Introduction to C++

Systems Programming

Introduction to C++

- Syntax differences between C and C++
- A Simple C++ Example
  - C++ Input/Output
- C++ Libraries
  - C++ Header Files
- Another Simple C++ Example
  - Inline Functions
- Call by Reference in C++
- References and Reference Parameters

Introduction to C++

- Default Arguments
- Unary Scope Resolution Operator
- Function Overloading
- Function Templates

Introduction to C++

- C++ was developed by Bjarne Stroustrup at Bell Laboratories
  - Originally called "C with classes"
  - The name C++ includes C's increment operator (++)
    - Indicate that C++ is an enhanced version of C
- C++ programs
  - Built from pieces called **classes** and **functions.**
- C++ Standard Library
  - Rich collections of existing classes and functions

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Why use C++

- Many claim it is a better C because it is all of C with additions:
- Objects {and object-oriented philisophy}
- Inheritance
- Polymorphism
- Exception handling
- Templates

A Simple C++ Example

```
// C++ simple example

#include <iostream>  //for C++ Input and Output
int main ()
{
  int number3;

  std::cout << "Enter a number:";
  std::cin >> number3;

  int number2, sum;

  std::cout << "Enter another number:";
  std::cin >> number2;

  sum = number2 + number3;
  std::cout << "Sum is: " << sum <<std::endl;

  return 0;
}
```

C++ style comments

standard output stream object
stream insertion operator

stream extraction operator
standard input stream object

stream manipulator
Concatenating insertion operators

A Simple C++ Program

- C++ file names can have one of several extensions
  - Such as: .cpp, .cxx or .C (uppercase)
- Commenting
  - A // comment is a maximum of one line long.
  - A /*…*/ C-style comments can be more than one line long.
- iostream
  - Must be included for any program that outputs data to the screen or inputs data from the keyboard using C++ style stream input/output.
- C++ requires you to specify the return type, possibly void, for all functions.
  - Specifying a parameter list with empty parentheses is equivalent to specifying a void parameter list in C.

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A Simple C++ Program

- Stream manipulator **std::endl**
  - Outputs a newline.
  - Flushes the output buffer.
- The notation **std::cout** specifies that we are using a **name (cout)** that belongs to a **“namespace” (std)**.

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18.5 Header Files

- C++ Standard Library header files
  - Each contains a portion of the Standard Library.
    - Function prototypes for the related functions
    - Definitions of various class types and functions
    - Constants needed by those functions
  - "Instruct" the compiler on how to interface with library and user-written components.
  - Header file names ending in **.h**
    - Are "old-style" header files
    - Superseded by the C++ Standard Library header files
  - Use **#include** directive to include class in a program.

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Fig. 18.2 C++ Standard Library header files

C++ Standard Library header files	Explanation
<iostream>	Contains function prototypes for the C++ standard input and standard output functions. This header file replaces header file <iostream.h>. This header is discussed in detail in Chapter 26, Stream Input/Output.
<iomanip>	Contains function prototypes for stream manipulators that format streams of data. This header file replaces header file <iomanip.h>. This header is used in Chapter 26, Stream Input/Output.
<cmath>	Contains function prototypes for math library functions. This header file replaces header file <math.h>.
<cstdlib>	Contains function prototypes for conversions of numbers to text, text to numbers, memory allocation, random numbers and various other utility functions. This header file replaces header file <stdlib>.
<ctime>	Contains function prototypes and types for manipulating the time and date. This header file replaces header file <time.h>.
<vector>, <list> <deque>, <queue>, <stack>, <map>, <set>, <bitset>	These header files contain classes that implement the C++ Standard Library containers. Containers store data during a program's execution.

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18.6 Inline Functions

- Inline functions
  - Reduce function call overhead—especially for small functions.
  - Qualifier inline before a function's return type in the function definition
    - "Advises" the compiler to generate a copy of the function's code in place (when appropriate) to avoid a function call.
  - Trade-off of inline functions
    - Multiple copies of the function code are inserted in the program (often making the program larger).
  - The compiler can ignore the inline qualifier and typically does so for all but the smallest functions.

