The GNU C Reference Manual

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Preface

This is a reference manual for the C programming language as implemented by the GNU Compiler Collection (GCC). Specifically, this manual aims to document:

- The 1989 ANSI C standard, commonly known as "C89"
- The 1999 ISO C standard, commonly known as "C99", to the extent that C99 is implemented by GCC
- The current state of GNU extensions to standard C

This manual describes C89 as its baseline. C99 features and GNU extensions are explicitly labeled as such.

By default, GCC will compile code as C89 plus GNU-specific extensions. Much of C99 is supported; once full support is available, the default compilation dialect will be C99 plus GNU-specific extensions. (Some of the GNU extensions to C89 ended up, sometimes slightly modified, as standard language features in C99.)

The C language includes a set of preprocessor directives, which are used for things such as macro text replacement, conditional compilation, and file inclusion. Although normally described in a C language manual, the GNU C preprocessor has been thoroughly documented in *The C Preprocessor*, a separate manual which covers preprocessing for C, C++, and Objective-C programs, so it is not included here.

Credits

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Some example programs are based on algorithms in Donald Knuth's *The Art of Computer Programming*.

Please send bug reports and suggestions to gnu-c-manual@gnu.org.

1 Lexical Elements

This chapter describes the lexical elements that make up C source code after preprocessing. These elements are called *tokens*. There are five types of tokens: keywords, identifiers, constants, operators, and separators. White space, sometimes required to separate tokens, is also described in this chapter.

1.1 Identifiers

Identifiers are sequences of characters used for naming variables, functions, new data types, and preprocessor macros. You can include letters, decimal digits, and the underscore character '`_`' in identifiers.

The first character of an identifier cannot be a digit.

Lowercase letters and uppercase letters are distinct, such that `foo` and `FOO` are two different identifiers.

When using GNU extensions, you can also include the dollar sign character '`$`' in identifiers.

1.2 Keywords

Keywords are special identifiers reserved for use as part of the programming language itself. You cannot use them for any other purpose.

Here is a list of keywords recognized by ANSI C89:

```
auto break case char const continue default do double else enum extern
float for goto if int long register return short signed sizeof static
struct switch typedef union unsigned void volatile while
```

ISO C99 adds the following keywords:

```
inline _Bool _Complex _Imaginary
```

and GNU extensions add these keywords:

```
__FUNCTION__ __PRETTY_FUNCTION__ __alignof __alignof__ __asm
__asm__ __attribute __attribute__ __builtin_offsetof __builtin_va_arg
__complex __complex__ __const __extension__ __func__ __imag __imag__
__inline __inline__ __label__ __null __real __real__
__restrict __restrict__ __signed __signed__ __thread __typeof
__volatile __volatile__
```

In both ISO C99 and C89 with GNU extensions, the following is also recognized as a keyword:

```
restrict
```

1.3 Constants

A constant is a literal numeric or character value, such as `5` or `'m'`. All constants are of a particular data type; you can use type casting to explicitly specify the type of a constant, or let the compiler use the default type based on the value of the constant.

1.3.1 Integer Constants

An integer constant is a sequence of digits, with an optional prefix to denote a number base.

If the sequence of digits is preceded by `0x` or `0X` (zero x or zero X), then the constant is considered to be hexadecimal (base 16). Hexadecimal values may use the digits from 0 to 9, as well as the letters `a` to `f` and `A` to `F`. Here are some examples:

```
0x2f
0x88
0xAB43
0xAbCd
0x1
```

If the first digit is 0 (zero), and the next character is not '`x`' or '`X`', then the constant is considered to be octal (base 8). Octal values may only use the digits from 0 to 7; 8 and 9 are not allowed. Here are some examples:

```
057
012
03
0241
```

In all other cases, the sequence of digits is assumed to be decimal (base 10). Decimal values may use the digits from 0 to 9. Here are some examples:

```
459
23901
8
12
```

There are various integer data types, for short integers, long integers, signed integers, and unsigned integers. You can force an integer constant to be of a long and/or unsigned integer type by appending a sequence of one or more letters to the end of the constant:

`u`
`U` Unsigned integer type.

`l`
`L` Long integer type.

For example, `45U` is an `unsigned int` constant. You can also combine letters: `45UL` is an `unsigned long int` constant. (The letters may be used in any order.)

Both ISO C99 and GNU C extensions add the integer types `long long int` and `unsigned long long int`. You can use two '`L`'s to get a `long long int` constant; add a '`U`' to that and you have an `unsigned long long int` constant. For example: `45ULL`.

1.3.2 Character Constants

A character constant is usually a single character enclosed within single quotation marks, such as `'Q'`. A character constant is of type `int` by default.

Some characters, such as the single quotation mark character itself, cannot be represented using only one character. To represent such characters, there are several "escape sequences" that you can use:

`\\` Backslash character.

`\?` Question mark character.

`\'` Single quotation mark.

`\"` Double quotation mark.

`\a` Audible alert.

`\b` Backspace character.

`\e` <ESC> character. (This is a GNU extension.)

`\f` Form feed.

`\n` Newline character.

`\r` Carriage return.

`\t` Horizontal tab.

`\v` Vertical tab.

`\o, \oo, \ooo`
Octal number.

`\xh, \xhh, \xhhh, ...`
Hexadecimal number.

To use any of these escape sequences, enclose the sequence in single quotes, and treat it as if it were any other character. For example, the letter m is `'m'` and the newline character is `'\n'`.

The octal number escape sequence is the backslash character followed by one, two, or three octal digits (0 to 7). For example, 101 is the octal equivalent of 65, which is the ASCII character `'A'`. Thus, the character constant `'\101'` is the same as the character constant `'A'`.

The hexadecimal escape sequence is the backslash character, followed by `x` and an unlimited number of hexadecimal digits (0 to 9, and `a` to `f` or `A` to `F`).

While the length of possible hexadecimal digit strings is unlimited, the number of character constants in any given character set is not. (The much-used extended ASCII character set, for example, has only 256 characters in it.) If you try to use a hexadecimal value that is outside the range of characters, you will get a compile-time error.

1.3.3 Real Number Constants

A real number constant is a value that represents a fractional (floating point) number. It consists of a sequence of digits which represents the integer (or "whole") part of the number, a decimal point, and a sequence of digits which represents the fractional part.

Either the integer part or the fractional part may be omitted, but not both. Here are some examples:

```
double a, b, c, d, e, f;

a = 4.7;

b = 4.;

c = 4;

d = .7;

e = 0.7;
```

(In the third assignment statement, the integer constant 4 is automatically converted from an integer value to a double value.)

Real number constants can also be followed by `e` or `E`, and an integer exponent. The exponent can be either positive or negative.

```
double x, y;

x = 5e2;    /* x is 5 * 100, or 500.0. */
y = 5e-2;   /* y is 5 * (1/100), or 0.05. */
```

You can append a letter to the end of a real number constant to cause it to be of a particular type. If you append the letter F (or f) to a real number constant, then its type is `float`. If you append the letter L (or l), then its type is `long double`. If you do not append any letters, then its type is `double`.

1.3.4 String Constants

A string constant is a sequence of zero or more characters, digits, and escape sequences enclosed within double quotation marks. A string constant is of type "array of characters". All string constants contain a null termination character (`\0`) as their last character. Strings are stored as arrays of characters, with no inherent size attribute. The null termination character lets string-processing functions know where the string ends.

Adjacent string constants are concatenated (combined) into one string, with the null termination character added to the end of the final concatenated string.

A string cannot contain double quotation marks, as double quotation marks are used to enclose the string. To include the double quotation mark character in a string, use the `\"` escape sequence. You can use any of the escape sequences that can be used as character constants in strings. Here are some example of string constants:

```
/* This is a single string constant. */
"tutti frutti ice cream"

/* These string constants will be concatenated, same as above. */
"tutti " "frutti" " ice " "cream"

/* This one uses two escape sequences. */
"\"hello, world!\""
```

If a string is too long to fit on one line, you can use a backslash `\` to break it up onto separate lines.

```
"Today's special is a pastrami sandwich on rye bread with \
a potato knish and a cherry soda."
```

Adjacent strings are automatically concatenated, so you can also have string constants span multiple lines by writing them as separate, adjacent, strings. For example:

```
"Tomorrow's special is a corned beef sandwich on "
"pumpernickel bread with a kasha knish and seltzer water."
```

is the same as

```
"Tomorrow's special is a corned beef sandwich on \
pumpernickel bread with a kasha knish and seltzer water."
```

To insert a newline character into the string, so that when the string is printed it will be printed on two different lines, you can use the newline escape sequence '`\n`'.

```
printf ("potato\nknish");
```

prints

```
potato
knish
```

1.4 Operators

An operator is a special token that performs an operation, such as addition or subtraction, on either one, two, or three operands. Full coverage of operators can be found in a later chapter. See Chapter 3 [Expressions and Operators], page 28.

1.5 Separators

A separator separates tokens. White space (see next section) is a separator, but it is not a token. The other separators are all single-character tokens themselves:

```
( ) [ ] { } ; , . :
```

1.6 White Space

White space is the collective term used for several characters: the space character, the tab character, the newline character, the vertical tab character, and the form-feed character. White space is ignored (outside of string and character constants), and is therefore optional, except when it is used to separate tokens. This means that

```
#include <stdio.h>

int
main()
{
  printf( "hello, world\n" );
  return 0;
}
```

and

```
#include <stdio.h> int main(){printf("hello, world\n");
return 0;}
```

are functionally the same program.

Although you must use white space to separate many tokens, no white space is required between operators and operands, nor is it required between other separators and that which they separate.

```
/* All of these are valid. */

x++;
x ++ ;
x=y+z;
x = y + z ;
x=array[2];
x = array [ 2 ] ;
fraction=numerator / *denominator_ptr;
fraction = numerator / * denominator_ptr ;
```

Furthermore, wherever one space is allowed, any amount of white space is allowed.

```
/* These two statements are functionally identical. */
x++;

x
       ++       ;
```

In string constants, spaces and tabs are not ignored; rather, they are part of the string. Therefore,

```
"potato knish"
```

is not the same as

```
"potato                         knish"
```

2 Data Types

2.1 Primitive Data Types

2.1.1 Integer Types

The integer data types range in size from at least 8 bits to at least 32 bits. The C99 standard extends this range to include integer sizes of at least 64 bits. You should use integer types for storing whole number values (and the `char` data type for storing characters). The sizes and ranges listed for these types are minimums; depending on your computer platform, these sizes and ranges may be larger.

While these ranges provide a natural ordering, the standard does not require that any two types have a different range. For example, it is common for `int` and `long` to have the same range. The standard even allows `signed char` and `long` to have the same range, though such platforms are very unusual.

- `signed char`
  The 8-bit `signed char` data type can hold integer values in the range of −128 to 127.
- `unsigned char`
  The 8-bit `unsigned char` data type can hold integer values in the range of 0 to 255.
- `char`
  Depending on your system, the `char` data type is defined as having the same range as either the `signed char` or the `unsigned char` data type (they are three distinct types, however). By convention, you should use the `char` data type specifically for storing ASCII characters (such as `'m'`), including escape sequences (such as `'\n'`).
- `short int`
  The 16-bit `short int` data type can hold integer values in the range of −32,768 to 32,767. You may also refer to this data type as `short`, `signed short int`, or `signed short`.
- `unsigned short int`
  The 16-bit `unsigned short int` data type can hold integer values in the range of 0 to 65,535. You may also refer to this data type as `unsigned short`.
- `int`
  The 32-bit `int` data type can hold integer values in the range of −2,147,483,648 to 2,147,483,647. You may also refer to this data type as `signed int` or `signed`.
- `unsigned int`
  The 32-bit `unsigned int` data type can hold integer values in the range of 0 to 4,294,967,295. You may also refer to this data type simply as `unsigned`.
- `long int`
  The 32-bit `long int` data type can hold integer values in the range of at least −2,147,483,648 to 2,147,483,647. (Depending on your system, this data type might be 64-bit, in which case its range is identical to that of the `long long int` data type.) You may also refer to this data type as `long`, `signed long int`, or `signed long`.
- `unsigned long int`
  The 32-bit `unsigned long int` data type can hold integer values in the range of at

least 0 to 4,294,967,295. (Depending on your system, this data type might be 64-bit, in which case its range is identical to that of the `unsigned long long int` data type.) You may also refer to this data type as `unsigned long`.

- `long long int`
  The 64-bit `long long int` data type can hold integer values in the range of −9,223,372,036,854,775,808 to 9,223,372,036,854,775,807. You may also refer to this data type as `long long`, `signed long long int` or `signed long long`. This type is not part of C89, but is both part of C99 and a GNU C extension.
- `unsigned long long int`
  The 64-bit `unsigned long long int` data type can hold integer values in the range of at least 0 to 18,446,744,073,709,551,615. You may also refer to this data type as `unsigned long long`. This type is not part of C89, but is both part of C99 and a GNU C extension.

Here are some examples of declaring and defining integer variables:

```
int foo;
unsigned int bar = 42;
char quux = 'a';
```

The first line declares an integer named `foo` but does not define its value; it is left uninitialized, and its value should not be assumed to be anything in particular.

2.1.2 Real Number Types

There are three data types that represent fractional numbers. While the sizes and ranges of these types are consistent across most computer systems in use today, historically the sizes of these types varied from system to system. As such, the minimum and maximum values are stored in macro definitions in the library header file `float.h`. In this section, we include the names of the macro definitions in place of their possible values; check your system's `float.h` for specific numbers.

- `float`
  The `float` data type is the smallest of the three floating point types, if they differ in size at all. Its minimum value is stored in the `FLT_MIN`, and should be no greater than `1e-37`. Its maximum value is stored in `FLT_MAX`, and should be no less than `1e37`.
- `double`
  The `double` data type is at least as large as the `float` type, and it may be larger. Its minimum value is stored in `DBL_MIN`, and its maximum value is stored in `DBL_MAX`.
- `long double`
  The `long double` data type is at least as large as the `float` type, and it may be larger. Its minimum value is stored in `LDBL_MIN`, and its maximum value is stored in `LDBL_MAX`.

All floating point data types are signed; trying to use `unsigned float`, for example, will cause a compile-time error.

Here are some examples of declaring and defining real number variables:

```
float foo;
double bar = 114.3943;
```

The first line declares a float named `foo` but does not define its value; it is left uninitialized, and its value should not be assumed to be anything in particular.

The real number types provided in C are of finite precision, and accordingly, not all real numbers can be represented exactly. Most computer systems that GCC compiles for use a binary representation for real numbers, which is unable to precisely represent numbers such as, for example, 4.2. For this reason, we recommend that you consider not comparing real numbers for exact equality with the `==` operator, but rather check that real numbers are within an acceptable tolerance.

There are other more subtle implications of these imprecise representations; for more details, see David Goldberg's paper *What Every Computer Scientist Should Know About Floating-Point Arithmetic* and section 4.2.2 of Donald Knuth's *The Art of Computer Programming*.

2.1.3 Complex Number Types

GCC introduced some complex number types as an extension to C89. Similar features were introduced in C99[1], but there were a number of differences. We describe the standard complex number types first.

2.1.3.1 Standard Complex Number Types

Complex types were introduced in C99. There are three complex types:

`float _Complex`

`double _Complex`

`long double _Complex`

The names here begin with an underscore and an uppercase letter in order to avoid conflicts with existing programs' identifiers. However, the C99 standard header file `<complex.h>` introduces some macros which make using complex types easier.

`complex`
Expands to `_Complex`. This allows a variable to be declared as `double complex` which seems more natural.

`I`
A constant of type `const float _Complex` having the value of the imaginary unit normally referred to as i.

The `<complex.h>` header file also declares a number of functions for performing computations on complex numbers, for example the `creal` and `cimag` functions which respectively return the real and imaginary parts of a `double complex` number. Other functions are also provided, as shown in this example:

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

void example (void)
{
  complex double z = 1.0 + 3.0*I;
  printf ("Phase is %f, modulus is %f\n", carg (z), cabs (z));
}
```

[1] C++ also has complex number support, but it is incompatible with the ISO C99 types.

2.1.3.2 GNU Extensions for Complex Number Types

GCC also introduced complex types as a GNU extension to C89, but the spelling is different. The floating-point complex types in GCC's C89 extension are:

`__complex__ float`

`__complex__ double`

`__complex__ long double`

GCC's extension allow for complex types other than floating-point, so that you can declare complex character types and complex integer types; in fact `__complex__` can be used with any of the primitive data types. We won't give you a complete list of all possibilities, but here are some examples:

- `__complex__ float`
  The `__complex__ float` data type has two components: a real part and an imaginary part, both of which are of the `float` data type.
- `__complex__ int`
  The `__complex__ int` data type also has two components: a real part and an imaginary part, both of which are of the `int` data type.

To extract the real part of a complex-valued expression, use the keyword `__real__`, followed by the expression. Likewise, use `__imag__` to extract the imaginary part.

```
__complex__ float a = 4 + 3i;

float b = __real__ a;          /* b is now 4. */
float c = __imag__ a;          /* c is now 3. */
```

This example creates a complex floating point variable `a`, and defines its real part as 4 and its imaginary part as 3. Then, the real part is assigned to the floating point variable `b`, and the imaginary part is assigned to the floating point variable `c`.

2.2 Enumerations

An enumeration is a custom data type used for storing constant integer values and referring to them by names. By default, these values are of type `signed int`; however, you can use the `-fshort-enums` GCC compiler option to cause the smallest possible integer type to be used instead. Both of these behaviors conform to the C89 standard, but mixing the use of these options within the same program can produce incompatibilities.

2.2.1 Defining Enumerations

You define an enumeration using the `enum` keyword, followed by the name of the enumeration (this is optional), followed by a list of constant names (separated by commas and enclosed in braces), and ending with a semicolon.

```
enum fruit {grape, cherry, lemon, kiwi};
```

That example defines an enumeration, `fruit`, which contains four constant integer values, `grape`, `cherry`, `lemon`, and `kiwi`, whose values are, by default, 0, 1, 2, and 3, respectively. You can also specify one or more of the values explicitly:

```
enum more_fruit {banana = -17, apple, blueberry, mango};
```

That example defines `banana` to be −17, and the remaining values are incremented by 1: `apple` is −16, `blueberry` is −15, and `mango` is -14. Unless specified otherwise, an enumeration value is equal to one more than the previous value (and the first value defaults to 0).

You can also refer to an enumeration value defined earlier in the same enumeration:

```
enum yet_more_fruit {kumquat, raspberry, peach,
                     plum = peach + 2};
```

In that example, `kumquat` is 0, `raspberry` is 1, `peach` is 2, and `plum` is 4.

You can't use the same name for an `enum` as a `struct` or `union` in the same scope.

2.2.2 Declaring Enumerations

You can declare variables of an enumeration type both when the enumeration is defined and afterward. This example declares one variable, named `my_fruit` of type `enum fruit`, all in a single statement:

```
enum fruit {banana, apple, blueberry, mango} my_fruit;
```

while this example declares the type and variable separately:

```
enum fruit {banana, apple, blueberry, mango};
enum fruit my_fruit;
```

(Of course, you couldn't declare it that way if you hadn't named the enumeration.)

Although such variables are considered to be of an enumeration type, you can assign them any value that you could assign to an `int` variable, including values from other enumerations. Furthermore, any variable that can be assigned an `int` value can be assigned a value from an enumeration.

However, you cannot change the values in an enumeration once it has been defined; they are constant values. For example, this won't work:

```
enum fruit {banana, apple, blueberry, mango};
banana = 15;  /* You can't do this! */
```

Enumerations are useful in conjunction with the `switch` statement, because the compiler can warn you if you have failed to handle one of the enumeration values. Using the example above, if your code handles `banana`, `apple` and `mango` only but not `blueberry`, GCC can generate a warning.

2.3 Unions

A union is a custom data type used for storing several variables in the same memory space. Although you can access any of those variables at any time, you should only read from one of them at a time—assigning a value to one of them overwrites the values in the others.

2.3.1 Defining Unions

You define a union using the `union` keyword followed by the declarations of the union's members, enclosed in braces. You declare each member of a union just as you would normally declare a variable—using the data type followed by one or more variable names separated by commas, and ending with a semicolon. Then end the union definition with a semicolon after the closing brace.

You should also include a name for the union between the `union` keyword and the opening brace. This is syntactically optional, but if you leave it out, you can't refer to that union data type later on (without a `typedef`, see Section 4.14 [The typedef Statement], page 54).

Here is an example of defining a simple union for holding an integer value and a floating point value:

```
union numbers
  {
    int i;
    float f;
  };
```

That defines a union named `numbers`, which contains two members, `i` and `f`, which are of type `int` and `float`, respectively.

2.3.2 Declaring Union Variables

You can declare variables of a union type when both you initially define the union and after the definition, provided you gave the union type a name.

2.3.2.1 Declaring Union Variables at Definition

You can declare variables of a union type when you define the union type by putting the variable names after the closing brace of the union definition, but before the final semicolon. You can declare more than one such variable by separating the names with commas.

```
union numbers
  {
    int i;
    float f;
  } first_number, second_number;
```

That example declares two variables of type `union numbers`, `first_number` and `second_number`.

2.3.2.2 Declaring Union Variables After Definition

You can declare variables of a union type after you define the union by using the `union` keyword and the name you gave the union type, followed by one or more variable names separated by commas.

```
union numbers
  {
    int i;
    float f;
  };
union numbers first_number, second_number;
```

That example declares two variables of type `union numbers`, `first_number` and `second_number`.

2.3.2.3 Initializing Union Members

You can initialize the first member of a union variable when you declare it:

```
union numbers
  {
    int i;
    float f;
  };
union numbers first_number = { 5 };
```

In that example, the `i` member of `first_number` gets the value 5. The `f` member is left alone.

Another way to initialize a union member is to specify the name of the member to initialize. This way, you can initialize whichever member you want to, not just the first one. There are two methods that you can use—either follow the member name with a colon, and then its value, like this:

```
union numbers first_number = { f: 3.14159 };
```

or precede the member name with a period and assign a value with the assignment operator, like this:

```
union numbers first_number = { .f = 3.14159 };
```

You can also initialize a union member when you declare the union variable during the definition:

```
union numbers
  {
    int i;
    float f;
  } first_number = { 5 };
```

2.3.3 Accessing Union Members

You can access the members of a union variable using the member access operator. You put the name of the union variable on the left side of the operator, and the name of the member on the right side.

```
union numbers
  {
    int i;
    float f;
  };
union numbers first_number;
first_number.i = 5;
first_number.f = 3.9;
```

Notice in that example that giving a value to the `f` member overrides the value stored in the `i` member.

2.3.4 Size of Unions

This size of a union is equal to the size of its largest member. Consider the first union example from this section:

```
union numbers
  {
    int i;
    float f;
  };
```

The size of the union data type is the same as `sizeof (float)`, because the `float` type is larger than the `int` type. Since all of the members of a union occupy the same memory space, the union data type size doesn't need to be large enough to hold the sum of all their sizes; it just needs to be large enough to hold the largest member.

2.4 Structures

A structure is a programmer-defined data type made up of variables of other data types (possibly including other structure types).

2.4.1 Defining Structures

You define a structure using the `struct` keyword followed by the declarations of the structure's members, enclosed in braces. You declare each member of a structure just as you would normally declare a variable—using the data type followed by one or more variable names separated by commas, and ending with a semicolon. Then end the structure definition with a semicolon after the closing brace.

You should also include a name for the structure in between the `struct` keyword and the opening brace. This is optional, but if you leave it out, you can't refer to that structure data type later on (without a `typedef`, see Section 4.14 [The typedef Statement], page 54).

Here is an example of defining a simple structure for holding the X and Y coordinates of a point:

```
struct point
  {
    int x, y;
  };
```

That defines a structure type named `struct point`, which contains two members, `x` and `y`, both of which are of type `int`.

Structures (and unions) may contain instances of other structures and unions, but of course not themselves. It is possible for a structure or union type to contain a field which is a pointer to the same type (see Section 2.7 [Incomplete Types], page 25).

2.4.2 Declaring Structure Variables

You can declare variables of a structure type when both you initially define the structure and after the definition, provided you gave the structure type a name.

2.4.2.1 Declaring Structure Variables at Definition

You can declare variables of a structure type when you define the structure type by putting the variable names after the closing brace of the structure definition, but before the final semicolon. You can declare more than one such variable by separating the names with commas.

```
struct point
  {
    int x, y;
  } first_point, second_point;
```

That example declares two variables of type `struct point`, `first_point` and `second_point`.

2.4.2.2 Declaring Structure Variables After Definition

You can declare variables of a structure type after defining the structure by using the `struct` keyword and the name you gave the structure type, followed by one or more variable names separated by commas.

```
struct point
  {
    int x, y;
  };
struct point first_point, second_point;
```

That example declares two variables of type `struct point`, `first_point` and `second_point`.

2.4.2.3 Initializing Structure Members

You can initialize the members of a structure type to have certain values when you declare structure variables.

If you do not initialize a structure variable, the effect depends on whether it has static storage (see Section 2.9 [Storage Class Specifiers], page 26) or not. If it is, members with integral types are initialized with 0 and pointer members are initialized to NULL; otherwise, the value of the structure's members is indeterminate.

One way to initialize a structure is to specify the values in a set of braces and separated by commas. Those values are assigned to the structure members in the same order that the members are declared in the structure in definition.

```
struct point
  {
    int x, y;
  };
struct point first_point = { 5, 10 };
```

In that example, the `x` member of `first_point` gets the value 5, and the `y` member gets the value 10.

Another way to initialize the members is to specify the name of the member to initialize. This way, you can initialize the members in any order you like, and even leave some of them uninitialized. There are two methods that you can use. The first method is available in C99 and as a C89 extension in GCC:

```
struct point first_point = { .y = 10, .x = 5 };
```

You can also omit the period and use a colon instead of '`=`', though this is a GNU C extension:

```
struct point first_point = { y: 10, x: 5 };
```

You can also initialize the structure variable's members when you declare the variable during the structure definition:

```
struct point
  {
    int x, y;
  } first_point = { 5, 10 };
```

You can also initialize fewer than all of a structure variable's members:

```
struct pointy
  {
    int x, y;
    char *p;
  };
struct pointy first_pointy = { 5 };
```

Here, `x` is initialized with 5, `y` is initialized with 0, and `p` is initialized with NULL. The rule here is that `y` and `p` are initialized just as they would be if they were static variables.

Here is another example that initializes a structure's members which are structure variables themselves:

```
struct point
  {
    int x, y;
  };

struct rectangle
  {
    struct point top_left, bottom_right;
  };

struct rectangle my_rectangle = { {0, 5}, {10, 0} };
```

That example defines the `rectangle` structure to consist of two `point` structure variables. Then it declares one variable of type `struct rectangle` and initializes its members. Since its members are structure variables, we used an extra set of braces surrounding the members that belong to the `point` structure variables. However, those extra braces are not necessary; they just make the code easier to read.

2.4.3 Accessing Structure Members

You can access the members of a structure variable using the member access operator. You put the name of the structure variable on the left side of the operator, and the name of the member on the right side.

```
struct point
  {
    int x, y;
  };

struct point first_point;

first_point.x = 0;
first_point.y = 5;
```

You can also access the members of a structure variable which is itself a member of a structure variable.

```
struct rectangle
  {
    struct point top_left, bottom_right;
  };

struct rectangle my_rectangle;

my_rectangle.top_left.x = 0;
my_rectangle.top_left.y = 5;

my_rectangle.bottom_right.x = 10;
my_rectangle.bottom_right.y = 0;
```

2.4.4 Bit Fields

You can create structures with integer members of nonstandard sizes, called *bit fields*. You do this by specifying an integer (`int`, `char`, `long int`, etc.) member as usual, and inserting a colon and the number of bits that the member should occupy in between the member's name and the semicolon.

```
struct card
  {
    unsigned int suit : 2;
    unsigned int face_value : 4;
  };
```

That example defines a structure type with two bit fields, `suit` and `face_value`, which take up 2 bits and 4 bits, respectively. `suit` can hold values from 0 to 3, and `face_value` can hold values from 0 to 15. Notice that these bit fields were declared as `unsigned int`; had they been signed integers, then their ranges would have been from -2 to 1, and from -8 to 7, respectively.

More generally, the range of an unsigned bit field of N bits is from 0 to $2^N - 1$, and the range of a signed bit field of N bits is from $-(2^N)/2$ to $((2^N)/2) - 1$.

Bit fields can be specified without a name in order to control which actual bits within the containing unit are used. However, the effect of this is not very portable and it is rarely useful. You can also specify a bit field of size 0, which indicates that subsequent bit fields not further bit fields should be packed into the unit containing the previous bit field. This is likewise not generally useful.

You may not take the address of a bit field with the address operator `&` (see Section 3.10 [Pointer Operators], page 35).

2.4.5 Size of Structures

The size of a structure type is equal to the sum of the size of all of its members, possibly including padding to cause the structure type to align to a particular byte boundary. The details vary depending on your computer platform, but it would not be atypical to see structures padded to align on four- or eight-byte boundaries. This is done in order to speed up memory accesses of instances of the structure type.

As a GNU extension, GCC allows structures with no members. Such structures have zero size.

If you wish to explicitly omit padding from your structure types (which may, in turn, decrease the speed of structure memory accesses), then GCC provides multiple methods of turning packing off. The quick and easy method is to use the `-fpack-struct` compiler option. For more details on omitting packing, please see the GCC manual which corresponds to your version of the compiler.

2.5 Arrays

An array is a data structure that lets you store one or more elements consecutively in memory. In C, array elements are indexed beginning at position zero, not one.

2.5.1 Declaring Arrays

You declare an array by specifying the data type for its elements, its name, and the number of elements it can store. Here is an example that declares an array that can store ten integers:

```
int my_array[10];
```

For standard C code, the number of elements in an array must be positive.

As a GNU extension, the number of elements can be as small as zero. Zero-length arrays are useful as the last element of a structure which is really a header for a variable-length object:

```
struct line
{
  int length;
  char contents[0];
};

{
  struct line *this_line = (struct line *)
    malloc (sizeof (struct line) + this_length);
  this_line -> length = this_length;
}
```

Another GNU extension allows you to declare an array size using variables, rather than only constants. For example, here is a function definition that declares an array using its parameter as the number of elements:

```
int
my_function (int number)
{
  int my_array[number];
  ...;
}
```

2.5.2 Initializing Arrays

You can initialize the elements in an array when you declare it by listing the initializing values, separated by commas, in a set of braces. Here is an example:

```
int my_array[5] = { 0, 1, 2, 3, 4 };
```

You don't have to explicitly initialize all of the array elements. For example, this code initializes the first three elements as specified, and then initializes the last two elements to a default value of zero:

```
int my_array[5] = { 0, 1, 2 };
```

When using either ISO C99, or C89 with GNU extensions, you can initialize array elements out of order, by specifying which array indices to initialize. To do this, include the array index in brackets, and optionally the assignment operator, before the value. Here is an example:

```
int my_array[5] = { [2] 5, [4] 9 };
```

Or, using the assignment operator:

```
int my_array[5] = { [2] = 5, [4] = 9 };
```

Both of those examples are equivalent to:

```
int my_array[5] = { 0, 0, 5, 0, 9 };
```

When using GNU extensions, you can initialize a range of elements to the same value, by specifying the first and last indices, in the form `[`*`first`*`] ... [`*`last`*`]` . Here is an example:

```
int new_array[100] = { [0 ... 9] = 1, [10 ... 98] = 2, 3 };
```

That initializes elements 0 through 9 to 1, elements 10 through 98 to 2, and element 99 to 3. (You also could explicitly write `[99] = 3`.) Also, notice that you *must* have spaces on both sides of the '`...`'.

If you initialize every element of an array, then you do not have to specify its size; its size is determined by the number of elements you initialize. Here is an example:

```
int my_array[] = { 0, 1, 2, 3, 4 };
```

Although this does not explicitly state that the array has five elements using `my_array[5]`, it initializes five elements, so that is how many it has.

Alternately, if you specify which elements to initialize, then the size of the array is equal to the highest element number initialized, plus one. For example:

```
int my_array[] = { 0, 1, 2, [99] = 99 };
```

In that example, only four elements are initialized, but the last one initialized is element number 99, so there are 100 elements.

2.5.3 Accessing Array Elements

You can access the elements of an array by specifying the array name, followed by the element index, enclosed in brackets. Remember that the array elements are numbered starting with zero. Here is an example:

```
my_array[0] = 5;
```

That assigns the value 5 to the first element in the array, at position zero. You can treat individual array elements like variables of whatever data type the array is made up of. For example, if you have an array made of a structure data type, you can access the structure elements like this:

```
struct point
{
  int x, y;
};
struct point point_array[2] = { {4, 5}, {8, 9} };
point_array[0].x = 3;
```

2.5.4 Multidimensional Arrays

You can make multidimensional arrays, or "arrays of arrays". You do this by adding an extra set of brackets and array lengths for every additional dimension you want your array to have. For example, here is a declaration for a two-dimensional array that holds five elements in each dimension (a two-element array consisting of five-element arrays):

```
int two_dimensions[2][5] { {1, 2, 3, 4, 5}, {6, 7, 8, 9, 10} };
```

Multidimensional array elements are accessed by specifying the desired index of both dimensions:

```
two_dimensions[1][3] = 12;
```

In our example, `two_dimensions[0]` is itself an array. The element `two_dimensions[0][2]` is followed by `two_dimensions[0][3]`, not by `two_dimensions[1][2]`.

2.5.5 Arrays as Strings

You can use an array of characters to hold a string (see Section 1.3.4 [String Constants], page 5). The array may be built of either signed or unsigned characters.

When you declare the array, you can specify the number of elements it will have. That number will be the maximum number of characters that should be in the string, including the null character used to end the string. If you choose this option, then you do not have to initialize the array when you declare it. Alternately, you can simply initialize the array to a value, and its size will then be exactly large enough to hold whatever string you used to initialize it.

There are two different ways to initialize the array. You can specify of comma-delimited list of characters enclosed in braces, or you can specify a string literal enclosed in double quotation marks.

Here are some examples:

```
char blue[26];
char yellow[26] = {'y', 'e', 'l', 'l', 'o', 'w', '\0'};
char orange[26] = "orange";
char gray[] = {'g', 'r', 'a', 'y', '\0'};
char salmon[] = "salmon";
```

In each of these cases, the null character `\0` is included at the end of the string, even when not explicitly stated. (Note that if you initialize a string using an array of individual characters, then the null character is *not* guaranteed to be present. It might be, but such an occurrence would be one of chance, and should not be relied upon.)

After initialization, you cannot assign a new string literal to an array using the assignment operator. For example, this *will not work*:

```
char lemon[26] = "custard";
lemon = "steak sauce";      /* Fails! */
```

However, there are functions in the GNU C library that perform operations (including copy) on string arrays. You can also change one character at a time, by accessing individual string elements as you would any other array:

```
char name[] = "bob";
name[0] = 'r';
```

It is possible for you to explicitly state the number of elements in the array, and then initialize it using a string that has more characters than there are elements in the array. This is not a good thing. The larger string will *not* override the previously specified size of the array, and you will get a compile-time warning. Since the original array size remains, any part of the string that exceeds that original size is being written to a memory location that was not allocated for it.

2.5.6 Arrays of Unions

You can create an array of a union type just as you can an array of a primitive data type.

```
union numbers
  {
    int i;
    float f;
  };
union numbers number_array [3];
```

That example creates a 3-element array of `union numbers` variables called `number_array`. You can also initialize the first members of the elements of a number array:

```
union numbers number_array [3] = { {3}, {4}, {5} };
```

The additional inner grouping braces are optional.

After initialization, you can still access the union members in the array using the member access operator. You put the array name and element number (enclosed in brackets) to the left of the operator, and the member name to the right.

```
union numbers number_array [3];
number_array[0].i = 2;
```

2.5.7 Arrays of Structures

You can create an array of a structure type just as you can an array of a primitive data type.

```
struct point
  {
    int x, y;
  };
struct point point_array [3];
```

That example creates a 3-element array of `struct point` variables called `point_array`. You can also initialize the elements of a structure array:

```
struct point point_array [3] = { {2, 3}, {4, 5}, {6, 7} };
```

As with initializing structures which contain structure members, the additional inner grouping braces are optional. But, if you use the additional braces, then you can partially initialize some of the structures in the array, and fully initialize others:

```
struct point point_array [3] = { {2}, {4, 5}, {6, 7} };
```

In that example, the first element of the array has only its `x` member initialized. Because of the grouping braces, the value 4 is assigned to the `x` member of the second array element, *not* to the `y` member of the first element, as would be the case without the grouping braces.

After initialization, you can still access the structure members in the array using the member access operator. You put the array name and element number (enclosed in brackets) to the left of the operator, and the member name to the right.

```
struct point point_array [3];
point_array[0].x = 2;
point_array[0].y = 3;
```

2.6 Pointers

Pointers hold memory addresses of stored constants or variables. For any data type, including both primitive types and custom types, you can create a pointer that holds the memory address of an instance of that type.

2.6.1 Declaring Pointers

You declare a pointer by specifying a name for it and a data type. The data type indicates of what type of variable the pointer will hold memory addresses.

To declare a pointer, include the indirection operator (see Section 3.10 [Pointer Operators], page 35) before the identifier. Here is the general form of a pointer declaration:

```
data-type * name;
```

White space is not significant around the indirection operator:

```
data-type *name;
data-type* name;
```

Here is an example of declaring a pointer to hold the address of an `int` variable:

```
int *ip;
```

Be careful, though: when declaring multiple pointers in the same statement, you must explicitly declare each as a pointer, using the indirection operator:

```
int *foo, *bar;  /* Two pointers. */
int *baz, quux;   /* A pointer and an integer variable. */
```

2.6.2 Initializing Pointers

You can initialize a pointer when you first declare it by specifying a variable address to store in it. For example, the following code declares an `int` variable '`i`', and a pointer which is initialized with the address of '`i`':

```
int i;
int *ip = &i;
```

Note the use of the address operator (see Section 3.10 [Pointer Operators], page 35), used to get the memory address of a variable. After you declare a pointer, you do *not* use the indirection operator with the pointer's name when assigning it a new address to point to. On the contrary, that would change the value of the variable that the points to, not the value of the pointer itself. For example:

```
int i, j;
int *ip = &i;  /* 'ip' now holds the address of 'i'. */
ip = &j;       /* 'ip' now holds the address of 'j'. */
*ip = &i;      /* 'j' now holds the address of 'i'. */
```

The value stored in a pointer is an integral number: a location within the computer's memory space. If you are so inclined, you can assign pointer values explicitly using literal integers, casting them to the appropriate pointer type. However, we do not recommend this practice unless you need to have extremely fine-tuned control over what is stored in memory, and you know exactly what you are doing. It would be all too easy to accidentally overwrite something that you did not intend to. Most uses of this technique are also non-portable.

It is important to note that if you do not initialize a pointer with the address of some other existing object, it points nowhere in particular and will likely make your program crash if you use it (formally, this kind of thing is called *undefined behavior*).

2.6.3 Pointers to Unions

You can create a pointer to a union type just as you can a pointer to a primitive data type.

```
union numbers
  {
    int i;
    float f;
  };
union numbers foo = {4};
union numbers *number_ptr = &foo;
```

That example creates a new union type, `union numbers`, and declares (and initializes the first member of) a variable of that type named `foo`. Finally, it declares a pointer to the type `union numbers`, and gives it the address of `foo`.

You can access the members of a union variable through a pointer, but you can't use the regular member access operator anymore. Instead, you have to use the indirect member access operator (see Section 3.16 [Member Access Expressions], page 38). Continuing with the previous example, the following example will change the value of the first member of `foo`:

```
number_ptr -> i = 450;
```

Now the `i` member in `foo` is 450.

2.6.4 Pointers to Structures

You can create a pointer to a structure type just as you can a pointer to a primitive data type.

```
struct fish
  {
    float length, weight;
  };
struct fish salmon = {4.3, 5.8};
struct fish *fish_ptr = &salmon;
```

That example creates a new structure type, `struct fish`, and declares (and initializes) a variable of that type named `salmon`. Finally, it declares a pointer to the type `struct fish`, and gives it the address of `salmon`.

You can access the members of a structure variable through a pointer, but you can't use the regular member access operator anymore. Instead, you have to use the indirect member access operator (see Section 3.16 [Member Access Expressions], page 38). Continuing with the previous example, the following example will change the values of the members of `salmon`:

```
fish_ptr -> length = 5.1;
fish_ptr -> weight = 6.2;
```

Now the `length` and `width` members in `salmon` are 5.1 and 6.2, respectively.

2.7 Incomplete Types

You can define structures, unions, and enumerations without listing their members (or values, in the case of enumerations). Doing so results in an incomplete type. You can't declare variables of incomplete types, but you can work with pointers to those types.

```
struct point;
```

At some time later in your program you will want to complete the type. You do this by defining it as you usually would:

```
struct point
  {
    int x, y;
  };
```

This technique is commonly used to for linked lists:

```
struct singly_linked_list
  {
    struct singly_linked_list *next;
    int x;
    /* other members here perhaps */
  };
struct singly_linked_list *list_head;
```

2.8 Type Qualifiers

There are two type qualifiers that you can prepend to your variable declarations which change how the variables may be accessed: `const` and `volatile`.

`const` causes the variable to be read-only; after initialization, its value may not be changed.

```
const float pi = 3.14159f;
```

In addition to helping to prevent accidental value changes, declaring variables with `const` can aid the compiler in code optimization.

`volatile` tells the compiler that the variable is explicitly changeable, and seemingly useless accesses of the variable (for instance, via pointers) should not be optimized away. You might use `volatile` variables to store data that is updated via callback functions or signal handlers. Section 3.20.4 [Sequence Points and Signal Delivery], page 44.

```
volatile float currentTemperature = 40.0;
```

2.9 Storage Class Specifiers

There are four storage class specifiers that you can prepend to your variable declarations which change how the variables are stored in memory: `auto`, `extern`, `register`, and `static`.

You use `auto` for variables which are local to a function, and whose values should be discarded upon return from the function in which they are declared. This is the default behavior for variables declared within functions.

```
void
foo (int value)
{
  auto int x = value;
  ...
  return;
}
```

`register` is nearly identical in purpose to `auto`, except that it also suggests to the compiler that the variable will be heavily used, and, if possible, should be stored in a register. You cannot use the address-of operator to obtain the address of a variable declared with `register`. This means that you cannot refer to the elements of an array declared with storage class `register`. In fact the only thing you can do with such an array is measure its size with `sizeof`. GCC normally makes good choices about which values to hold in registers, and so `register` is not often used.

`static` is essentially the opposite of `auto`: when applied to variables within a function or block, these variables will retain their value even when the function or block is finished. This is known as *static storage duration*.

```
int
sum (int x)
{
  static int sumSoFar = 0;
  sumSoFar = sumSoFar + x;
  return sumSoFar;
}
```

You can also declare variables (or functions) at the top level (that is, not inside a function) to be `static`; such variables are visible (global) to the current source file (but not other source files). This gives an unfortunate double meaning to `static`; this second meaning is known as *static linkage*. Two functions or variables having static linkage in separate files are entirely separate; neither is visible outside the file in which it is declared.

Uninitialized variables that are declared as `extern` are given default values of `0`, `0.0`, or `NULL`, depending on the type. Uninitialized variables that are declared as `auto` or `register` (including the default usage of `auto`) are left uninitialized, and hence should not be assumed to hold any particular value.

`extern` is useful for declaring variables that you want to be visible to all source files that are linked into your project. You cannot initialize a variable in an `extern` declaration, as no space is actually allocated during the declaration. You must make both an `extern` declaration (typically in a header file that is included by the other source files which need to access the variable) and a non-`extern` declaration which is where space is actually allocated to store the variable. The `extern` declaration may be repeated multiple times.

```
extern int numberOfClients;

...

int numberOfClients = 0;
```

See Chapter 6 [Program Structure and Scope], page 64, for related information.

2.10 Renaming Types

Sometimes it is convenient to give a new name to a type. You can do this using the `typedef` statement. See Section 4.14 [The typedef Statement], page 54, for more information.

3 Expressions and Operators

3.1 Expressions

An *expression* consists of at least one operand and zero or more operators. Operands are typed objects such as constants, variables, and function calls that return values. Here are some examples:

```
47
2 + 2
cosine(3.14159) /* We presume this returns a floating point value. */
```

Parentheses group subexpressions:

```
( 2 * ( ( 3 + 10 ) - ( 2 * 6 ) ) )
```

Innermost expressions are evaluated first. In the above example, `3 + 10` and `2 * 6` evaluate to `13` and `12`, respectively. Then `12` is subtracted from `13`, resulting in `1`. Finally, `1` is multiplied by `2`, resulting in `2`. The outermost parentheses are completely optional.

An *operator* specifies an operation to be performed on its operand(s). Operators may have one, two, or three operands, depending on the operator.

3.2 Assignment Operators

Assignment operators store values in variables. C provides several variations of assignment operators.

The standard assignment operator `=` simply stores the value of its right operand in the variable specified by its left operand. As with all assignment operators, the left operand (commonly referred to as the "lvalue") cannot be a literal or constant value.

```
int x = 10;
float y = 45.12 + 2.0;
int z = (2 * (3 + function () ));

struct foo {
  int bar;
  int baz;
} quux = {3, 4};
```

Note that, unlike the other assignment operators described below, you can use the plain assignment operator to store values of a structure type.

Compound assignment operators perform an operation involving both the left and right operands, and then assign the resulting expression to the left operand. Here is a list of the compound assignment operators, and a brief description of what they do:

- `+=`

  Adds the two operands together, and then assign the result of the addition to the left operand.

- `-=`

  Subtract the right operand from the left operand, and then assign the result of the subtraction to the left operand.

- `*=`

  Multiply the two operands together, and then assign the result of the multiplication to the left operand.

- `/=`

  Divide the left operand by the right operand, and assign the result of the division to the left operand.

- `%=`

  Perform modular division on the two operands, and assign the result of the division to the left operand.

- `<<=`

  Perform a left shift operation on the left operand, shifting by the number of bits specified by the right operand, and assign the result of the shift to the left operand.

- `>>=`

  Perform a right shift operation on the left operand, shifting by the number of bits specified by the right operand, and assign the result of the shift to the left operand.

- `&=`

  Perform a bitwise conjunction operation on the two operands, and assign the result of the operation to the left operand.

- `^=`

  Performs a bitwise exclusive disjunction operation on the two operands, and assign the result of the operation to the left operand.

- `|=`

  Performs a bitwise inclusive disjunction operation on the two operands, and assign the result of the operation to the left operand.

Here is an example of using one of the compound assignment operators:

```
x += y;
```

Since there are no side effects wrought by evaluating the variable `x` as an lvalue, the above code produces the same result as:

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

3.3 Incrementing and Decrementing

The increment operator `++` adds 1 to its operand. The operand must be a either a variable of one of the primitive data types, a pointer, or an enumeration variable. You can apply the increment operator either before or after the operand. Here are some examples:

```
char w = '1';
int x = 5;
char y = 'B';
float z = 5.2;
int *p = &x;

++w;    /* w is now the character '2' (not the value 2). */
x++;    /* x is now 6. */
++y;    /* y is now 'C' (on ASCII systems). */
z++;    /* z is now 6.2. */
++p;    /* p is now &x + sizeof(int). */
```

(Note that incrementing a pointer only makes sense if you have reason to believe that the new pointer value will be a valid memory address.)

A prefix increment adds 1 before the operand is evaluated. A postfix increment adds 1 after the operand is evaluated. In the previous examples, changing the position of the operator would make no difference. However, there are cases where it does make a difference:

```
int x = 5;
printf ("%d \n", x++);     /* Print x and then increment it. */
/* x is now equal to 6. */
printf ("%d \n", ++x);     /* Increment x and then print it. */
```

The output of the above example is:

```
5
7
```

Likewise, you can subtract 1 from an operand using the decrement operator:

```
int x = 5;

x--; /* x is now 4. */
```

The concepts of prefix and postfix application apply here as with the increment operator.

3.4 Arithmetic Operators

C provides operators for standard arithmetic operations: addition, subtraction, multiplication, and division, along with modular division and negation. Usage of these operators is straightforward; here are some examples:

```
/* Addition. */
x = 5 + 3;
y = 10.23 + 37.332;
quux_pointer = foo_pointer + bar_pointer;

/* Subtraction. */
x = 5 - 3;
y = 57.223 - 10.903;
quux_pointer = foo_pointer - bar_pointer;
```

You can add and subtract memory pointers, but you cannot multiply or divide them.

```
/* Multiplication. */
x = 5 * 3;
y = 47.4 * 1.001;
/* Division. */
x = 5 / 3;
y = 940.0 / 20.2;
```

Integer division of positive values truncates towards zero, so 5/3 is 1. However, if either operand is negative, the direction of rounding is implementation-defined. Section A.5 [Signed Integer Division], page 75 for information about overflow in signed integer division.

You use the modulus operator `%` to obtain the remainder produced by dividing its two operands. You put the operands on either side of the operator, and it does matter which operand goes on which side: `3 % 5` and `5 % 3` do not have the same result. The operands must be expressions of a primitive data type.

```
/* Modular division. */
x = 5 % 3;
y = 74 % 47;
```

Modular division returns the remainder produced after performing integer division on the two operands. The operands must be of a primitive integer type.

```
/* Negation. */
int x = -5;
float y = -3.14159;
```

If the operand you use with the negative operator is of an unsigned data type, then the result cannot negative, but rather is the maximum value of the unsigned data type, minus the value of the operand.

Many systems use twos-complement arithmetic, and on such systems the most negative value a signed type can hold is further away from zero than the most positive value. For example, on one platform, this program:

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

int main (int argc, char *argv[])
{
  int x;
  x = INT_MAX;
  printf("INT_MAX  = %d\n", x);
  x = INT_MIN;
  printf("INT_MIN  = %d\n", x);
  x = -x;
  printf("-INT_MIN = %d\n", x);
  return 0;
}
```

Produces this output:

```
INT_MAX  = 2147483647
INT_MIN  = -2147483648
-INT_MIN = -2147483648
```

Trivially, you can also apply a positive operator to a numeric expression:

```
int x = +42;
```

Numeric values are assumed to be positive unless explicitly made negative, so this operator has no effect on program operation.

3.5 Complex Conjugation

As a GNU extension, you can use the complex conjugation operator `~` to perform complex conjugation on its operand — that is, it reverses the sign of its imaginary component. The operand must be an expression of a complex number type. Here is an example:

```
__complex__ int x = 5 + 17i;

printf ("%d  \n", (x * ~x));
```

Since an imaginary number $(a + bi)$ multiplied by its conjugate is equal to $a^2 + b^2$, the above `printf` statement will print 314, which is equal to $25 + 289$.

3.6 Comparison Operators

You use the comparison operators to determine how two operands relate to each other: are they equal to each other, is one larger than the other, is one smaller than the other, and so on. When you use any of the comparison operators, the result is either 1 or 0, meaning true or false, respectively.

(In the following code examples, the variables `x` and `y` stand for any two expressions of arithmetic types, or pointers.)

The equal-to operator `==` tests its two operands for equality. The result is 1 if the operands are equal, and 0 if the operands are not equal.

```
if (x == y)
  puts ("x is equal to y");
else
  puts ("x is not equal to y");
```

The not-equal-to operator `!=` tests its two operands for inequality. The result is 1 if the operands are not equal, and 0 if the operands *are* equal.

```
if (x != y)
  puts ("x is not equal to y");
else
  puts ("x is equal to y");
```

Comparing floating-point values for exact equality or inequality can produce unexpected results. Section 2.1.2 [Real Number Types], page 9 for more information.

You can compare function pointers for equality or inequality; the comparison tests if two function pointers point to the same function or not.

Beyond equality and inequality, there are operators you can use to test if one value is less than, greater than, less-than-or-equal-to, or greater-than-or-equal-to another value. Here are some code samples that exemplify usage of these operators:

```
if (x < y)
  puts ("x is less than y");
```

```
if (x <= y)
  puts ("x is less than or equal to y");
if (x > y)
  puts ("x is greater than y");
if (x >= y)
  puts ("x is greater than or equal to y");
```

3.7 Logical Operators

Logical operators test the truth value of a pair of operands. Any nonzero expression is considered true in C, while an expression that evaluates to zero is considered false.

The logical conjunction operator `&&` tests if two expressions are both true. If the first expression is false, then the second expression is not evaluated.

```
if ((x == 5) && (y == 10))
  printf ("x is 5 and y is 10");
```

The logical disjunction operator `||` tests if at least one of two expressions it true. If the first expression is true, then the second expression is not evaluated.

```
if ((x == 5) || (y == 10))
   printf ("x is 5 or y is 10");
```

You can prepend a logical expression with a negation operator `!` to flip the truth value:

```
if (!(x == 5))
  printf ("x is not 5");
```

Since the second operand in a logical expression pair is not necessarily evaluated, you can write code with perhaps unintuitive results:

```
if (foo && x++)
  bar();
```

If `foo` is ever zero, then not only would `bar` not be called, but `x` would not be incremented. If you intend to increment `x` regardless of the value of `foo`, you should do so outside of the conjunction expression.

3.8 Bit Shifting

You use the left-shift operator `<<` to shift its first operand's bits to the left. The second operand denotes the number of bit places to shift. Bits shifted off the left side of the value are discarded; new bits added on the right side will all be 0.

```
x = 47;     /* 47 is 00101111 in binary. */
x << 1;     /* 00101111 << 1 is 01011110. */
```

Similarly, you use the right-shift operator `>>` to shift its first operand's bits to the right. Bits shifted off the right side are discarded; new bits added on the left side are *usually* 0, but if the first operand is a signed negative value, then the added bits will be either 0 *or* whatever value was previously in the leftmost bit position.

```
x = 47;    /* 47 is 00101111 in binary. */
x >> 1;    /* 00101111 >> 1 is 00010111. */
```

For both `<<` and `>>`, if the second operand is greater than the bit-width of the first operand, or the second operand is negative, the behavior is undefined.

You can use the shift operators to perform a variety of interesting hacks. For example, given a date with the day of the month numbered as `d`, the month numbered as `m`, and the year `y`, you can store the entire date in a single number `x`:

```
int d = 12;
int m = 6;
int y = 1983;
int x = (((y << 4) + m) << 5) + d;
```

You can then extract the original day, month, and year out of `x` using a combination of shift operators and modular division:

```
d = x % 32;
m = (x >> 5) % 16;
y = x >> 9;
```

3.9 Bitwise Logical Operators

C provides operators for performing bitwise conjunction, inclusive disjunction, exclusive disjunction, and negation (complement).

Biwise conjunction examines each bit in its two operands, and when two corresponding bits are both 1, the resulting bit is 1. All other resulting bits are 0. Here is an example of how this works, using binary numbers:

```
11001001 & 10011011 = 10001001
```

Bitwise inclusive disjunction examines each bit in its two operands, and when two corresponding bits are both 0, the resulting bit is 0. All other resulting bits are 1.

```
11001001 | 10011011 = 11011011
```

Bitwise exclusive disjunction examines each bit in its two operands, and when two corresponding bits are different, the resulting bit is 1. All other resulting bits are 0.

```
11001001 ^ 10011011 = 01010010
```

Bitwise negation reverses each bit in its operand:

```
~11001001 = 00110110
```

In C, you can only use these operators with operands of an integer (or character) type, and for maximum portability, you should only use the bitwise negation operator with unsigned integer types. Here are some examples of using these operators in C code:

```
unsigned int foo = 42;
unsigned int bar = 57;
unsigned int quux;

quux = foo & bar;
quux = foo | bar;
quux = foo ^ bar;
quux = ~foo;
```

3.10 Pointer Operators

You can use the address operator `&` to obtain the memory address of an object.

```
int x = 5;
int *pointer_to_x = &x;
```

It is not necessary to use this operator to obtain the address of a function, although you can:

```
extern int foo (void);
int (*fp1) (void) = foo; /* fp1 points to foo */
int (*fp2) (void) = &foo; /* fp2 also points to foo */
```

Function pointers and data pointers are not compatible, in the sense that you cannot expect to store the address of a function into a data pointer, and then copy that into a function pointer and call it successfully. It might work on some systems, but it's not a portable technique.

As a GNU extension to C89, you can also obtain the address of a label with the label address operator `&&`. The result is a `void*` pointer which can be used with `goto`. See Section 4.10 [The goto Statement], page 52.

Given a memory address stored in a pointer, you can use the indirection operator `*` to obtain the value stored at the address. (This is called *dereferencing* the pointer.)

```
int x = 5;
int y;
int *ptr;

ptr = &x;     /* ptr now holds the address of x. */

y = *ptr;     /* y gets the value stored at the address
                 stored in ptr. */
```

Avoid using dereferencing pointers that have not been initialized to a known memory location.

3.11 The sizeof Operator

You can use the `sizeof` operator to obtain the size (in bytes) of the data type of its operand. The operand may be an actual type specifier (such as `int` or `float`), as well as any valid expression. When the operand is a type name, it must be enclosed in parentheses. Here are some examples:

```
size_t a = sizeof(int);
size_t b = sizeof(float);
size_t c = sizeof(5);
size_t d = sizeof(5.143);
size_t e = sizeof a;
```

The result of the `sizeof` operator is of a type called `size_t`, which is defined in the header file `<stddef.h>`. `size_t` is an unsigned integer type, perhaps identical to `unsigned int` or `unsigned long int`; it varies from system to system.

The `size_t` type is often a convenient type for a loop index, since it is guaranteed to be able to hold the number of elements in any array; this is not the case with `int`, for example.

The `sizeof` operator can be used to automatically compute the number of elements in an array:

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

static const int values[] = { 1, 2, 48, 681 };
#define ARRAYSIZE(x) (sizeof x/sizeof x[0])

int main (int argc, char *argv[])
{
    size_t i;
    for (i = 0; i < ARRAYSIZE(values); i++)
    {
        printf("%d\n", values[i]);
    }
    return 0;
}
```

There are two cases where this technique does not work. The first is where the array element has zero size (GCC supports zero-sized structures as a GNU extension). The second is where the array is in fact a function parameter (see Section 5.4 [Function Parameters], page 58).

3.12 Type Casts

You can use a type cast to explicitly cause an expression to be of a specified data type. A type cast consists of a type specifier enclosed in parentheses, followed by an expression. To ensure proper casting, you should also enclose the expression that follows the type specifier in parentheses. Here is an example:

```
float x;
int y = 7;
int z = 3;
x = (float) (y / z);
```

In that example, since `y` and `z` are both integers, integer division is performed, and even though `x` is a floating-point variable, it receives the value 2. Explicitly casting the result of the division to `float` does no good, because the computed value of `y/z` is already 2.

To fix this problem, you need to convert one of the operands to a floating-point type before the division takes place:

```
float x;
int y = 7;
int z = 3;
x = (y / (float)z);
```

Here, a floating-point value close to 2.333... is assigned to `x`.

Type casting only works with scalar types (that is, integer, floating-point or pointer types). Therefore, this is not allowed:

```
struct fooTag { /* members ... */ };
struct fooTag foo;
unsigned char byteArray[8];

foo = (struct fooType) byteArray; /* Fail! */
```

3.13 Array Subscripts

You can access array elements by specifying the name of the array, and the array subscript (or index, or element number) enclosed in brackets. Here is an example, supposing an integer array called `my_array`:

```
my_array[0] = 5;
```

The array subscript expression `A[i]` is defined as being identical to the expression `(*((A)+(i)))`. This means that many uses of an array name are equivalent to a pointer expression. It also means that you cannot subscript an array having the `register` storage class.

3.14 Function Calls as Expressions

A call to any function which returns a value is an expression.

```
int function(void);
...
a = 10 + function();
```

3.15 The Comma Operator

You use the comma operator `,` to separate two (ostensibly related) expressions. For instance, the first expression might produce a value that is used by the second expression:

```
x++, y = x * x;
```

More commonly, the comma operator is used in `for` statements, like this:

```
/* Using the comma operator in a for statement. */

for (x = 1, y = 10;  x <=10 && y >=1;  x++, y--)
  {
    ...
  }
```

This lets you conveniently set, monitor, and modify multiple control expressions for the `for` statement.

A comma is also used to separate function parameters; however, this is *not* the comma operator in action. In fact, if the comma operator is used as we have discussed here in a function call, then the compiler will interpret that as calling the function with an extra parameter.

If you want to use the comma operator in a function argument, you need to put parentheses around it. That's because commas in a function argument list have a different meaning: they separate arguments. Thus,

```
foo (x,  y=47,  x,  z);
```

is interpreted as a function call with four arguments, but

```
foo (x,  (y=47,  x),  z);
```

is a function call with just three arguments. (The second argument is `(y=47, x)`.)

3.16 Member Access Expressions

You can use the member access operator `.` to access the members of a structure or union variable. You put the name of the structure variable on the left side of the operator, and the name of the member on the right side.

```
struct point
{
  int x, y;
};

struct point first_point;

first_point.x = 0;
first_point.y = 5;
```

You can also access the members of a structure or union variable via a pointer by using the indirect member access operator `->`. `x->y` is equivalent to `(*x).y`.

```
struct fish
  {
    int length, weight;
  };

struct fish salmon;

struct fish *fish_pointer = &salmon;

fish_pointer->length = 3;
fish_pointer->weight = 9;
```

See Section 2.6 [Pointers], page 23.

3.17 Conditional Expressions

You use the conditional operator to cause the entire conditional expression to evaluate to either its second or its third operand, based on the truth value of its first operand. Here's an example:

```
a ? b : c
```

If expression `a` is true, then expression `b` is evaluated and the result is the value of `b`. Otherwise, expression `c` is evaluated and the result is `c`.

Expressions `b` and `c` must be compatible. That is, they must both be

1. arithmetic types
2. compatible `struct` or `union` types

3. pointers to compatible types (one of which might be the NULL pointer)

   Alternatively, one operand is a pointer and the other is a `void*` pointer.

   Here is an example

```
a = (x == 5) ? y : z;
```

Here, if `x` equals 5, then `a` will receive the value of `y`. Otherwise, `a` will receive the value of `z`. This can be considered a shorthand method for writing a simple `if...else` statement. The following example will accomplish the same task as the previous one:

```
if (x == 5)
    a = y;
else
    a = z;
```

If the first operand of the conditional operator is true, then the third operand is never evaluated. Similarly, if the first operand is false, then the second operand is never evaluated. The first operand is always evaluated.

3.18 Statements and Declarations in Expressions

As a GNU C extension, you can build an expression using compound statement enclosed in parentheses. This allows you to included loops, switches, and local variables within an expression.

Recall that a compound statement (also known as a block) is a sequence of statements surrounded by braces. In this construct, parentheses go around the braces. Here is an example:

```
({ int y = function (); int z;
    if (y > 0) z = y;
   else z = - y;
   z; })
```

That is a valid (though slightly more complex than necessary) expression for the absolute value of `function ()`.

The last thing in the compound statement should be an expression followed by a semicolon; the value of this subexpression serves as the value of the entire construct. (If you use some other kind of statement last within the braces, the construct has type `void`, and thus effectively no value.)

This feature is especially useful in making macro definitions "safe" (so that they evaluate each operand exactly once). For example, the "maximum" function is commonly defined as a macro in standard C as follows:

```
#define max(a,b) ((a) > (b) ? (a) : (b))
```

But this definition computes either `a` or `b` twice, with bad results if the operand has side effects. In GNU C, if you know the type of the operands (here let's assume `int`), you can define the macro safely as follows:

```
#define maxint(a,b) \
  ({int _a = (a), _b = (b); _a > _b ? _a : _b; })
```

If you don't know the type of the operand, you can still do this, but you must use `typeof` expressions or type naming.

Embedded statements are not allowed in constant expressions, such as the value of an enumeration constant, the width of a bit field, or the initial value of a static variable.

3.19 Operator Precedence

When an expression contains multiple operators, such as `a + b * f()`, the operators are grouped based on rules of *precedence*. For instance, the meaning of that expression is to call the function `f` with no arguments, multiply the result by `b`, then add that result to `a`. That's what the C rules of operator precedence determine for this expression.

The following is a list of types of expressions, presented in order of highest precedence first. Sometimes two or more operators have equal precedence; all those operators are applied from left to right unless stated otherwise.

1. Function calls, array subscripting, and membership access operator expressions.
2. Unary operators, including logical negation, bitwise complement, increment, decrement, unary positive, unary negative, indirection operator, address operator, type casting, and `sizeof` expressions. When several unary operators are consecutive, the later ones are nested within the earlier ones: `!-x` means `!(-x)`.
3. Multiplication, division, and modular division expressions.
4. Addition and subtraction expressions.
5. Bitwise shifting expressions.
6. Greater-than, less-than, greater-than-or-equal-to, and less-than-or-equal-to expressions.
7. Equal-to and not-equal-to expressions.
8. Bitwise AND expressions.
9. Bitwise exclusive OR expressions.
10. Bitwise inclusive OR expressions.
11. Logical AND expressions.
12. Logical OR expressions.
13. Conditional expressions (using `?:`). When used as subexpressions, these are evaluated right to left.
14. All assignment expressions, including compound assignment. When multiple assignment statements appear as subexpressions in a single larger expression, they are evaluated right to left.
15. Comma operator expressions.

The above list is somewhat dry and is apparently straightforward, but it does hide some pitfalls. Take this example:

```
foo = *p++;
```

Here `p` is incremented as a side effect of the expression, but `foo` takes the value of `*(p++)` rather than `(*p)++`, since the unary operators bind right to left. There are other examples of potential surprises lurking behind the C precedence table. For this reason if there is the slightest risk of the reader misunderstanding the meaning of the program, you should use parentheses to make your meaning clear.

3.20 Order of Evaluation

In C you cannot assume that multiple subexpressions are evaluated in the order that seems natural. For instance, consider the expression `++a * f()`. Does this increment `a` before or after calling the function `f`? The compiler could do it in either order, so you cannot make assumptions.

This manual explains the semantics of the C language in the abstract. However, an actual compiler translates source code into specific actions in an actual computer, and may re-order operations for the sake of efficiency. The correspondence between the program you write and the things the computer actually does are specified in terms of *side effects* and *sequence points*.

3.20.1 Side Effects

A *side effect* is one of the following:

1. accessing a `volatile` object
2. modifying an object
3. modifying a file
4. a call to a function which performs any of the above side effects

These are essentially the externally-visible effects of running a program. They are called side effects because they are effects of expression evalation beyond the expression's actual resulting value.

The compiler is allowed to perform the operations of your program in an order different to the order implied by the source of your program, provided that in the end all the necessary side effects actually take place. The compiler is also allowed to entirely omit some operations; for example it's allowed to skip evaluating part of an expression if it can be certain that the value is not used and evaluating that part of the expression won't produce any needed side effects.

3.20.2 Sequence Points

Another requirement on the compiler is that side effects should take place in the correct order. In order to provide this without over-constraining the compiler, the C89 and C90 standards specify a list of sequence points. A *sequence point* is one of the following:

1. a call to a function (after argument evaluation is complete)
2. the end of the left-hand operand of the and operator `&&`
3. the end of the left-hand operand of the or operator `||`
4. the end of the left-hand operand of the comma operator `,`
5. the end of the first operand of the ternary operator `a ? b : c`
6. the end of a full declarator[1]
7. the end of an initialisation expression
8. the end of an expression statement (i.e. an expression followed by `;`)
9. the end of the controlling expression of an `if` or `switch` statement

[1] a full declarator is a declaration of a function or an object which is not part of another object

10. the end of the controlling expression of a `while` or `do` statement
11. the end of any of the three controlling expressions of a `for` statement
12. the end of the expression in a return statement
13. immediately before the return of a library function
14. after the actions associated with an item of formatted I/O (as used for example with the `strftime` or the `printf` and `scanf` famlies of functions).
15. immediately before and after a call to a comparison function (as called for example by `qsort`)

At a sequence point, all the side effects of previous expression evaluations must be complete, and no side effects of later evaluations may have taken place.

This may seem a little hard to grasp, but there is another way to consider this. Imagine you wrote a library (some of whose functions are external and perhaps others not) and compiled it, allowing someone else to call one of your functions from their code. The definitions above ensure that, at the time they call your function, the data they pass in has values which are consistent with the behaviour specified by the abstract machine, and any data returned by your function has a state which is also consistent with the abstract machine. This includes data accessible via pointers (i.e. not just function parameters and identifiers with external linkage).

The above is a slight simplification, since compilers exist that perform whole-program optimisation at link time. Importantly however, although they might perform optimisations, the visible side effects of the program must be the same as if they were produced by the abstract machine.

3.20.3 Sequence Points Constrain Expressions

The code fragment

```
i = i + 1;
```

is quite normal and no doubt occurs in many programs. However, the quite similar code fragment

```
i = ++i + 1;
```

is a little harder to understand; what is the final value of `i`? The C standards (both C89 and C99) both forbid this construct in conforming programs.

Between two sequence points,

1. an object may have its stored value modified at most once by the evaluation of an expression
2. the prior value of the object shall be read only to determine the value to be stored.

The first of these two conditions forbids expressions like `foo(x=2, ++x)`. The second condition forbids expressions like `a[i++] = i`.

`int x=0; foo(++x, ++x)`
: Not allowed in a conforming program; modifies `x` twice before argument evaluation is complete.

`int x=0; bar((++x,++x))`
: Allowed; the function `bar` takes one argument (the value 2 is passed here), and there is a sequence point at the comma operator.

`*p++ || *p++`
: Allowed; there is a sequence point at `||`.

`int x = 1, y = x++;`
: Allowed; there is a sequence point after the full declarator of `x`.

`x=2; x++;` Allowed; there is a sequence point at the end of the first expression statement.

`if (x++ > MAX) x = 0;`
: Allowed; there is a sequence point at the end of the controlling expression of the `if`[2].

`(x=y) ? ++x : x--;`
: Allowed; there is a sequence point before the `?`, and only one of the two following expressions is evaluated.

`int *p=malloc(sizeof(*p)), *q=p; *p=foo(); bar((*p)++,(*q)++);`
: Not allowed; the object at `p` is being modified twice before the evaluation of the arguments to `bar` is complete. The fact that this is done once via `p` and once via `q` is irrelevant, since they both point to the same object.

Let's go back to the example we used to introduce the problem of the order of evaluation, `++a * f()`. Suppose the code actually looks like this:

```
static int a = 1;

static int f (void)
{
  a = 100;
  return 3;
}

int foo (void)
{
   return ++a * f();
}
```

Is this code allowed in a standard-conforming program? Although the expression in `foo` modifies `a` twice, this is not a problem. Let's look at the two possible cases.

The right operand `f()` is evaluated first
: Since `f` returns a value other than void, it must contain a `return` statement. Therefore, there is a sequence point at the end of the return expression. That comes between the modification to `a` that `f` makes and the evaluation of the left operand.

The left operand `++a` is evaluated first
: First, `a` is incremented. Then the arguments to `f` are evaluated (there are zero of them). Then there is a sequence point before `f` is actually called.

[2] However if for example `MAX` is `INT_MAX` and `x` is of type `int`, we clearly have a problem with overflow. See Appendix A [Overflow], page 71.

So, we see that our program is standard-conforming. Notice that the above argument does not actually depend on the details of the body of the function `f`. It only depends on the function containing something ending in a sequence point – in our example this is a return statement, but an expression statement or a full declarator would do just as well.

However, the result of executing this code depends on the order of evaluation of the operands of `*`. If the left-hand operand is evaluated first, `foo` returns 6. Otherwise, it returns 303. The C standard does not specify in which order the operands should be evaluated, and also does not require an implementation either to document the order or even to stick to one order. The effect of this code is *unspecified*, meaning that one of several specific things will happen, but the C standards do not say which.

3.20.4 Sequence Points and Signal Delivery

Signals are mainly documented in the GNU C Library manual rather than this document, even though the C standards consider the compiler and the C library together to be "the implementation".

When a signal is received, this will happen between sequence points. Side effects on `volatile` objects prior to the previous sequence point will have occurred, but other updates may not have occurred yet. This even applies to straight assignments, such as `x=0;`, because the code generated for that statement may require more than one instruction, meaning that it can be interrupted part-way through by the delivery of a signal.

The C standard is quite restrictive about what data access can occur within a signal handler. They can of course use `auto` variables, but in terms of reading or writing other objects, they must be `volatile sig_atomic_t`. The `volatile` type qualifier ensures that access to the variable in the other parts of the program doesn't span sequence points and the use of the `sig_atomic_t` type ensures that changes to the variable are atomic with respect to signal delivery.

The POSIX standard also allows a small number of library functions to be called from a signal handler. These functions are referred to as the set of *async-signal-safe* functions. If your program is intended to run on a POSIX system but not on other systems, you can safely call these from your signal handler too.

4 Statements

You write statements to cause actions and to control flow within your programs. You can also write statements that do not do anything at all, or do things that are uselessly trivial.

4.1 Labels

You can use labels to identify a section of source code for use with a later `goto` (see Section 4.10 [The goto Statement], page 52). A label consists of an identifier (such as those used for variable names) followed by a colon. Here is an example:

