DM560

Introduction to Programming in C++

Types
Control Structures

Marco Chiarandini

Department of Mathematics & Computer Science
University of Southern Denmark

[*Based on slides by Bjarne Stroustrup*]

Outline

Most programming tasks involve manipulating data. We will:

- describe how to input and output data
- present the notion of a variable for holding data
- introduce the central notions of “Type” and “Type Safety”

Outline

1. Data Types

2. Type safety

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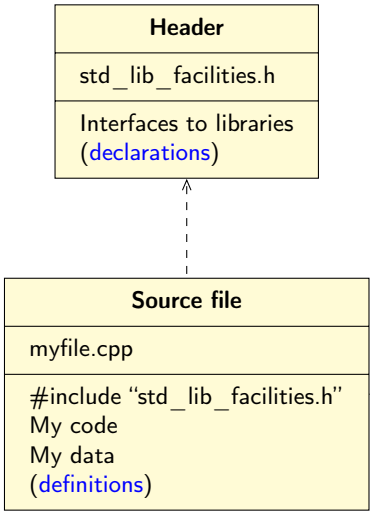
Input and Output

```
// read first name:
#include <iostream> // eller #include "std_lib_facilities.h" our course header
int main()
{
  cout << "Please enter your first name (followed " << "by 'enter'):\n";
  string first_name;
  cin >> first_name;
  cout << "Hello, " << first_name << '\n';
}
// - note how several values can be output by a single statement
// - a statement that introduces a variable is called a declaration
// - a variable holds a value of a specified type
// - the final return 0; is optional in main()
//   (but you may need to include it to pacify your compiler)
```

Source Files



Input and type

- We read into a variable
  Here, `first_name`
- A variable has a type
  Here, `string`
- The type of a variable determines what operations we can do on it
  – Here, `cin>>first_name;` reads characters until a whitespace character is seen (“a word”)
  – White space: space, tab, newline, ...

String Input

```
// read first and second name:
int main()
{
  cout << "please enter your first and second names\n";
  string first;
  string second;
  cin >> first >> second;
  // read two strings
  string name = first + ' ' + second;
  // concatenate strings
  // separated by a space
  cout << "Hello, "<< name << '\n';
}
// We left out here the line #include "std_lib_facilities.h" to save space and
// reduce distraction
// Don't forget it in real code!
// Similarly, we leave out the Windows-specific keep_window_open();
```

Integers

```
// read name and age:
int main()
{
  cout << "please enter your first name and age\n";
  string first_name;
  // string variable
  int age;
  // integer variable
  cin >> first_name >> age; // read
  cout << "Hello, " << first_name << " age " << age << '\n';
}
```

Integers and Strings

Strings

- `cin >>` reads a word
- `cout <<` writes
- `+` concatenates
- `+= s` adds the string `s` at end
- `++` is an error
- `-` is an error
- ...

Integers and floating-point numbers

- `cin >>` reads a number
- `cout <<` writes
- `+` adds
- `+= n` increments by the int `n`
- `++` increments by 1
- `-` subtracts
- ...

The type of a variable determines which operations are valid and what their meanings are for that type (that's called overloading or operator overloading)

Names

A name in a C++ program

- Starts with a letter, contains letters, digits, and underscores (only)
  `x, number_of_elements, Fourier_transform, z2`
  Not names:
  - `12x`
  - `time$to$market`
  - `main line`

  Do not start names with underscores: `_foo`
  those are reserved for implementation and system entities

- Users can't define names that are taken as keywords
  E.g.:
  - `int`
  - `if`
  - `while`
  - `double`

Names

Choose meaningful names

- Abbreviations and acronyms can confuse people
  `mtbf`, `TLA`, `myw`, `nbv`
- Short names can be meaningful
  (only) when used conventionally:
  - `x` is a local variable
  - `i` is a loop index
- Don't use overly long names
  Ok:
  `partial_sum`, `element_count`, `staple_partition`
  Too long:
  `the_number_of_elements`,
  `remaining_free_slots_in_the_symbol_table`

Simple Arithmetic

```
// do a bit of very simple arithmetic:
int main()
{
  cout << "please enter a floating-point number: "; // prompt for a number
  double n;      // floating-point variable
  cin >> n;
  cout << "n == " << n
  << "\nn+1 == " << n+1     // '\n' means ``a newline''
  << "\nthree times n == " << 3*n
  << "\ntwice n == " << n+n
  << "\nn squared == " << n*n
  << "\nhalf of n == " << n/2
  << "\nsquare root of n == " << sqrt(n) // library function
  << '\n';
}
```

