmax) error("line too long");
    mptr=mline; ch=line; nexch=ch+1;

    /* copy back to line buffer and strip parity for keeps */

    while (*ch++= *mptr++&127);
    ch=line;
    }

    /*********************************/
    /*      Reset input buffer       */
    /*********************************/

resetptr()
    {
    ch=line; nexch=ch+1; *ch=0;
    }

    /*********************************/
    /*    Get next input character   */
    /*********************************/

gch()
    {
    if (*ch==0) return 0;
    else { nexch++; return (*ch++);}
    }

    /*********************************/
    /* Save this character in buffer*/
    /*********************************/

keepch(c)
    char c;
    {
    *mptr=c;
    if (mptr<mpmax) mptr++;
    return c;
    }

    /*********************************/
    /*    Get options from user      */
    /*********************************/

ask()
    {
    resetptr();          /* clear input line      */
    clearscreen;         /* clear the screen      */
    display("        RatC : Lancaster implementation");
    display("        -------------------------------");
    nl; nl;
    glbflag=1;  nxtlab=1;  mulfile=0;
    display("Defaults:");
    display("       Globals defined    y");
    display("           First label    1");
```

```
    display("        Multiple files   n");
    nl;
    display("       Change defaults ? ");
    if (reply()) defaults();

    litlab=getlabel();  /* first label = literal pool */

            /* see if user wants to interleave c-text */
    ctext=0;
    display("      C-text to appear ? ");
    ctext=reply();

    resetptr();                         /* erase line */
    }

defaults()
    {
    int k,num[1];

          /* see if user wants us to allocate static  */
          /* variables by name in this module         */
          /* (pseudo external capability)             */
    display("     Globals to be defined ? ");
    glbflag=reply();

      /* get first allowable # for compiler-generated */
      /* labels (so user can append modules)          */
    while(1)
        {
        display("Starting number for labels ? ");
        gets(line);
        if (*ch==0) {num[0]=0; break;}
        if (k=number(num)) break;
        }
    nxtlab=num[0];

                    /* find out if one input file only */
    display("      Multiple input files ? ");
    mulfile=reply();
    }

    /*********************************/
    /* Print a string to console    */
    /*********************************/

display(str)
    char *str;
    {
    int k;

    k=0;
    putchar(eolch);
    while (str[k]) putchar(str[k++]);
    }
```

```
reply()
	{
	resetptr();	/* clear input buffer */
	gets(line);
	if ((*ch=='Y') | (*ch=='y')) return 1; else return 0;
	}

	/********************************/
	/*	Get output filename	*/
	/********************************/

openout()
	{
	resetptr();	/* erase line	*/
	output=0;	/* start with none	*/
	display("	Output filename ? ");
	gets(line);
	if (*ch==0) return;	/* none given */
	if ((output=fopen(line,"w"))==NULL)
		{ output=0; error("Open failure"); }
	resetptr();
	}

	/********************************/
	/*	Get (next) input file	*/
	/********************************/

openin()
	{
	input=0;	/* none to start with	*/
	while (input==0)
		{
		resetptr();
		if (eof) break;
		display("		Input filename ? ");
		gets(line);
		if (*ch==0) { eof=1; break; }
		if ((input=fopen(line,"r"))==NULL)
			{ input=0; display("Open failure"); }
		}
	resetptr();
	}

	/********************************/
	/*	Open an include file	*/
	/********************************/

openinclude()
	{
	skipblanks();
	if ((input2=fopen(ch,"r"))==NULL)
		{ input2=0; error("Open failure on include file"); }
	resetptr();
	}
```

```
    /***********************************/
    /*      Close the output file      */
    /***********************************/

closeout()
    {
    if (output) fclose(output);
    output=0;
    }

    /***********************************/
    /*        Error reporting          */
    /***********************************/

errlval()
    {
    error("must be lvalue");
    }

errmulti(sname)
    char *sname;
    {
    error("already defined");
    comment;
    outstr(sname); nl;
    }

errname()
    {
    error("illegal symbol name"); skipchars();
    }

    /***********************************/
    /* Report type and position of     */
    /* an error in the source line     */
    /***********************************/

error(ptr)
    char ptr[];
    {
    char *k;

    comment;outstr(line);nl;comment;
    k=line;
    while (k<ch)
        {
        if (*k==tabch) tab; else space;
        ++k;
        }
    outbyte('^');
    nl; comment; outstr("------ ");
    outstr(ptr);
    outstr(" ------");
    display(line); display(ptr);  /* to console too */
    nl;
```

```
    ++errcnt;
    }

    /**********************************/
    /*    Report errors for user    */
    /**********************************/

errorsummary()
    {
    if (ncmp) error("missing closing bracket");
        /* open compound statement  */
    nl;
    outdec(errcnt);     /* total # errors   */
    outstr(" errors in compilation.");
    nl;

    nl;
    outdec(inscnt); /* total # instructions */
    outstr(" instructions generated.");
    nl;

    nl;
    outdec(lncnt);  /* total # source lines */
    outstr(" source lines.");
    nl;
    }

    /**********************************/
    /*     Output a character      */
    /**********************************/

outbyte(c)
    char c;
    {
    if (c==0) return 0;
    if (output)
        {
        if ((putc(c,output))<=0)
            { closeout(); error("output file error"); }
        }
    else putchar(c);
    return c;
    }

    /**********************************/
    /* Output a number in decimal   */
    /**********************************/

outdec(num)
    int num;
    {
    int k, zs;
    char c;

    zs=0;
```

```
    k=10000;
    if (num<0)
        {
        num=(-num);
        outbyte('-');
        }
    while (k>=1)
        {
        c=num/k+'0';
        if ((c!='0')|(k==1)|(zs)) { zs=1; outbyte(c); }
        num=num%k;
        k=k/10;
        }
    }

    /**********************************/
    /*      Output a string           */
    /**********************************/

outstr(ptr)
    char ptr[];
    {
    int k;

    /* ignore length byte if there is one */
    if (ptr[0]<32) k=1; else k=0;
    while (outbyte(ptr[k++]));
    }

    /**********************************/
    /*       Print a label            */
    /**********************************/

outlabel(label)
    int label;
    {
    outstr("cc");
    outdec(label);
    }

    /**********************************/
    /*     Instruction output         */
    /**********************************/

outline(ptr)
    char ptr[];
    { outtab(ptr); nl; }

outtab(ptr)
    char ptr[];
    { tab; outstr(ptr); inscnt++; }

    /**********************************/
    /*     Evaluate condition         */
    /**********************************/
```

```

test(label)
	int label;
	{
	needbrack("(");
	expression();
	needbrack(")");
	testjump(label);
	nl;
	}

	/**********************************/
	/*    Store a value in memory   */
	/**********************************/

store(lval)
	int *lval;
	{
	if (lval[1]==0) putmem(lval[0]);
	else putstk(lval[1]);
	}

	/**********************************/
	/*    Get a value from memory   */
	/**********************************/

rvalue(lval)
	int *lval;
	{
	if ((lval[0]!=0) & (lval[1]==0)) getmem(lval[0]);
	else indirect(lval[1]);
	}

	/**********************************/
	/*   Load direct 8 or 16 bits   */
	/*    into primary register     */
	/**********************************/

getmem(sym)
	char *sym;
	{
	if ((sym[ident]!=pointer) & (sym[type]==cchar))
	    outtab("ldir.b");
	else outtab("ldir.w");
	outline(sym+name+1);
	}

	/**********************************/
	/* Given offset from SP, get    */
	/* address into primary register*/
	/**********************************/

getloc(sym)
	char *sym;
	{
```

```
    outtab("addr"); tab;
    outdec(((sym[offset]&255)+((sym[offset+1]&255)<<8))-sp);
    nl;
    }

    /*********************************/
    /*  Store direct 8 or 16 bits   */
    /*    from primary register     */
    /*********************************/

putmem(sym)
    char *sym;
    {
    if ((sym[ident]!=pointer) & (sym[type]==cchar))
        outtab("sdir.b");
    else outtab("sdir.w");
    tab; outstr(sym+name);
    nl;
    }

    /*********************************/
    /* Store indirect 8 or 16 bits  */
    /* at address on top of stack   */
    /*********************************/

putstk(typeobj)
    char typeobj;
    {
    pop();
    if (typeobj==cchar) outline("sind.b");
    else outline("sind.w");
    }

    /*********************************/
    /*  Load indirect 8 or 16 bits  */
    /*  at address in primary reg   */
    /*    into primary register     */
    /*********************************/

indirect(typeobj)
    char typeobj;
    {
    if (typeobj==cchar) outline("lind.b");
    else outline("lind.w");
    }

    /*********************************/
    /*      Call subroutine         */
    /*********************************/

call(sname)
    char *sname;
    {
    outtab("call");
    tab; outstr("_"); outstr(sname);
```

```
    nl;
    }

    /********************************/
    /*  Subroutine call to address  */
    /*   on top of stack, return    */
    /*    address left on stack     */
    /********************************/

callstk()
    {
    outline("scall");
    sp=sp+intwidth;
    }

    /********************************/
    /*  Jump to specified internal  */
    /*        label number          */
    /********************************/

jump(label)
    int label;
    {
    outtab("ujump");
    tab; outlabel(label);
    nl;
    }

    /********************************/
    /* Jump to specified label if   */
    /* primary reg  is false (zero) */
    /********************************/

testjump(label)
    int label;
    {
    outtab("fjump");
    tab; outlabel(label);
    }

    /********************************/
    /* Modify stack pointer to new  */
    /*       value indicated        */
    /********************************/

modstk(newsp)
    int newsp;
    {
    int k;
    k=newsp-sp;
    if (k==0) return newsp;
    outtab("modstk");
    tab; outdec(k);
    nl;
    return newsp;
```

```
    }

    /*  start of main segment          */
header()    { outline("start"); }
    /*  swap primary and secondary     */
swap()      { outline("swap"); }
    /*  partial load immediate         */
immed()     { outtab("limm");tab; }
    /*  push primary onto stack        */
push()      { outline("push"); sp=sp-intwidth; }
    /*  pop top of stack into secondary */
pop()       { outline("pop"); sp=sp+intwidth; }
    /*  swap primary and top of stack   */
swapstk()   { outline("xchange"); }
    /*  return from subroutine         */
ret()       { outline("return"); }

    /********************************/
    /*   Arithmetic and logical     */
    /*  instructions - result in    */
    /*      primary register        */
    /********************************/

    /*  scale primary by n                          */
scale(n)
    int n;
    {
    outtab("scale");
    tab; outdec(n); nl;
    }
    /*  add primary and secondary                   */
add()       { outline("add"); }
    /*  subtract primary from secondary             */
sub()       { outline("sub"); }
    /*  multiply primary and secondary              */
mult()      { outline("mult"); }
    /*  divide secondary by primary                 */
    /*  quotient in primary, rem in secondary       */
div()       { outline("div"); }
    /*  mod of secondary divided by primary         */
    /*  rem in primary, quotient in secondary       */
mod()       { div(); swap(); }
    /*  inclusive or of primary and secondary       */
or()        { outline("or"); }
    /*  exclusive or of primary and secondary       */
xor()       { outline("xor"); }
    /*  logical and of primary and secondary        */
and()       { outline("and"); }
    /*  arithmetic shift right of secondary,        */
    /*  number of times in primary                  */
asr()       { outline("asr"); }
    /*  arithmetic shift left                       */
asl()       { outline("asl"); }
    /*  twos complement of primary                  */
neg()       { outline("neg"); }
```

```
        /*  increment primary by n                    */
inc(n)
        int n;
        {
        outtab("inc");
        tab; outdec(n); nl;
        }
        /*  decrement primary by n                    */
dec(n)
        int n;
        {
        outtab("dec");
        tab; outdec(n); nl;
        }

        /*********************************/
        /* Conditional instructions -   */
        /* compare secondary against    */
        /* primary, put 1 in primary if */
        /*     true, otherwise 0        */
        /*********************************/

