Chapter 7

Basic Types

Basic Types

- C's ***basic*** (built-in) ***types:***
  - Integer types, including
    - long integers,
    - short integers, and
    - unsigned integers
  - Floating types
    - `float`,
    - `double`, and
    - `long double`
  - `char`
  - `_Bool` (C99)

Integer Types

- C supports two fundamentally different kinds of numeric types:
  - integer types and
  - floating types.
- Values of an ***integer type*** are whole numbers.
- Values of a ***floating type*** can have a fractional part as well.
- The integer types, in turn, are divided into two categories:
  - signed and
  - unsigned.

Signed and Unsigned Integers

- The leftmost bit of a ***signed*** integer (known as the ***sign bit***) is 0 if the number is positive or zero, 1 if it's negative.
- The largest 16-bit integer has the binary representation 0111111111111111, which has the value 32,767 ($2^{15} - 1$).
- The largest 32-bit integer is // 宇宙的年齡，當今理論和觀測認為這個年齡在136億年
  01111111111111111111111111111111
  which has the value 2,147,483,647 ($2^{31} - 1$). // 地球的年齡大約在45.4億年
- An integer with no sign bit (the leftmost bit is considered part of the number's magnitude) is said to be ***unsigned.***
- The largest 16-bit unsigned integer is 65,535 ($2^{16} - 1$).
- The largest 32-bit unsigned integer is 4,294,967,295 ($2^{32} - 1$).

Signed and Unsigned Integers

- By default, integer variables are signed in C—the leftmost bit is reserved for the sign.
- To tell the compiler that a variable has no sign bit, declare it to be `unsigned`.
- Unsigned numbers are primarily useful for
  - systems programming and
  - low-level, machine-dependent applications.

Integer Types

- The `int` type is usually 32 bits, but may be 16 bits on older CPUs.
- ***Long*** integers may have more bits than ordinary integers;
- ***Short*** integers may have fewer bits.
- The specifiers `long` and `short`,
  - as well as `signed` and `unsigned`,
  - can be combined with `int` to form integer types.
- Only six combinations produce different types:

```
short int          unsigned short int
int                unsigned int
long int           unsigned long int
```

- The order of the specifiers doesn't matter.
- Also, the word `int` can be dropped (`long int` can be abbreviated to just `long`).

Integer Types

- The range of values
  - represented by each of the six integer types
  - varies from one machine to another.
- However, the C standard
  - requires that `short int`, `int`, and `long int`
  - must each cover a certain minimum range of values.
- Also, `int` must not be shorter than `short int`, and `long int` must not be shorter than `int`.

Integer Types

- Typical ranges of values for the integer types on a 16-bit machine:

Type	*Smallest Value*	*Largest Value*
`short int`	–32,768	32,767
`unsigned short int`	0	65,535
`int`	–32,768	32,767
`unsigned int`	0	65,535
`long int`	–2,147,483,648	2,147,483,647
`unsigned long int`	0	4,294,967,295

Integer Types

- Typical ranges on a 32-bit machine:

Type	*Smallest Value*	*Largest Value*
`short int`	–32,768	32,767
`unsigned short int`	0	65,535
`int`	–2,147,483,648	2,147,483,647
`unsigned int`	0	4,294,967,295
`long int`	–2,147,483,648	2,147,483,647
`unsigned long int`	0	4,294,967,295

Integer Types

- Typical ranges on a 64-bit machine:

Type	*Smallest Value*	*Largest Value*
`short int`	–32,768	32,767
`unsigned short int`	0	65,535
`int`	–2,147,483,648	2,147,483,647
`unsigned int`	0	4,294,967,295
`long int`	-2^{63}	$2^{63}-1$
`unsigned long int`	0	$2^{64}-1$

- The `<limits.h>` header
  - defines macros that represent the smallest and largest values of each integer type.

Integer Types in C99

- C99 provides two additional standard integer types, `long long int` and `unsigned long long int`.
- Both `long long` types are required to be at least 64 bits wide.
- The range of `long long int` values is typically
  - -2^{63} (–9,223,372,036,854,775,808) to
  - $2^{63}-1$ (9,223,372,036,854,775,807).
- The range of `unsigned long long int` values is usually
  - 0 to
  - $2^{64}-1$ (18,446,744,073,709,551,615).

Integer Types in C99

- The `short int`, `int`, `long int`, and `long long int` types (along with the `signed char` type)
  - are called ***standard signed integer types*** in C99.
- The `unsigned short int`, `unsigned int`, `unsigned long int`, and `unsigned long long int` types (along with the `unsigned char` type and the `_Bool` type)
  - are called ***standard unsigned integer types.***
- In addition to the standard integer types, the C99 standard allows implementation-defined ***extended integer types,*** both signed and unsigned.