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Another Simple C++ Program

```
1  // Fig. 18.3: fig18_03.cpp
2  // Using an inline function to calculate the volume of a cube.
3  #include <iostream>
4  using std::cout;
5  using std::cin;
6  using std::endl;
7
8  // Definition of inline function cube. Definition of function appears
9  // before function is called, so a function prototype is not required.
10 // First line of function definition acts as the prototype.
11 inline double cube( const double side )
12 {
13    return side * side * side; // calculate the cube of side
14 } // end function cube
15
16 int main()
17 {
18    double sideValue; // stores value entered by user
19
```

`using` avoids repeating `std::`

`inline` qualifier

Complete function definition so the compiler knows how to expand a `cube` function call into its inlined code.

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Another Simple C++ Program

```
20    for ( int i = 1; i <= 3; i++ )
21    {
22       cout << "\nEnter the side length of your cube: ";
23       cin >> sideValue; // read value from user
24
25       // calculate cube of sideValue and display result
26       cout << "Volume of cube with side "
27          << sideValue << " is " << cube( sideValue ) << endl;
28    }
29
30    return 0; // indicates successful termination
31 } // end main
```

cube function call that could be inlined

```
Enter the side length of your cube: 1.0
Volume of cube with side 1 is 1

Enter the side length of your cube: 2.3
Volume of cube with side 2.3 is 12.167

Enter the side length of your cube: 5.4
Volume of cube with side 5.4 is 157.464
```

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Fig. 18.4 C++ keywords

C++ keywords				
Keywords common to the C and C++ programming languages				
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			

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Fig. 18.4 C++ keywords

C++ keywords				
C++-only keywords				
and	and_eq	asm	bitand	bitor
bool	catch	class	compl	const_cast
delete	dynamic_cast	explicit	export	false
friend	inline	mutable	namespace	new
not	not_eq	operator	or	or_eq
private	protected	public	reinterpret_cast	static_cast
template	this	throw	true	try
typeid	typename	using	virtual	wchar_t
xor	xor_eq			

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18.6 Inline Functions (Cont.)

- using statements help eliminate the need to repeat the namespace prefix
  - Ex: std::
- for statement's condition evaluates to either 0 (false) or nonzero (true)
  - Type bool represents boolean (true/false) values.
    - The two possible values of a bool are the keywords true and false.
      - When true and false are converted to integers, they become the values 1 and 0, respectively.
      - When non-boolean values are converted to type bool, non-zero values become true, and zero or null pointer values become false.

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18.7 References and Reference Parameters

- Reference Parameter
  - An alias for its corresponding argument in a function call.
  - & placed after the parameter type in the function prototype and function header
  - Example
    - int &count in a function header
      - Pronounced as "count is a reference to an int"
  - Parameter name in the called function body actually refers to the original variable in the calling function.

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Call by Reference and Call by Value in C++

```
1  // Fig. 18.5: fig18_05.cpp
2  // Comparing pass-by-value and pass-by-reference with references.
3  #include <iostream>
4  using std::cout;
5  using std::endl;
6
7  int squareByValue( int ); // function prototype (value pass)
8  void squareByReference( int & ); // function prototype (reference pass)
9
10 int main()
11 {
12    int x = 2; // value to square using squareByValue
13    int z = 4; // value to square using squareByReference
14
15    // demonstrate squareByValue
16    cout << "x = " << x << " before squareByValue\n";
17    cout << "Value returned by squareByValue: "
18       << squareByValue( x ) << endl;
19    cout << "x = " << x << " after squareByValue\n" <<
20
21    // demonstrate squareByReference
22    cout << "z = " << z << " before squareByReference" << endl;
23    squareByReference( z );
24    cout << "z = " << z << " after squareByReference" << endl;
25    return 0; // indicates successful termination
26 } // end main
```

Function illustrating pass-by-value

Function illustrating pass-by-reference

Variable is simply mentioned by name in both function calls

Call by Reference and Call by Value in C++

```
27
28 // squareByValue multiplies number by itself, stores the
29 // result in number and returns the new value of number
30 int squareByValue( int number )
31 {
32    return number *= number; // caller's argument not modified
33 } // end function squareByValue
34
35 // squareByReference multiplies numberRef by itself and stores the result
36 // in the variable to which numberRef refers in the caller
37 void squareByReference( int &numberRef )
38 {
39    numberRef *= numberRef; // caller's argument modified
40 } // end function squareByReference
```

```
x = 2 before squareByValue
Value returned by squareByValue: 4
x = 2 after squareByValue

z = 4 before squareByReference
z = 16 after squareByReference
```