        /*  test for =               */
eq()          { outline("testeq"); }
        /*  !=                       */
ne()          { outline("testne"); }
        /*  < (signed)               */
lt()          { outline("testlt"); }
        /*  <=                       */
le()          { outline("testle"); }
        /*  > (signed)               */
gt()          { outline("testgt"); }
        /*  >= (signed)              */
ge()          { outline("testge"); }
        /*  <  (unsigned)            */
ult()         { outline("testult"); }
        /*  <= (unsigned)            */
ule()         { outline("testule"); }
        /*  > (unsigned)             */
ugt()         { outline("testugt"); }
        /*  >= (unsigned)            */
uge()         { outline("testuge"); }

        /*********************************/
        /*    Dump the literal pool     */
        /*********************************/

dumplits()
        {
        int j,k;

        if (litptr==0) return;     /* if nothing there, exit  */
        outlabel(litlab); colon;   /* print literal label     */
        k=0;                       /* init an index ...       */
        while (k<litptr)           /* ... to loop with        */
```

```
        {
        defbyte();            /* pseudo-op to define byte*/
        j=5;                  /* max bytes per line      */
        while (j--)
            {
            outdec((litq[k++]));
            if ((j==0) | (k>=litptr))
                {  nl; break; }
            comma;            /* separate bytes          */
            }
        }
    }

    /********************************/
    /*   Dump all static variables  */
    /********************************/

dumpglbs()
    {
    int j;

    if (glbflag==0) return;   /* don't if user said no   */
    cptr=startglb;
    while (cptr<glbptr)
        {
        if (cptr[ident]!=function)
                          /* do if anything but function */
            {
            outstr(cptr); colon;
                          /* output name as label        */
            defstorage(); /* define storage              */
            j=((cptr[offset]&255)+
                ((cptr[offset+1]&255)<<8));
                          /* calculate # bytes           */
            if ((cptr[type]==cint) |
                (cptr[ident]==pointer))
                j=j*intwidth;
            outdec(j);    /* need that many              */
            nl;
            }
        cptr=cptr+symsiz;
        }
    }

    /*  literal definitions         */
defbyte()   { outtab("db "); }
defstorage()    { outtab("ds "); }

    /*  end of assembly             */
trailer()
    {
    outtab("end");
    if (hasmain) outtab("start");
    nl;
    }
```

```
/**********************************/
/*  <<< end of the compiler >>> */
/**********************************/

[ style 87.8 ]
```

CROSS-REFERENCE LISTING

```
NULL              1933  1952  1965

add()              795   977 *2331
addglb()           290  1040  1113 *1167
addloc()           307  1156 *1213
addmac()           263 *1260
address           *344   364   366   367
addwhile()         459 *1309
alpha()           1352 *1634
amatch()           254   256   322   324   384   386   390   392
                   394   396   398   434 *1530
an()              1354  1503  1504  1540  1624  1624  1625 *1648
                  1785  1788
and()              615 *2347
argptr            *345   360   362   363   364   365   366   367
argstk            *161   299   307   308   308   319   320   349
                   371   371
argtop            *276   319   323   325   341  *342   364
array             #71    967  1027  1033  1110  1143
ask()              227 *1849
asl()              770 *2352
asr()              763 *2350
astreq()           294 *1489  1537

bslch             #30   1422  1429
bspch             #24   1426

c                 *345 *1368  1380  1381 *1418  1422  1424  1425
                  1426  1427  1428  1429  1430  1431  1433 *1446
                  1634 *1635  1637  1637  1638  1638  1639  1642
                 *1643  1645  1645  1648 *1649  1651  1651  1652
                  1652  1653  1653  1654 *1738  1795  1795  1799
                  1799  1837 *1838  1840  1842  2056 *2057  2059
                  2062  2065  2066 *2077  2088  2089  2089
call()            1079 *2240
callfunction()     984   988   990 *1061
callstk()         1080 *2254
cchar             #78    255   323   385  1153  2176  2203  2219
                  2232
ch                *152   313   383   562   584   606   630   630
                   660   660   703   703   723   723   754   754
                   783   783   818   818   818   953   953  1069
                  1277  1277  1352  1354  1377  1378  1450  1452
```

	1520	1521	1521	1521	1537	1539	1539	1539
	1540	1585	1585	1606	1612	1613	1624	1625
	1626	1665	1683	1705	1707	1709	1715	1723
	1723	1741	1741	1742	1744	1744	1747	1747
	1749	1751	1753	1755	1762	1766	1768	1775
	1778	1780	1785	1788	1790	1806	1806	1810
	1811	1820	1820	1820	1829	1830	1891	1919
	1919	1932	1951	1965	2014			
charwidth	#19	861	873	918	922	933	937	1153
chmax	*152	193	1705					
cint	#79	257	290	325	387	793	803	859
	871	888	916	920	931	935	975	1026
	1040	1144	2444					
clearscreen	#20	1852						
closeout()	237	*1974	2063					
cmode	*173	221	513	523	1717	1740		
colon	#37	296	436	440	444	460	464	2407
	2438							
comma	#38	2418						
comment	#40	230	1594	1719	1993	2012	2012	2020
compound()	389	*411						
constant()	1045	*1392						
cptr	*178	670	671	676	677	689	690	695
	696	709	710	715	716	729	730	735
	736	791	792	793	801	802	803	1173
	1173	1179	1181	1182	1183	1184	1185	1187
	1219	1219	1225	1227	1228	1229	1230	1231
	1233	2432	2433	2435	2438	2441	2442	2444
	2445	2450	2450					
crch	#28	1427						
ctext	*172	1717	1868	1870				
dec()	872	873	921	922	932	933	*2363	
declglb()	255	257	*1092					
declloc()	385	387	*1124					
defaults()	1863	*1875						
defbyte()	2411	*2455						
defstorage()	2440	*2456						
delwhile()	467	*1321						
display()	1853	1854	1857	1858	1859	1860	1862	1869
	1882	1889	1897	*1905	1930	1949	1953	2023
	2023							
div()	834	*2338	2341					
doasm()	259	402	*511					
dobreak()	357	*485						
docont()	399	*498						
doif()	391	*423						
doreturn()	395	*474						
dowhile()	393	*451						
dumpglbs()	235	*2427						
dumplits()	234	*2402						
endglb	#49	#50	1174					
endloc	#51	1220						
eof	*166	199	252	383	415	518	1610	1667

	1684	1699	1700	1781	1948	1951		
eolch	#26	#35	1424	1705	1911			
eq()	639	*2378						
errcnt	*163	207	2025	2037				
errlval()	546	855	867	912	927	*1984		
errmulti()	286	287	304	1106	1137	*1989		
errname()	351	1105	1136	1266	*1997			
error()	280	293	311	315	326	369	373	896
	960	969	1048	1176	1222	1276	1281	1315
	1329	1455	1557	1562	1575	1593	1756	1769
	1805	1934	1966	1986	1992	1999	*2007	2034
	2063							
errorsummary()	238	*2032						
expression()	403	476	*531	973	1072	2140		
fclose()	1712	1976						
ffch	#27	1428						
findglb()	284	1029	1106	1173	*1194			
findloc()	304	360	1021	1137	1219	*1240		
findmac()	*1289	1794						
flab1	*425	429	430	436	440			
flab2	*425	439	444					
flev	*425	427	433	443				
fopen()	1933	1952	1965					
fsp	*425	428	432	442				
function	#73	286	287	288	290	290	985	996
	1029	1040	2435					
gch()	1277	1278	1354	1422	1424	1456	1459	1461
	1612	1613	1624	1626	1671	1685	1747	1752
	1757	1759	1765	1770	1772	1791	1802	*1827
ge()	701	*2388						
getarg()	323	325	*341					
getc()	1703							
getlabel()	429	439	457	458	*1337	1865		
getloc()	1023	*2187						
getmem()	2164	*2173						
getqchar()	1396	*1414						
getqstring()	1397	*1443						
gets()	1890	1918	1931	1950				
glbflag	*170	1856	1883	2431				
glbptr	*136	191	1174	1179	1186	1186	1200	2433
gt()	741	*2386						
hasmain	*179	210	295	2462				
header()	295	*2303						
hier1()	535	*538	548	1015				
hier10()	816	832	839	*847	855	867	879	886
	895							
hier11()	909	*944						
hier2()	543	*555						
hier3()	560	569	*577					
hier4()	582	591	*599					
hier5()	604	613	*621					
hier6()	626	637	644	*652				

hier7()	657	668	687	707	727	*747		
hier8()	752	761	768	*776				
hier9()	781	790	800	*811	825			
id	1167	*1168	1181	1213	*1214	1227		
ident	#57	286	362	671	677	690	696	710
	716	730	736	792	802	859	871	916
	920	931	935	965	967	985	996	1026
	1027	1029	1033	1181	1227	2176	2203	2435
	2445							
immed()	900	998	1034	1049	1395	1396	1399	*2307
inbyte()	354	705	725	1380	1540	1624	*1663	
inc()	860	861	917	918	936	937	*2356	
inchar()	*1681	1777	1777	1780	1783	1783		
indirect()	2165	*2229						
inline()	516	1608	1668	1683	*1692	1780		
input	*167	200	1698	1701	1713	1944	1945	1952
	1953							
input2	*169	201	1701	1713	1713	1965	1966	
inscnt	*164	208	2042	2130				
intwidth	#18	308	371	793	803	860	872	917
	921	932	936	975	1075	1144	1149	1154
	2257	2309	2311	2446				
j	*344	350	350	356	362	*1095	1103	1104
	1110	1111	1113	*1127	1134	1135	1143	1148
	1153	1156	*2404	2412	2413	2416	*2429	2441
	2446	2446	2447					
jump()	439	463	491	504	*2265			
k	*541	543	546	552	*558	560	562	563
	*580	582	584	585	*602	604	606	607
	*624	626	629	630	631	*655	657	660
	661	662	*750	752	754	755	*779	781
	783	784	*814	816	818	819	*850	855
	867	879	880	886	887	895	896	909
	912	927	940	*947	950	970	980	991
	993	995	1003	*1011	1015	1017	*1095	1102
	1109	1110	1113	*1127	1140	1141	1144	1144
	1149	1153	1154	1155	*1312	1316	1317	1318
	*1349	1353	1354	1355	1356	*1367	1370	1371
	1373	1374	1375	1381	1381	1383	1383	1384
	*1417	1420	1424	1425	1426	1427	1428	1429
	1430	1431	1433	1435	*1473	1475	1479	1481
	*1493	1495	1496	1501	1505	*1517	1520	1521
	*1534	1537	1539	*1694	1703	1705	1707	1710
	*1737	1787	1790	1790	1793	1793	1798	1799
	*1877	1892	*1908	1910	1912	1912	*2010	2013
	2014	2016	2017	*2076	2080	2086	2088	2089
	2090	2091	2091	*2102	2105	2105	2106	*2293
	2294	2295	2297	*2404	2408	2409	2415	2416
keepch()	1746	1751	1757	1760	1764	1770	1773	1795
	1799	1802	1804	*1837				
label	2113	*2114	2117	2136	*2137	2142	2265	*2266

