Software Engineering 2 (C++)

CSY2006

Module Overview/Objectives (provisional)

- Introduction to Software Engineering (SE), Programming Languages, Comparison of C++ and Java (all along the course), Visual C++ IDE
- Preprocessors, Data Types, Arrays, Variables, Operators, Expressions, Statements and Blocks ,
- Control Flow Statements: Decision Making, Looping and Branching
- Structures and Functions, Introduction to Classes and Objects
- Inheritance
- Arrays and Strings

Module Overview/Objectives (provisional)

- Polymorphism (Operator Overloading)
- Pointers
- Virtual Functions
- Streams and Files
- Namespaces, Templates and Exceptions
- Searching and Sorting Algorithms
- Data Structures (Linked List, Stacks, Queues, Binary Trees, Graphs, Expression Evaluation)

Software Engineering

- The application of a systematic, disciplined, quantifiable approach to the development, operation and maintenance of software

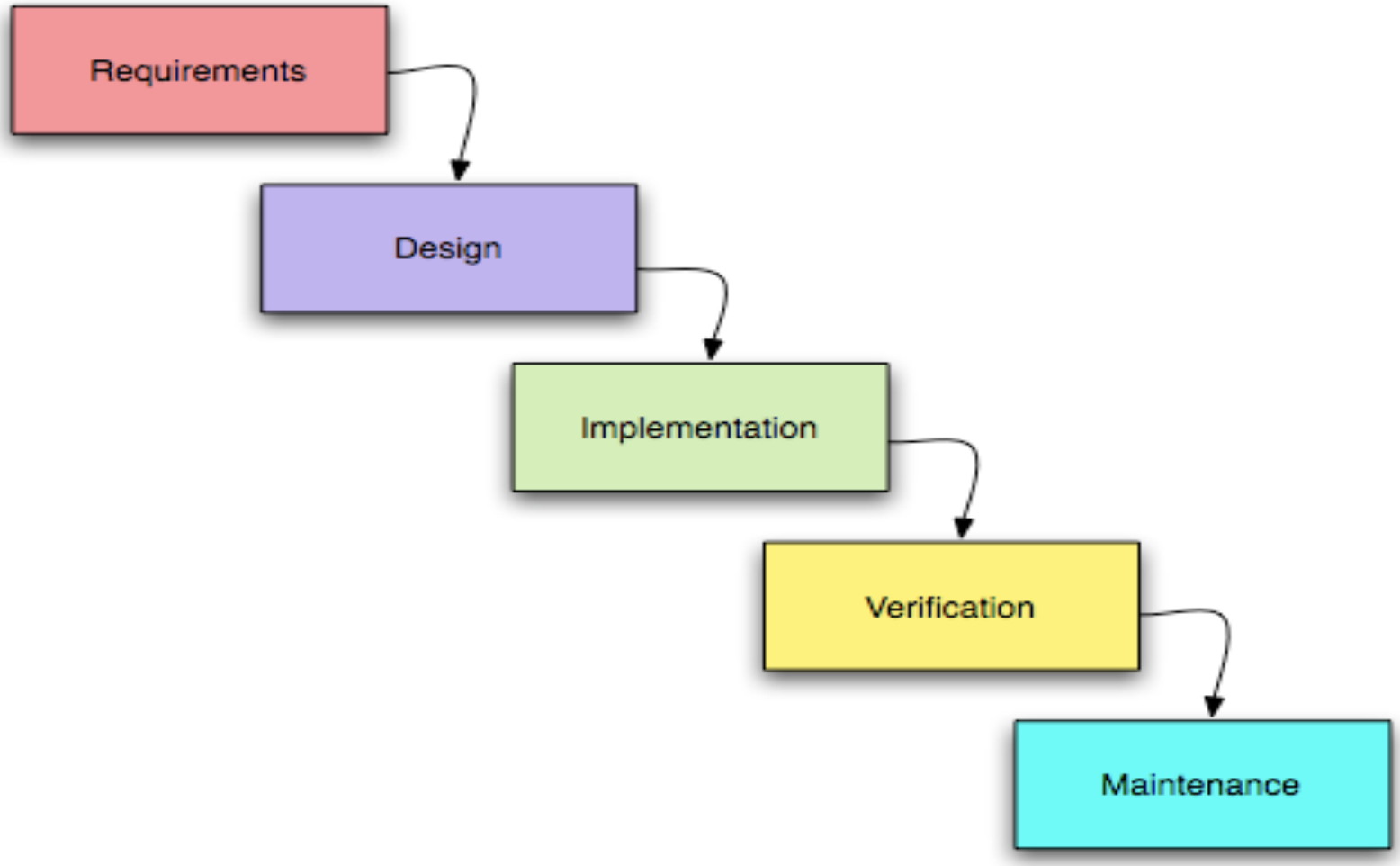
  -IEEE

- It is the application of Engineering to software because it integrates significant mathematics, computer science and practices whose origins are in Engineering