Integer Constants

- ***Constants*** are numbers that appear in the text of a program.
- C allows integer constants to be written in
  - decimal (base 10),
  - octal (base 8), or
  - hexadecimal (base 16).

Octal and Hexadecimal Numbers

- Octal numbers use only the digits 0 through 7.
  - Each position in an octal number represents a power of 8.
  - The octal number 237 represents the decimal number $2 \times 8^2 + 3 \times 8^1 + 7 \times 8^0 = 128 + 24 + 7 = 159$.
- A hexadecimal (or hex) number is written using the digits 0 through 9 plus the letters A through F,
  - which stand for 10 through 15, respectively.
  - The hex number 1AF has the decimal value $1 \times 16^2 + 10 \times 16^1 + 15 \times 16^0 = 256 + 160 + 15 = 431$.

Integer Constants

- ***Decimal*** constants contain digits between 0 and 9, but must not begin with a zero:

```
15   255   32767
```

- ***Octal*** constants contain only digits between 0 and 7, and must begin with a zero:

```
017   0377   077777
```

- ***Hexadecimal*** constants contain digits between 0 and 9 and letters between `a` and `f`, and always begin with `0x`:

```
0xf   0xff   0x7fff
```

- The letters in a hexadecimal constant may be either upper or lower case:

```
0xff   0xfF   0xFf   0xFF   0Xff   0XfF   0XFf   0XFF
```


Integer Constants

- The type of a *decimal* integer constant is normally `int`.
- If the value of the constant is too large to store as an `int`, the constant has type `long int` instead.
- If the constant is too large to store as a `long int`, the compiler will try `unsigned long int` as a last resort.
- For an *octal* or *hexadecimal* constant, the rules are slightly different: the compiler will go through the types `int`, `unsigned int`, `long int`, and `unsigned long int` until it finds one capable of representing the constant.

Integer Constants

- To force the compiler to treat a constant as a long integer, just follow it with the letter `L` (or `l`):

  ```
  15L   0377L   0x7fffL
  ```

- To indicate that a constant is unsigned, put the letter `U` (or `u`) after it:

  ```
  15U   0377U   0x7fffU
  ```

- `L` and `U` may be used in combination:

  ```
  0xffffffffUL
  ```

  The order of the `L` and `U` doesn't matter, nor does their case.

Integer Constants in C99

- In C99, integer constants
  - that end with either `LL` or `ll` (the case of the two letters must match)
  - have type `long long int`.
- Adding the letter `U` (or `u`)
  - before or after the `LL` or `ll`
  - denotes a constant of type `unsigned long long int`.
- C99's general rules for determining the type of an integer constant are a bit different from those in C89.
- The type of a decimal constant
  - with no suffix (`U`, `u`, `L`, `l`, `LL`, or `ll`)
  - is the "smallest" of the types `int`, `long int`, or `long long int` that can represent the value of that constant.

Integer Constants in C99

- For an octal or hexadecimal constant,
  - the list of possible types is `int`, `unsigned int`, `long int`, `unsigned long int`, `long long int`, and `unsigned long long int`, in that order.
- Any suffix at the end of a constant
  - changes the list of possible types.
  - A constant that ends with `U` (or `u`) must have one of the types `unsigned int`, `unsigned long int`, or `unsigned long long int`.
  - A decimal constant that ends with `L` (or `l`) must have one of the types `long int` or `long long int`.

Integer Overflow

- When arithmetic operations are performed on integers,
  - it's possible that the result will be too large to represent.
- For example, when an arithmetic operation is performed on two `int` values,
  - the result must be able to be represented as an `int`.
- If the result can't be represented as an `int` (because it requires too many bits),
  - we say that ***overflow*** has occurred.

Integer Overflow

- The behavior when integer overflow occurs depends on whether the operands were signed or unsigned.
- When overflow occurs during an operation on *signed* integers, the program's behavior is undefined.
- When overflow occurs during an operation on *unsigned* integers, the result *is* defined:
  - we get the correct answer modulo 2^n,
  - where *n* is the number of bits used to store the result.

```
4 = 100 mod 16      /* 100 - 16*6 = 4 */
```


Reading and Writing Integers

- Reading and writing unsigned, short, and long integers requires new conversion specifiers.
- When reading or writing an *unsigned* integer, use the letter `u`, `o`, or `x` instead of `d` in the conversion specification.

```
unsigned int u;

scanf("%u", &u);  /* reads  u in base 10 */
printf("%u", u);  /* writes u in base 10 */
scanf("%o", &u);  /* reads  u in base  8 */
printf("%o", u);  /* writes u in base  8 */
scanf("%x", &u);  /* reads  u in base 16 */
printf("%x", u);  /* writes u in base 16 */
```


Reading and Writing Integers

- When reading or writing a *short* integer, put the letter `h` in front of `d`, `o`, `u`, or `x`:

```
short s;

scanf("%hd", &s);
printf("%hd", s);
```

- When reading or writing a *long* integer, put the letter `l` ("ell," not "one") in front of `d`, `o`, `u`, or `x`.
- When reading or writing a *long long* integer (C99 only), put the letters `ll` in front of `d`, `o`, `u`, or `x`.