```
               2269  2278 *2279  2282
laststst       *175   204   391   393   395   397   399   402
                403   404
le()            682 *2384
legalname      *344   351   358
len            1489 *1491  1496  1530 *1532  1537
line           *150   193   519  1715  1720  1723  1741  1806
               1811  1820  1890  1918  1931  1933  1950  1952
               2012  2013  2023
linemax        #112   193   194
linesize       #111  #112  *150  *151
lit            1514 *1515  1520  1530 *1531  1537
litabsz        #105  #106  *140
litlab         *159  1400  1865  2407
litmax         #106  1453
litptr         *141   197  1449  1453  1459  1462  2406  2409
               2416
litq           *140  1459  1462  2415
lncnt          *165   209  1706  2047
locptr         *136   192   298   334   427   433   443   455
                465  1220  1225  1232  1232  1246
lt()            721 *2382
lval           *533   535   535   538  *539   543   547   549
                555  *556   560   563   577  *578   582   585
                599  *600   604   607   621  *622   626   631
                652  *653   657   662   670   689   709   729
                747  *748   752   755   776  *777   781   784
                791   801   811  *812   816   819   847  *848
                855   856   857   858   862   867   868   869
                870   874   879   880   886   887   888   889
                889   890   895   897   901   903   909   913
                914   915   919   928   929   930   934   944
               *945   950   951   966   978   979   987   991
               1006 *1007  1015  1024  1025  1026  1031  1032
               1037  1041  1042  1045  1045  2150 *2151  2153
               2153  2154  2161 *2162  2164  2164  2164  2165
lval2          *541   548   548  *558   569   569  *580   591
                591  *602   613   613  *624   637   637   644
                644  *655   668   668   676   687   687   695
                707   707   715   727   727   735  *750   761
                761   768   768  *779   790   790   800   800
               *814   825   825   832   832   839   839

macb           *143   214   217
macbmax        *146   217  1280
macbptr        *145   214  1274  1278  1280
macbsize       #117  *143   217
macp           *147   215   216  1295
macpmax        *148   216  1271
macpptr        *148   215  1271  1274  1296
macssize       #119  *144
mact           *144   213  1295
mactptr        *145   213  1270  1274  1274
mactsize       #118  *147   216
main()         *189
```

offset	#60	287	288	364	365	366	367	1184
	1185	1230	1231	2191	2191	2441	2442	
openin()	229	1699	*1942					
openinclude()	261	*1962						
openout()	228	*1926						
or()	571	*2343						
outbyte()	#35	#36	#37	#38	#39	#40	1401	2019
	*2056	2084	2089	2106				
outdec()	1050	1404	2037	2042	2047	*2073	2117	2191
	2297	2328	2360	2367	2415	2447		
outlabel()	436	440	444	460	464	1400	*2113	2269
	2282	2407						
outline()	*2124	2179	2219	2220	2232	2233	2256	2303
	2305	2309	2311	2313	2315	2331	2333	2335
	2338	2343	2345	2347	2350	2352	2354	2378
	2380	2382	2384	2386	2388	2390	2392	2394
	2396							
output	*168	202	1929	1933	1934	1976	1976	1977
	2060	2062						
outstr()	231	296	296	519	901	999	1035	1594
	1720	1994	2012	2020	2021	2022	2038	2043
	2048	*2099	2116	2130	2206	2244	2244	2438
outtab()	2126	*2128	2177	2178	2190	2204	2205	2243
	2268	2281	2296	2307	2327	2359	2366	2455
	2456	2461	2462					
parse()	233	*250						
pointer	#72	350	356	671	677	690	696	710
	716	730	736	792	802	859	871	916
	920	931	935	965	1026	1103	1111	1134
	1148	1153	2176	2203	2445			
pop()	570	592	614	638	645	669	688	708
	728	762	769	794	804	826	833	840
	976	2218	*2311					
preprocess()	1609	1669	*1735					
primary()	950	*1006						
ptr	*275	284	286	287	288	*487	489	490
	491	*500	502	503	504	*851	858	859
	859	870	871	871	889	889	901	903
	915	916	916	920	920	930	931	931
	935	935	*948	951	958	965	967	975
	979	984	985	990	995	996	999	*1009
	1021	1023	1024	1025	1026	1027	1029	1029
	1031	1033	1035	1037	1040	1041	1061	*1062
	1068	1073	1079	1079	*1171	1179	1180	*1197
	1199	1200	1202	1203	1203	1204	1204	*1217
	1225	1226	*1243	1245	1246	1248	1249	1249
	1250	1250	1309	*1310	1318	2007	*2008	2021
	2023	2099	*2100	2105	2106	2124	*2125	2126
	2128	*2129	2130					
push()	547	568	590	612	636	643	667	686
	706	726	760	767	789	799	824	831
	838	856	868	913	928	972	1068	1074
	*2309							
putc()	2062							

putchar()	#20	#20	#20	1911	1912	2065		
putmem()	2153	*2200						
putstk()	2154	*2215						
quoch	#29	1762	1764	1766	1773			
quote	*177	219	220	1448	1456			
readwhile()	489	502	1323	*1326				
reply()	1863	1870	1883	1898	*1915			
resetptr()	281	522	1267	1702	*1818	1851	1872	1917
	1928	1935	1947	1955	1967			
ret()	331	478	*2315					
rvalue()	535	548	563	569	585	591	607	613
	631	637	644	662	668	687	707	727
	755	761	768	784	790	800	819	825
	832	839	857	869	880	887	914	929
	966	987	*2161					
scale()	793	803	975	*2324				
skipblanks()	265	312	561	583	605	627	658	753
	782	817	952	1067	1351	1519	1536	1584
	*1602	1627	1964					
skipchars()	311	961	1052	*1622	1999			
sn	*1262	1270	1273					
sname	*1009	1019	1021	1029	1040	*1095	1105	1106
	1106	1113	*1127	1136	1137	1137	1156	1167
	*1168	1173	1180	1194	*1195	1202	1203	1213
	*1214	1219	1226	1240	*1241	1248	1249	*1262
	1264	1270	1289	*1290	1298	1299	1346	*1347
	1354	1355	1356	*1738	1790	1793	1793	1794
	1799	1989	*1990	1994	2240	*2241	2244	
sp	*160	198	319	333	428	432	442	456
	466	1081	1081	1155	1155	1156	2191	2257
	2257	2294	2309	2309	2311	2311		
space	#39	2016						
startglb	#48	#49	191	1199	2432			
startloc	#50	192	298	334	1245			
stasm	#129	402						
statement()	328	*381	415	431	441	462		
statik	#84	1183						
stbreak	#127	397						
stcont	#128	399						
stexp	#130	403						
stif	#124	391						
stkloc	#85	1229						
storage	#59	1183	1229					
store()	549	862	874	919	934	*2150		
str	1588	*1589	1591	1594	1905	*1906	1912	1912
str1	1470	*1471	1478	1479	1489	*1490	1498	1499
	1501	1503						
str2	1470	*1471	1476	1478	1479	1489	*1490	1498
	1500	1501	1504					
streq()	313	703	703	723	723	754	754	1203
	1249	1299	*1470	1520	1585			
streturn	#126	328	395					

```
stwhile          #125   393
sub()             805 *2333
swap()          *2305  2341
swapstk()        1073 *2313
sym              2173 *2174  2176  2176  2179  2187 *2188  2191
                 2191  2200 *2201  2203  2203  2206
symname()         278   302   351  1019  1105  1136  1264 *1346
symsiz           #45    #49   #50   #51  1186  1204  1232  1250
                 2450
symtab           #48    #51  *135
symtbsz          #46    #51  *135

t                 341  *342   363
tab              #36   2016  2130  2190  2206  2244  2269  2282
                 2297  2307  2328  2360  2367
tabch            #25    #36  1277  1425  1613  1744  1747  2016
test()            430   461 *2136
testjump()       2142 *2278
trailer()         236 *2459
typ              1092 *1093  1113  1124 *1125  1144  1153  1156
                 1167 *1168  1182  1213 *1214  1228
type             #58    363   793   803   859   871   889   903
                  916   920   931   935   975   979  1025  1037
                 1182  1228  2176  2203  2444
typeobj          2215 *2216  2219  2229 *2230  2232

uge()             692   698 *2396
ugt()             732   738 *2394
ule()             673   679 *2392
ult()             712   718 *2390
unit            *1694  1701  1701  1703  1712

val              1364 *1365  1384  1392 *1393  1395  1396  1397
                 1404  1414 *1415  1435  1443 *1444  1449
value            1167 *1169  1184  1185  1213 *1215  1230  1231
variable         #70    350  1104  1135

wq               #92   *137   195  *453   455   456   457   458
                  459   460   461   463   464   465   466  1328
wqlab           #100    458   461   464   491
wqloop           #99    457   460   463   504
wqmax            #92   1314
wqptr           *138    195  1314  1318  1323  1323  1328  1330
wqsiz            #91    #92  1317  1323  1330
wqsp             #98    456   466   490   503
wqsym            #97    455   465
wqtabsz          #90    #92  *137

xor()             593 *2345

zs              *2076  2079  2089  2089
```

FUNCTION LIST (SORTED BY LINE NUMBER)

189	main()
250	parse()
273	newfunc()
341	getarg(t,argto
381	statement()
411	compound()
423	doif()
451	dowhile()
474	doreturn()
485	dobreak()
498	docont()
511	doasm()
531	expression()
538	hier1(lval)
555	hier2(lval)
577	hier3(lval)
599	hier4(lval)
621	hier5(lval)
652	hier6(lval)
747	hier7(lval)
776	hier8(lval)
811	hier9(lval)
847	hier10(lval)
944	hier11(lval)
1006	primary(lval)
1061	callfunction(p
1092	declglb(typ)
1124	declloc(typ)
1167	addglb(sname,i
1194	findglb(sname)
1213	addloc(sname,i
1240	findloc(sname)
1260	addmac()
1289	findmac(sname)
1309	addwhile(ptr)
1321	delwhile()
1326	readwhile()
1337	getlabel()
1346	symname(sname)
1364	number(val)
1392	constant(val)
1414	getqchar(val)
1443	getqstring(val
1470	streq(str1,
1489	astreq(str1,
1514	match(lit)
1530	amatch(lit,
1550	needsub()
1573	needsemi()
1582	needstend()
1588	needbrack(str)
1602	skipblanks()
1622	skipchars()
1634	alpha(c)
1642	numeric(c)
1648	an(c)
1663	inbyte()
1681	inchar()
1692	inline()
1735	preprocess()
1818	resetptr()
1827	gch()
1837	keepch(c)
1849	ask()
1875	defaults()
1905	display(str)
1915	reply()
1926	openout()
1942	openin()
1962	openinclude()
1974	closeout()
1984	errlval()
1989	errmulti(sname
1997	errname()
2007	error(ptr)
2032	errorsummary()
2056	outbyte(c)
2073	outdec(num)
2099	outstr(ptr)
2113	outlabel(label
2124	outline(ptr)
2128	outtab(ptr)
2136	test(label)
2150	store(lval)
2161	rvalue(lval)
2173	getmem(sym)
2187	getloc(sym)
2200	putmem(sym)
2215	putstk(typeobj
2229	indirect(typeo
2240	call(sname)
2254	callstk()
2265	jump(label)
2278	testjump(label
2290	modstk(newsp)
2303	header()
2305	swap()
2307	immed()
2309	push()
2311	pop()
2313	swapstk()
2315	ret()
2324	scale(n)
2331	add()
2333	sub()
2335	mult()
2338	div()
2341	mod()
2343	or()
2345	xor()
2347	and()
2350	asr()
2352	asl()
2354	neg()
2356	inc(n)
2363	dec(n)
2378	eq()
2380	ne()
2382	lt()
2384	le()
2386	gt()
2388	ge()
2390	ult()
2392	ule()
2394	ugt()
2396	uge()
2402	dumplits()
2427	dumpglbs()
2455	defbyte()
2456	defstorage()
2459	trailer()

FUNCTION LIST (SORTED BY NAME)