  - ACM

… much more than just programming

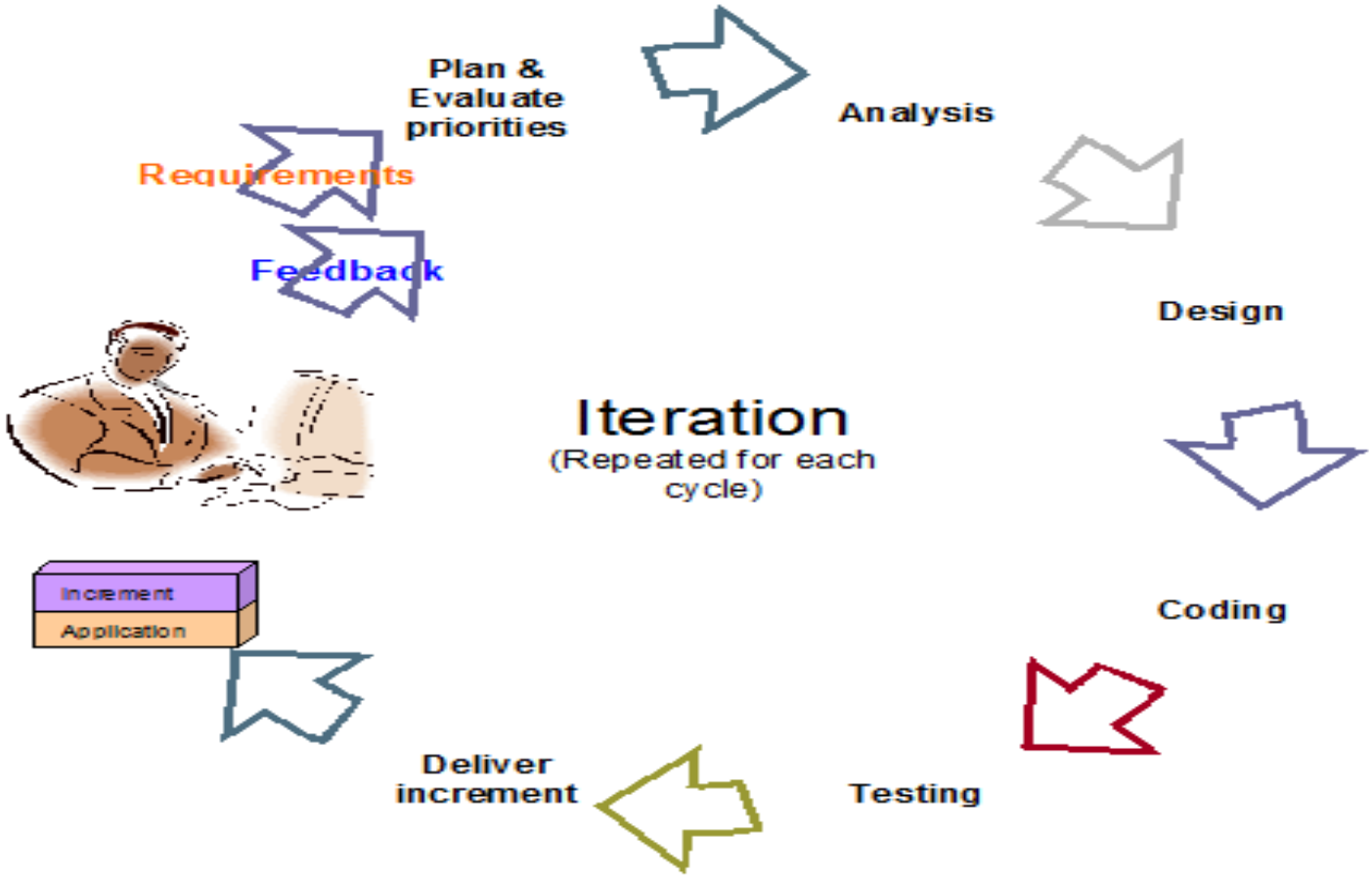
Traditional Software Development Process



Software Development Process

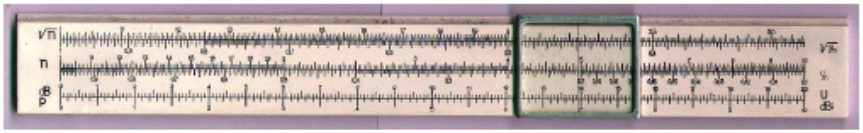
- *Software requirements* specify *what* a program must accomplish. Requirements are expressed in a document called a *Software Requirements Specification*
- A *software design* indicates how a program will accomplish its requirements
- *Implementation* is the process of writing the source code that will solve the problem
- *Verification/Testing* is the act of ensuring that a program will solve the intended problem given all of the constraints under which it must perform
- *Maintenance* is the act of improving software programs after delivery for reusing it in the future

Agile Software Development



Augustine's Law – Growth of Software: Order of Magnitude Every 10 Years

In The Beginning



1960's	*1970's*	*1980's*	*1990's*	*2000+*
				
F-4A 1000 LOC	*F-15A 50,000 LOC*	*F-16C 300K LOC*	*F-22 1.7M LOC*	*F-35 >6M LOC*
				

Programming Languages

- Machine Language consisting of binary code (0s and 1s). Computers understand only this. It is processor dependent.
- Assembly Language consisting of mnemonics (symbols) to make programming less tedious and faster. (e.g. Load A, Add B, Store C). An *Assembler* converts assembly language into machine language. It is also processor dependent.
- High-level Language consisting of English-like instructions to make programming simpler and faster. (e.g. C= A+B). A compiler/interpreter helps convert high-level language into machine language. It is not processor dependent.

Some High-level languages

- *procedural languages*: programs are a series of commands
  - **Pascal** (1970): designed for education
  - **C** (1972): operating systems and device drivers
- *functional programming*: functions map inputs to outputs
  - **Lisp** (1958) / **Scheme** (1975), **Haskell** (1990)
- *object-oriented languages*: programs use interacting "objects"
  - **Smalltalk** (1980): first major object-oriented language
  - **C++** (1985): "object-oriented" improvements to C
  - **Java** (1995): general purpose language and world's most widely used computer programming language. (Deitel & Deitel)

C/C++ vs Java

- C++:
  - Power and control: What to do? How to do it?
- Java:
  - “Do it my way and I’ll do more of the work for you”
  - But it may be less efficient than doing it yourself
  - Some things cannot be done in Java alone (JNI)
- **Java hides many things from you**
  - And decides how you will do things
- **Java prevents you doing some things and checks others**
  - **C++ trusts that you know what you are doing**
  - If you do not, then you can REALLY break things
- Do you want/need the power/control of C/C++?

What is C++?

Procedural C
Global Functions
File-specific functions
Structs
Pointers (addresses)
Low-level memory access
C Preprocessor

Variables
Arrays
Loops
Conditionals

Classes
- Grouping of related data together
- With associated methods (functions)
'new' for object creation
'delete' for object destruction
Constructors, Destructors
Operator Overloading
Assignment operators
Conversion operators
Inheritance (sub-classing)
Virtual functions & polymorphism
Access control (private/public/protected)

Function Libraries
Standard functions
Custom libraries
O/S functions

Templates
(Generic classes)

Non-C features
e.g. References

Class Libraries
(+templated classes)
Standard library
Custom libraries
Platform specific libraries

What about Java?

Procedural C

~~Global Functions~~
~~File-specific functions~~
~~Structs~~
~~Pointers (addresses)~~
~~Low-level memory access~~
~~C Preprocessor~~

Variables
Arrays
Loops
Conditionals

Classes

- Grouping of related data together
- With associated methods (functions)

'new' for object creation
~~'delete' for object destruction~~
Constructors, ~~Destructors~~
~~Operator Overloading~~
~~Assignment operators~~
~~Conversion operators~~ (toString()?)
Inheritance (sub-classing)
(ONLY) Virtual functions & polymorphism
Access control (private/public/protected)

~~**Function Libraries**~~
~~Standard functions~~
~~Custom libraries~~
~~O/S functions~~
Java Native Interface

~~**Templates**~~
'Generics' (weaker)

Non-C features
(ONLY) references

Class Libraries
(Standardised)
Collections
Networking
Graphics

What Sun changed for Java

- Remember: C++ came first
  - The Java changes were deliberate!
- Java is cross-platform
  - Interpreted intermediate byte-code (.class files)
  - Standard cross-platform class libraries
  - Libraries include graphics (AWT, SWING, …), networking, …
  - Platform independent type sizes
  - *Cannot take advantage of platform-specific features*
- Java prevents things which are potentially dangerous
  - Pointer arithmetic (but it can be fast)
  - Writing outside arrays (checks take time)
  - Low-level access to memory (dangerous per powerful)
  - Uninitialised data (initialisation takes time)
- Java forces you to use objects
  - Even when it would be quicker not to
- Java does garbage collection for you
  - Safer(?), but may execute slower than freeing memory yourself

So which is better: Java or C++?

- What does ‘better’ mean?
- What are you trying to do?
- Do you need the power and control that C++ gives you?
- With less options, things may seem simpler
  - Potentially harder to make mistakes
  - But you lose the flexibility to optimise
- If you know both, then you have more options (and the basics are very similar)

Basic Data Types - Summary

Type	Minimum size (bits)	Minimum range of values (Depends upon the size on your platform)
`char`	8	-128 to 127 (Java chars are 16 bit!)
`short`	16	-32768 to 32767
`long`	32	-2147483648 to 2147483647
`float`	Often 32	Single precision (implementation defined) e.g. 23 bit mantissa, 8 bit exponent
`double`	Often 64	Double precision (implementation defined) e.g. 52 bit mantissa, 11 bit exponent
`long double`	≥ double	Extended precision, implementation defined
`int`	≥ short	varies

`ints`, `bools` and `booleans`

- In C++ integer types (char, short, long, int) can be used in conditions
  - (In C++ the value is silently converted to a C++ `bool` type)
- When using integer types:
  - true is equivalent to non-zero (or 1), false is equivalent to zero
- Example:

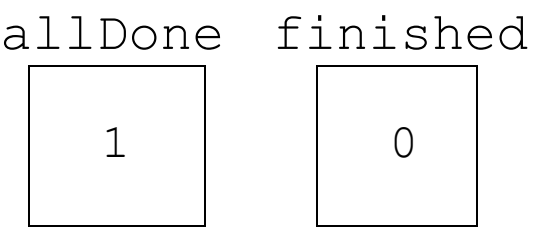
```
int x = 6;
 if ( x )
{
   x = x - 2;
}
```

- In Java this would be an error (x not boolean)
- In C++ this is valid (it means '`if( x != 0 )`')

The `bool` Data Type

- Represents values that are `true` or `false`
- `bool` variables are stored as small integers
- `false` is represented by 0, `true` by 1:

```
bool allDone = true;
bool finished = false;
```



Boolean Variables

Program 2-17

```
1  // This program demonstrates boolean variables.
2  #include <iostream>
3  using namespace std;
4
5  int main()
6  {
7     bool boolValue;
8
9     boolValue = true;
10    cout << boolValue << endl;
11    boolValue = false;
12    cout << boolValue << endl;
13    return 0;
14 }
```

Program Output

```
1
0
```

From a High-Level Program to an Executable File

a) Create file containing the program with a text editor.

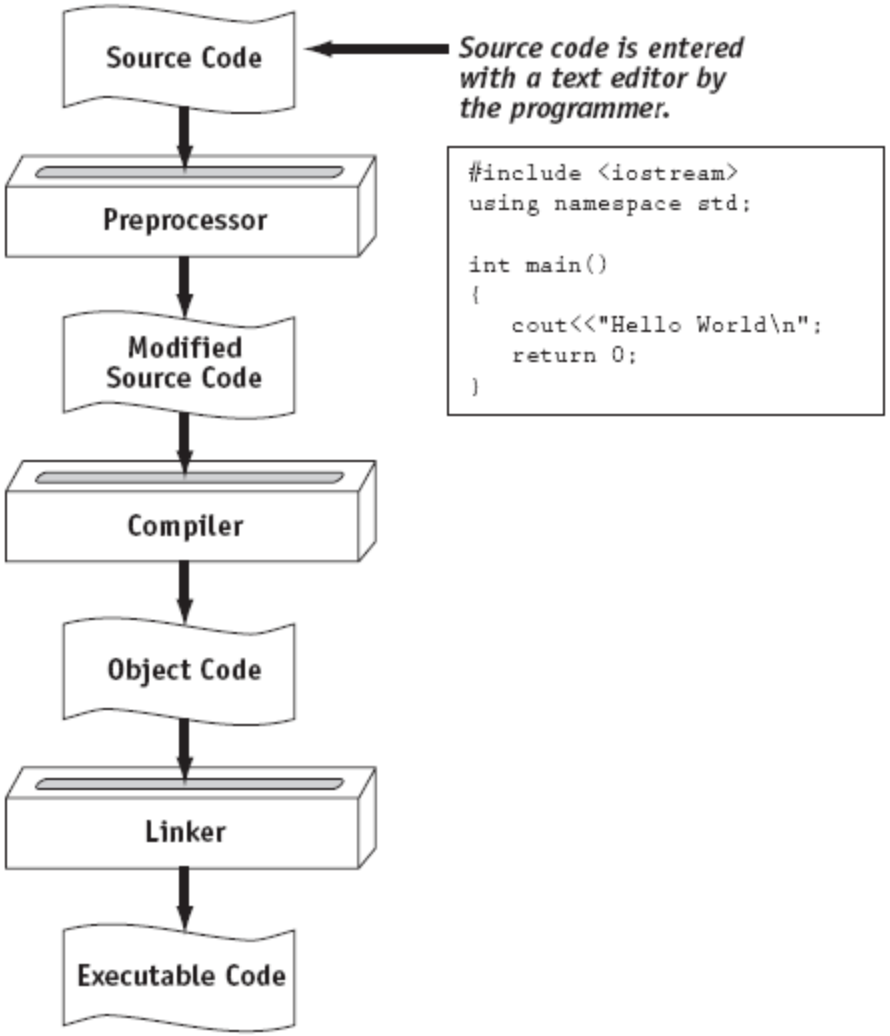
b) Run preprocessor to convert source file directives to source code program statements.

c) Run compiler to convert source program into machine instructions.

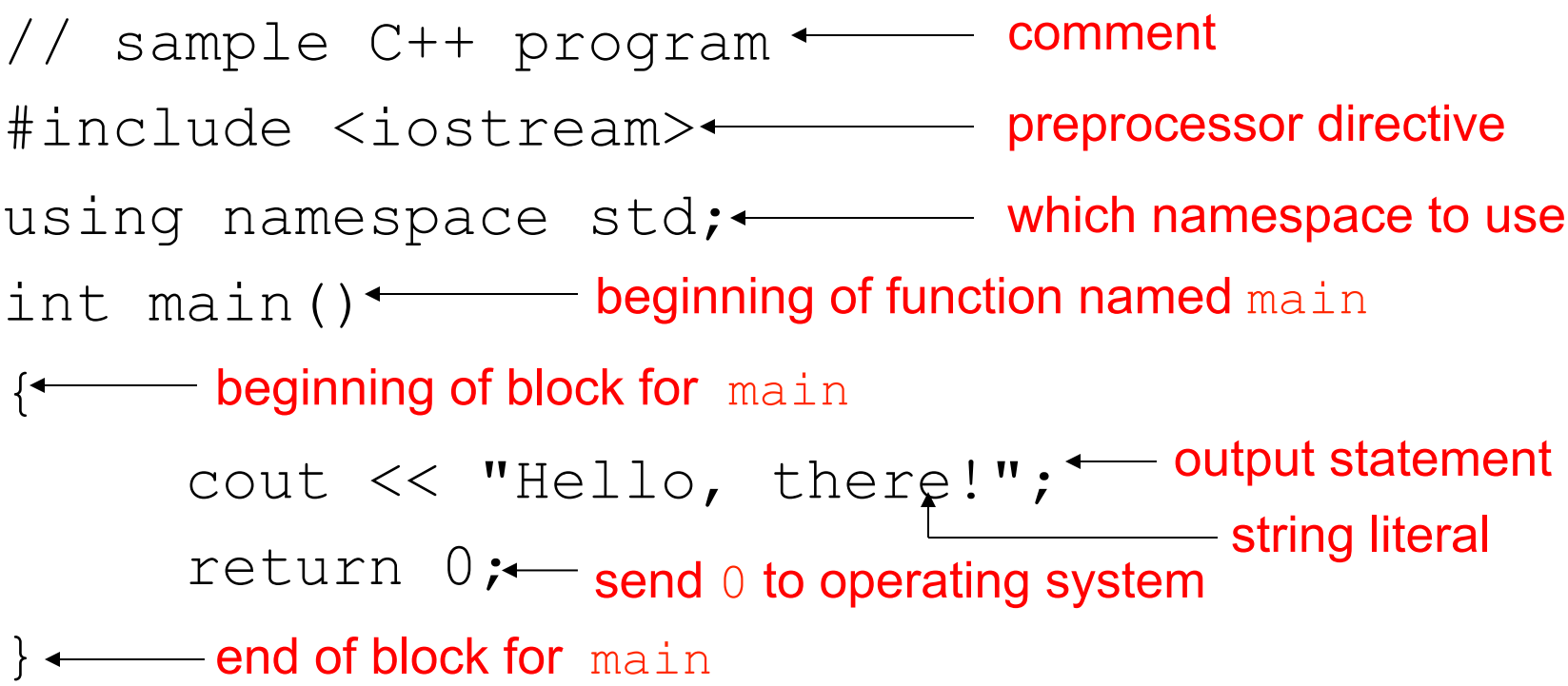
d) Run linker to connect hardware-specific code to machine instructions, producing an executable file.

- Steps b–d are often performed by a single command or button click.
- Errors detected at any step will prevent execution of following steps.

From a High-Level Program to an Executable File



The Parts of a C++ Program



Note: For Visual Studio and Visual C++ IDE, use cin.get() or system("PAUSE") to prevent console from disappearing!

Hello World Program

```
//*************************************
// This program prints Hello World!
//*************************************
#include <iostream>
using namespace std;
int main ()
{
  cout << "Hello World!";
  cin.get(); //system(“PAUSE”);
  return 0;
}
```

Special Characters

Character	Name	Meaning
//	Double slash	Beginning of a comment
#	Pound sign	Beginning of preprocessor directive
< >	Open/close brackets	Enclose filename in #include
( )	Open/close parentheses	Used when naming a function
{ }	Open/close brace	Encloses a group of statements
" "	Open/close quotation marks	Encloses string of characters
;	Semicolon	End of a programming statement

The `cout` Object

- Displays output on the computer screen
- You use the stream insertion operator `<<` to send output to `cout`:

```
cout << "Programming is fun!";
```

The `cout` Object

- Can be used to send more than one item to cout:

```
cout << "Hello " << "there!";
```

Or:

```
cout << "Hello ";
cout << "there!";
```

The `cout` Object

- This produces one line of output:

```
cout << "Programming is ";
cout << "fun!";
```

The `endl` Manipulator

- You can use the **`endl`** manipulator to start a new line of output. This will produce two lines of output:

```
cout << "Programming is" << endl;
cout << "fun!";
```

The `endl` Manipulator

```
cout << "Programming is" << endl;
cout << "fun!";
```

The `endl` Manipulator

- You do NOT put quotation marks around **`endl`**

- The last character in **`endl`** is a lowercase L, not the number 1.

`endl` ← This is a lowercase L

The \n Escape Sequence

- You can also use the **\n** escape sequence to start a new line of output. This will produce two lines of output:

```
cout << "Programming is\n";
cout << "fun!";
```

Notice that the \n is INSIDE the string.

The \n Escape Sequence

```
cout << "Programming is\n";
cout << "fun!";
```

The `cin` Object

- Standard input object
- Like `cout`, requires `iostream` file
- Used to read input from keyboard
- Information retrieved from `cin` with `>>`
- Input is stored in one or more variables

The `cin` Object

Program 3-1

```
1  // This program asks the user to enter the length and width of
2  // a rectangle. It calculates the rectangle's area and displays
3  // the value on the screen.
4  #include <iostream>
5  using namespace std;
6
7  int main()
8  {
9     int length, width, area;
10
11    cout << "This program calculates the area of a ";
12    cout << "rectangle.\n";
13    cout << "What is the length of the rectangle? ";
14    cin >> length;
15    cout << "What is the width of the rectangle? ";
16    cin >> width;
17    area = length * width;
18    cout << "The area of the rectangle is " << area << ".\n";
19    return 0;
20 }
```

Program Output with Example Input Shown in Bold

```
This program calculates the area of a rectangle.
What is the length of the rectangle? 10 [Enter]
What is the width of the rectangle? 20 [Enter]
The area of the rectangle is 200.
```

The `cin` Object

- **`cin`** converts data to the type that matches the variable:

```
int height;
cout << "How tall is the room? ";
cin >> height;
```

Displaying a Prompt

- A prompt is a message that instructs the user to enter data.
- You should always use **`cout`** to display a prompt before each **`cin`** statement.

```
cout << "How tall is the room? ";
cin >> height;
```

The `cin` Object

- Can be used to input more than one value:

```
cin >> height >> width;
```

- Multiple values from keyboard must be separated by spaces

- Order is important: first value entered goes to first variable, etc.

The `cin` Object Gathers Multiple Values

Program 3-2

```
1  // This program asks the user to enter the length and width of
2  // a rectangle. It calculates the rectangle's area and displays
3  // the value on the screen.
4  #include <iostream>
5  using namespace std;
6
7  int main()
8  {
9     int length, width, area;
10
11    cout << "This program calculates the area of a ";
12    cout << "rectangle.\n";
13    cout << "Enter the length and width of the rectangle ";
14    cout << "separated by a space.\n";
15    cin >> length >> width;
16    area = length * width;
17    cout << "The area of the rectangle is " << area << endl;
18    return 0;
19 }
```

Program Output with Example Input Shown in Bold

```
This program calculates the area of a rectangle.
Enter the length and width of the rectangle separated by a space.
10 20 [Enter]
The area of the rectangle is 200
```

The `cin` Object Reads Different Data Types

Program 3-3

```
1  // This program demonstrates how cin can read multiple values
2  // of different data types.
3  #include <iostream>
4  using namespace std;
5
6  int main()
7  {
8     int whole;
9     double fractional;
10    char letter;
11
12    cout << "Enter an integer, a double, and a character: ";
13    cin >> whole >> fractional >> letter;
14    cout << "Whole: " << whole << endl;
15    cout << "Fractional: " << fractional << endl;
16    cout << "Letter: " << letter << endl;
17    return 0;
18 }
```

Program Output with Example Input Shown in Bold

```
Enter an integer, a double, and a character: 4 5.7 b [Enter]
Whole: 4
Fractional: 5.7
Letter: b
```

The `#include` Directive

- Inserts the contents of another file into the program
- This is a preprocessor directive, not part of C++ language
- `#include` lines not seen by compiler
- Do not place a semicolon at end of `#include` line

Variable Definition

Program 2-7

```
1  // This program has a variable.
2  #include <iostream>
3  using namespace std;
4
5  int main()
6  {
7     int number;
8
9     number = 5;
10    cout << "The value in number is " << number << endl;
11    return 0;
12 }
```

Program Output

```
The value in number is 5
```

Named Constants

- Named constant (constant variable): variable whose content cannot be changed during program execution
- Used for representing constant values with descriptive names:

```
const double TAX_RATE = 0.0675;
const int NUM_STATES = 50;
```

- Often named in uppercase letters

Named Constants

Program 2-28

```
 1 // This program calculates the circumference of a circle.
 2 #include <iostream>
 3 using namespace std;
 4
 5 int main()
 6 {
 7    // Constants
 8    const double PI = 3.14159;
 9    const double DIAMETER = 10.0;
10
11    // Variable to hold the circumference
12    double circumference;
13
14    // Calculate the circumference.
15    circumference = PI * DIAMETER;
16
17    // Display the circumference.
18    cout << "The circumference is: " << circumference << endl;
19    return 0;
20 }
```

Program Output

```
The circumference is: 31.4159
```

Programming Style

- The visual organization of the source code
- Includes the use of spaces, tabs, and blank lines
- Does not affect the syntax of the program
- Affects the readability of the source code

Programming Style

Common elements to improve readability:

- Braces { } aligned vertically
- Indentation of statements within a set of braces
- Blank lines between declaration and other statements
- Long statements wrapped over multiple lines with aligned operators

Standard and Prestandard C++

Older-style C++ programs:

- Use `.h` at end of header files:
- `#include <iostream.h>`
- Use `#define` preprocessor directive instead of `const` definitions
- Do not use `using namespace` convention
- May not compile with a standard C++ compiler

#define directive

Program 2-31

```
1  // This program calculates the circumference of a circle.
2  #include <iostream>
3  using namespace std;
4
5  #define PI 3.14159
6  #define DIAMETER 10.0
7
8  int main()
9  {
10    // Variable to hold the circumference
11    double circumference;
12
13    // Calculate the circumference.
14    circumference = PI * DIAMETER;
15
16    // Display the circumference.
17    cout << "The circumference is: " << circumference << endl;
18    return 0;
19 }
```

Program Output

```
The circumference is: 31.4159
```

Binary Arithmetic Operators

SYMBOL	OPERATION	EXAMPLE	VALUE OF `ans`
+	addition	`ans = 7 + 3;`	10
–	subtraction	`ans = 7 - 3;`	4
*	multiplication	`ans = 7 * 3;`	21
/	division	`ans = 7 / 3;`	2
%	modulus	`ans = 7 % 3;`	1

A Closer Look at the / Operator

- / (division) operator performs integer division if both operands are integers

```
cout << 13 / 5;     // displays 2
cout << 91 / 7;     // displays 13
```

- If either operand is floating point, the result is floating point

```
cout << 13 / 5.0;   // displays 2.6
cout << 91.0 / 7;   // displays 13.0
```

A Closer Look at the % Operator

- % (modulus) operator computes the remainder resulting from integer division

```
cout << 13 % 5;    // displays 3
```

- % requires integers for both operands

```
cout << 13 % 5.0; // error
```

Mathematical Expressions

- Can create complex expressions using multiple mathematical operators
- An expression can be a literal, a variable, or a mathematical combination of constants and variables
- Can be used in assignment, `cout`, other statements:

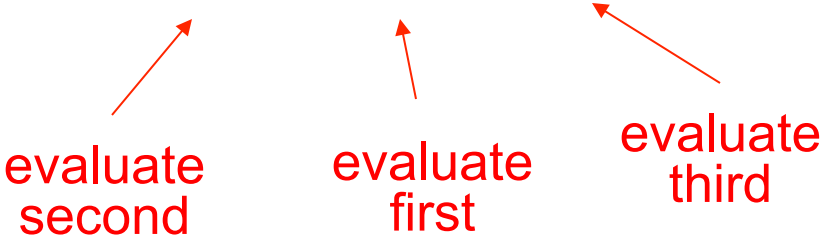
```
area = 2 * PI * radius;
cout << "border is: " << 2*(l+w);
```

Order of Operations

In an expression with more than one operator, evaluate in this order:

- `-` (unary negation), in order, left to right
- `*` `/` `%`, in order, left to right
- `+` `-`, in order, left to right

In the expression `2 + 2 * 2 - 2`



Order of Operations

Table 3-2 Some Simple Expressions and Their Values

Expression	Value
`5 + 2 * 4`	13
`10 / 2 - 3`	2
`8 + 12 * 2 - 4`	28
`4 + 17 % 2 - 1`	4
`6 - 3 * 2 + 7 - 1`	6

Associativity of Operators

- `-` (unary negation) associates right to left
- `*, /, %, +, -` associate right to left
- parentheses ( ) can be used to override the order of operations:

```
 2 + 2  *  2 - 2  = 4
(2 + 2) *  2 - 2  = 6
 2 + 2  * (2 - 2) = 2
(2 + 2) * (2 - 2) = 0
```

Grouping with Parentheses

Table 3-4 More Simple Expressions and Their Values

Expression	Value
`(5 + 2) * 4`	28
`10 / (5 - 3)`	5
`8 + 12 * (6 - 2)`	56
`(4 + 17) % 2 - 1`	0
`(6 - 3) * (2 + 7) / 3`	9

Type Casting

- Used for manual data type conversion
- Useful for floating point division using ints:

```
double m;
m = static_cast<double>(y2-y1)
                        /(x2-x1);
```

- Useful to see `int` value of a `char` variable:

```
char ch = 'C';
cout << ch << " is "
     << static_cast<int>(ch);
```

Type Casting

Program 3-9

```
1  // This program uses a type cast to avoid integer division.
2  #include <iostream>
3  using namespace std;
4
5  int main()
6  {
7     int books;         // Number of books to read
8     int months;        // Number of months spent reading
9     double perMonth;   // Average number of books per month
10
11    cout << "How many books do you plan to read? ";
12    cin >> books;
13    cout << "How many months will it take you to read them? ";
14    cin >> months;
15    perMonth = static_cast<double>(books) / months;
16    cout << "That is " << perMonth << " books per month.\n";
17    return 0;
18 }
```

Program Output with Example Input Shown in Bold

```
How many books do you plan to read? 30 [Enter]
How many months will it take you to read them? 7 [Enter]
That is 4.28571 books per month.
```

C-Style and Prestandard Type Cast Expressions

- C-Style cast: data type name in `()`

```
cout << ch << " is " << (int)ch;
```

- Prestandard C++ cast: value in `()`

```
cout << ch << " is " << int(ch);
```

- Both are still supported in C++, although `static_cast` is preferred

Multiple Assignment and Combined Assignment

- The = can be used to assign a value to multiple variables:

```
x = y = z = 5;
```

- Value of = is the value that is assigned
- Associates right to left:

```
x = (y = (z = 5));
```

value is 5

value is 5

value is 5

Combined Assignment

- The combined assignment operators provide a shorthand for these types of statements.
- The statement

```
sum = sum + 1;
```

is equivalent to

```
sum += 1;
```

Combined Assignment Operators

Table 3-9

Operator	Example Usage	Equivalent to
`+=`	`x += 5;`	`x = x + 5;`
`-=`	`y -= 2;`	`y = y - 2;`
`*=`	`z *= 10;`	`z = z * 10;`
`/=`	`a /= b;`	`a = a / b;`
`%=`	`c %= 3;`	`c = c % 3;`

Formatting Output

- Can control how output displays for numeric, string data:
  - size
  - position
  - number of digits
- Requires `iomanip` header file

Stream Manipulators

- Used to control how an output field is displayed
- Some affect just the next value displayed:
  - `setw(x)`: print in a field at least `x` spaces wide. Use more spaces if field is not wide enough

The `setw` Stream Manipulator

Program 3-13

```
1  // This program displays three rows of numbers.
2  #include <iostream>
3  #include <iomanip>      // Required for setw
4  using namespace std;
5
6  int main()
7  {
8     int num1 = 2897, num2 = 5,    num3 = 837,
9         num4 = 34,   num5 = 7,    num6 = 1623,
10        num7 = 390,  num8 = 3456, num9 = 12;
11
12    // Display the first row of numbers
13    cout << setw(6) << num1 << setw(6)
14         << num2 << setw(6) << num3 << endl;
15
16    // Display the second row of numbers
17    cout << setw(6) << num4 << setw(6)
18         << num5 << setw(6) << num6 << endl;
19
20    // Display the third row of numbers
21    cout << setw(6) << num7 << setw(6)
22         << num8 << setw(6) << num9 << endl;
23    return 0;
24 }
```

Continued…

The `setw` Stream Manipulator

Program Output

```
 2897     5   837
   34     7  1623
  390  3456    12
```

Stream Manipulators

- Some affect values until changed again:
  - `fixed`: use decimal notation for floating-point values
  - `setprecision(x)`: when used with `fixed`, print floating-point value using `x` digits after the decimal. Without `fixed`, print floating-point value using x significant digits
  - `showpoint`: always print decimal for floating-point values

More Stream Manipulators

Program 3-17

```
1  // This program asks for sales figures for 3 days. The total
2  // sales are calculated and displayed in a table.
3  #include <iostream>
4  #include <iomanip>
5  using namespace std;
6
7  int main()
8  {
9     double day1, day2, day3, total;
10
11    // Get the sales for each day.
12    cout << "Enter the sales for day 1: ";
13    cin >> day1;
14    cout << "Enter the sales for day 2: ";
15    cin >> day2;
16    cout << "Enter the sales for day 3: ";
17    cin >> day3;
18
19    // Calculate the total sales.
20    total = day1 + day2 + day3;
```

Continued…

More Stream Manipulators

```
21
22      // Display the sales figures.
23      cout << "\nSales Figures\n";
24      cout << "-------------\n";
25      cout << setprecision(2) << fixed;
26      cout << "Day 1: " << setw(8) << day1 << endl;
27      cout << "Day 2: " << setw(8) << day2 << endl;
28      cout << "Day 3: " << setw(8) << day3 << endl;
29      cout << "Total: " << setw(8) << total << endl;
30      return 0;
31  }
```

Program Output with Example Input Shown in Bold

```
Enter the sales for day 1:  1321.87 [Enter]
Enter the sales for day 2:  1869.26 [Enter]
Enter the sales for day 3:  1403.77 [Enter]

Sales Figures
-------------
Day 1:    1321.87
Day 2:    1869.26
Day 3:    1403.77
Total:    4594.90
```

Stream Manipulators

Table 3-12

Stream Manipulator	Description
`setw(n)`	Establishes a print field of *n* spaces.
`fixed`	Displays floating-point numbers in fixed point notation.
`showpoint`	Causes a decimal point and trailing zeroes to be displayed, even if there is no fractional part.
`setprecision(n)`	Sets the precision of floating-point numbers.
`left`	Causes subsequent output to be left justified.
`right`	Causes subsequent output to be right justified.