Object-Oriented Programming

Lecture 2: C++ Structure

Programming Paradigms

When to choose C++

“If you’re not at all interested in performance, shouldn’t you be in the Python room down the hall?”
— Scott Meyers (author of Effective Modern C++)

- Despite its many competitors C++ has remained popular for ~30 years and will continue to be so in the foreseeable future.
- Why?
  - Complex problems and programs can be effectively implemented
  - OOP works in the real world!
  - No other language quite matches C++’s combination of performance, expressiveness, and ability to handle complex programs.

- Choose C++ when:
  - Program performance matters
    - Dealing with large amounts of data, multiple CPUs, complex algorithms, etc.
  - Programmer productivity is less important
    - It is faster to produce working code in Python, R, Matlab or other scripting languages!
  - The programming language itself can help organize your code
    - Not everything is a vector or matrix, right Matlab?
  - Access to libraries that will help with your problem
    - Ex. Nvidia’s CUDA Thrust library for GPUs
  - Your group uses it already!

Programming Paradigms

Programming languages are classified in many ways based on their features:

- **Imperative**
  - **Structured/Procedural**
  - **Object-Oriented**
- **Declarative**
  - **Functional**
  - **Logic**

Procedural Programming

In **procedural programming**, programs are mainly composed of three basic control structures:

- **Sequence** statements (execution in order)
- **Selection** statements (branching, if-else/switch)
- **Iteration** statements (looping, for/while)

After the source code get transformed to machine code, all program structures are reduced to simple and jumping/branching instructions.

Blocks and Subroutines

In addition to the basic control structures:

- **Blocks** are used to enable groups of statements to be treated as if they were one statement
- **Subroutines** (procedures, functions, methods, or subprograms) are used to allow a sequence to be referred to by a single statement

Object-Oriented Programming

- In object-oriented programming, programs are mainly composed of interrelated objects:
- An object is a computational entity which has both state and behavior Objects are self-contained by bundling data and operations together, this notion is called encapsulation By encapsulation, an object is mainly used by sending it a message via its methods (or member functions) Objects are often used for modeling things found in the real world

Objects

- An **object** can be created, stored and manipulated, **without** knowing its internal structure
- In C++, an object is created from a **class** and is an ***instance*** of a class
- A **class** is a user-defined type which is used as a blueprint for creating objects
- A **class** in C++ can be designed in a way that it behaves **"just like a built-in type"**

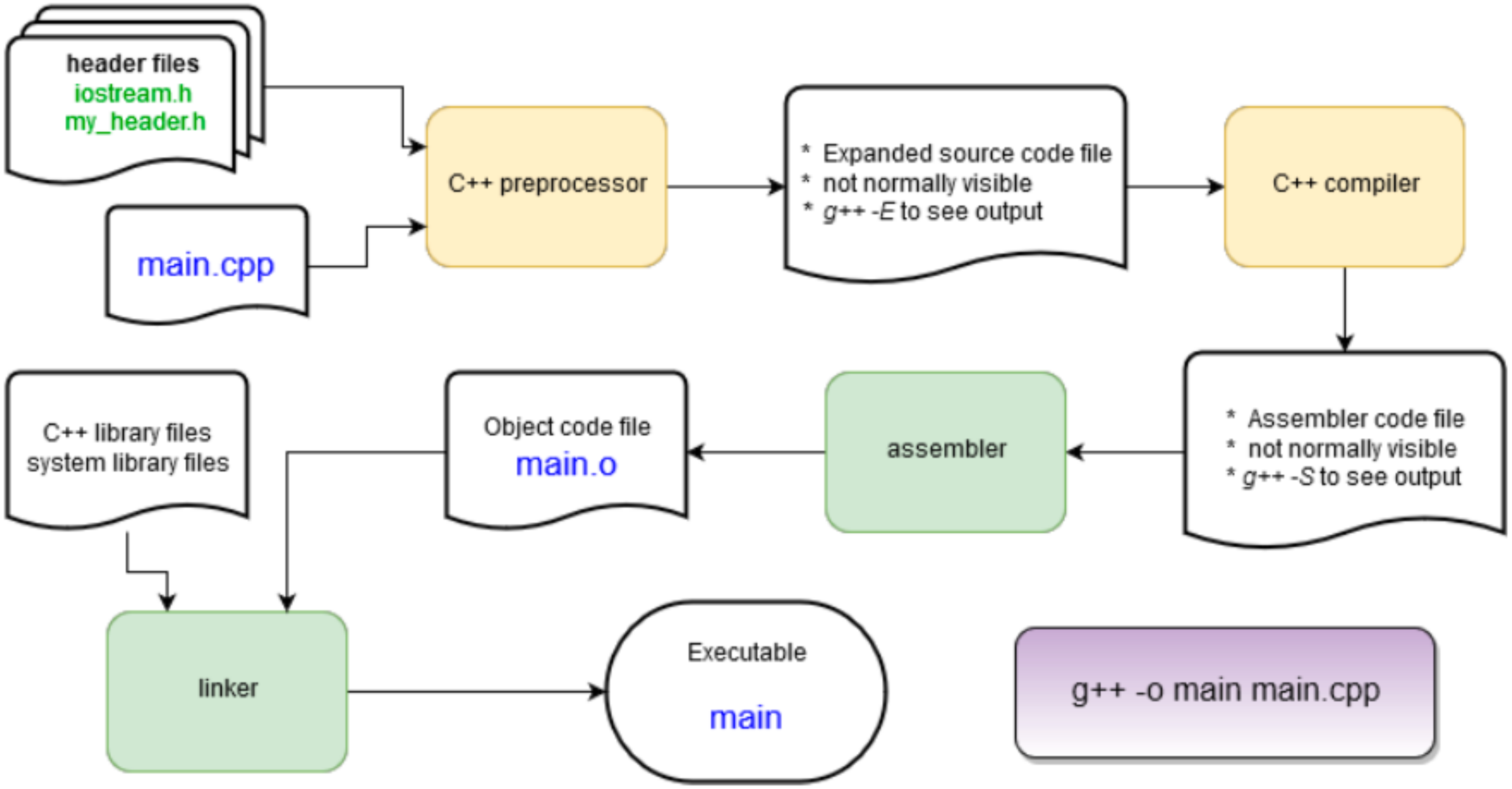
A **variable** (of a built-in type) can be considered an object. We sometimes used the term **"object"** to refer to a variable.