A Simple Computation

```
int main()
// inch to cm conversion
{
  const double cm_per_inch = 2.54; // number of centimeters per inch
  int length = 1;    // length in inches
  while (length != 0)  // length == 0 is used to exit the program
  { // a compound statement (a block)
    cout << "Please enter a length in inches: ";
    cin >> length;
    cout << length << "in. = "
    << cm_per_inch*length << "cm.\n";
  }
}
```

A while-statement repeatedly executes until its condition becomes false

Another Simple Computation

Solve Quadratic Equations

- $ax^2 + bx + c = 0$: `a * x * x + b * x + c = 0`

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

```
#include <iostream>
#include <cmath> // For sqrt() function.
using namespace std;
int main()
{
  double root1, root2, a, b, c, root;
  cout << "Enter the coefficients a, b, c: ";
  cin >> a >> b >> c;
  root = sqrt(b * b - 4.0 * a * c);
  root1 = 0.5 * (root - b) / a;
  root2 = - 0.5 * (root + b) / a;
  cout << "The solutions are " << root1 << " and " << root2 <<  "/n" <<endl;
  return(0);
}
```

Types and Literals

Built-in types	Types	Literals
Boolean	`bool`	`true false`
Character	`char`	`'a', 'x', '4', 'n', '$'`
Integer	`int`, `short`, `long`	`0, 1, 123, -6, 034, 0xa3`
Floating-point	`double` and `float`	`1.2, 13.345, .3, -0.54, 1.2e3, .3F`

Standard-library types	Types	Literals
String	`string`	`'asdf', 'Howdy, all y all!'`
Complex Numbers	`complex<Scalar>`	`complex<double>(12.3,99)`
		`complex<float>(1.3F)`

If you need more details, see the book! (pages 66-67, 1077-1080)

Types

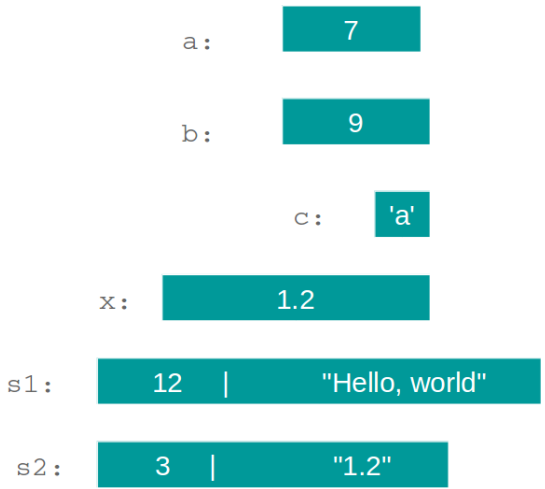
- C++ provides a set of types called built-in types
  E.g. `bool, char, int, double`

- C++ programmers can define new types called user-defined types
  We'll get to that eventually

- The C++ standard library provides a set of types
  E.g. `string, vector, complex`
  Technically, these are user-defined types
  they are built using only facilities available to every user

Declaration and Initialization

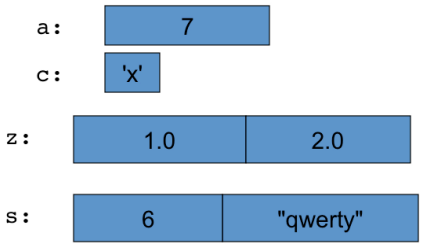
```
int a = 7;

int b = 9;

char c = 'a';

double x = 1.2;

string s1 = "Hello,
  world";
string s2 = "1.2";
```



Objects

- An object is some memory that can hold a value of a given type
- A variable is a named object
- A declaration names an object

```
int a = 7;
char c = 'x';
complex<double>
  z(1.0,2.0);
string s = "qwerty";
```



Types and Objects

- type defines a set of possible values and a set of operations (for an object)
- object is some memory that holds a value of a given type
- value is a set of bits in memory interpreted according to a type
- literal is a value conforming a type
- variable is a named object
- declaration is a statement that gives a name to an object
- definition is a declaration that sets aside memory for an object

Outline

Type Safety

- Language rule: type safety
  Every object will be used only according to its type
  - A variable will be used only after it has been initialized
  - Only operations defined for the variable's declared type will be applied
  - Every operation defined for a variable leaves the variable with a valid value

- Ideal: static type safety
  A program that violates type safety will not compile
  The compiler reports every violation (in an ideal system)

- Ideal: dynamic type safety
  If you write a program that violates type safety it will be detected at run time
  $\rightsquigarrow$ Some code (typically "the run-time system") detects every violation not found by the compiler (in an ideal system)

Type Safety

- Type safety is a very big deal
  Try very hard not to violate it
  "when you program, the compiler is your best friend"

- C++ is not (completely) statically type safe
  - No widely-used language is (completely) statically type safe
  - Being completely statically type safe may interfere with your ability to express ideas