Program: Summing a Series of Numbers (Revisited)

- The `sum.c` program (Chapter 6) sums a series of integers.
- One problem with this program is that the sum (or one of the input numbers) might exceed the largest value allowed for an `int` variable.
- Here's what might happen if the program is run on a machine whose integers are 16 bits long:

```
This program sums a series of integers.
Enter integers (0 to terminate): 10000 20000 30000 0
The sum is: -5536
```

- When overflow occurs with signed numbers, the outcome is undefined.
- The program can be improved by using `long` variables.

sum2.c

```
/* Sums a series of numbers (using long variables) */

#include <stdio.h>

int main(void)
{
  long n, sum = 0;

  printf("This program sums a series of integers.\n");
  printf("Enter integers (0 to terminate): ");

  scanf("%ld", &n);
  while (n != 0) {
    sum += n;
    scanf("%ld", &n);
  }
  printf("The sum is: %ld\n", sum);

  return 0;
}
```


Floating Types

- C provides three ***floating types,*** corresponding to different floating-point formats:
  - `float` Single-precision floating-point
  - `double` Double-precision floating-point
  - `long double` Extended-precision floating-point

Floating Types

- `float` is suitable when the amount of precision isn't critical.
- `double` provides enough precision for most programs.
- `long double` is rarely used.
- The C standard doesn't state how much precision the `float`, `double`, and `long double` types provide, since that depends on how numbers are stored.
- Most modern computers follow the specifications in IEEE Standard 754 (also known as IEC 60559).

The IEEE Floating-Point Standard

- IEEE Standard 754 was developed by the Institute of Electrical and Electronics Engineers.
  - It has two primary formats for floating-point numbers: single precision (32 bits) and double precision (64 bits).
- Numbers are stored in a form of scientific notation, with each number having a ***sign,*** an ***exponent,*** and a ***fraction.***
- In single-precision format, the exponent is 8 bits long, while the fraction occupies 23 bits.
- The maximum value is approximately 3.40×10^{38}, with a precision of about 6 decimal digits.

Floating Types

- Characteristics of `float` and `double` when implemented according to the IEEE standard:

Type	*Smallest Positive Value*	*Largest Value*	*Precision*
`float`	1.17549×10^{-38}	3.40282×10^{38}	6 digits
`double`	2.22507×10^{-308}	1.79769×10^{308}	15 digits

- On computers that don't follow the IEEE standard, this table won't be valid.
- In fact, on some machines,
  - `float` may have the same set of values as `double`, or
  - `double` may have the same values as `long double`.

Floating Types

- Macros that define the characteristics of the floating types can be found in the `<float.h>` header.
- In C99, the floating types are divided into two categories.
  - ***Real floating types***
    - `float`, `double`, `long double`
  - ***Complex types***
    - `float _Complex`,
    - `double _Complex`,
    - `long double _Complex`

Floating Constants

- Floating constants can be written in a variety of ways.
- Valid ways of writing the number 57.0:

```
57.0   57.   57.0e0   57E0   5.7e1   5.7e+1
.57e2   570.e-1
```

- A floating constant
  - must contain a decimal point and/or an exponent;
  - the exponent indicates the power of 10 by which the number is to be scaled.
- If an exponent is present,
  - it must be preceded by the letter `E` (or `e`).
  - An optional `+` or `-` sign may appear after the `E` (or `e`).

Floating Constants

- By default, floating constants
  - are stored as double-precision numbers.
- To indicate that only single precision is desired,
  - put the letter `F` (or `f`) at the end of the constant
  - (for example, `57.0F`).
- To indicate that a constant should be stored in `long double` format,
  - put the letter `L` (or `l`) at the end (`57.0L`).

Reading and Writing Floating-Point Numbers

- The conversion specifications `%e`, `%f`, and `%g` are used for reading and writing single-precision floating-point numbers.
- When reading a value of type `double`, put the letter `l` in front of `e`, `f`, or `g`:

```
double d;
scanf("%lf", &d);
```

`%g: 浮點數輸出，取%f或%e兩者中較精簡者。`

- *Note:* Use `l` only in a `scanf` format string, not a `printf` string.
- In a `printf` format string, the `e`, `f`, and `g` conversions can be used to write either `float` or `double` values.
- When reading or writing a value of type `long double`, put the letter `L` in front of `e`, `f`, or `g`.