```
2331  add()
1167  addglb(sname,i
1213  addloc(sname,i
1260  addmac()
1309  addwhile(ptr)
1634  alpha(c)
1530  amatch(lit,
1648  an(c)
2347  and()
1849  ask()
2352  asl()
2350  asr()
1489  astreq(str1,
2240  call(sname)
1061  callfunction(p
2254  callstk()
1974  closeout()
 411  compound()
1392  constant(val)
2363  dec(n)
1092  declglb(typ)
1124  declloc(typ)
1875  defaults()
2455  defbyte()
2456  defstorage()
1321  delwhile()
1905  display(str)
2338  div()
 511  doasm()
 485  dobreak()
 498  docont()
 423  doif()
 474  doreturn()
 451  dowhile()
2427  dumpglbs()
2402  dumplits()
2378  eq()
1984  errlval()
1989  errmulti(sname
1997  errname()
2007  error(ptr)
2032  errorsummary()
 531  expression()
1194  findglb(sname)
1240  findloc(sname)
1289  findmac(sname)
1827  gch()
2388  ge()
 341  getarg(t,argto
1337  getlabel()
2187  getloc(sym)
2173  getmem(sym)
1414  getqchar(val)
1443  getqstring(val
2386  gt()
2303  header()
 538  hier1(lval)
 847  hier10(lval)
 944  hier11(lval)
 555  hier2(lval)
 577  hier3(lval)
 599  hier4(lval)
 621  hier5(lval)
 652  hier6(lval)
 747  hier7(lval)
 776  hier8(lval)
 811  hier9(lval)
2307  immed()
1663  inbyte()
2356  inc(n)
1681  inchar()
2229  indirect(typeo
1692  inline()
2265  jump(label)
1837  keepch(c)
2384  le()
2382  lt()
 189  main()
1514  match(lit)
2341  mod()
2290  modstk(newsp)
2335  mult()
2380  ne()
1588  needbrack(str)
1573  needsemi()
1582  needstend()
1550  needsub()
2354  neg()
 273  newfunc()
1364  number(val)
1642  numeric(c)
1942  openin()
1962  openinclude()
1926  openout()
2343  or()
2056  outbyte(c)
2073  outdec(num)
2113  outlabel(label
2124  outline(ptr)
2099  outstr(ptr)
2128  outtab(ptr)
 250  parse()
2311  pop()
1735  preprocess()
1006  primary(lval)
2309  push()
2200  putmem(sym)
2215  putstk(typeobj
1326  readwhile()
1915  reply()
1818  resetptr()
2315  ret()
2161  rvalue(lval)
2324  scale(n)
1602  skipblanks()
1622  skipchars()
 381  statement()
2150  store(lval)
1470  streq(str1,
2333  sub()
2305  swap()
2313  swapstk()
1346  symname(sname)
2136  test(label)
2278  testjump(label
2459  trailer()
2396  uge()
2394  ugt()
2392  ule()
2390  ult()
2345  xor()
```

Appendix 3: C Style Analysis

The features of a program that contribute to its 'elegance' are very much subjective, and often instinctive. A superficial analysis of a program's 'style' (that is, its visual presentation), while not being the only factor, is certainly an indicative, and easily automated, component.

Presented here is a suite of programs (specifically using some of the many 'software tools' available under the UNIX operating system, but generally programmable in any high-level language) that performs a textual analysis of a C program, yielding a percentage 'style score'.

STYLE ANALYSIS

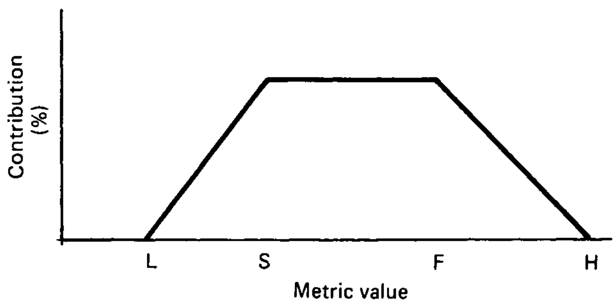
The features that contribute to the style score are based on proposals made by Rees (1982), adapted for C rather than Pascal:

Module length	The average length, in non-blank lines, of function definitions; functions that are prolific and too short tend to obscure the program logic, while those that are too long are difficult to dismember.
Identifier length	The average length, in characters, of user identifiers; brief identifier names (such as i or c) are often meaningless, while overlong names make the program verbose (most programmers will know that selection of pithy, meaningful identifier names is often one of the most time-consuming operations in writing a program).
Comments	The percentage of all lines that contain comments; over-commenting is as much of a sin as under-commenting; some comments, however, are always necessary, even in the shortest of programs.
Indentation	The ratio of initial spaces to total number of characters; indentation can be used to good effect to indicate the program structure.

Blank lines	The percentage of all lines that are blank; blank lines separate functional units of a program.
Line length	The average number of non-blank characters per line; sensible use of multiple statement lines can make a program visually concise, but not obscure.
Embedded spaces	The average number of embedded spaces per line; embedded spaces do for a line what blank lines do for a function.
Constant definitions	The percentage of all user identifiers that are defined constants: use of manifest constants not only makes a program easier to modify, it also associates meaning with the constant.
Reserved words	The number of different reserved words and standard functions used; the variety of reserved words used is indicative of command of the language.
Included files	The extent to which a program is segmented by using "#include" files; separating functional units of a program into different files breaks it down into more manageable chunks.
Goto statements	The number of occurrences of a "goto" statement; advocates of structured programming will usually allow the use of a single "goto" in a program to handle a special exit condition – more than that is a cardinal sin.

A score is associated with each of the above metrics, each contributing a different maximum percentage to the final score, in recognition of the fact that some factors are more important than others. All scores are additive, with the exception of the last, which is subtractive. Too high or too low a figure for each metric is detrimental to the final score.

The individual score is determined by reference to a table which specifies, for each metric (see figure below)



(1) the point L, below which no score is obtained
(2) the point S, the start of the 'ideal' range for the metric

(3) the point F, the finish of the ideal range
(4) the point H, above which no score is obtained.

Values between S and F score maximum marks; those between L and S, and F and H, score marks depending on their exact position within the range.

THE STYLE COMMAND

This is a command file, written in the UNIX command language (the 'shell'), to control the application of the various programs within the suite to the data (that is, the C program being analysed).

```
: ----- initialise some variables
TMP1=/tmp/TMP1$$
TMP2=/tmp/TMP2$$
RESULTS=/tmp/STATS$$
LIB=.
:
: ----- clean up on exit
trap "rm -f $TMP1 $TMP2 $RESULTS; trap ''0; exit" 0 1 2 13 15
:
: ----- analyse all programs presented
for i do
    echo; echo 'Style analysis of' $i
    if test -r $i
    then                :
                        : ----- count comment lines and total lines
          awk -f $LIB/style.cnt.awk $i >$RESULTS
                        :
                        : ----- replace tabs by spaces
                        : ----- convert to lower case
                        : ----- remove strings
                        : ----- remove comments
          $LIB/style.detab < $i |\
              tr 'A-Z' 'a-z' |\
              awk "/^main[ ]*\(/ { flag=1 }\
                            { if (flag+0) print }" |\
              sed -f $LIB/style.str.sed |\
              sed -n -f $LIB/style.com.sed >$TMP1
```

```
                    :
                    : ----- sort program words
        tr -cs 'a-z0-9' '\012' <$TMP1 |\
            sed -n '/^[a-z]/p' |\
            sort -u >$TMP2
                    :
                    : ----- find length of user identifiers
        comm -23 $TMP2 $LIB/style.dict |\
            awk '{totl+=length};\
                  END {printf "NL ";if (NR) print (totl/NR);else print 0;
                       print "ID " NR }' >>$RESULTS
                    :
                    : ----- count variety of reserved words
        comm -12 $TMP2 $LIB/style.dict |\
            (echo -n "RW ";wc -l;) >>$RESULTS
                    :
                    : ----- produce remaining metrics
        awk -f $LIB/style.met.awk $TMP1 >>$RESULTS
                    :
                    : ----- and analyse
        $LIB/style.stan <$RESULTS
    else echo "   Cannot read"; echo
    fi
done
```

THE PROGRAM STYLE.CNT.AWK

This program uses the awk pattern processor available under UNIX to count the number of commented lines, preprocessor directive lines and the total number of lines. As with all the remaining programs in the suite, it could easily, if not so concisely, be written in C.

```
# count commented lines
{if (index($0,"/*")||index($0,"*/")) comments++}

# count preprocessor lines
/^#include/     { includes++ }
/^#define/      { defines++ }
```

```
# report include files, defines, comment lines and total lines
END     {print "IF "(includes+0); print "DF "(defines+0)
         print "CL "(comments+0); print "TL "(NR+0)}
```

THE PROGRAM STYLE. DETAB

This program is translated from the version given by Kernighan and Plauger (1976) using the Ratfor programming language.

```
/************************************************************/
/* Detab - convert tabs to appropriate number of spaces    */
/*                                                          */
/* transcribed from Kernighan & Plauger's "Software Tools" */
/************************************************************/

#include        <stdio.h>
#define         MAXLINE 132
#define         TABSIZE 8

main()
{       int     ch, tabs[MAXLINE], col=1;

        settabs(tabs);

        while ( (ch=getchar()) != EOF )
                if ( ch=='\t' )
                        do      { putchar(' '); col++; }
                        while   ( !tabpos(col,tabs) );
                else if ( ch=='\n' )
                        { putchar('\n'); col=1; }
                else    { putchar(ch); col++; }
}

        /* set up tab positions */

settabs(tabs)
int     tabs[MAXLINE];

{       int     i;

        for ( i=1; i<=MAXLINE; i++ )
                if ( (i%TABSIZE)==1 ) tabs[i]=1;  else tabs[i]=0;
```

```
}

        /* see if we're at a tab position */

tabpos(col, tabs)
int     col, tabs[MAXLINE];

{
        if ( col>MAXLINE ) return(1); else return(tabs[col]);
}


[ style 82.7 ]
```

THE PROGRAM STYLE.STR.SED

This program uses another of the UNIX software tools, sed, a stream editor, to remove characters between double or single quotes, to obviate their inclusion in subsequent metric calculations.

```
# Destring a C program and replace comment delimiters
# with single characters (easier later)

# take out both types of string
s/'[^']*'//g
s/"[^"]*"//g

# replace comment delimiters
s/\/\*/\/g
s/\*\//`/g
```

THE PROGRAM STYLE.COM.SED

The sed utility is used again to remove all comments now that they have been counted.

```
# Decomment a C program

:start
                                        # strip trailing spaces
/[ ]*$/         s/[ ]*$//
                                        # lose comment-only lines
```

```
/^[ ]*\.*`$/    d
                                        # strip short comments
/\.*`/          s/\[^\]*`//g
                                        # strip multi-line comments
/^[ ]*\.*$/     bloop
/\.*$/          {               s/[ ]*\.*$//p
                                :loop
                                n
                                        # ensure flag reset
                                tdummy
                                :dummy
                                        # keep going until delimiter
                                s/^[^\]*`//
                /^[ ]*$/        d
                                tstart
                                bloop
                }
                                        # print whatever's left
                p
```

THE FILE STYLE. DICT

This file contains all words that are considered to be either reserved words or standard library functions. This can be used as a reference against which to compare all program words and hence count the reserved word usage.

alloc	else	for	null	stderr
argc	entry	fprintf	printf	stdin
argv	eof	fputs	putc	stdout
auto	extern	freopen	putchar	struct
break	fclose	fscanf	register	switch
case	fdopen	ftell	return	typedef
char	feof	getc	scanf	union
close	ferror	getchar	short	unsigned
continue	fgets	goto	sizeof	while
default	file	if	sprintf	
do	float	int	sscanf	
double	fopen	long	static	

THE PROGRAM STYLE.MET.AWK

This program, the last stage before analysis, uses awk again to produce all the remaining metrics.

```
# Produce "style" metrics for a C program

# Compute number of blank lines
                    { if (NF==0) {blank++; next } }

# Compute number of non-blank characters and imbedded spaces
                    { nbchars=0
                      for (i=NF; i>0; i-- ) nbchars+=length($i)
                      nonblank+=nbchars
                      start=index($0,$1)
                      imbedded+=length-nbchars-(start-1) }

# Compute amount of indentation
/^[ ]/              { indented+=(index($0,$1)-1) }

# Compute total number of characters
                    { chars+=length }

# Compute number of modules
/^[a-z_][a-z_0-9]*[ a-z_0-9]*\(.*\)/    { module++ }

# Compute number of gotos
/^goto[ ]+|[ ]+goto[ ]+/                { jumps++ }

# Report results
END {
        print "NR " (NR+0)
        print "LC " (NR-blank)
        print "NB " (nonblank+0)
        print "IN " (indented+0)
        print "TC " (chars+0)
        print "BL " (blank+0)
        print "IM " (imbedded+0)
        print "MO " (module+0)
        print "JU " (jumps+0)
```

THE PROGRAM STYLE.STAN

This program analyses the results produced by the preceding programs. The input to the program consists of a sequence of lines containing two fields each, where the first is an identifying label, and the second is the associated metric. The array 'max' represents the percentage weighting for each metric; the arrays 'lo', 'lotol', 'hitol' and 'hi' represent the points L, S, F and H respectively, as discussed earlier. It is these arrays that may need customising to reflect individual preference.