Receives copy of argument in `main`

Receives reference to argument in `main`

Modifies variable in `main`

18.7 References and Reference Parameters

- References
  - are used as aliases for other variables within a function.
    - All operations supposedly performed on the alias (i.e., the reference) are actually performed on the original variable.
    - An alias is simply another name for the original variable.
    - Must be initialized in their declarations.
      - It cannot be reassigned afterward.
  - Example
    - ```
      int count = 1;
      int &cRef = count;
      cRef++;
      ```
      - Increments `count` through alias `cRef`.

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      ```

References and Reference Parameters

```
1  // Fig. 18.6: fig18_06.cpp
2  // References must be initialized.
3  #include <iostream>
4  using std::cout;
5  using std::endl;
6
7  int main()
8  {
9     int x = 3;
10    int &y = x; // y refers to (is an alias for) x
11
12    cout << "x = " << x << endl << "y = " << y << endl;
13    y = 7; // actually modifies x
14    cout << "x = " << x << endl << "y = " << y << endl;
15    return 0; // indicates successful termination
16 } // end main
```

```
x = 3
y = 3
x = 7
y = 7
```

Creating a reference as an alias to another variable in the function

Assign 7 to **x** through alias **y**

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References and Reference Parameters

```
1  // Fig. 18.7: fig18_07.cpp
2  // References must be initialized.
3  #include <iostream>
4  using std::cout;
5  using std::endl;
6
7  int main()
8  {
9     int x = 3;
10    int &y; // Error: y must be initialized
11
12    cout << "x = " << x << endl << "y = " << y << endl;
13    y = 7;
14    cout << "x = " << x << endl << "y = " << y << endl;
15    return 0; // indicates successful termination
16 } // end main
```

Borland C++ command-line compiler error message:

```
Error E2304 C:\examples\ch18\Fig18_07\fig18_07.cpp 10:
   Reference variable 'y' must be initialized in function main()
```

Microsoft Visual C++ compiler error message:

```
C:\examples\ch18\Fig18_07\fig18_07.cpp(10) : error C2530: 'y' :
   references must be initialized
```

GNU C++ compiler error message:

```
fig18_07.cpp:10: error: 'y' declared as a reference but not initialized
```

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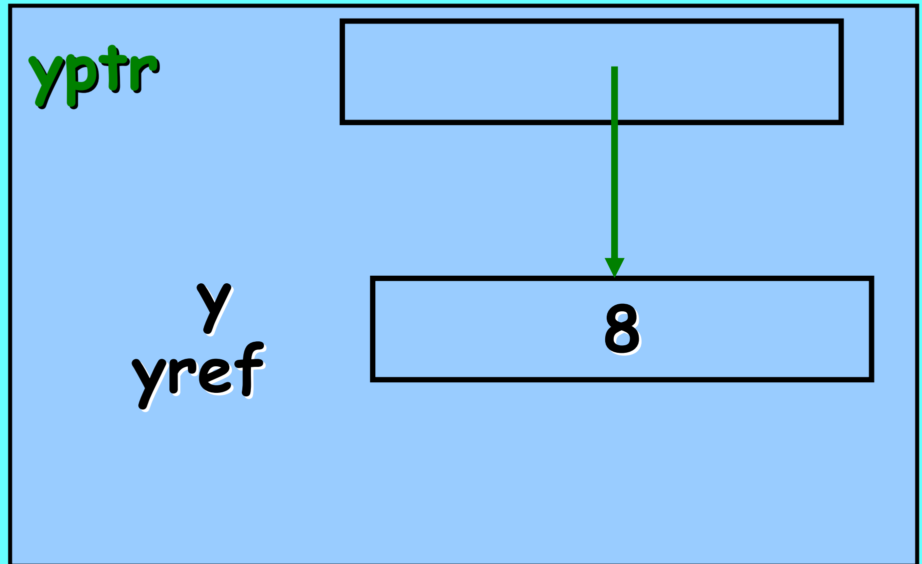
References

```
// Three ways in C++
#include <stdio.h>
int main ()
{
  int y = 8;
  int &yref = y;
  int *yptr = &y;

printf(" y  = %d\n using ref y  = %d\n using pointer y  = %d\n",
         y, yref, *yptr);
  return 0;
}
```




```
$ g++ -o ref ref.cpp
$ ./ref
 y  = 8
 using ref y  = 8
 using pointer y  = 8
```