Character Types

- The only remaining basic type is `char`, the character type.
- The values of type `char`
  - can vary from one computer to another,
  - because different machines may have different underlying character sets.

Character Sets

- Today's most popular character set
  - is ***ASCII*** (American Standard Code for Information Interchange),
  - a 7-bit code capable of representing 128 characters.
- ASCII
  - is often extended to a 256-character code known as ***Latin-1***
  - that provides the characters necessary for Western European and many African languages.

Character Sets

- A variable of type `char` can be assigned any single character:

```
char ch;

ch = 'a';   /* lower-case a */
ch = 'A';   /* upper-case A */
ch = '0';   /* zero         */
ch = ' ';   /* space        */
```

- Notice that character constants are enclosed in single quotes, not double quotes.

Operations on Characters

- Working with characters in C is simple, because of one fact: *C treats characters as small integers.*
- In ASCII, character codes
  - range from 0000000 to 1111111,
  - which we can think of as the integers from 0 to 127.
- The character
  - `'a'` has the value 97, `'A'` has the value 65,
  - `'0'` has the value 48, and `' '` has the value 32.
- Character constants actually have `int` type rather than `char` type.

Operations on Characters

- When a character appears in a computation, C uses its integer value.
- Consider the following examples, which assume the ASCII character set:

```
char ch;
int i;

i = 'a';        /* i is now 97   */
ch = 65;        /* ch is now 'A' */
ch = ch + 1;    /* ch is now 'B' */
ch++;           /* ch is now 'C' */
```


Operations on Characters

- Characters can be compared, just as numbers can.
- An `if` statement that converts a lower-case letter to upper case:

```
if ('a' <= ch && ch <= 'z')
  ch = ch - 'a' + 'A';
```

- Comparisons such as `'a' <= ch` are done using the integer values of the characters involved.
- These values depend on the character set in use, so programs that use <, <=, >, and >= to compare characters may not be portable.

Operations on Characters

- The fact that characters have the same properties as numbers has advantages.
- For example, it is easy to write a `for` statement whose control variable steps through all the upper-case letters:

```
for (ch = 'A'; ch <= 'Z'; ch++) …
```

- Disadvantages of treating characters as numbers:
  - Can lead to errors that won't be caught by the compiler.
  - Allows meaningless expressions such as `'a' * 'b' / 'c'`.
  - Can hamper (阻礙) portability, since programs may rely on assumptions about the underlying character set.

Signed and Unsigned Characters

- The `char` type—like the integer types—exists in both signed and unsigned versions.
- Signed characters normally have values between –128 and 127.
- Unsigned characters have values between 0 and 255.
- Some compilers treat `char` as a signed type, while others treat it as an unsigned type. Most of the time, it doesn't matter.
- C allows the use of the words `signed` and `unsigned` to modify `char`:

```
signed char sch;
unsigned char uch;
```


Signed and Unsigned Characters

- C89 uses the term ***integral types*** to refer to both the integer types and the character types.
- Enumerated types are also integral types.

- C99 doesn't use the term "integral types."
- Instead, it expands the meaning of "integer types" to include the character types and the enumerated types.
- C99's `_Bool` type is considered to be an unsigned integer type.

Arithmetic Types

- The integer types and floating types are collectively known as ***arithmetic types*.**
- A summary of the arithmetic types in C89, divided into categories and subcategories:
  - Integral (整數的) types
    - `char`
    - Signed integer types (`signed char`, `short int`, `int`, `long int`)
    - Unsigned integer types (`unsigned char`, `unsigned short int`, `unsigned int`, `unsigned long int`)
    - Enumerated types
  - Floating types (`float`, `double`, `long double`)

Arithmetic Types

- C99 has a more complicated hierarchy:
  - Integer types
    - `char`
    - Signed integer types, both standard (`signed char`, `short int`, `int`, `long int`, `long long int`) and extended
    - Unsigned integer types, both standard (`unsigned char`, `unsigned short int`, `unsigned int`, `unsigned long int`, `unsigned long long int`, `_Bool`) and extended
    - Enumerated types
  - Floating types
    - Real floating types (`float`, `double`, `long double`)
    - Complex types (`float _Complex`, `double _Complex`, `long double _Complex`)

Escape Sequences

- A character constant is usually one character enclosed in single quotes.
- However, certain special characters
  - —including the new-line character—
  - can't be written in this way, because they're invisible (nonprinting) or because they can't be entered from the keyboard.
- ***Escape sequences*** provide a way to represent these characters.
- There are two kinds of escape sequences: ***character escapes*** and ***numeric escapes***.

Escape Sequences

- A complete list of character escapes:

Name	***Escape Sequence***	
Alert (bell)	`\a`	
Backspace	`\b`	
Form feed	`\f`	`// 換頁`
New line	`\n`	
Carriage return	`\r`	
Horizontal tab	`\t`	
Vertical tab	`\v`	
Backslash	`\\`	
Question mark	`\?`	
Single quote	`\'`	
Double quote	`\"`	

Escape Sequences

- Character escapes are handy, but they don't exist for all nonprinting ASCII characters.
  - Character escapes are also useless for representing characters beyond the basic 128 ASCII characters.
- Numeric escapes, which can represent any character, are the solution to this problem.
  - A numeric escape for a particular character uses the character's octal or hexadecimal value.
  - For example, the ASCII escape character (decimal value: 27) has the value 33 in octal and 1B in hex.

Escape Sequences

- An ***octal escape sequence***
  - consists of the `\` character followed by an octal number with at most three digits, such as `\33` or `\033`.
- A ***hexadecimal escape sequence***
  - consists of `\x` followed by a hexadecimal number, such as `\x1b` or `\x1B`.
  - The `x` must be in lower case, but the hex digits can be upper or lower case.

Escape Sequences

- When used as a character constant, an escape sequence must be enclosed in single quotes.
- For example, a constant representing the escape character would be written `'\33'` (or `'\x1b'`).
- Escape sequences tend to get a bit cryptic (模糊/隱藏), so it's often a good idea to use `#define` to give them names:

```
#define ESC '\33'
```

- Escape sequences can be embedded in strings as well.

Character-Handling Functions

- Calling C's `toupper` library function is a fast and portable way to convert case:

```
ch = toupper(ch); // int toupper(int);
```

- `toupper` returns the upper-case version of its argument.
- Programs that call `toupper` need to have the following `#include` directive at the top:

```
#include <ctype.h>
```

- The C library provides many other useful character-handling functions.

Reading and Writing Characters Using `scanf` and `printf`

- The `%c` conversion specification allows `scanf` and `printf` to read and write single characters:

```
char ch;

scanf("%c", &ch);  /* reads one character */
printf("%c", ch);  /* writes one character */
```

- `scanf` doesn't skip white-space characters.

- To force `scanf` to skip white space before reading a character, put a space in its format string just before `%c`:

```
scanf(" %c", &ch);
```


Reading and Writing Characters Using `scanf` and `printf`

- Since `scanf` doesn't normally skip white space,
  - it's easy to detect the end of an input line:
  - check to see if the character just read is the new-line character.
- A loop that reads and ignores all remaining characters in the current input line:

```
do {
  scanf("%c", &ch);
} while (ch != '\n');
```

- When `scanf` is called the next time, it will read the first character on the next input line.

Reading and Writing Characters Using `getchar` and `putchar`

- For single-character input and output, `getchar` and `putchar` are an alternative to `scanf` and `printf`.
- `putchar` writes a character:

```
putchar(ch);          // int putchar(int);
```

- Each time `getchar` is called, it reads one character, which it returns:

```
ch = getchar();       // int getchar(void);
```

- `getchar` returns an `int` value rather than a `char` value, so `ch` will often have type `int`.
- Like `scanf`, `getchar` doesn't skip white-space characters as it reads.

Reading and Writing Characters Using `getchar` and `putchar`

- Using `getchar` and `putchar` (rather than `scanf` and `printf`) saves execution time.
  - `getchar` and `putchar` are much simpler than `scanf` and `printf`, which are designed to read and write many kinds of data in a variety of formats.
  - They are usually implemented as macros for additional speed.
- `getchar` has another advantage.
  - Because it returns the character that it reads, `getchar` lends (增添) itself to various C idioms (慣用語法).

Reading and Writing Characters Using `getchar` and `putchar`

- Consider the `scanf` loop that we used to skip the rest of an input line:

```
do {
  scanf("%c", &ch);
} while (ch != '\n');
```

- Rewriting this loop using `getchar` gives us the following:

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


Reading and Writing Characters Using `getchar` and `putchar`

- Moving the call of `getchar` into the controlling expression allows us to condense the loop:

```
while ((ch = getchar()) != '\n')
  ;
```

- The `ch` variable isn't even needed; we can just compare the return value of `getchar` with the new-line character:

```
while (getchar() != '\n')
  ;
```

Reading and Writing Characters Using `getchar` and `putchar`

- `getchar` is useful in
  - loops that skip characters as well as
  - loops that search for characters.
- A statement that uses `getchar` to skip an indefinite number of blank characters:

```
while ((ch = getchar()) == ' ')
  ;
```

- When the loop terminates, `ch` will contain the first nonblank character that `getchar` encountered.

Reading and Writing Characters Using `getchar` and `putchar`

- Be careful when mixing `getchar` and `scanf`.
- `scanf` has a tendency to leave behind characters that it has "peeked" at but not read, including the new-line character:

```
printf("Enter an integer: ");
scanf("%d", &i);
printf("Enter a command: ");
command = getchar();
```

- `scanf` will leave behind any characters that weren't consumed during the reading of `i`, including (but not limited to) the new-line character.
- `getchar` will fetch the first leftover character.

Program: Determining the Length of a Message

- The `length.c` program displays the length of a message entered by the user:

```
Enter a message: Brevity is the soul of wit.
Your message was 27 character(s) long.
```

- The length includes spaces and punctuation, but not the new-line character at the end of the message.
- We could use either `scanf` or `getchar` to read characters; most C programmers would choose `getchar`.
- `length2.c` is a shorter program that eliminates the variable used to store the character read by `getchar`.

`length.c`

```
/* Determines the length of a message */

#include <stdio.h>

int main(void)
{
  char ch;
  int len = 0;

  printf("Enter a message: ");
  ch = getchar();
  while (ch != '\n') {
    len++;
    ch = getchar();
  }
  printf("Your message was %d character(s) long.\n", len);

  return 0;
}
```

length2.c

```
/* Determines the length of a message */

#include <stdio.h>

int main(void)
{
  int len = 0;

  printf("Enter a message: ");
  while (getchar() != '\n')
    len++;
  printf("Your message was %d character(s) long.\n", len);

  return 0;
}
```


Type Conversion

- For a computer to perform an arithmetic operation,
  - the operands must usually be of the same size (the same number of bits) and be stored in the same way.
- When operands of different types are mixed in expressions,
  - the C compiler may have to generate instructions that change the types of some operands so that hardware will be able to evaluate the expression.
  - If we add a 16-bit `short` and a 32-bit `int`, the compiler will arrange for the `short` value to be converted to 32 bits.
  - If we add an `int` and a `float`, the compiler will arrange for the `int` to be converted to `float` format.

Type Conversion

- Because the compiler handles these conversions automatically,
  - without the programmer's involvement,
  - they're known as ***implicit conversions.***
- C also allows the programmer to perform ***explicit conversions,*** using the cast operator.
- The rules for performing implicit conversions
  - are somewhat complex,
  - primarily because C has so many different arithmetic types.

Type Conversion

- Implicit conversions are performed:
  - When the operands in an arithmetic or logical expression don't have the same type. (C performs what are known as the ***usual arithmetic conversions.***)
  - When the type of the expression on the right side of an assignment doesn't match the type of the variable on the left side.
  - When the type of an argument in a function call doesn't match the type of the corresponding parameter.
  - When the type of the expression in a `return` statement doesn't match the function's return type.
- Chapter 9 discusses the last two cases.

The Usual Arithmetic Conversions

- The usual arithmetic conversions are applied to the operands of most binary operators.
- If `f` has type `float` and `i` has type `int`, the usual arithmetic conversions will be applied to the operands in the expression `f + i`.
- Clearly it's safer to convert `i` to type `float` (matching `f`'s type) rather than convert `f` to type `int` (matching `i`'s type).
  - When an integer is converted to `float`, the worst that can happen is a minor loss of precision.
  - Converting a floating-point number to `int`, on the other hand, causes the fractional part of the number to be lost.
  - Worse still, the result will be meaningless if the original number is larger than the largest possible integer or smaller than the smallest integer.

The Usual Arithmetic Conversions

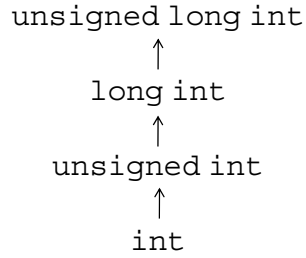
- Strategy behind the usual arithmetic conversions: convert operands to the "narrowest" type that will safely accommodate both values.
- Operand types can often be made to match
  - by converting the operand of the narrower type
  - to the type of the other operand (this act is known as ***promotion***).
- Common promotions include the ***integral promotions,*** which convert a character or short integer to type `int` (or to `unsigned int` in some cases).
- The rules for performing the usual arithmetic conversions can be divided into two cases:
  - The type of either operand is a floating type.
  - Neither operand type is a floating type.

The Usual Arithmetic Conversions

- ***The type of either operand is a floating type.***
  - If one operand has type `long double`, then convert the other operand to type `long double`.
  - Otherwise, if one operand has type `double`, convert the other operand to type `double`.
  - Otherwise, if one operand has type `float`, convert the other operand to type `float`.
- Example:
  - If one operand has type `long int` and the other has type `double`,
  - the `long int` operand is converted to `double`.

The Usual Arithmetic Conversions

- ***Neither operand type is a floating type.***
  - First perform integral promotion on both operands.
- Then use the following diagram to promote the operand whose type is narrower:



The Usual Arithmetic Conversions

- When a signed operand is combined with an unsigned operand, the signed operand is converted to an unsigned value.
- This rule can cause obscure (含糊的) programming errors.
- It's best to use unsigned integers as little as possible and, especially, never mix them with signed integers.

The Usual Arithmetic Conversions

- Example of the usual arithmetic conversions:

```
char c;
short int s;
int i;
unsigned int u;
long int l;
unsigned long int ul;
float f;
double d;
long double ld;

i = i + c;     /* c is converted to int               */
i = i + s;     /* s is converted to int               */
u = u + i;     /* i is converted to unsigned int      */
l = l + u;     /* u is converted to long int          */
ul = ul + l;   /* l is converted to unsigned long int */
f = f + ul;    /* ul is converted to float            */
d = d + f;     /* f is converted to double            */
ld = ld + d;   /* d is converted to long double       */
```


Conversion During Assignment

- The usual arithmetic conversions don't apply to assignment.
- Instead, the expression on the right side of the assignment is converted to the type of the variable on the left side:

```
char c;
int i;
float f;
double d;

i = c;   /* c is converted to int   */
f = i;   /* i is converted to float */
d = f;   /* f is converted to double */
```


Conversion During Assignment

- Assigning a floating-point number to an integer variable drops the fractional part of the number:

```
int i;

i = 842.97;     /* i is now 842 */
i = -842.97;    /* i is now -842 */
```

- Assigning a value to a variable of a narrower type
  - will give a meaningless result (or worse)
  - if the value is outside the range of the variable's type:

```
c = 10000;     /*** WRONG ***/
i = 1.0e20;    /*** WRONG ***/
f = 1.0e100;   /*** WRONG ***/
```

Conversion During Assignment

- It's a good idea
  - to append the `f` suffix to a floating-point constant
  - if it will be assigned to a `float` variable:

```
f = 3.14159f;
```

- Without the suffix, the constant `3.14159`
  - would have type `double`,
  - possibly causing a warning message.

Implicit Conversions in C99

- C99's rules for implicit conversions are somewhat different.
- Each integer type has an "integer conversion rank."
- Ranks from highest to lowest:
  1. `long long int`, `unsigned long long int`
  2. `long int`, `unsigned long int`
  3. `int`, `unsigned int`
  4. `short int`, `unsigned short int`
  5. `char`, `signed char`, `unsigned char`
  6. `_Bool`
- C99's "integer promotions"
  - involve converting any type whose rank is less than `int` and `unsigned int`
  - to `int` (provided that all values of the type can be represented using `int`) or else to `unsigned int`.

Implicit Conversions in C99

- C99's rules for performing the usual arithmetic conversions can be divided into two cases:
  - The type of either operand is a floating type.
  - Neither operand type is a floating type.

- ***The type of either operand is a floating type.***
  - As long as neither operand has a complex type, the rules are the same as before. (The conversion rules for complex types are discussed in Chapter 27.)

Implicit Conversions in C99

- ***Neither operand type is a floating type.*** Perform integer promotion on both operands. Stop if the types of the operands are now the same. Otherwise, use the following rules:
  - If both operands have signed types or both have unsigned types, convert the operand whose type has lesser integer conversion rank to the type of the operand with greater rank.
  - If the unsigned operand has rank greater or equal to the rank of the type of the signed operand, convert the signed operand to the type of the unsigned operand.
  - If the type of the signed operand can represent all of the values of the type of the unsigned operand, convert the unsigned operand to the type of the signed operand.
  - Otherwise, convert both operands to the unsigned type corresponding to the type of the signed operand.

Implicit Conversions in C99

- All arithmetic types
  - can be converted to `_Bool` type.
- The result of the conversion
  - is 0 if the original value is 0;
  - otherwise, the result is 1.

Casting

- Although C's implicit conversions are convenient, we sometimes need a greater degree of control over type conversion.
- For this reason, C provides ***casts.***
- A cast expression has the form

  (*type-name*) *expression*

  type-name specifies the type to which the expression should be converted.

Casting

- Using a cast expression to compute the fractional part of a `float` value:

```
float f, frac_part;

frac_part = f - (int) f;
```

- The difference between `f` and `(int) f`
  - is the fractional part of `f`,
  - which was dropped during the cast.
- Cast expressions enable us to document type conversions that would take place anyway:

```
i = (int) f;  /* f is converted to int */
```


Casting

- Cast expressions also let us force the compiler to perform conversions.
- Example:

```
float quotient;
int dividend, divisor;

quotient = dividend / divisor;
```

- To avoid truncation during division, we need to cast one of the operands:

```
quotient = (float) dividend / divisor;
```

- Casting `dividend` to `float` causes the compiler to convert `divisor` to `float` also.

