SECOND EDITION

THE C PROGRAMMING LANGUAGE

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argument list is intended to permit older C programs to compile with new compilers. But it's a bad idea to use it with new programs. If the function takes arguments, declare them; if it takes no arguments, use `void`.

Given `atof`, properly declared, we could write `atoi` (convert a string to `int`) in terms of it:

```
/* atoi:  convert string s to integer using atof */
int atoi(char s[])
{
    double atof(char s[]);

    return (int) atof(s);
}
```

Notice the structure of the declarations and the `return` statement. The value of the expression in

```
return expression;
```

is converted to the type of the function before the return is taken. Therefore, the value of `atof`, a `double`, is converted automatically to `int` when it appears in this `return`, since the function `atoi` returns an `int`. This operation does potentially discard information, however, so some compilers warn of it. The cast states explicitly that the operation is intended, and suppresses any warning.

Exercise 4-2. Extend `atof` to handle scientific notation of the form

```
123.45e-6
```

where a floating-point number may be followed by `e` or `E` and an optionally signed exponent. □

4.3 External Variables

A C program consists of a set of external objects, which are either variables or functions. The adjective "external" is used in contrast to "internal," which describes the arguments and variables defined inside functions. External variables are defined outside of any function, and are thus potentially available to many functions. Functions themselves are always external, because C does not allow functions to be defined inside other functions. By default, external variables and functions have the property that all references to them by the same name, even from functions compiled separately, are references to the same thing. (The standard calls this property *external linkage*.) In this sense, external variables are analogous to Fortran COMMON blocks or variables in the outermost block in Pascal. We will see later how to define external variables and functions that are visible only within a single source file.

Because external variables are globally accessible, they provide an alternative to function arguments and return values for communicating data between functions. Any function may access an external variable by referring to it by name, if the name has been declared somehow.

If a large number of variables must be shared among functions, external variables are more convenient and efficient than long argument lists. As pointed out in Chapter 1, however, this reasoning should be applied with some caution, for it can have a bad effect on program structure, and lead to programs with too many data connections between functions.

External variables are also useful because of their greater scope and lifetime. Automatic variables are internal to a function; they come into existence when the function is entered, and disappear when it is left. External variables, on the other hand, are permanent, so they retain values from one function invocation to the next. Thus if two functions must share some data, yet neither calls the other, it is often most convenient if the shared data is kept in external variables rather than passed in and out via arguments.

Let us examine this issue further with a larger example. The problem is to write a calculator program that provides the operators +, -, *, and /. Because it is easier to implement, the calculator will use reverse Polish notation instead of infix. (Reverse Polish is used by some pocket calculators, and in languages like Forth and Postscript.)

In reverse Polish notation, each operator follows its operands; an infix expression like

```
(1 - 2) * (4 + 5)
```

is entered as

```
1 2 - 4 5 + *
```

Parentheses are not needed; the notation is unambiguous as long as we know how many operands each operator expects.

The implementation is simple. Each operand is pushed onto a stack; when an operator arrives, the proper number of operands (two for binary operators) is popped, the operator is applied to them, and the result is pushed back onto the stack. In the example above, for instance, 1 and 2 are pushed, then replaced by their difference, -1. Next, 4 and 5 are pushed and then replaced by their sum, 9. The product of -1 and 9, which is -9, replaces them on the stack. The value on the top of the stack is popped and printed when the end of the input line is encountered.

The structure of the program is thus a loop that performs the proper operation on each operator and operand as it appears:

```
while (next operator or operand is not end-of-file indicator)
    if (number)
        push it
    else if (operator)
        pop operands
        do operation
        push result
    else if (newline)
        pop and print top of stack
    else
        error
```

The operations of pushing and popping a stack are trivial, but by the time error detection and recovery are added, they are long enough that it is better to put each in a separate function than to repeat the code throughout the whole program. And there should be a separate function for fetching the next input operator or operand.

The main design decision that has not yet been discussed is where the stack is, that is, which routines access it directly. One possibility is to keep it in `main`, and pass the stack and the current stack position to the routines that push and pop it. But `main` doesn't need to know about the variables that control the stack; it only does push and pop operations. So we have decided to store the stack and its associated information in external variables accessible to the `push` and `pop` functions but not to `main`.