References and Reference Parameters

- Returning a reference from a function
  - Functions can return references to variables.
    - Should only be used when the variable is static.
  - A Dangling reference
    - Returning a reference to an automatic variable
      - That variable no longer exists after the function ends.

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18.9 Default Arguments

- Default argument
  - A default value to be passed to a parameter.
    - Used when the function call does not specify an argument for that parameter.
  - Must be the rightmost argument(s) in a function's parameter list.
  - Should be specified with the first occurrence of the function name.
    - Typically in the function prototype.

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Default Arguments

```
1  // Fig. 18.8: fig18_08.cpp
2  // Using default arguments.
3  #include <iostream>
4  using std::cout;
5  using std::endl;
6
7  // function prototype that specifies default arguments
8  int boxVolume( int length = 1, int width = 1, int height = 1 );
9
10 int main()
11 {
12    // no arguments--use default values for all dimensions
13    cout << "The default box volume is: " << boxVolume();
14
15    // specify length; default width and height
16    cout << "\n\nThe volume of a box with length 10,\n"
17       << "width 1 and height 1 is: " << boxVolume( 10 );
18
19    // specify length and width; default height
20    cout << "\n\nThe volume of a box with length 10,\n"
21       << "width 5 and height 1 is: " << boxVolume( 10, 5 );
22
23    // specify all arguments
24    cout << "\n\nThe volume of a box with length 10,\n"
25       << "width 5 and height 2 is: " << boxVolume( 10, 5, 2 )
26       << endl;
27    return 0; // indicates successful termination
28 } // end main
```

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Default arguments

Calling function with no arguments

Calling function with one argument

Calling function with two arguments

Calling function with three arguments

Default Arguments

```
29
30 // function boxVolume calculates the volume of a box
31 int boxVolume( int length, int width, int height )
32 {
33    return length * width * height;
34 } // end function boxVolume
```

```
The default box volume is: 1

The volume of a box with length 10,
width 1 and height 1 is: 10

The volume of a box with length 10,
width 5 and height 1 is: 50

The volume of a box with length 10,
width 5 and height 2 is: 100
```

Note that default arguments were specified in the function prototype, so they are not specified in the function header

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18.10 Unary Scope Resolution Operator

- Unary scope resolution operator (::)
  - Used to access a global variable when a local variable of the same name is in scope.
  - Cannot be used to access a local variable of the same name in an outer block.

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18.10 Unary Scope Resolution Operator

```
1  // Fig. 18.9: fig18_09.cpp
2  // Using the unary scope resolution operator.
3  #include <iostream>
4  using std::cout;
5  using std::endl;
6
7  int number = 7; // global variable named number
8
9  int main()
10 {
11    double number = 10.5; // local variable named number
12
13    // display values of local and global variables
14    cout << "Local double value of number = " << number
15       << "\nGlobal int value of number = " << ::number << endl;
16    return 0; // indicates successful termination
17 } // end main
```

```
Local double value of number = 10.5
Global int value of number = 7
```

Unary scope resolution operator used to access global variable **number**

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18.11 Function Overloading

- Overloaded functions
  - Overloaded functions have
    - The same name
    - But different sets of parameters
  - Compiler selects proper function to execute based on number, types and order of arguments in the function call.
  - Commonly used to create several functions of the same name that perform similar tasks, but on different data types.

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Function Overloading

```
1  // Fig. 18.10: fig18_10.cpp
2  // Overloaded functions.
3  #include <iostream>
4  using std::cout;
5  using std::endl;
6
7  // function square for int values
8  int square( int x )
9  {
10    cout << "square of integer " << x << " is ";
11    return x * x;
12 } // end function square with int argument
13
14 // function square for double values
15 double square( double y )
16 {
17    cout << "square of double " << y << " is ";
18    return y * y;
19 } // end function square with double argument
20
21 int main()
22 {
23    cout << square( 7 ); // calls int version
24    cout << endl;
25    cout << square( 7.5 ); // calls double version
26    cout << endl;
27    return 0; // indicates successful termination
28 } // end main
```

```
square of integer 7 is 49
square of double 7.5 is 56.25
```

Defining a **`square`** function for **`int`s**

Defining a **`square`** function for **`double`s**

Output confirms that the proper function was called in each case

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Constructor overload

```
class Listnode
{
Listnode ()
{
   link = NULL;
}
Listnode( string word)
{
    link = NULL;
    lword = word;
}
…
Private:
  Listnode* link;
  string   lword;
};
```

18.12 Function Templates

- A more compact and convenient form of overloading.
  - Identical program logic and operations for each data type.
- Function template definition
  - Written by programmer once.
  - Essentially defines a whole family of overloaded functions.
  - Begins with the **template** keyword.
  - Contains a template parameter list of formal type and the parameters for the function template are enclosed in angle brackets (**< >**).
  - Formal type parameters
    - Preceded by keyword **typename** or keyword **class**.
    - Placeholders for fundamental types or user-defined types.

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18.12 Function Templates

- Function-template specializations
  - Generated automatically by the compiler to handle each type of call to the function template.
  - Example for function template **max** with type parameter **T** called with **int** arguments
    - Compiler detects a **max** invocation in the program code.
    - **int** is substituted for **T** throughout the template definition.
    - This produces function-template specialization **max< int >**.

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Function Template Example

```
1  // Fig. 18.12: maximum.h
2  // Definition of function template maximum.
3
4  template < class T >  // or template< typename T >
5  T maximum( T value1, T value2, T value3 )
6  {
7     T maximumValue = value1; // assume value1 is maximum
8
9     // determine whether value2 is greater than maximumValue
10    if ( value2 > maximumValue )
11       maximumValue = value2;
12
13    // determine whether value3 is greater than maximumValue
14    if ( value3 > maximumValue )
15       maximumValue = value3;
16
17    return maximumValue;
18 } // end function template maximum
```

Using formal type parameter **T** in place of data type

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Common Programming Error 18.11

- Not placing keyword `class` or keyword `typename` before every formal type parameter of a function template (e.g., writing `< class S, T >` instead of `< class S, class T >`) is a syntax error.

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Function Template Example

```
1  // Fig. 18.13: fig18_13.cpp
2  // Function template maximum test program.
3  #include <iostream>
4  using std::cout;
5  using std::cin;
6  using std::endl;
7
8  #include "maximum.h" // include definition of function template maximum
9
10 int main()
11 {
12    // demonstrate maximum with int values
13    int int1, int2, int3;
14
15    cout << "Input three integer values: ";
16    cin >> int1 >> int2 >> int3;
17
18    // invoke int version of maximum
19    cout << "The maximum integer value is: "
20       << maximum( int1, int2, int3 );
21
22    // demonstrate maximum with double values
23    double double1, double2, double3;
24
25    cout << "\n\nInput three double values: ";
26    cin >> double1 >> double2 >> double3;
27
```

Invoking **maximum** with **int** arguments

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Function Template Example

```
28    // invoke double version of maximum
29    cout << "The maximum double value is: "
30       << maximum( double1, double2, double3 );
31
32    // demonstrate maximum with char values
33    char char1, char2, char3;
34
35    cout << "\n\nInput three characters: ";
36    cin >> char1 >> char2 >> char3;
37
38    // invoke char version of maximum
39    cout << "The maximum character value is: "
40       << maximum( char1, char2, char3 ) << endl;
41    return 0; // indicates successful termination
42 } // end main
```

Invoking **maximum** with **double** arguments

Invoking **maximum** with **char** arguments

```
Input three integer values: 1 2 3
The maximum integer value is: 3

Input three double values: 3.3 2.2 1.1
The maximum double value is: 3.3

Input three characters: A C B
The maximum character value is: C
```

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