Casting

- C regards (*type-name*) as a unary operator.
- Unary operators have higher precedence than binary operators, so the compiler interprets

```
(float) dividend / divisor
```

as

```
((float) dividend) / divisor
```

- Other ways to accomplish the same effect:

```
quotient = dividend / (float) divisor;
quotient = (float) dividend / (float) divisor;
```


Casting

- Casts are sometimes necessary to avoid overflow:

```
long i;
int j = 1000;

i = j * j;   /* overflow may occur */
```

- Using a cast avoids the problem:

```
i = (long) j * j;
```

- The statement

```
i = (long) (j * j);   /*** WRONG ***/
```

wouldn't work, since the overflow would already have occurred by the time of the cast.

Type Definitions

- The `#define` directive can be used to create a "Boolean type" macro:

```
#define BOOL int
```

- There's a better way using a feature known as a ***type definition:***

```
typedef int Bool;
```

- `Bool` can now be used in the same way as the built-in type names.
- Example:

```
Bool flag;   /* same as int flag; */
```


Advantages of Type Definitions

- Type definitions can make a program more understandable.
- If the variables `cash_in` and `cash_out` will be used to store dollar amounts, declaring `Dollars` as

```
typedef float Dollars;
```

and then writing

```
Dollars cash_in, cash_out;
```

is more informative than just writing

```
float cash_in, cash_out;
```

Advantages of Type Definitions

- Type definitions can also make a program easier to modify.
- To redefine `Dollars` as `double`, only the type definition need be changed:

```
typedef double Dollars;
```

- Without the type definition, we would need to
  - locate all `float` variables that store dollar amounts
  - and change their declarations.

Type Definitions and Portability

- Type definitions are an important tool for writing portable programs.
- One of the problems with moving a program from one computer to another is that types may have different ranges on different machines.
- If `i` is an `int` variable, an assignment like

```
i = 100000;
```

  is fine on a machine with 32-bit integers, but will fail on a machine with 16-bit integers.

Type Definitions and Portability

- For greater portability, consider using `typedef` to define new names for integer types.
- Suppose that we're writing a program that needs variables capable of storing product quantities in the range 0–50,000.
- We could use `long` variables for this purpose,
  - but we'd rather use `int` variables,
  - since arithmetic on `int` values may be faster than operations on `long` values.
  - Also, `int` variables may take up less space.

Type Definitions and Portability

- Instead of using the `int` type to declare quantity variables, we can define our own "quantity" type:

```
typedef int Quantity;
```

  and use this type to declare variables:

```
Quantity q;
```

- When we transport the program to a machine with shorter integers, we'll change the type definition:

```
typedef long Quantity;
```

- Note that changing the definition of `Quantity` may affect the way `Quantity` variables are used.

Type Definitions and Portability

- The C library itself uses `typedef` to create names for types
  - that can vary from one C implementation to another;
  - these types often have names that end with `_t`.
- Typical definitions of these types:

```
typedef long int ptrdiff_t;
typedef unsigned long int size_t;
typedef int wchar_t;
```

- In C99, the `<stdint.h>` header uses `typedef` to define names for integer types with a particular number of bits.

The `sizeof` Operator

- The value of the expression

  `sizeof ( type-name )`

  is an unsigned integer

  representing the number of bytes required to store a value belonging to *type-name*.

- `sizeof(char)` is always 1, but the sizes of the other types may vary.
- On a 32-bit machine, `sizeof(int)` is normally 4.

The `sizeof` Operator

- The `sizeof` operator can also be applied to constants, variables, and expressions in general.
  - If `i` and `j` are `int` variables, then `sizeof(i)` is 4 on a 32-bit machine, as is `sizeof(i + j)`.
- When applied to an expression
  - —as opposed to a type—
  - `sizeof` doesn't require parentheses.
  - We could write `sizeof i` instead of `sizeof(i)`.
- Parentheses may be needed anyway because of operator precedence.
  - The compiler interprets `sizeof i + j` as `(sizeof i) + j`, because `sizeof` takes precedence over binary `+`.

The `sizeof` Operator

- Printing a `sizeof` value requires care, because the type of a `sizeof` expression is an implementation-defined type named `size_t`.
- In C89, it's best to convert the value of the expression to a known type before printing it:

```
printf("Size of int: %lu\n",
       (unsigned long) sizeof(int));
```

- The `printf` function in C99
  - can display a `size_t` value directly
  - if the letter `z` is included in the conversion specification:

```
printf("Size of int: %zu\n", sizeof(int));
```