Translating this outline into code is easy enough. If for now we think of the program as existing in one source file, it will look like this:

```
#includes
#defines

function declarations for main

main() { ... }

external variables for push and pop

void push(double f) { ... }
double pop(void) { ... }

int getop(char s[]) { ... }

routines called by getop
```

Later we will discuss how this might be split into two or more source files.

The function `main` is a loop containing a big `switch` on the type of operator or operand; this is a more typical use of `switch` than the one shown in Section 3.4.

```
#include <stdio.h>
#include <stdlib.h>    /* for atof() */

#define MAXOP   100    /* max size of operand or operator */
#define NUMBER  '0'    /* signal that a number was found */

int getop(char []);
void push(double);
double pop(void);

/* reverse Polish calculator */
main()
{
    int type;
    double op2;
    char s[MAXOP];

    while ((type = getop(s)) != EOF) {
        switch (type) {
        case NUMBER:
            push(atof(s));
            break;
        case '+':
            push(pop() + pop());
            break;
        case '*':
            push(pop() * pop());
            break;
        case '-':
            op2 = pop();
            push(pop() - op2);
            break;
        case '/':
            op2 = pop();
            if (op2 != 0.0)
                push(pop() / op2);
            else
                printf("error: zero divisor\n");
            break;
        case '\n':
            printf("\t%.8g\n", pop());
            break;
        default:
            printf("error: unknown command %s\n", s);
            break;
        }
    }
    return 0;
}
```

Because + and * are commutative operators, the order in which the popped operands are combined is irrelevant, but for - and / the left and right operands must be distinguished. In

```
push(pop() - pop());     /* WRONG */
```

the order in which the two calls of pop are evaluated is not defined. To guarantee the right order, it is necessary to pop the first value into a temporary variable as we did in main.

```
#define MAXVAL   100    /* maximum depth of val stack */

int sp = 0;             /* next free stack position */
double val[MAXVAL];     /* value stack */

/* push:  push f onto value stack */
void push(double f)
{
    if (sp < MAXVAL)
        val[sp++] = f;
    else
        printf("error: stack full, can't push %g\n", f);
}



/* pop:  pop and return top value from stack */
double pop(void)
{
    if (sp > 0)
        return val[--sp];
    else {
        printf("error: stack empty\n");
        return 0.0;
    }
}
```

A variable is external if it is defined outside of any function. Thus the stack and stack index that must be shared by push and pop are defined outside of these functions. But main itself does not refer to the stack or stack position—the representation can be hidden.

Let us now turn to the implementation of getop, the function that fetches the next operator or operand. The task is easy. Skip blanks and tabs. If the next character is not a digit or a decimal point, return it. Otherwise, collect a string of digits (which might include a decimal point), and return NUMBER, the signal that a number has been collected.

```
#include <ctype.h>

int getch(void);
void ungetch(int);

/* getop:  get next operator or numeric operand */
int getop(char s[])
{
    int i, c;

    while ((s[0] = c = getch()) == ' ' || c == '\t')
        ;
    s[1] = '\0';
    if (!isdigit(c) && c != '.')
        return c;      /* not a number */
    i = 0;
    if (isdigit(c))    /* collect integer part */
        while (isdigit(s[++i] = c = getch()))
            ;
    if (c == '.')      /* collect fraction part */
        while (isdigit(s[++i] = c = getch()))
            ;
    s[i] = '\0';
    if (c != EOF)
        ungetch(c);
    return NUMBER;
}
```

What are `getch` and `ungetch`? It is often the case that a program cannot determine that it has read enough input until it has read too much. One instance is collecting the characters that make up a number: until the first non-digit is seen, the number is not complete. But then the program has read one character too far, a character that it is not prepared for.

The problem would be solved if it were possible to "un-read" the unwanted character. Then, every time the program reads one character too many, it could push it back on the input, so the rest of the code could behave as if it had never been read. Fortunately, it's easy to simulate un-getting a character, by writing a pair of cooperating functions. `getch` delivers the next input character to be considered; `ungetch` remembers the characters put back on the input, so that subsequent calls to `getch` will return them before reading new input.

How they work together is simple. `ungetch` puts the pushed-back characters into a shared buffer—a character array. `getch` reads from the buffer if there is anything there, and calls `getchar` if the buffer is empty. There must also be an index variable that records the position of the current character in the buffer.

Since the buffer and the index are shared by `getch` and `ungetch` and must retain their values between calls, they must be external to both routines. Thus we can write `getch`, `ungetch`, and their shared variables as: