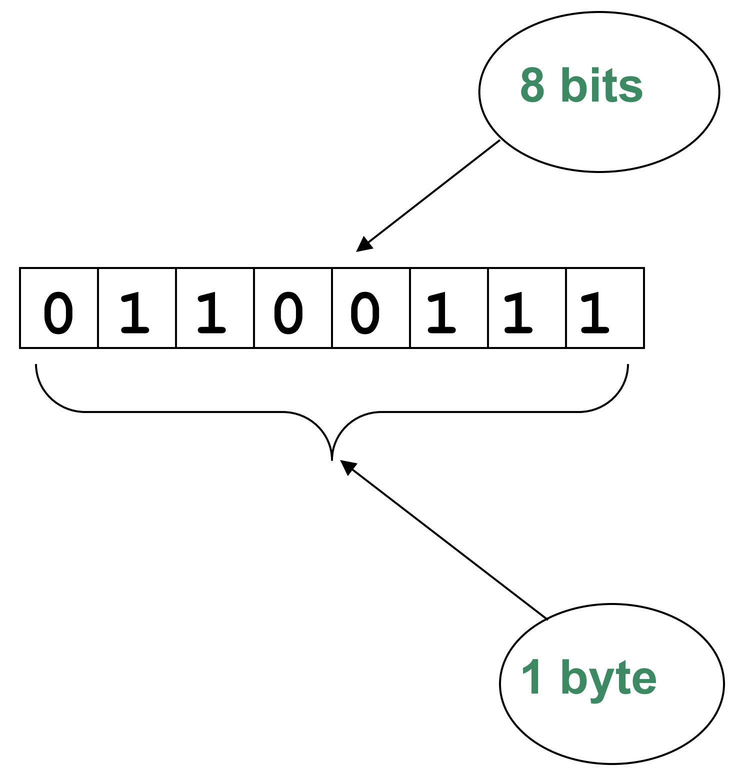
Main Memory Organization

- Bit
  - Smallest piece of memory
  - Stands for binary digit
  - Has values 0 (off) or 1 (on)
- Byte
  - Is 8 consecutive bits
- Word
  - Usually 4 consecutive bytes
  - Has an address



Data Storage

- All data is stored in binary bits in main memory
- The meaning of a set of bits depends on the ***encoding***
  - Encoding determines the length of a meaningful chunk
  - We use bytes (8-bits) as our most common unit
  - Encoding also determines how those bits should be read

8-bit Binary	8-bit Integer	8-bit Character (ASCII)
0100 0001	65	‘A’
0100 0010	66	‘B’
0100 0011	67	‘C’

Simple Data Types

- Data type: set of values together with a set of operations
- C++ data types fall into three categories:

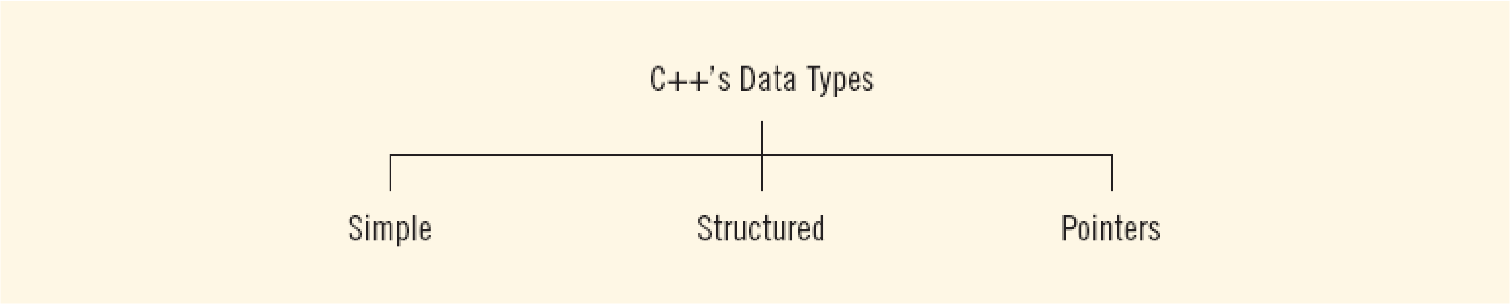


FIGURE 2-1 C++ data types

Simple Data Types

- Three categories of simple data
  - Integral: integers (numbers without a decimal)
  - Floating-point: decimal numbers
  - Enumeration type: user-defined data type

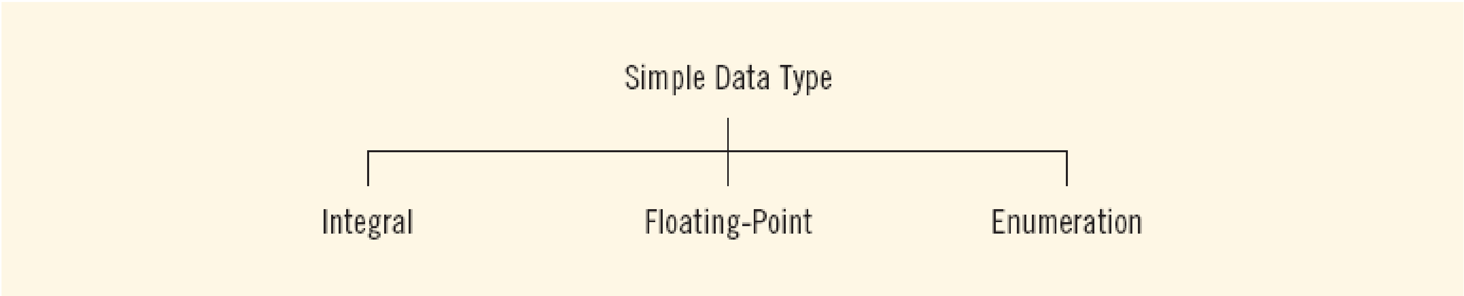


FIGURE 2-2 Simple data types

Simple Data Types (continued)

- Integral data types are further classified into the following categories:

char	unsigned char	characters
short	unsigned short	whole numbers
int	unsigned int	whole numbers
long	unsigned long	whole numbers
long long	unsigned long long	whole numbers
bool		Boolean values

`int` Data Type

- Examples:

  ```
  -6728
  0
  78
  +763
  ```

- Positive integers do not need a + sign
- No commas are used within an integer
  - Commas are used for separating items in a list

`char` Data Type

- The smallest integral data type
- Used for <u>characters</u>: letters, digits, and special symbols
- Each character is enclosed in single quotes
  - `'A','a','0','*','+','$','&',' '`
- A blank space is a character

`bool` Data Type

- `bool` type
  - Two values: `true` and `false`
  - Manipulate logical (Boolean) expressions
- `true` and `false` are called logical values
- `bool`, `true`, and `false` are reserved words

Simple Data Types

TABLE 2-2 Values and Memory Allocation for Three Simple Data Types

Data Type	Values	Storage (in bytes)
`int`	-2147483648 to 2147483647	4 4*8=32 bits
`bool`	`true` and `false`	1
`char`	-128 to 127	1

- Different compilers may allow different ranges of values

Floating-Point Data Types

- C++ uses scientific notation to represent real numbers (floating-point notation)

TABLE 2-3 Examples of Real Numbers Printed in C++ Floating-Point Notation

Real Number	C++ Floating-Point Notation
75.924	7.592400E1
0.18	1.800000E-1
0.0000453	4.530000E-5
-1.482	-1.482000E0
7800.0	7.800000E3

Floating-Point Data Types (continued)