```
main()          /* analyse style results */
{
        static int
           max[] =     {  9, 12, 12, 11,  8, 15,  6, 14,-20,  5,  8 },

                    /* ch  cl  in  bl  sp  ml  rw  id  go  if  df */

           lo[] =      {  8,  8,  8,  8,  1,  4,  4,  4,  1,  0, 10 },
           lotol[] =   { 12, 15, 24, 15,  4, 10, 16,  5,  3,  3, 15 },
           hitol[] =   { 25, 25, 48, 30, 10, 25, 30, 10,199,  3, 25 },
           hi[] =      { 30, 35, 60, 35, 12, 35, 36, 14,200,  4, 30 };

        float   param[11];

        static char
           *ident[] = { "  characters per line ",      /* ch */
                         "% comment lines       ",      /* cl */
                         "% indentation         ",      /* in */
                         "% blank lines         ",      /* bl */
                         "  spaces per line     ",      /* sp */
                         "  module length       ",      /* ml */
                         "  reserved words      ",      /* rw */
                         "  identifier length   ",      /* id */
                         "  gotos               ",      /* go */
                         "  include files       ",      /* if */
                         "% defines             " };    /* df */
        int     i;

        float   blank, nonblank, comments, includes, defines,
                indented, imbedded, modules, jumps, ids,
                nameleng, score, oldscore, fact, totalchars,
                wordcount, linecount, totallines, lines, f;
```

```
    char    s[8];

    for (i=0; i<16; i++)
          { scanf("%s %f",s,&f);
            if (!strcmp(s,"IF")) includes=f;
            else if (!strcmp(s,"DF")) defines=f;
            else if (!strcmp(s,"NR")) lines=f;
            else if (!strcmp(s,"NL")) nameleng=f;
            else if (!strcmp(s,"ID")) ids=f;
            else if (!strcmp(s,"RW")) wordcount=f;
            else if (!strcmp(s,"CL")) comments=f;
            else if (!strcmp(s,"TL")) totallines=f;
            else if (!strcmp(s,"LC")) linecount=f;
            else if (!strcmp(s,"NB")) nonblank=f;
            else if (!strcmp(s,"IN")) indented=f;
            else if (!strcmp(s,"TC")) totalchars=f;
            else if (!strcmp(s,"BL")) blank=f;
            else if (!strcmp(s,"IM")) imbedded=f;
            else if (!strcmp(s,"MO")) modules=f;
            else if (!strcmp(s,"JU")) jumps=f; }

printf("\n     TC    TL    MO    LC    BL    CL     NB     IN    RW    ID");
printf("    IM    NL    IF    DF    JU\n");

    /* total characters, excluding comment-only lines */
printf("%6ld", (long int)totalchars);
    /* total lines */
printf("%5d", (int)totallines);
    /* number of function definitions */
printf("%5d", (int)modules);
    /* number of lines, excluding comment-only lines & blank lines */
printf("%5d", (int)linecount);
    /* number of blank lines */
printf("%5d", (int)blank);
    /* number of lines containing comments */
printf("%5d", (int)comments);
    /* number of non-blank characters, excluding comment-only lines */
printf("%6ld", (long int)nonblank);
```

```
        /* number of leading spaces (amount of indentation) */
    printf("%6ld", (long int)indented);
        /* number of different reserved words */
    printf("%5d", (int)wordcount);
        /* number of user identifiers */
    printf("%5d", (int)ids);
        /* number of embedded spaces, excluding comments */
    printf("%5d", (int)imbedded);
        /* average length of user identifiers */
    printf("%5.2f", nameleng);
        /* number of #include's */
    printf("%5d", (int)includes);
        /* number of #define's */
    printf("%5d", (int)defines);
        /* number of goto's */
    printf("%5d\n", (int)jumps);

                      linecount=lines-blank;
        if (linecount)  nonblank/=linecount;
        if (totallines) comments/=(totallines/100);
        if (totalchars) indented/=(totalchars/100);
        if (lines)      blank/=(lines/100);
        if (linecount)  imbedded/=linecount;
        if (modules)    modules=linecount/modules;
        if (ids)        defines/= (ids/100);

        param[0]=nonblank;
        param[1]=comments;
        param[2]=indented;
        param[3]=blank;
        param[4]=imbedded;
        param[5]=modules;
        param[6]=wordcount;
        param[7]=nameleng;
        param[8]=jumps;
        param[9]=includes;
        param[10]=defines;
```

```
        oldscore=0;

        for (i=0; i<=10; i++) {
                if (lotol[i]<=param[i] && param[i]<=hitol[i])
                        score+=max[i];
                else if (lo[i]<=param[i] && param[i]<lotol[i])
                      { fact=((param[i]-lo[i])/(lotol[i]-lo[i]));
                        score+=max[i]*fact; }
                else if (hitol[i]<param[i] && param[i]<=hi[i])
                      { fact=((hi[i]-param[i])/(hi[i]-hitol[i]));
                        score+=max[i]*fact; }
                printf("\n%5.1f%s : %5.1f   (max %2d)",
                        param[i],ident[i],score-oldscore,max[i]);
                oldscore=score;
        }
        printf("\n\nScore %5.1f\n",score);
}


[ style 63.9 ]
```

THE OUTPUT

The output of the program suite, run for illustrative purposes against one of its own programs, is

```
 Style analysis of style.detab.c

  TC   TL   MO   LC   BL   CL    NB    IN   RW   ID   IM   NL   IF   DF   JL
 706   43    3   25   11    7   418   168   10   13  120 4.62    1    2    (

16.7  characters per line  :   9.0   (max  9)
16.3% comment lines        :  12.0   (max 12)
23.8% indentation          :  11.8   (max 12)
30.6% blank lines          :   9.8   (max 11)
 4.8  spaces per line      :   8.0   (max  8)
 8.3  module length        :  10.8   (max 15)
10.0  reserved words       :   3.0   (max  6)
 4.6  identifier length    :   8.6   (max 14)
```

(table continued overleaf)

```
  0.0  gotos                :   0.0    (max -20)
  1.0  include files        :   1.7    (max   5)
 15.4% defines              :   8.0    (max   8)

Score  82.7
```

Appendix 4: Screen Characteristics

adm5.h

```
        /* These are terminal control commands for an ADM5. */
        /*             (Lear Siegler, 1981)                 */

    #define HOME printf("\036")
    #define CLEAR printf("\033Y")
    #define CURSOR(l,p) printf("\033=%c%c", 31+l, 31+p)
```

vt100.h

```
     /* These are terminal control commands for a VT100. */
     /* They are but a few of the many available for     */
     /* this device. The command names are chosen to     */
     /* attempt to convey their purpose. The cursor      */
     /* positioning command CURSOR is unusual for this   */
     /* device, in that it requires an ascii string to   */
     /* represent the positioning digits.                */
     /* HOME is 1,1 .       (DEC, 1979)                  */

#define HOME printf("\033[H")

#define CLEARDOWN printf("\033[J")
#define CLEAR2EOL printf("\033[K")
#define CLEARSCRN printf("\033[2J")
#define CLEARLINE printf("\033[2K")
#define BOLD printf("\033[1m")
#define ULINE printf("\033[4m")
#define BLINK printf("\033[5m")
```

(*continued overleaf*)

```
#define REVERSE printf("\033[7m")
#define CANCEL printf("\033[0m")

#define CURSOR(l,p) printf("\033[%c%c;%c%cH",48+l/10,48+l%10,48+p/10,48+p%10)
```

Appendix 5: Tabulated and Listed Information

ALPHABETIC LIST OF C RESERVED WORDS

auto	storage class specifier
break	statement
case	statement prefix within a switch statement
char	type specifier
continue	statement
default	statement prefix within a switch statement
do	statement
double	type specifier
else	statement
entry	(reserved for future use)
enum	type specifier
extern	storage class specifier
float	type specifier
for	statement
goto	statement
if	statement
int	type specifier
long	type specifier
register	storage class specifier
return	statement
short	type specifier
sizeof	unary operator
static	storage class specifier
struct	type specifier
switch	statement
typedef	storage class specifier
union	type specifier
unsigned	type specifier
void	type specifier
while	statement

Use of any of these reserved words as identifiers will cause syntax errors. The ease with which such errors can be related to the source of the problem will depend on the particular implementation of C.

C ARITHMETIC OPERATORS

<table>
<tr><th>Operator</th><th>Name</th><th>Associativity</th><th>RatC</th></tr>
<tr><td>()</td><td>parentheses</td><td>left to right</td><td>hier11</td></tr>
<tr><td>[ ]</td><td>brackets</td><td></td><td>hier11</td></tr>
<tr><td>-></td><td>pointer</td><td></td><td>no</td></tr>
<tr><td>.</td><td>dot</td><td></td><td>no</td></tr>
<tr><td>++</td><td>increment</td><td>right to left</td><td>hier10</td></tr>
<tr><td>--</td><td>decrement</td><td></td><td>hier10</td></tr>
<tr><td>(type)</td><td>cast</td><td></td><td>no</td></tr>
<tr><td>*</td><td>contents of</td><td></td><td>hier10</td></tr>
<tr><td>&</td><td>address of</td><td></td><td>hier10</td></tr>
<tr><td>-</td><td>unary minus</td><td></td><td>hier10</td></tr>
<tr><td>~</td><td>one's complement</td><td></td><td>no</td></tr>
<tr><td>!</td><td>logical NOT</td><td></td><td>no</td></tr>
<tr><td>sizeof</td><td>size of</td><td></td><td>no</td></tr>
<tr><td>*</td><td>multiply</td><td>left to right</td><td>hier9</td></tr>
<tr><td>/</td><td>divide</td><td></td><td>hier9</td></tr>
<tr><td>%</td><td>modulus</td><td></td><td>hier9</td></tr>
<tr><td>+</td><td>plus</td><td>left to right</td><td>hier8</td></tr>
<tr><td>-</td><td>minus</td><td></td><td>hier8</td></tr>
<tr><td>>></td><td>shift right</td><td>left to right</td><td>hier7</td></tr>
<tr><td><<</td><td>shift left</td><td></td><td>hier7</td></tr>
<tr><td>></td><td>greater than</td><td>left to right</td><td>hier6</td></tr>
<tr><td>>=</td><td>greater than or equal</td><td></td><td>hier6</td></tr>
<tr><td><=</td><td>less than or equal</td><td></td><td>hier6</td></tr>
<tr><td><</td><td>less than</td><td></td><td>hier6</td></tr>
<tr><td>==</td><td>equal</td><td>left to right</td><td>hier5</td></tr>
<tr><td>!=</td><td>not equal</td><td></td><td>hier5</td></tr>
<tr><td>&</td><td>bitwise AND</td><td>left to right</td><td>hier4</td></tr>
<tr><td>^</td><td>bitwise exclusive OR</td><td>left to right</td><td>hier3</td></tr>
<tr><td>|</td><td>bitwise inclusive OR</td><td>left to right</td><td>hier2</td></tr>
<tr><td>&&</td><td>logical AND</td><td>left to right</td><td>no</td></tr>
<tr><td>||</td><td>logical OR</td><td>left to right</td><td>no</td></tr>
<tr><td>?:</td><td>conditional</td><td>right to left</td><td>no</td></tr>
</table>

=	equals	right to left	hier1
+=	plus equals		hier1
-=	minus equals		hier1
*=	multiply equals		hier1
/=	divide equals		hier1
%=	modulus equals		hier1
>>=	shift right equals		hier1
<<=	shift left equals		hier1
&=	and equals		hier1
^=	exclusive or equals		hier1
|=	inclusive or equals		hier1
,	comma	left to right	no

C BASIC DATA TYPES

C supports the following basic data types.

char	A character variable holds any character from the available character set represented as the appropriate integer character code.
int	Up to three sizes of integers may be available: *short int*, *int* and *long int*. *int* represents the normal size of integer; *short int*, if supported, will be no bigger than *int*; *long int*, if supported, will be no smaller than *int*. Integers may be treated as signed, which is the default, or unsigned: *unsigned short int*, *unsigned int* or *unsigned long int*, where the word *int* is optional.
float	Represents a single-precision floating point number.
double	Represents a double-precision floating point number.
enum	Enumerated type, which may take any of a defined set of values.

ASCII CHARACTER SET (OCTAL)

000 nul ↑@	020 dle ↑P	040 sp	060 0	100 @	120 P	140	160 p
001 soh ↑A	021 dc1 ↑Q	041 !	061 1	101 A	121 Q	141 a	161 q
002 stx ↑B	022 dc2 ↑R	042 "	062 2	102 B	122 R	142 b	162 r
003 etx ↑C	023 dc3 ↑S	043 #	063 3	103 C	123 S	143 c	163 s
004 eot ↑D	024 dc4 ↑T	044 $	064 4	104 D	124 T	144 d	164 t
005 enq ↑E	025 nak ↑U	045 %	065 5	105 E	125 U	145 e	165 u
006 ack ↑F	026 syn ↑V	046 &	066 6	106 F	126 V	146 f	166 v
007 bel ↑G	027 etb ↑W	047 '	067 7	107 G	127 W	147 g	167 w
010 bs ↑H	030 can ↑X	050 (	070 8	110 H	130 X	150 h	170 x
011 ht ↑I	031 em ↑Y	051)	071 9	111 I	131 Y	151 i	171 y
012 nl ↑J	032 sub ↑Z	052 *	072 :	112 J	132 Z	152 j	172 z
013 vt ↑K	033 esc	053 +	073 ;	113 K	133 [	153 k	173 {
014 np ↑L	034 fs	054 ,	074 <	114 L	134 \	154 l	174 |
015 cr ↑M	035 gs	055 -	075 =	115 M	135]	155 m	175 }
016 so ↑N	036 rs	056 .	076 >	116 N	136 ^	156 n	176 ~
017 si ↑O	037 us	057 /	077 ?	117 O	137 _	157 o	177 del

ASCII CHARACTER SET (DECIMAL)

000 00 nul ↑@	016 10 dle ↑P	032 20 sp	048 30 0	064 40 @	080 50 P	096 60 `	112 70 p
001 01 soh ↑A	017 11 dc1 ↑Q	033 21 !	049 31 1	065 41 A	081 51 Q	097 61 a	113 71 q
002 02 stx ↑B	018 12 dc2 ↑R	034 22 "	050 32 2	066 42 B	082 52 R	098 62 b	114 72 r
003 03 etx ↑C	019 13 dc3 ↑S	035 23 #	051 33 3	067 43 C	083 53 S	099 63 c	115 73 s
004 04 eot ↑D	020 14 dc4 ↑T	036 24 $	052 34 4	068 44 D	084 54 T	100 64 d	116 74 t
005 05 enq ↑E	021 15 nak ↑U	037 25 %	053 35 5	069 45 E	085 55 U	101 65 e	117 75 u
006 06 ack ↑F	022 16 syn ↑V	038 26 &	054 36 6	070 46 F	086 56 V	102 66 f	118 76 v
007 07 bel ↑G	023 17 etb ↑W	039 27 '	055 37 7	071 47 G	087 57 W	103 67 g	119 77 w
008 08 bs ↑H	024 18 can ↑X	040 28 (	056 38 8	072 48 H	088 58 X	104 68 h	120 78 x
009 09 ht ↑I	025 19 em ↑Y	041 29)	057 39 9	073 49 I	089 59 Y	105 69 i	121 79 y
010 0A nl ↑J	026 1A sub ↑Z	042 2A *	058 3A :	074 4A J	090 5A Z	106 6A j	122 7A z
011 0B vt ↑K	027 1B esc	043 2B +	059 3B ;	075 4B K	091 5B [	107 6B k	123 7B {
012 0C np ↑L	028 1C fs	044 2C ,	060 3C <	076 4C L	092 5C \	108 6C l	124 7C |
013 0D cr ↑M	029 1D gs	045 2D -	061 3D =	077 4D M	093 5D]	109 6D m	125 7D }
014 0E so ↑N	030 1E rs	046 2E .	062 3E >	078 4E N	094 5E ^	110 6E n	126 7E ~
015 0F si ↑O	031 1F us	047 2F /	063 3F ?	079 4F O	095 5F _	111 6F o	127 7F del

ESCAPE CHARACTERS

The backslash character is used to construct 'escape sequences'. That is, it enables the user to represent certain non-printing characters by a pair of characters, backslash and one other. The characters represented in this way are

\b	backspace	BS
\f	form feed	FF
\n	newline	NL
\r	carriage return	CR
\t	horizontal tab	HT
\'	single quote	'
\\	backslash	\

A digit string of no more than three digits may also follow a backslash. This digit string is taken to be the octal representation of the required character in the underlying character set. For example, we may use

\0	null character	NUL
\7	bell	BEL
\177	rubout	DEL

Escape sequences such as those illustrated above may be used in strings, particularly control strings