- C++ is not (completely) dynamically type safe
  - Many languages are dynamically type safe
  - Being completely dynamically type safe may interfere with the ability to express ideas and often makes generated code bigger and/or slower

- Almost all of what you'll be taught here is type safe
  We'll specifically mention anything that is not

Assignment and Increment

```
// changing the value of a variable
int a = 7;          // a variable of type int called a
                          // initialized to the integer value 7

a = 9;             // assignment: now change a's value to 9


a = a+a;           // assignment: now double a's value


a += 2;            // increment a's value by 2


++a;              // increment a's value (by 1)
```

7

9

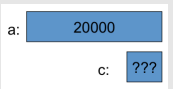
18

20

21

A type-safety violation
(“implicit narrowing”)

```
// Beware: C++ does not prevent you from trying to put a large value
// into a small variable (though a compiler may warn)

int main()
{
  int a = 20000;
  char c = a;
  int b = c;
  if (a != b)            //  != means ‘‘not equal’’
  cout << "oops!: " << a << "!=" << b << '\n';
  else
  cout << "Wow! We have large characters\n";
}
```



⇝ Try it to see what value b gets on your machine

A Technical Detail

- In memory, everything is just bits; type is what gives meaning to the bits

  (bits/binary) 01100001 is the int 97 is the char 'a'
  (bits/binary) 01000001 is the int 65 is the char 'A'
  (bits/binary) 00110000 is the int 48 is the char '0'

```
char c = 'a';
cout << c;       // print the value of character c, which is a
int i = c;
cout << i;       // print the integer value of the character c, which is 97
```

- This is just as in "the real world":
  What does "42" mean?
  You don't know until you know the unit used
  Meters? Feet? Degrees Celsius? $s? a street number? Height in inches? ...

A Type-safety Violation

Uninitialized variables

```
// Beware: C++ does not prevent you from trying to use a variable
// before you have initialized it  (though a compiler typically warns)

int main()
{
  int x;                  // x gets a 'random' initial value
  char c;          // c gets a 'random' initial value
  double d;        // d gets a 'random' initial value
                   //    not every bit pattern is a valid floating-point value
  double dd = d;           // potential error: some implementations
                           // can't copy invalid floating-point values
  cout << " x: " << x << " c: " << c << " d: " << d << '\n';
}
```

⇝ Always initialize your variables – beware: 'debug mode' may initialize (valid exception to this rule: input variable)

Type Conversions

They can be:

- safe (bool to char, bool to int, bool to double, char to int, char to double, int to double)
- unsafe (narrowing conversions: double to int, double to char, double to bool, int to char, int to bool, char to bool)
  The compilers accets them but warns against them. Use {} initialization to outlaw narrowing

They can be:

- implicit

```
char ch;
int x;
ch = x;      (where ch is char and x is int)
```

- explicit, type casting

```
(type) expression
```

About Efficiency

- For now, don't worry about efficiency
  Concentrate on correctness and simplicity of code

- C++ is derived from C, which is a systems programming language
  - C++'s built-in types map directly to computer main memory
    a `char` is stored in a byte
    an `int` is stored in a word
    a double fits in a floating-point register
  - C++'s built-in operations map directly to machine instructions
    an integer `+` is implemented by an integer add operation
    an integer `=` is implemented by a simple copy operation
  - C++ provides direct access to most of the facilities provided by modern hardware

- C++ help users build safer, more elegant, and efficient new types and operations using built-in types and operations.
  E.g., `string`
  Eventually, we'll show some of how that's done

Another Simple Computation

```
// inch to cm and cm to inch conversion:

int main()
{
  const double cm_per_inch = 2.54;
  int val;
  char unit;
  while (cin >> val >> unit) {  // keep reading
    if (unit == 'i')            // 'i' for inch
      cout << val << "in == " << val*cm_per_inch << "cm\n";
    else if (unit == 'c')       // 'c' for cm
      cout << val << "cm == " << val/cm_per_inch << "in\n";
    else
      return 0; // terminate on a 'bad unit', e.g. 'q'
  }
}
```

C++14 Hint

You can use the type of an initializer as the type of a variable

```
// 'auto' means 'the type of the initializer'
auto x = 1;      // 1 is an int, so x is an int
auto y = 'c';    // 'c' is a char, so y is a char
auto d = 1.2;    // 1.2 is a double, so d is a double

auto s = ``Howdy'';  // ``Howdy'' is a string literal of type const char[]
                     // so don't do that until you know what it means!

auto sq = sqrt(2);       // sq is the right type for the result of sqrt(2)
                         // and you don't have to remember what that is
auto duh;                // error: no initializer for auto
```