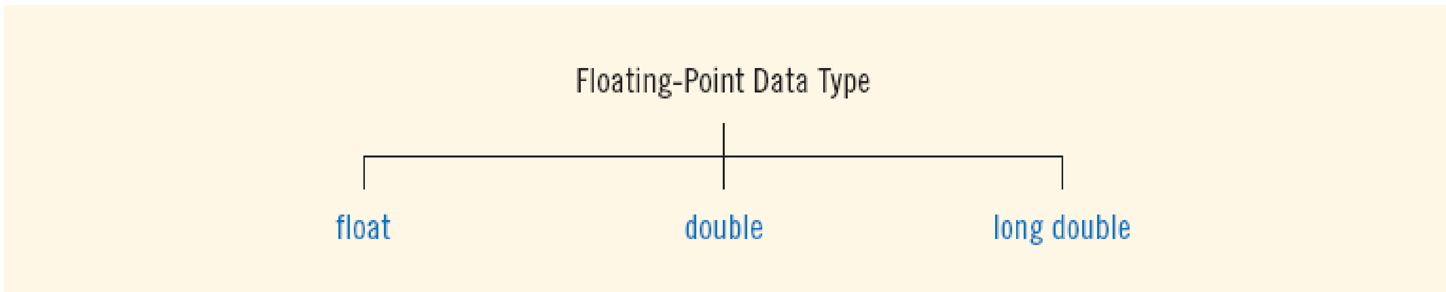


FIGURE 2-4 Floating-point data types

- `float`: represents any real number
  - Range: -3.4E+38 to 3.4E+38 (four bytes)
- `double`: represents any real number
  - Range: -1.7E+308 to 1.7E+308 (eight bytes)
- On most newer compilers, data types `double` and `long double` are same

Floating-Point Data Types (continued)

- Maximum number of significant digits (decimal places) for float values is 6 or 7
- Maximum number of significant digits for double is 15
- Precision: maximum number of significant digits
  - Float values are called single precision
  - Double values are called double precision

Arithmetic Operators

- C++ arithmetic operators:

+	Addition
-	Subtraction
*	Multiplication
/	Division
%	Modulus

- +, -, *, and / can be used with integral and floating-point data types
- % can be used with integral data types only
- These are *binary operators*
  - They operate on 2 *operands*

Order of Precedence

- All operations inside of () are evaluated first
- *, /, and % are at the same level of precedence and are evaluated next
- + and – have the same level of precedence and are evaluated last
- When operators are on the same level
  - Performed from left to right (associativity)
- `3 * 7 - 6 + 2 * 5 / 4 + 6` means

  `(((3 * 7) - 6) + ((2 * 5) / 4 )) + 6`

Overflow and Underflow

- Occurs when assigning a value that is too large (overflow) or too small (underflow) to be held in a variable
- Variable contains value that is ‘wrapped around’ the set of possible values

Overflow Example

- `// Create a short int initialized to`
- `// the largest value it can hold`
- `short int num = 32767;`

- `cout << num;       // Displays 32767`
- `num = num + 1;`
- `cout << num;       // Displays -32768`

Handling Overflow and Underflow

- Different systems handle the problem differently. They may
  - display a warning / error message
  - display a dialog box and ask what to do
  - stop the program
  - continue execution with the incorrect value

Expressions

Entire expression is evaluated according to precedence rules

- If all operands are integers
  - Expression is called an <u>integral expression</u>
    - Yields an integral result
    - Example: `2 + 3 * 5`
- If all operands are floating-point
  - Expression is called a <u>floating-point expression</u>
    - Yields a floating-point result
    - Example: `12.8 * 17.5 - 34.50`

Mixed Expressions

- Mixed expression:
  - Has operands of different data types
  - Contains integers and floating-point
- Examples of mixed expressions:

```
2 + 3.5
6 / 4 + 3.9
5.4 * 2 - 13.6 + 18 / 2
```

Mixed Expressions (cont'd.)

Data types are ranked by largest value they can hold

DATA TYPE HIERARCHY

Promotion **Demotion**

long double	8
double	8
float	4
long long	8
long int	4
int	4
short	2
char	1

Mixed Expressions (cont'd.)

- Evaluation rules:
  - If expression has different types of operands
    - char, short, unsigned short are automatically promoted to int
    - All operands are promoted to the data type with the highest rank in the expression
    - When using the = operator, the type of the expression on right will be converted to type of the variable on ***left*** (promotion or demotion)

Data Types and Conversion

- The data type assigned to a literal or variable tells the computer how it is encoded
  - That is, how to interpret it
- You can also tell the computer to treat a literal or variable with a different encoding
  - This is called *type casting* or *type coercion*

```
static_cast<dataTypeName>( expression )
```

Rounding off a number

Suppose we need to round a real number to the nearest hundredth (2 decimal digits), we could do it by using the following procedure:

Number to be rounded off: **2.3449**

1) Move decimal point 2 places to the right -> 2.3449 * 100.0 => 234.49
2) Add 0.5 -> 234.49 + 0.5 => 234.99
3) Round the result downward (get the largest integral value that is not greater than the result -> => 234.0
4) Divide it by 100.0 -> 234.0 / 100.0 => **2.34**

Suppose we have a value in a variable called length (type double) and we want to round it off, we could use the following expression to implement the steps shown above:

```
length = floor((length * 100.0) + 0.5)/100.0
```