```
printf("\t result = \n");
```

and also as character constants.

```
bell = '\7'
```

CONVERSION CHARACTERS FOR OUTPUT

Conversion characters	*Argument type*	*Comment*
c	char	Single character
d	int	Signed (if negative) decimal
ld or D	long	Signed (if negative) decimal
u	int	Unsigned decimal
lu or U	long	Unsigned decimal
o	int	Unsigned octal, zs
lo or O	long	Unsigned octal, zs

x	int	Unsigned hexadecimal, zs
lx or X	long	Unsigned hexadecimal, zs (zs . . . zero suppressed)
f	float or double	Decimal notation
e	float or double	Scientific notation
g	float or double	Shortest of %e, %f
s	string	

Any invalid conversion character is printed!

These conversion characters may be used in the control string of the function *printf*, and its variants *fprintf*, and *sprintf*. Examples of their use may be found in table 3.2.

CONVERSION CHARACTERS FOR INPUT

Conversion characters	*Argument type*
c	Pointer to char
d	Pointer to int
hd	Pointer to short
ld or D	Pointer to long
o	Pointer to int
ho	Pointer to short
lo or O	Pointer to long
x	Pointer to int
hx	Pointer to short
lx or X	Pointer to long
f	Pointer to float
lf or F	Pointer to double
e	Pointer to float
le or E	Pointer to double
s	Pointer to array of char

These conversion characters are for use in the control string of the function *scanf*, and its variants *fscanf*, and *sscanf*. Examples of their use are given in example 3.1.

INPUT-OUTPUT FUNCTIONS

Some or all of the functions below may be available in your implementation of C. Where appropriate we assume

arglist	is one or more arguments
cstring	is a control string
mstring	is the mode of a file, "r", "w", or "a"
fptr	is a pointer to a file

Functions that do not use files

getchar getchar( )

Read a character from the standard input. EOF is returned on end of file or when an error occurs.

putchar putchar(ch)

Write the character 'ch' to standard output, and return the character written.

printf printf(cstring, arglist)

Formatted print to standard output.

scanf scanf(cstring, arglist)

Read formatted from standard input. The function returns the number of arguments to which an assignment was made, or EOF, or NULL if the input did not match the first item of the control string.

gets char *gets(string)

Reads from the standard input a string, which is terminated by a newline character, into 'string'. *gets* returns its argument with the terminating newline character replaced by the null character.

puts puts(string)

Copies the string 'string' to standard output and appends a newline character.

sprintf sprintf(string, cstring, arglist)

Formatted write to the string 'string'.

sscanf sscanf(string, cstring, arglist)

Formatted read from the string 'string'.

Functions using files

fopen FILE *fopen(string, mstring)

Open the file with name 'string' in mode 'mstring'. The function returns as a result either a pointer to a file or NULL if the attempt to open was unsuccessful.

getc int getc(fptr)

Returns the next character from the file 'fptr'. EOF is returned on end of file or when an error occurs.

putc putc(ch, fptr)

Writes the character 'ch' to the file 'fptr'. EOF is returned on error, otherwise the character 'ch' is returned.

fgets char *fgets(string, n, fptr)

Reads into 'string' no more than n – 1 characters from 'fptr'. The read terminates upon finding a newline character, which is stored in 'string' followed by NULL. The function returns NULL on end of file or error, otherwise the first argument is returned.

fputs fputs(string, fptr)

Writes 'string' to 'fptr' with no newline appended.

fprintf fprintf(fptr, cstring, arglist)

Formatted write to 'fptr'.

fscanf fscanf(fptr, cstring, arglist)

Read formatted from 'fptr'.

fflush fflush(fptr)

Flush the output buffer of file 'fptr'.

ferror ferror(fptr)

Returns non-zero if an error has occurred while reading or writing 'fptr'. The error indication persists until the file is closed.

feof feof(fptr)

Returns non-zero when end of file has been reached on 'fptr'.

fclose fclose(fptr)

Any buffers associated with 'fptr' are emptied and the file is closed.

FUNCTIONS FOR STRING OPERATIONS

In what follows we assume the following declarations

```
char ch;
char *string1, *string2;
```

Some of the following functions may be available for string operations.

strcat `char *strcat(string1, string2)`

Append a copy of 'string2' to the end of 'string1'. *strcat* returns a pointer to the result.

strcmp `strcmp(string1, string2)`

Returns an argument less than, equal to, or greater than zero according as 'string1' is lexicographically less than, equal to, or greater than 'string2'.

strcpy `char *strcpy(string1, string2)`

Copies 'string2' to 'string1' and terminates when the null character has been moved.

strlen `strlen(string1)`

Returns the number of non-null characters in 'string1'.

strchr `char *strchr(string1, ch)`

Returns a pointer to the first occurrence of character 'ch' in 'string1'.

strrchr `char *strrchr(string1, ch)`

Returns a pointer to the last occurrence of character 'ch' in 'string1'.

strtok `char *strtok(string1, string2)`

Returns a pointer to the next occurrence of one of the characters from 'string2' (the 'separators') in 'string1' (the 'token'), and writes a NULL in place of the separator. Subsequent calls with a NULL first argument step through the same string until no more tokens remain, at which time a NULL is returned.

The following variants limit their operation to the first 'n' characters of the string.

strncat `char *strncat(string1, string2, n)`

strncmp `char *strncmp(string1, string2, n)`

strncpy `char *strncpy(string1, string2, n)`

MATHEMATICAL FUNCTIONS

While not normally considered to be a 'general-purpose' programming language, C implementations will usually offer a range of mathematical functions. Some or all of the following functions, in which 'x' and 'y' are of type *double*, might appear in an appropriate library file.

sqrt double sqrt(x)

Returns the square root of 'x'.

pow double pow(x, y)

Returns 'x' to the power 'y'.

fabs double fabs(x)

Returns the absolute value of 'x'.

ceil double ceil(x)

Returns the smallest integer not less than 'x'.

floor double floor(x)

Returns the largest integer not greater than 'x'.

exp double exp(x)

Returns the exponential function of 'x'.

log double log(x)
Returns the natural logarithm of 'x'.

log10 double log10(x)

Returns the logarithm base 10 of 'x'.

sinh double sinh(x)

Returns the hyperbolic function sinh of 'x'.

cosh double cosh(x)

Returns the hyperbolic function cosh of 'x'.

tanh double tanh(x)

Returns the hyperbolic function tanh of 'x'.

sin double sin(x)

Returns sine of 'x' when 'x' is in radians.

cos double cos(x)

Returns cosine of 'x' when 'x' is in radians.

asin double asin(x)

Returns, in radians, the arc sine of 'x'.

acos double acos(x)

Returns, in radians, the arc cosine of 'x'.

atan double atan(x)

Returns, in radians, the arc tangent of 'x' in the range −pi/2 to pi/2.

atan2 double atan2(x, y)

Returns, in radians, the arc tangent of 'x'/'y' in the range −pi to pi.

Appendix 6: Syntax Diagrams for C

In attempting to teach, or to use, a programming language, it is extremely helpful to have access to a concise specification of the syntax of the language, perhaps in the form of syntax diagrams. Unfortunately, it is not yet possible to provide a full and accurate description of the syntax of C in this fashion. This, it is suggested (Fitzhorn and Johnson, 1982), is because 'the language's syntax has never experienced a period of rigorous definition and design.' Early indications of this appear in Kernighan and Ritchie (1978) where it is admitted that 'the summary of C syntax is intended more for aiding comprehension than as an exact statement of the language.' This, coupled with the later observation that C is an evolving language, gives an honest, if disappointing indication of why the C syntax is not so rigorously well-defined as might be expected. Authors and teachers are faced with a clear choice of either saying little or nothing about the definition of C syntax, or of presenting a syntax that might be considered erroneous. We have opted for presenting syntax diagrams that use the description of C syntax given by Fitzhorn and Johnson (1982), who acknowledge the critique by Anderson (1980). Readers are therefore cautioned to treat the following as an honest attempt to describe a useful syntax for C, rather than as a definitive syntax of C.

In the syntax diagrams that follow, upper case symbols are C keywords whereas lower case symbols are the names of syntactic elements. Three syntactic elements are not defined in the diagrams; their definitions are more concisely, if less formally, given here.

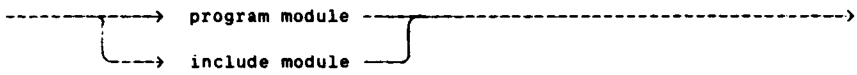
ident — An identifier is any sequence of upper case letters, lower case letters, digits or underscores. The sequence must start with a letter or an underscore.

constant — A constant is a character constant, an integer constant or a floating constant. A character constant is a character enclosed by single quote marks. An integer constant is a digit sequence, which may be in hexadecimal form (starting 0x or 0X), in octal form (starting with 0), or in decimal form (starting with a non-zero digit). A floating constant is a digit sequence which should contain a decimal point and may contain an exponent indicator (e, or E) followed by a signed or unsigned exponent.

string A string is any sequence of characters enclosed by double quote marks (").

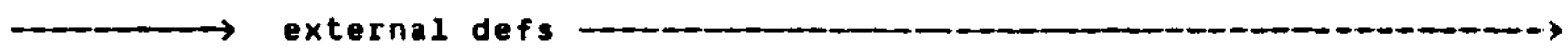
(a) PROGRAM DEFINITION

1. C program

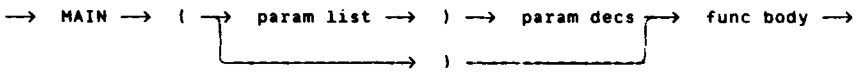


2. program module

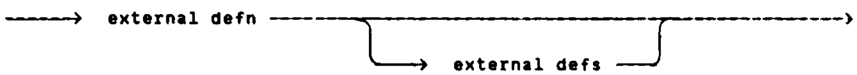
3. include module



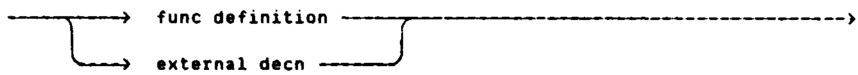
4. main function



5. external defs



6. external defn



7. external decs