```
treet:
```

You should be aware that label names do not interfere with other identifier names:

```
int treet = 5;     /* treet the variable. */
treet:             /* treet the label. */
```

The ISO C standard mandates that a label must be followed by at least one statement, possibly a null statement (see Section 4.9 [The Null Statement], page 52). GCC will compile code that does not meet this requirement, but be aware that if you violate it, your code may have portability issues.

4.2 Expression Statements

You can turn any expression into a statement by adding a semicolon to the end of the expression. Here are some examples:

```
5;
2 + 2;
10 >= 9;
```

In each of those, all that happens is that each expression is evaluated. However, they are useless because they do not store a value anywhere, nor do they actually do anything, other than the evaluation itself. The compiler is free to ignore such statements.

Expression statements are only useful when they have some kind of side effect, such as storing a value, calling a function, or (this is esoteric) causing a fault in the program. Here are some more useful examples:

```
x++;
y = x + 25;
puts ("Hello, user!");
*cucumber;
```

The last of those statements, `*cucumber;`, could potentially cause a fault in the program if the value of `cucumber` is both not a valid pointer and has been declared as `volatile`.

4.3 The `if` Statement

You can use the `if` statement to conditionally execute part of your program, based on the truth value of a given expression. Here is the general form of an `if` statement:

```
if (test)
  then-statement
else
  else-statement
```

If *test* evaluates to true, then *then-statement* is executed and *else-statement* is not. If *test* evaluates to false, then *else-statement* is executed and *then-statement* is not. The `else` clause is optional.

Here is an actual example:

```
if (x == 10)
  puts ("x is 10");
```

If `x == 10` evaluates to true, then the statement `puts ("x is 10");` is executed. If `x == 10` evaluates to false, then the statement `puts ("x is 10");` is not executed.

Here is an example using `else`:

```
if (x == 10)
  puts ("x is 10");
else
  puts ("x is not 10");
```

You can use a series of `if` statements to test for multiple conditions:

```
if (x == 1)
  puts ("x is 1");
else if (x == 2)
  puts ("x is 2");
else if (x == 3)
  puts ("x is 3");
else
  puts ("x is something else");
```

This function calculates and displays the date of Easter for the given year `y`:

```
void
easterDate (int y)
{
  int n = 0;
  int g = (y % 19) + 1;
  int c = (y / 100) + 1;
  int x = ((3 * c) / 4) - 12;
  int z = (((8 * c) + 5) / 25) - 5;
  int d = ((5 * y) / 4) - x - 10;
  int e = ((11 * g) + 20 + z - x) % 30;

  if (((e == 25) && (g > 11)) || (e == 24))
    e++;

  n = 44 - e;

  if (n < 21)
    n += 30;

  n = n + 7 - ((d + n) % 7);

  if (n > 31)
```

```
    printf ("Easter: %d April %d", n - 31, y);
  else
    printf ("Easter: %d March %d", n, y);
}
```

4.4 The `switch` Statement

You can use the `switch` statement to compare one expression with others, and then execute a series of sub-statements based on the result of the comparisons. Here is the general form of a `switch` statement:

```
switch (test)
  {
    case compare-1:
      if-equal-statement-1
    case compare-2:
      if-equal-statement-2
    ...
    default:
      default-statement
  }
```

The `switch` statement compares *test* to each of the *compare* expressions, until it finds one that is equal to *test*. Then, the statements following the successful case are executed. All of the expressions compared must be of an integer type, and the *compare-N* expressions must be of a constant integer type (e.g., a literal integer or an expression built of literal integers).

Optionally, you can specify a default case. If *test* doesn't match any of the specific cases listed prior to the default case, then the statements for the default case are executed. Traditionally, the default case is put after the specific cases, but that isn't required.

```
switch (x)
  {
    case 0:
      puts ("x is 0");
      break;
    case 1:
      puts ("x is 1");
      break;
    default:
      puts ("x is something else");
      break;
  }
```

Notice the usage of the `break` statement in each of the cases. This is because, once a matching case is found, not only are its statements executed, but so are the statements for all following cases:

```
int x = 0;
switch (x)
  {
    case 0:
      puts ("x is 0");
    case 1:
      puts ("x is 1");
    default:
      puts ("x is something else");
  }
```

The output of that example is:

```
x is 0
x is 1
x is something else
```

This is often not desired. Including a `break` statement at the end of each case redirects program flow to after the `switch` statement.

As a GNU C extension, you can also specify a range of consecutive integer values in a single `case` label, like this:

```
case low ... high:
```

This has the same effect as the corresponding number of individual `case` labels, one for each integer value from *low* to *high*, inclusive.

This feature is especially useful for ranges of ASCII character codes:

```
case 'A' ... 'Z':
```

Be careful to include spaces around the `...`; otherwise it may be parsed incorrectly when you use it with integer values. For example, write this:

```
case 1 ... 5:
```

instead of this:

```
case 1...5:
```

It is common to use a `switch` statement to handle various possible values of `errno`. In this case a portable program should watch out for the possibility that two macros for `errno` values in fact have the same value, for example `EWOULDBLOCK` and `EAGAIN`.

4.5 The `while` Statement

The `while` statement is a loop statement with an exit test at the beginning of the loop. Here is the general form of the `while` statement:

```
while (test)
  statement
```

The `while` statement first evaluates *test*. If *test* evaluates to true, *statement* is executed, and then *test* is evaluated again. *statement* continues to execute repeatedly as long as *test* is true after each execution of *statement*.

This example prints the integers from zero through nine:

```
int counter = 0;
while (counter < 10)
  printf ("%d ", counter++);
```

A `break` statement can also cause a `while` loop to exit.

4.6 The `do` Statement

The `do` statement is a loop statement with an exit test at the end of the loop. Here is the general form of the `do` statement:

```
do
  statement
while (test);
```

The `do` statement first executes *statement*. After that, it evaluates *test*. If *test* is true, then *statement* is executed again. *statement* continues to execute repeatedly as long as *test* is true after each execution of *statement*.

This example also prints the integers from zero through nine:

```
int x = 0;
do
  printf ("%d ", x++);
while (x < 10);
```

A `break` statement can also cause a `do` loop to exit.

4.7 The `for` Statement

The `for` statement is a loop statement whose structure allows easy variable initialization, expression testing, and variable modification. It is very convenient for making counter-controlled loops. Here is the general form of the `for` statement:

```
for (initialize; test; step)
  statement
```

The `for` statement first evaluates the expression *initialize*. Then it evaluates the expression *test*. If *test* is false, then the loop ends and program control resumes after *statement*. Otherwise, if *test* is true, then *statement* is executed. Finally, *step* is evaluated, and the next iteration of the loop begins with evaluating *test* again.

Most often, *initialize* assigns values to one or more variables, which are generally used as counters, *test* compares those variables to a predefined expression, and *step* modifies those variables' values. Here is another example that prints the integers from zero through nine:

```
int x;
for (x = 0; x < 10; x++)
  printf ("%d ", x);
```

First, it evaluates *initialize*, which assigns `x` the value 0. Then, as long as `x` is less than 10, the value of `x` is printed (in the body of the loop). Then `x` is incremented in the *step* clause and the test re-evaluated.

All three of the expressions in a `for` statement are optional, and any combination of the three is valid. Since the first expression is evaluated only once, it is perhaps the most commonly omitted expression. You could also write the above example as:

```
int x = 1;
for (; x <= 10; x++)
  printf ("%d ", x);
```

In this example, `x` receives its value prior to the beginning of the `for` statement.

If you leave out the *test* expression, then the `for` statement is an infinite loop (unless you put a `break` or `goto` statement somewhere in *statement*). This is like using `1` as *test*; it is never false.

This `for` statement starts printing numbers at 1 and then continues indefinitely, always printing `x` incremented by 1:

```
for (x = 1; ; x++)
  printf ("%d ", x);
```

If you leave out the *step* expression, then no progress is made toward completing the loop—at least not as is normally expected with a `for` statement.

This example prints the number 1 over and over, indefinitely:

```
for (x = 1; x <= 10;)
  printf ("%d ", x);
```

Perhaps confusingly, you cannot use the comma operator (see Section 3.15 [The Comma Operator], page 37) for monitoring multiple variables in a `for` statement, because as usual the comma operator discards the result of its left operand. This loop:

```
int x, y;
for (x = 1, y = 10; x <= 10, y >= 1; x+=2, y--)
  printf ("%d %d\n", x, y);
```

Outputs:

```
1 10
3 9
5 8
7 7
9 6
11 5
13 4
15 3
17 2
19 1
```

If you need to test two conditions, you will need to use the `&&` operator:

```
int x, y;
for (x = 1, y = 10; x <= 10 && y >= 1; x+=2, y--)
  printf ("%d %d\n", x, y);
```

A `break` statement can also cause a `for` loop to exit.

Here is an example of a function that computes the summation of squares, given a starting integer to square and an ending integer to square:

```
int
sum_of_squares (int start, int end)
{
  int i, sum = 0;
  for (i = start; i <= end; i++)
    sum += i * i;
  return sum;
}
```

4.8 Blocks

A *block* is a set of zero or more statements enclosed in braces. Blocks are also known as *compound statements*. Often, a block is used as the body of an `if` statement or a loop statement, to group statements together.

```
for (x = 1; x <= 10; x++)
  {
    printf ("x is %d\n", x);

    if ((x % 2) == 0)
      printf ("%d is even\n", x);
    else
      printf ("%d is odd\n", x);
  }
```

You can also put blocks inside other blocks:

```
for (x = 1; x <= 10; x++)
  {
    if ((x % 2) == 0)
      {
        printf ("x is %d\n", x);
        printf ("%d is even\n", x);
      }
    else
      {
        printf ("x is %d\n", x);
        printf ("%d is odd\n", x);
      }
  }
```

You can declare variables inside a block; such variables are local to that block. In C89, declarations must occur before other statements, and so sometimes it is useful to introduce a block simply for this purpose:

```
{
  int x = 5;
  printf ("%d\n", x);
}
printf ("%d\n", x);    /* Compilation error! x exists only
                          in the preceding block. */
```

4.9 The Null Statement

The *null statement* is merely a semicolon alone.

```
;
```

A null statement does not do anything. It does not store a value anywhere. It does not cause time to pass during the execution of your program.

Most often, a null statement is used as the body of a loop statement, or as one or more of the expressions in a `for` statement. Here is an example of a `for` statement that uses the null statement as the body of the loop (and also calculates the integer square root of `n`, just for fun):

```
for (i = 1; i*i < n; i++)
  ;
```

Here is another example that uses the null statement as the body of a `for` loop and also produces output:

```
for (x = 1; x <= 5; printf ("x is now %d\n", x), x++)
  ;
```

A null statement is also sometimes used to follow a label that would otherwise be the last thing in a block.

4.10 The `goto` Statement

You can use the `goto` statement to unconditionally jump to a different place in the program. Here is the general form of a `goto` statement:

```
goto label;
```

You have to specify a label to jump to; when the `goto` statement is executed, program control jumps to that label. See Section 4.1 [Labels], page 45. Here is an example:

```
goto end_of_program;
...
end_of_program:
```

The label can be anywhere in the same function as the `goto` statement that jumps to it, but a `goto` statement cannot jump to a label in a different function.

You *can* use `goto` statements to simulate loop statements, but we do not recommend it—it makes the program harder to read, and GCC cannot optimize it as well. You should use `for`, `while`, and `do` statements instead of `goto` statements, when possible.

As an extension, GCC allows a goto statement to jump to an address specified by a `void*` variable. To make this work, you also need to take the address of a label by using the unary operator `&&` (not `&`). Here is a contrived example:

```
enum Play { ROCK=0, PAPER=1, SCISSORS=2 };
enum Result { WIN, LOSE, DRAW };

static enum Result turn (void)
{
  const void * const jumptable[] = {&&rock, &&paper, &&scissors};
  enum Play opp;                /* opponent's play */
  goto *jumptable[select_option (&opp)];
 rock:
  return opp == ROCK ? DRAW : (opp == PAPER ? LOSE : WIN);
 paper:
  return opp == ROCK ? WIN  : (opp == PAPER ? DRAW : LOSE);
 scissors:
  return opp == ROCK ? LOSE : (opp == PAPER ? WIN  : DRAW);
}
```

4.11 The `break` Statement

You can use the `break` statement to terminate a `while`, `do`, `for`, or `switch` statement. Here is an example:

```
int x;
for (x = 1; x <= 10; x++)
  {
    if (x == 8)
      break;
    else
      printf ("%d ", x);
  }
```

That example prints numbers from 1 to 7. When `x` is incremented to 8, `x == 8` is true, so the `break` statement is executed, terminating the `for` loop prematurely.

If you put a `break` statement inside of a loop or `switch` statement which itself is inside of a loop or `switch` statement, the `break` only terminates the innermost loop or `switch` statement.

4.12 The `continue` Statement

You can use the `continue` statement in loops to terminate an iteration of the loop and begin the next iteration. Here is an example:

```
for (x = 0; x < 100; x++)
  {
    if (x % 2 == 0)
      continue;
    else
      sum_of_odd_numbers + = x;
  }
```

If you put a `continue` statement inside a loop which itself is inside a loop, then it affects only the innermost loop.

4.13 The `return` Statement

You can use the `return` statement to end the execution of a function and return program control to the function that called it. Here is the general form of the `return` statement:

```
return return-value;
```

return-value is an optional expression to return. If the function's return type is `void`, then it is invalid to return an expression. You can, however, use the `return` statement without a return value.

If the function's return type is not the same as the type of *return-value*, and automatic type conversion cannot be performed, then returning *return-value* is invalid.

If the function's return type is not `void` and no return value is specified, then the `return` statement is valid unless the function is called in a context that requires a return value. For example:

```
x = cosine (y);
```

In that case, the function `cosine` was called in a context that required a return value, so the value could be assigned to `x`.

Even in contexts where a return value is not required, it is a bad idea for a non-`void` function to omit the return value. With GCC, you can use the command line option `-Wreturn-type` to issue a warning if you omit the return value in such functions.

Here are some examples of using the `return` statement, in both a `void` and non-`void` function:

```
void
print_plus_five (int x)
{
  printf ("%d ", x + 5);
  return;
}

int
square_value (int x)
{
  return x * x;
}
```

4.14 The `typedef` Statement

You can use the `typedef` statement to create new names for data types. Here is the general form of the `typedef` statement:

```
typedef old-type-name new-type-name
```

old-type-name is the existing name for the type, and may consist of more than one token (e.g., `unsigned long int`). *new-type-name* is the resulting new name for the type, and must be a single identifier. Creating this new name for the type does not cause the old name to cease to exist. Here are some examples:

```
typedef unsigned char byte_type;
typedef double real_number_type;
```

In the case of custom data types, you can use `typedef` to make a new name for the type while defining the type:

```
typedef struct fish
{
  float weight;
  float length;
  float probability_of_being_caught;
} fish_type;
```

To make a type definition of an array, you first provide the type of the element, and then establish the number of elements at the end of the type definition:

```
typedef char array_of_bytes [5];
array_of_bytes five_bytes = {0, 1, 2, 3, 4};
```

When selecting names for types, you should avoid ending your type names with a `_t` suffix. The compiler will allow you to do this, but the POSIX standard reserves use of the `_t` suffix for standard library type names.

5 Functions

You can write functions to separate parts of your program into distinct subprocedures. To write a function, you must at least create a function definition. It is a good idea also to have an explicit function declaration; you don't have to, but if you leave it out, then the default implicit declaration might not match the function itself, and you will get some compile-time warnings.

Every program requires at least one function, called `main`. That is where the program's execution begins.

5.1 Function Declarations

You write a function declaration to specify the name of a function, a list of parameters, and the function's return type. A function declaration ends with a semicolon. Here is the general form:

```
return-type function-name (parameter-list);
```

return-type indicates the data type of the value returned by the function. You can declare a function that doesn't return anything by using the return type `void`.

function-name can be any valid identifier (see Section 1.1 [Identifiers], page 2).

parameter-list consists of zero or more parameters, separated by commas. A typical parameter consists of a data type and an optional name for the parameter. You can also declare a function that has a variable number of parameters (see Section 5.5 [Variable Length Parameter Lists], page 59), or no parameters using `void`. Leaving out *parameter-list* entirely also indicates no parameters, but it is better to specify it explicitly with `void`.

Here is an example of a function declaration with two parameters:

```
int foo (int, double);
```

If you include a name for a parameter, the name immediately follows the data type, like this:

```
int foo (int x, double y);
```

The parameter names can be any identifier (see Section 1.1 [Identifiers], page 2), and if you have more than one parameter, you can't use the same name more than once within a single declaration. The parameter names in the declaration need not match the names in the definition.

You should write the function declaration above the first use of the function. You can put it in a header file and use the `#include` directive to include that function declaration in any source code files that use the function.

5.2 Function Definitions

You write a function definition to specify what a function actually does. A function definition consists of information regarding the function's name, return type, and types and names of parameters, along with the body of the function. The function body is a series of statements enclosed in braces; in fact it is simply a block (see Section 4.8 [Blocks], page 51).

Here is the general form of a function definition:

```
return-type
function-name (parameter-list)
{
  function-body
}
```

return-type and *function-name* are the same as what you use in the function declaration (see Section 5.1 [Function Declarations], page 56).

parameter-list is the same as the parameter list used in the function declaration (see Section 5.1 [Function Declarations], page 56), except you *must* include names for the parameters in a function definition.

Here is an simple example of a function definition—it takes two integers as its parameters and returns the sum of them as its return value:

```
int
add_values (int x, int y)
{
  return x + y;
}
```

For compatibility with the original design of C, you can also specify the type of the function parameters *after* the closing parenthesis of the parameter list, like this:

```
int
add_values (x, y)
    int x, int y;
{
  return x + y;
}
```

However, we strongly discourage this style of coding; it can cause subtle problems with type casting, among other problems.

5.3 Calling Functions

You can call a function by using its name and supplying any needed parameters. Here is the general form of a function call:

```
function-name (parameters)
```

A function call can make up an entire statement, or it can be used as a subexpression. Here is an example of a standalone function call:

```
foo (5);
```

In that example, the function '`foo`' is called with the parameter `5`.

Here is an example of a function call used as a subexpression:

```
a = square (5);
```

Supposing that the function '`square`' squares its parameter, the above example assigns the value 25 to `a`.

If a parameter takes more than one argument, you separate parameters with commas:

```
a = quux (5, 10);
```

5.4 Function Parameters

Function parameters can be any expression—a literal value, a value stored in variable, an address in memory, or a more complex expression built by combining these.

Within the function body, the parameter is a local copy of the value passed into the function; you cannot change the value passed in by changing the local copy.

```
int x = 23;
foo (x);
...
/* Definition for function foo. */
int foo (int a)
{
  a = 2 * a;
  return a;
}
```

In that example, even though the parameter `a` is modified in the function '`foo`', the variable `x` that is passed to the function does not change. If you wish to use the function to change the original value of `x`, then you would have to incorporate the function call into an assignment statement:

```
x = foo (x);
```

If the value that you pass to a function is a memory address (that is, a pointer), then you can access (and change) the data stored at the memory address. This achieves an effect similar to pass-by-reference in other languages, but is not the same: the memory address is simply a value, just like any other value, and cannot itself be changed. The difference between passing a pointer and passing an integer lies in what you can do using the value within the function.

Here is an example of calling a function with a pointer parameter:

```
void
foo (int *x)
{
  *x = *x + 42;
}
...
int a = 15;
foo (&a);
```

The formal parameter for the function is of type pointer-to-`int`, and we call the function by passing it the address of a variable of type `int`. By dereferencing the pointer within the function body, we can both see and change the value stored in the address. The above changes the value of `a` to '`57`'.

Even if you don't want to change the value stored in the address, passing the address of a variable rather than the variable itself can be useful if the variable type is large and you need to conserve memory space or limit the performance impact of parameter copying. For example:

```
struct foo
{
  int x;
  float y;
  double z;
};

void bar (const struct foo *a);
```

In this case, unless you are working on a computer with very large memory addresses, it will take less memory to pass a pointer to the structure than to pass an instance of the structure.

One type of parameter that is always passed as a pointer is any sort of array:

```
void foo (int a[]);
...
int x[100];
foo (x);
```

In this example, calling the function `foo` with the parameter `a` does not copy the entire array into a new local parameter within `foo`; rather, it passes `x` as a pointer to the first element in `x`. Be careful, though: within the function, you cannot use `sizeof` to determine the size of the array `x`—`sizeof` instead tells you the size of the pointer `x`. Indeed, the above code is equivalent to:

```
void foo (int *a);
...
int x[100];
foo (x);
```

Explicitly specifying the length of the array in the parameter declaration will not help. If you really need to pass an array by value, you can wrap it in a `struct`, though doing this will rarely be useful (passing a `const`-qualified pointer is normally sufficient to indicate that the caller should not modify the array).

5.5 Variable Length Parameter Lists

You can write a function that takes a variable number of arguments; these are called *variadic functions*. To do this, the function needs to have at least one parameter of a known data type, but the remaining parameters are optional, and can vary in both quantity and data type.

You list the initial parameters as normal, but then after that, use an ellipsis: '`...`'. Here is an example function prototype:

```
int add_multiple_values (int number, ...);
```

To work with the optional parameters in the function definition, you need to use macros that are defined in the library header file '`<stdarg.h>`', so you must `#include` that file. For a detailed description of these macros, see *The GNU C Library* manual's section on variadic functions.

Here is an example:

```
int
add_multiple_values (int number, ...)
{
  int counter, total = 0;

  /* Declare a variable of type 'va_list'. */
  va_list parameters;

  /* Call the 'va_start' function. */
  va_start (parameters, number);

  for (counter = 0; counter < number; counter++)
    {
      /* Get the values of the optional parameters. */
      total += va_arg (parameters, int);
    }

  /* End use of the 'parameters' variable. */
  va_end (parameters);

  return total;
}
```

To use optional parameters, you need to have a way to know how many there are. This can vary, so it can't be hard-coded, but if you don't know how many optional parameters you have, then you could have difficulty knowing when to stop using the '`va_arg`' function. In the above example, the first parameter to the '`add_multiple_values`' function, '`number`', is the number of optional parameters actually passed. So, we might call the function like this:

```
sum = add_multiple_values (3, 12, 34, 190);
```

The first parameter indicates how many optional parameters follow it.

Also, note that you don't actually need to use '`va_end`' function. In fact, with GCC it doesn't do anything at all. However, you might want to include it to maximize compatibility with other compilers.

See Section "Variadic Functions" in *The GNU C Library Reference Manual*.

5.6 Calling Functions Through Function Pointers

You can also call a function identified by a pointer. The indirection operator `*` is optional when doing this.

```
#include <stdio.h>

void foo (int i)
{
  printf ("foo %d!\n", i);
}
```

```
void bar (int i)
{
  printf ("%d bar!\n", i);
}

void message (void (*func)(int), int times)
{
  int j;
  for (j=0; j<times; ++j)
    func (j);  /* (*func) (j); would be equivalent. */
}

void example (int want_foo)
{
  void (*pf)(int) = &bar; /* The & is optional. */
  if (want_foo)
    pf = foo;
  message (pf, 5);
}
```

5.7 The `main` Function

Every program requires at least one function, called '`main`'. This is where the program begins executing. You do not need to write a declaration or prototype for `main`, but you do need to define it.

The return type for `main` is always `int`. You do not have to specify the return type for `main`, but you can. However, you *cannot* specify that it has a return type other than `int`.

In general, the return value from `main` indicates the program's *exit status*. A value of zero or EXIT_SUCCESS indicates success and EXIT_FAILURE indicates an error. Otherwise, the significance of the value returned is implementation-defined.

Reaching the `}` at the end of `main` without a return, or executing a `return` statement with no value (that is, `return;`) are both equivalent. In C89, the effect of this is undefined, but in C99 the effect is equivalent to `return 0;`.

You can write your `main` function to have no parameters (that is, as `int main (void)`), or to accept parameters from the command line. Here is a very simple `main` function with no parameters:

```
int
main (void)
{
  puts ("Hi there!");
  return 0;
}
```

To accept command line parameters, you need to have two parameters in the `main` function, `int argc` followed by `char *argv[]`. You can change the names of those parameters, but they must have those data types—`int` and array of pointers to `char`. `argc` is the number of command line parameters, including the name of the program itself. `argv` is an

array of the parameters, as character strings. `argv[0]`, the first element in the array, is the name of the program as typed at the command line[1]; any following array elements are the parameters that followed the name of the program.

Here is an example `main` function that accepts command line parameters, and prints out what those parameters are:

```
int
main (int argc, char *argv[])
{
  int counter;

  for (counter = 0; counter < argc; counter++)
    printf ("%s\n", argv[counter]);

  return 0;
}
```

5.8 Recursive Functions

You can write a function that is recursive—a function that calls itself. Here is an example that computes the factorial of an integer:

```
int
factorial (int x)
{
  if (x < 1)
    return 1;
  else
    return (x * factorial (x - 1));
}
```

Be careful that you do not write a function that is infinitely recursive. In the above example, once `x` is 1, the recursion stops. However, in the following example, the recursion does not stop until the program is interrupted or runs out of memory:

```
int
watermelon (int x)
{
  return (watermelon (x));
}
```

Functions can also be indirectly recursive, of course.

5.9 Static Functions

You can define a function to be static if you want it to be callable only within the source file where it is defined:

[1] Rarely, `argv[0]` can be a null pointer (in this case `argc` is 0) or `argv[0][0]` can be the null character. In any case, `argv[argc]` is a null pointer.

```
static int
foo (int x)
{
  return x + 42;
}
```

This is useful if you are building a reusable library of functions and need to include some subroutines that should not be callable by the end user.

Functions which are defined in this way are said to have *static linkage*. Unfortunately the `static` keyword has multiple meanings; Section 2.9 [Storage Class Specifiers], page 26.

5.10 Nested Functions

As a GNU C extension, you can define functions within other functions, a technique known as nesting functions.

Here is an example of a tail-recursive factorial function, defined using a nested function:

```
int
factorial (int x)
{
  int
  factorial_helper (int a, int b)
  {
    if (a < 1)
    {
      return b;
    }
    else
    {
      return factorial_helper ((a - 1), (a * b));
    }
  }

 return factorial_helper (x, 1);
}
```

Note that nested functions must be defined along with variable declarations at the beginning of a function, and all other statements follow.

6 Program Structure and Scope

Now that we have seen all of the fundamental elements of C programs, it's time to look at the big picture.

6.1 Program Structure

A C program may exist entirely within a single source file, but more commonly, any non-trivial program will consist of several custom header files and source files, and will also include and link with files from existing libraries.

By convention, header files (with a ".h" extension) contain variable and function declarations, and source files (with a ".c" extension) contain the corresponding definitions. Source files may also store declarations, if these declarations are not for objects which need to be seen by other files. However, header files almost certainly should not contain any definitions.

For example, if you write a function that computes square roots, and you wanted this function to be accessible to files other than where you define the function, then you would put the function declaration into a header file (with a ".h" file extension):

```
/* sqrt.h */

double
computeSqrt (double x);
```

This header file could be included by other source files which need to use your function, but do not need to know how it was implemented.

The implementation of the function would then go into a corresponding source file (with a ".c" file extension):

```
/* sqrt.c */
#include "sqrt.h"

double
computeSqrt (double x)
{
  double result;
  ...
  return result;
}
```

6.2 Scope

Scope refers to what parts of the program can "see" a declared object. A declared object can be visible only within a particular function, or within a particular file, or may be visible to an entire set of files by way of including header files and using `extern` declarations.

Unless explicitly stated otherwise, declarations made at the top-level of a file (i.e., not within a function) are visible to the entire file, including from within functions, but are not visible outside of the file.

Declarations made within functions are visible only within those functions.

A declaration is not visible to declarations that came before it; for example:

```
int x = 5;
int y = x + 10;
```

will work, but:

```
int x = y + 10;
int y = 5;
```

will not.

See Section 2.9 [Storage Class Specifiers], page 26, for more information on changing the scope of declared objects. Also see Section 5.9 [Static Functions], page 62.

7 A Sample Program

To conclude our description of C, here is a complete program written in C, consisting of both a C source file and a header file. This program is an expanded version of the quintessential "hello world" program, and serves as an example of how to format and structure C code for use in programs for FSF Project GNU. (You can always download the most recent version of this program, including sample makefiles and other examples of how to produce GNU software, from `http://www.gnu.org/software/hello`.)

This program uses features of the preprocessor; for a description of preprocessor macros, see *The C Preprocessor*, available as part of the GCC documentation.

7.1 `hello.c`

```
/* hello.c -- print a greeting message and exit.

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   2005, 2006, 2007 Free Software Foundation, Inc.

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   any later version.

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   MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
   GNU General Public License for more details.

   You should have received a copy of the GNU General Public License
   along with this program; if not, write to the Free Software Foundation,
   Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301, USA.  */

#include <config.h>
#include "system.h"

/* String containing name the program is called with.  */
const char *program_name;

static const struct option longopts[] =
{
  { "greeting", required_argument, NULL, 'g' },
  { "help", no_argument, NULL, 'h' },
  { "next-generation", no_argument, NULL, 'n' },
  { "traditional", no_argument, NULL, 't' },
  { "version", no_argument, NULL, 'v' },
  { NULL, 0, NULL, 0 }
};

static void print_help (void);
static void print_version (void);

int
main (int argc, char *argv[])
{
  int optc;
  int t = 0, n = 0, lose = 0;
```

```
  const char *greeting = NULL;

  program_name = argv[0];

  /* Set locale via LC_ALL.  */
  setlocale (LC_ALL, "");

#if ENABLE_NLS
  /* Set the text message domain.  */
  bindtextdomain (PACKAGE, LOCALEDIR);
  textdomain (PACKAGE);
#endif

  /* Even exiting has subtleties.  The /dev/full device on GNU/Linux
     can be used for testing whether writes are checked properly.  For
     instance, hello >/dev/full should exit unsuccessfully.  On exit,
     if any writes failed, change the exit status.  This is
     implemented in the Gnulib module "closeout".  */
  atexit (close_stdout);

  while ((optc = getopt_long (argc, argv, "g:hntv", longopts, NULL)) != -1)
    switch (optc)
      {
      /* One goal here is having --help and --version exit immediately,
         per GNU coding standards.  */
      case 'v':
        print_version ();
        exit (EXIT_SUCCESS);
        break;
      case 'g':
        greeting = optarg;
        break;
      case 'h':
        print_help ();
        exit (EXIT_SUCCESS);
        break;
      case 'n':
        n = 1;
        break;
      case 't':
        t = 1;
        break;
      default:
        lose = 1;
        break;
      }

  if (lose || optind < argc)
    {
      /* Print error message and exit.  */
      if (optind < argc)
        fprintf (stderr, _("%s: extra operand: %s\n"),
 program_name, argv[optind]);
      fprintf (stderr, _("Try `%s --help' for more information.\n"),
               program_name);
      exit (EXIT_FAILURE);
    }
```

```
  /* Print greeting message and exit. */
  if (t)
    printf (_("hello, world\n"));

  else if (n)
    /* TRANSLATORS: Use box drawing characters or other fancy stuff
       if your encoding (e.g., UTF-8) allows it.  If done so add the
       following note, please:

       [Note: For best viewing results use a UTF-8 locale, please.]
    */
printf (_("\
+---------------+\n\
| Hello, world! |\n\
+---------------+\n\
"));

  else
    {
      if (!greeting)
        greeting = _("Hello, world!");
      puts (greeting);
    }

  exit (EXIT_SUCCESS);
}



/* Print help info.  This long message is split into
   several pieces to help translators be able to align different
   blocks and identify the various pieces.  */

static void
print_help (void)
{
  /* TRANSLATORS: --help output 1 (synopsis)
     no-wrap */
       printf (_("\
Usage: %s [OPTION]...\n"), program_name);

  /* TRANSLATORS: --help output 2 (brief description)
     no-wrap */
  fputs (_("\
Print a friendly, customizable greeting.\n"), stdout);

  puts ("");
  /* TRANSLATORS: --help output 3: options 1/2
     no-wrap */
  fputs (_("\
  -h, --help          display this help and exit\n\
  -v, --version       display version information and exit\n"), stdout);

  puts ("");
  /* TRANSLATORS: --help output 4: options 2/2
     no-wrap */
  fputs (_("\
```

```
  -t, --traditional       use traditional greeting format\n\
  -n, --next-generation   use next-generation greeting format\n\
  -g, --greeting=TEXT     use TEXT as the greeting message\n"), stdout);

  printf ("\n");
  /* TRANSLATORS: --help output 5 (end)
     TRANSLATORS: the placeholder indicates the bug-reporting address
     for this application.  Please add _another line_ with the
     address for translation bugs.
     no-wrap */
  printf (_("\
Report bugs to <%s>.\n"), PACKAGE_BUGREPORT);
}



/* Print version and copyright information.  */

static void
print_version (void)
{
  printf ("hello (GNU %s) %s\n", PACKAGE, VERSION);
  /* xgettext: no-wrap */
  puts ("");

  /* It is important to separate the year from the rest of the message,
     as done here, to avoid having to retranslate the message when a new
     year comes around.  */
  printf (_("\
Copyright (C) %s Free Software Foundation, Inc.\n\
License GPLv3+: GNU GPL version 3 or later\
<http://gnu.org/licenses/gpl.html>\n\
This is free software: you are free to change and redistribute it.\n\
There is NO WARRANTY, to the extent permitted by law.\n"),
              "2007");
}
```

7.2 system.h

```
/* system.h: system-dependent declarations; include this first.
   Copyright (C) 1996, 2005, 2006, 2007 Free Software Foundation, Inc.

   This program is free software; you can redistribute it and/or modify
   it under the terms of the GNU General Public License as published by
   the Free Software Foundation; either version 3, or (at your option)
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   along with this program; if not, write to the Free Software Foundation,
   Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301, USA.  */

#ifndef HELLO_SYSTEM_H
```

```
#define HELLO_SYSTEM_H

/* Assume ANSI C89 headers are available.  */
#include <locale.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

/* Use POSIX headers.  If they are not available, we use the substitute
   provided by gnulib.  */
#include <getopt.h>
#include <unistd.h>

/* Internationalization.  */
#include "gettext.h"
#define _(str) gettext (str)
#define N_(str) gettext_noop (str)

/* Check for errors on write.  */
#include "closeout.h"

#endif /* HELLO_SYSTEM_H */
```

Appendix A Overflow

[This appendix, written principally by Paul Eggert, is from the GNU Autoconf manual. We thought that it would be helpful to include here. –TJR]

In practice many portable C programs assume that signed integer overflow wraps around reliably using two's complement arithmetic. Yet the C standard says that program behavior is undefined on overflow, and in a few cases C programs do not work on some modern implementations because their overflows do not wrap around as their authors expected. Conversely, in signed integer remainder, the C standard requires overflow behavior that is commonly not implemented.

A.1 Basics of Integer Overflow

In languages like C, unsigned integer overflow reliably wraps around; e.g., `UINT_MAX + 1` yields zero. This is guaranteed by the C standard and is portable in practice, unless you specify aggressive, nonstandard optimization options suitable only for special applications.

In contrast, the C standard says that signed integer overflow leads to undefined behavior where a program can do anything, including dumping core or overrunning a buffer. The misbehavior can even precede the overflow. Such an overflow can occur during addition, subtraction, multiplication, division, and left shift.

Despite this requirement of the standard, many C programs assume that signed integer overflow silently wraps around modulo a power of two, using two's complement arithmetic, so long as you cast the resulting value to a signed integer type or store it into a signed integer variable. If you use conservative optimization flags, such programs are generally portable to the vast majority of modern platforms, with a few exceptions discussed later.

For historical reasons the C standard also allows implementations with ones' complement or signed magnitude arithmetic, but it is safe to assume two's complement nowadays.

Also, overflow can occur when converting an out-of-range value to a signed integer type. Here a standard implementation must define what happens, but this might include raising an exception. In practice all known implementations support silent wraparound in this case, so you need not worry about other possibilities.

A.2 Examples of Code Assuming Wraparound Overflow

There has long been a tension between what the C standard requires for signed integer overflow, and what C programs commonly assume. The standard allows aggressive optimizations based on assumptions that overflow never occurs, but many practical C programs rely on overflow wrapping around. These programs do not conform to the standard, but they commonly work in practice because compiler writers are understandably reluctant to implement optimizations that would break many programs, unless perhaps a user specifies aggressive optimization.

The C Standard says that if a program has signed integer overflow its behavior is undefined, and the undefined behavior can even precede the overflow. To take an extreme example:

```
if (password == expected_password)
  allow_superuser_privileges ();
```

```
else if (counter++ == INT_MAX)
  abort ();
else
  printf ("%d password mismatches\n", counter);
```

If the `int` variable `counter` equals `INT_MAX`, `counter++` must overflow and the behavior is undefined, so the C standard allows the compiler to optimize away the test against `INT_MAX` and the `abort` call. Worse, if an earlier bug in the program lets the compiler deduce that `counter == INT_MAX` or that `counter` previously overflowed, the C standard allows the compiler to optimize away the password test and generate code that allows superuser privileges unconditionally.

Despite this requirement by the standard, it has long been common for C code to assume wraparound arithmetic after signed overflow, and all known practical C implementations support some C idioms that assume wraparound signed arithmetic, even if the idioms do not conform strictly to the standard. If your code looks like the following examples it will almost surely work with real-world compilers.

Here is an example derived from the 7th Edition Unix implementation of `atoi` (1979-01-10):

```
char *p;
int f, n;
...
while (*p >= '0' && *p <= '9')
  n = n * 10 + *p++ - '0';
return (f ? -n : n);
```

Even if the input string is in range, on most modern machines this has signed overflow when computing the most negative integer (the `-n` overflows) or a value near an extreme integer (the first `+` overflows).

Here is another example, derived from the 7th Edition implementation of `rand` (1979-01-10). Here the programmer expects both multiplication and addition to wrap on overflow:

```
static long int randx = 1;
...
randx = randx * 1103515245 + 12345;
return (randx >> 16) & 077777;
```

In the following example, derived from the GNU C Library 2.5 implementation of `mktime` (2006-09-09), the code assumes wraparound arithmetic in `+` to detect signed overflow:

```
time_t t, t1, t2;
int sec_requested, sec_adjustment;
...
t1 = t + sec_requested;
t2 = t1 + sec_adjustment;
if (((t1 < t) != (sec_requested < 0))
    || ((t2 < t1) != (sec_adjustment < 0)))
  return -1;
```

If your code looks like these examples, it is probably safe even though it does not strictly conform to the C standard. This might lead one to believe that one can generally assume wraparound on overflow, but that is not always true, as can be seen in the next section.

A.3 Optimizations That Break Wraparound Arithmetic

Compilers sometimes generate code that is incompatible with wraparound integer arithmetic. A simple example is an algebraic simplification: a compiler might translate `(i * 2000) / 1000` to `i * 2` because it assumes that `i * 2000` does not overflow. The translation is not equivalent to the original when overflow occurs: e.g., in the typical case of 32-bit signed two's complement wraparound `int`, if `i` has type `int` and value `1073742`, the original expression returns −2147483 but the optimized version returns the mathematically correct value 2147484.

More subtly, loop induction optimizations often exploit the undefined behavior of signed overflow. Consider the following contrived function `sumc`:

```
int
sumc (int lo, int hi)
{
  int sum = 0;
  int i;
  for (i = lo; i <= hi; i++)
    sum ^= i * 53;
  return sum;
}
```

To avoid multiplying by 53 each time through the loop, an optimizing compiler might internally transform `sumc` to the equivalent of the following:

```
int
transformed_sumc (int lo, int hi)
{
  int sum = 0;
  int hic = hi * 53;
  int ic;
  for (ic = lo * 53; ic <= hic; ic += 53)
    sum ^= ic;
  return sum;
}
```

This transformation is allowed by the C standard, but it is invalid for wraparound arithmetic when `INT_MAX / 53 < hi`, because then the overflow in computing expressions like `hi * 53` can cause the expression `i <= hi` to yield a different value from the transformed expression `ic <= hic`.

For this reason, compilers that use loop induction and similar techniques often do not support reliable wraparound arithmetic when a loop induction variable like `ic` is involved. Since loop induction variables are generated by the compiler, and are not visible in the source code, it is not always trivial to say whether the problem affects your code.

Hardly any code actually depends on wraparound arithmetic in cases like these, so in practice these loop induction optimizations are almost always useful. However, edge cases in this area can cause problems. For example:

```
int j;
for (j = 1; 0 < j; j *= 2)
  test (j);
```

Here, the loop attempts to iterate through all powers of 2 that `int` can represent, but the C standard allows a compiler to optimize away the comparison and generate an infinite loop, under the argument that behavior is undefined on overflow. As of this writing this optimization is not done by any production version of GCC with `-O2`, but it might be performed by other compilers, or by more aggressive GCC optimization options, and the GCC developers have not decided whether it will continue to work with GCC and `-O2`.

A.4 Practical Advice for Signed Overflow Issues

Ideally the safest approach is to avoid signed integer overflow entirely. For example, instead of multiplying two signed integers, you can convert them to unsigned integers, multiply the unsigned values, then test whether the result is in signed range.

Rewriting code in this way will be inconvenient, though, particularly if the signed values might be negative. Also, it may hurt performance. Using unsigned arithmetic to check for overflow is particularly painful to do portably and efficiently when dealing with an integer type like `uid_t` whose width and signedness vary from platform to platform.

Furthermore, many C applications pervasively assume wraparound behavior and typically it is not easy to find and remove all these assumptions. Hence it is often useful to maintain nonstandard code that assumes wraparound on overflow, instead of rewriting the code. The rest of this section attempts to give practical advice for this situation.

If your code wants to detect signed integer overflow in `sum = a + b`, it is generally safe to use an expression like `(sum < a) != (b < 0)`.

If your code uses a signed loop index, make sure that the index cannot overflow, along with all signed expressions derived from the index. Here is a contrived example of problematic code with two instances of overflow.

```
for (i = INT_MAX - 10; i <= INT_MAX; i++)
  if (i + 1 < 0)
    {
      report_overflow ();
      break;
    }
```

Because of the two overflows, a compiler might optimize away or transform the two comparisons in a way that is incompatible with the wraparound assumption.

If your code uses an expression like `(i * 2000) / 1000` and you actually want the multiplication to wrap around on overflow, use unsigned arithmetic to do it, e.g., `((int) (i * 2000u)) / 1000`.

If your code assumes wraparound behavior and you want to insulate it against any GCC optimizations that would fail to support that behavior, you should use GCC's `-fwrapv` option, which causes signed overflow to wrap around reliably (except for division and remainder, as discussed in the next section).

If you need to port to platforms where signed integer overflow does not reliably wrap around (e.g., due to hardware overflow checking, or to highly aggressive optimizations), you should consider debugging with GCC's `-ftrapv` option, which causes signed overflow to raise an exception.

A.5 Signed Integer Division and Integer Overflow

Overflow in signed integer division is not always harmless: for example, on CPUs of the i386 family, dividing `INT_MIN` by `-1` yields a SIGFPE signal which by default terminates the program. Worse, taking the remainder of these two values typically yields the same signal on these CPUs, even though the C standard requires `INT_MIN % -1` to yield zero because the expression does not overflow.

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