```
------> external decn ---+-----------------------------+---------->
                         |                             |
                         +--> external decs -----------+
```

8. external decn

```
--+----> func declaration ---+------------------------------>
  |                          |
  +----> external data decs -+
```

(b) FUNCTION DEFINITIONS

9. func definition

```
---> func header ---> param decs -----> func body -------------->
```

10. func header

```
---> func sc -------> func type header ------------------------->
```

11. func type header

```
------+------> simple type header ---+-------------------------->
      |                              |
      +------> complex type header --+
```

12. simple type header

```
+-----------> simple type -----+-> ident --> ( --> param list --> ) -->
|                              |
+--> type spec --> pointer ----+
```

13. complex type header

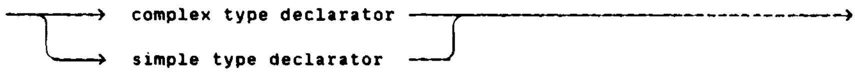
```
----> type spec ----> complex header ----> complex postfix ----------->
```

```
14. complex header

--> ( --> pointer --> ident --> ( --> param list --> ) --> ) -->
                  |                                     |
                  --> complex header --> complex postfix --


15. param list

---------------------------------------------------------------->
                      |                       |
                      ----> ident list -------


16. ident list

----> ident ----------------------------------------------------->
               |                           |
               ----> , ----> ident list ---


17. param decs

----------------------------------------------------------------->
  |                                                              |
  --> param sc --> type spec --> param defs --> ; --> param decs -


18. param defs

-----> data declarator ------------------------------------------>
                           |                         |
                           ---> , -----> param defs --


19. func body

----> { --> internal data decs --> statement list --> } --------->
```

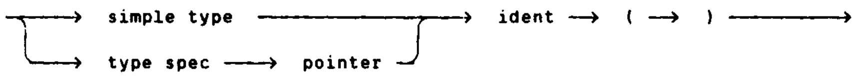
(c) FUNCTION DECLARATIONS

```
20. func declaration

----> func sc -----> func type declarator ----------------------->
```

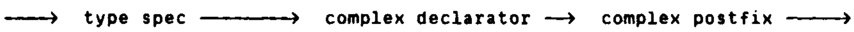
21. func type declarator



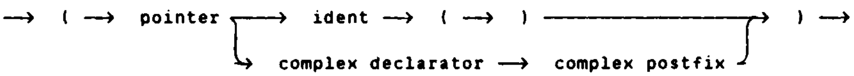
22. simple type declarator



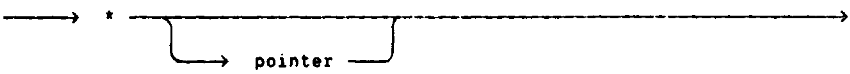
23. complex type declarator



24. complex declarator

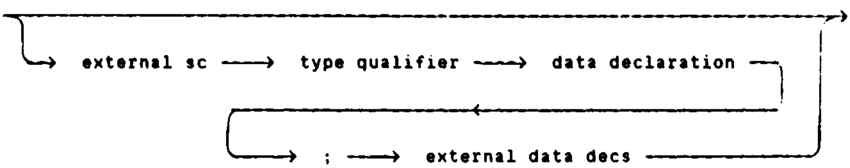


25. pointer

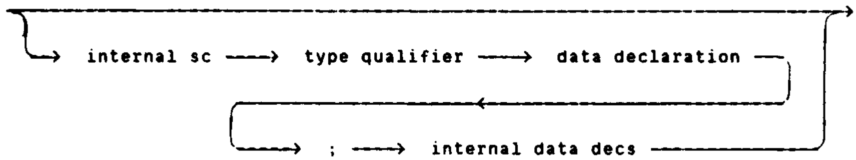


(d) DATA DECLARATIONS

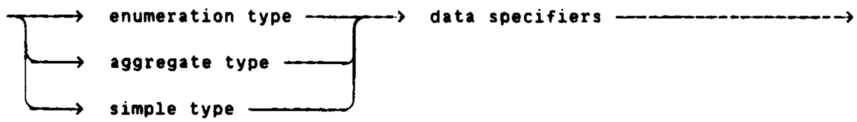
26. external data decs



27. internal data decs

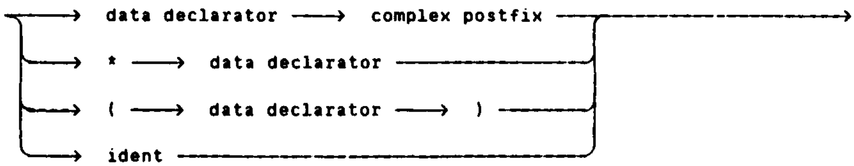


28. data declaration

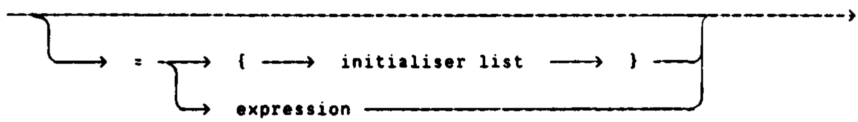


29. data specifiers

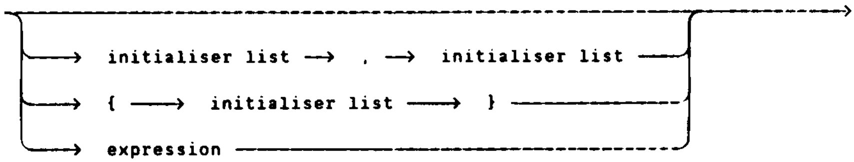
30. data declarator



31. initialiser

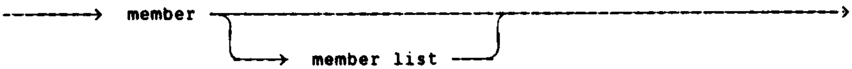


32. initialiser list



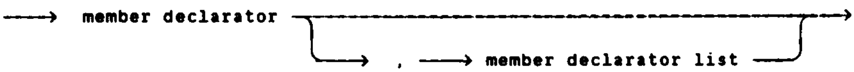
33. aggregate declarator

34. member list

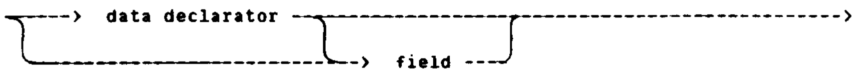


35. member

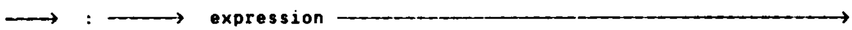
36. member declarator list



37. member declarator

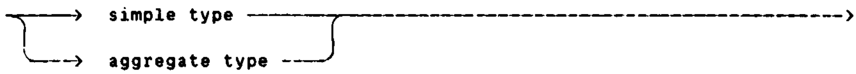


38. field

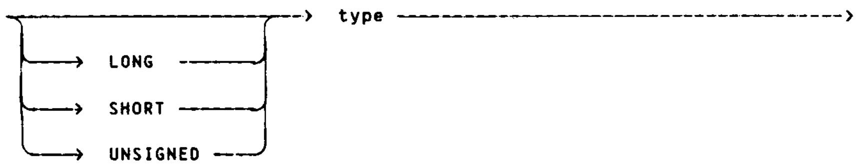


(e) TYPE ANALYSIS

39. type spec

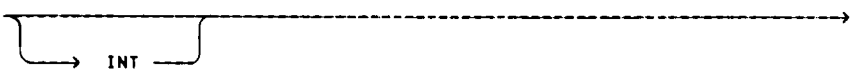


40. simple type

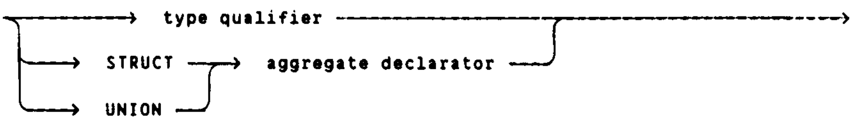


41. type

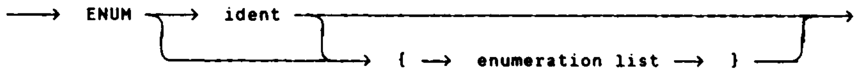
42. integer type



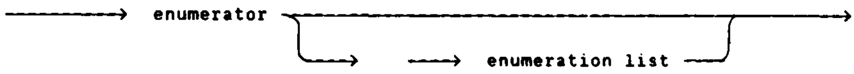
43. aggregate type



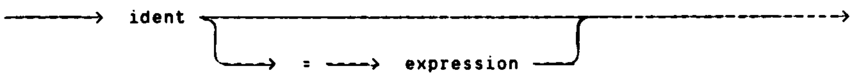
44. enumeration type



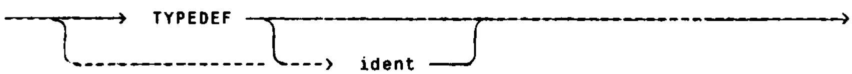
45. enumeration list



46. enumerator

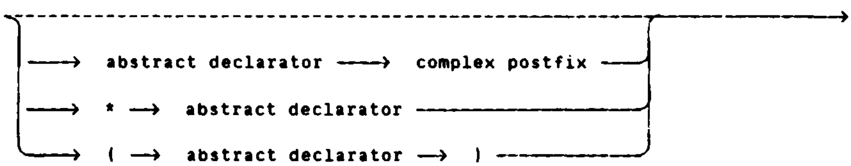


47. type qualifier

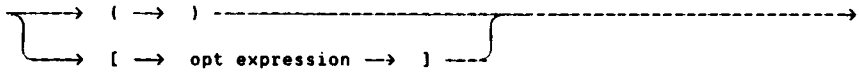


48. typename

49. abstract declarator

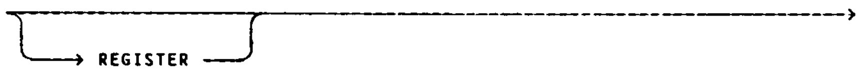


50. complex postfix

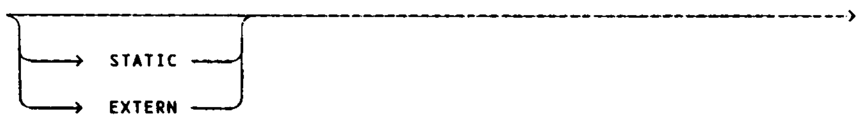


51. func sc

52. param sc



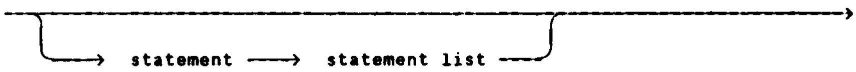
53. external sc



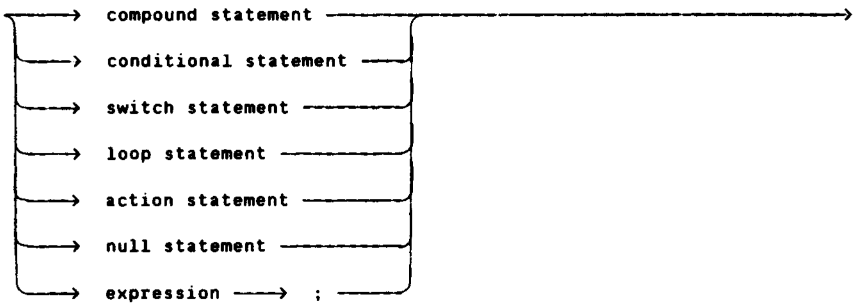
54. internal sc

(f) STATEMENTS

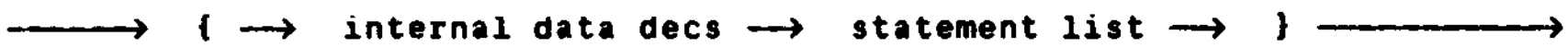
55. statement list



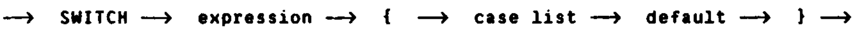
56. statement



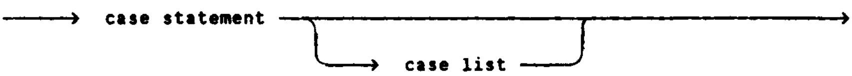
57. compound statement



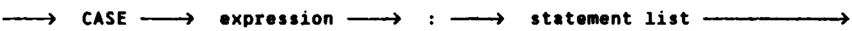
58. switch statement



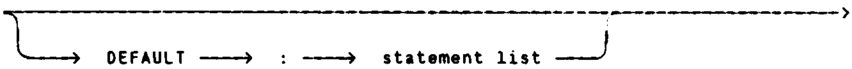
59. case list



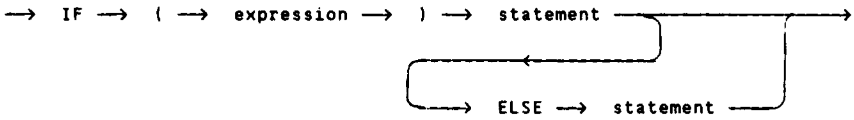
60. case statement



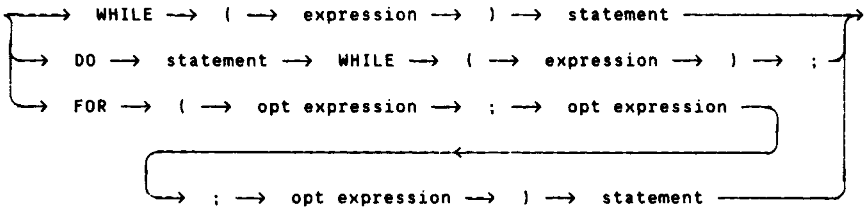
61. default



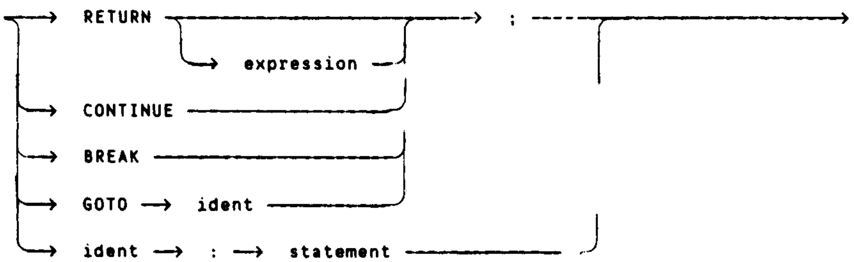
62. conditional statement



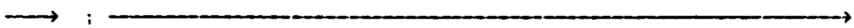
63. loop statement



64. action statement

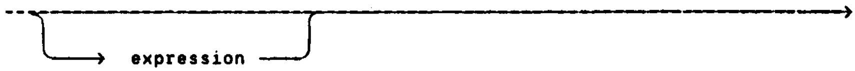


65. null statement

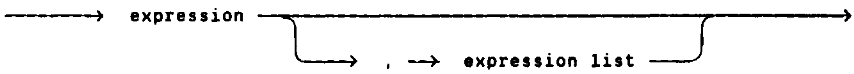


(g) EXPRESSIONS

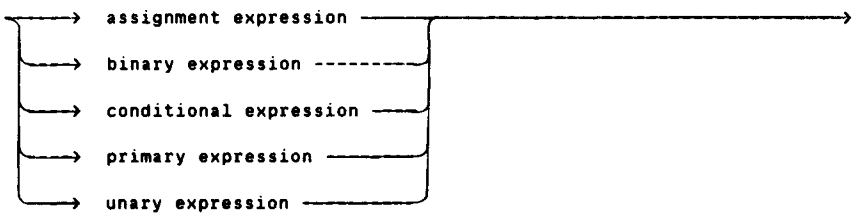
66. opt expression



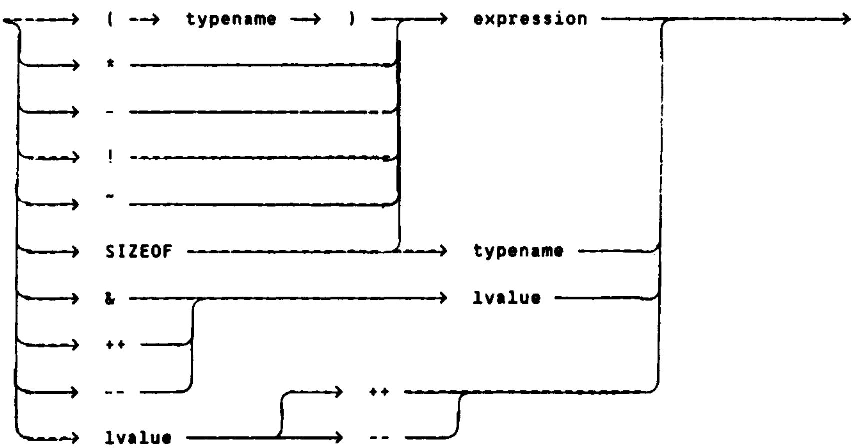
67. expression list



68. expression



69. unary expression



70. binary expression

```
———> expression ———> binop ———> expression ———————————>
```

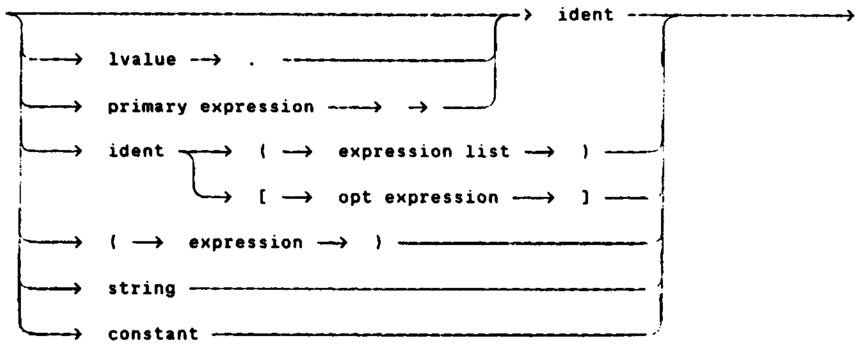
71. assignment expression

```
———> lvalue ———> assignop ———> expression ———————————>
```

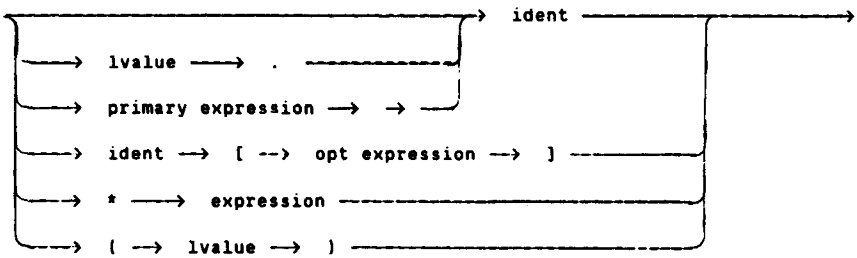
72. conditional expression

```
———> expression —> ? —> expression —> : —> expression ————>
```

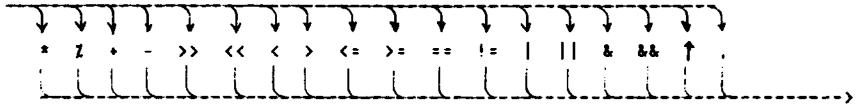
73. primary expression



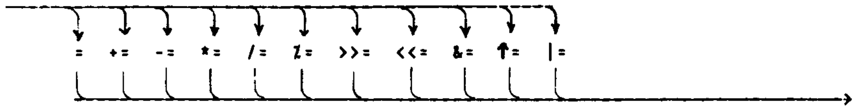
74. lvalue



75. binop



76. assignop



SYNTACTIC ELEMENTS IN ORDER OF DEFINITION

1. C program
2. program module
3. include module
4. main function
5. external defs
6. external defn
7. external decs
8. external decn
9. func definition
10. func header
11. func type header
12. simple type header
13. complex type header
14. complex header
15. param list
16. ident list
17. param decs
18. param defs
19. func body
20. func declaration
21. func type declarator
22. simple type declarator
23. complex type declarator
24. complex declarator
25. pointer
26. external data decs
27. internal data decs
28. data declaration
29. data specifiers
30. data declarator
31. initialiser
32. initialiser list
33. aggregate declarator
34. member list
35. member
36. member declarator list
37. member declarator
38. field
39. type spec
40. simple type
41. type
42. integer type
43. aggregate type
44. enumeration type
45. enumeration list
46. enumerator
47. type qualifier
48. typename
49. abstract declarator
50. complex postfix
51. func sc
52. param sc
53. external sc
54. internal sc
55. statement list
56. statement
57. compound statement
58. switch statement
59. case list
60. case statement
61. default
62. conditional statement
63. loop statement
64. action statement
65. null statement
66. opt expression
67. expression list
68. expression
69. unary expression
70. binary expression
71. assignment expression
72. conditional expression
73. primary expression
74. lvalue
75. binop
76. assignop

SYNTACTIC ELEMENTS IN ALPHABETIC ORDER

49. abstract declarator
64. action statement
33. aggregate declarator
43. aggregate type
71. assignment expression
76. assignop
70. binary expression
75. binop
1. C program
59. case list
60. case statement
24. complex declarator
14. complex header
50. complex postfix
23. complex type declarator
13. complex type header
57. compound statement
72. conditional expression
62. conditional statement
28. data declaration
30. data declarator
29. data specifiers
61. default
45. enumeration list
44. enumeration type
46. enumerator
68. expression
67. expression list
26. external data decs
8. external decn
7. external decs
6. external defn
5. external defs
53. external sc
38. field
19. func body
20. func declaration
9. func definition
10. func header
51. func sc
21. func type declarator
11. func type header
16. ident list
3. include module
31. initialiser
32. initialiser list
42. integer type
27. internal data decs
54. internal sc
63. loop statement
74. lvalue
4. main function
35. member
37. member declarator
36. member declarator list
34. member list
65. null statement
66. opt expression
17. param decs
18. param defs
15. param list
52. param sc
25. pointer
73. primary expression
2. program module
40. simple type
22. simple type declarator
12. simple type header
56. statement
55. statement list
58. switch statement
41. type
47. type qualifier
39. type spec
48. typename
69. unary expression

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