Extending Classes

In OOP, a **class** can be defined and extended in many ways:

- By **inheritance**, a class can be defined as an extension of existing classes, forming a class hierarchy
- By overriding existing methods of existing classes, **polymorphism** can be achieved and objects from related types can be used in the same way with varying behavior

Encapsulation, **inheritance**, and **polymorphism** are major concepts in OOP. We will explore more on these topics later.


header files
iostream.h
my_header.h
main.cpp
C++ preprocessor
* Expanded source code file
* not normally visible
* *g++ -E* to see output
C++ compiler
* Assembler code file
* not normally visible
* *g++ -S* to see output
assembler
Object code file
main.o
C++ library files
system library files
linker
Executable
main
g++ -o main main.cpp

Working with Objects

Example: Interacting withStrings

```
  // 1. What are you expecting the program to do?
  // 2. What's wrong with the code?
  // 3. Does it compile?
  // 4. Does it work as expected?
  // 5. If not, what would you do to correct the
  program?

#include <iostream>

int main()
{
    std::cout << "Please enter P1 name: ";
    std::string p1_name;
    std::cin >> p1_name;
    std::cout << "Player 1: " << p1_name << std::endl;

    std::cout << "Please enter P2 name: ";
    std::string p2_name;
    std::cin >> p2_name;
    std::cout << "Player 2: " << p2_name << std::endl;
    return 0;
}
```

Slight change

- Let’s put the message into some variables of type *string* and print some numbers.
- Things to note:
  - Strings can be concatenated with a + operator.
  - No messing with null terminators as in C
- Some string notes:
  - Access a string character by brackets or function:
    - msg[0] -> “H” or msg.at(0) -> “H”
    - C++ strings are *mutable* – they can be changed in place.

```
#include <iostream>

using namespace std;

int main()
{
    string hello = "Hello";
    string world = "world!";
    string msg = hello + " " + world ;
    cout <<  msg << endl;
    msg[0] = 'h';
    cout <<  msg << endl;
    return 0;
}
```

Blocks and Scope of Variables

A block defines an extent to which an inner object/variable exists:

```cpp
#include <iostream>

int main()
{
    {
        std::cout << "Please enter P1 name: ";
        std::string p1_name;
        std::cin >> p1_name;

        std::cout << "Please enter P2 name: ";
        std::string p2_name;
        std::cin >> p2_name;
    }

    // `p1_name` and `p2_name` doesn't exist here!
    std::cout << "Player 1: " << p1_name << std::endl;
    std::cout << "Player 2: " << p2_name << std::endl;
    return 0;
}
```

Objects vs Variables

In some language (e.g. Rust), a primitive variable can be used like an object.

```rust
println!("{}", (-10_i32).abs());
```

In C++, some object can be used like a variable.

```cpp
std::complex<double> a = 2;
std::complex<double> b = 3i;
a += b; // `a` becomes `2 + 3i`
```

“auto” Keyword

- allows the compiler to automatically deduce the type of a variable from its initializer. When used in the context of object creation, auto can simplify the syntax and make the code more readable, especially when dealing with complex types.

Object Creation

In C++, an object/variable is created at the point of its **definition**.

```
auto spaces = string(5, ' ');
auto ext = string{'t', 'x', 't'};
```

More examples:
(with **`auto`**)

```
string s1;   // default init.
string s2{}; // value init.
auto t1 = s1; // copy init.
auto t2 = "Hello"s; // also copy

string stars(5, '*');          // direct init.
auto dashes = string(5, '-'); // ?

  // list initialization
string bom{'\xEF', '\xBB', '\xBF'};
```

References: https://en.cppreference.com/w/cpp/language/initialization

C++ Pragramming Environments

Basic Syntax

- C++ syntax is very similar to C, Java, or C#. Here's a few things up front and we'll cover more as we go along.
- Curly braces are used to denote a code block:

```
{ … some code … }
```

- Statements end with a semicolon:

```
int a ;
a = 1 + 3 ;
```

- Comments are marked for a single line with a **//** or for multilines with a pair of **/*** and ***/** :

```
// this is a comment.
/* everything in here
         is a comment */
```

- Variables can be declared at any time in a code block.

```
void my_function() {
   int a ;
   a=1 ;
   int b;
}
```

- Functions are sections of code that are called from other code. Functions always have a return argument type, a function name, and then a list of arguments:

```
int my_function(int x) {
    return x ;
}
```

```
// No arguments? Still need ()
void my_function() {
        /* do something...
           but a void value means the
           return statement can be skipped.*/
}
```

- Variables are declared with a type and a name:

```
// Usually enter the type
int x = 100;
float y;
vector<string> vec ;
// Sometimes it can be inferred
auto z = x;
```

- A sampling of Operators:
  - Arithmetic: + - * / % ++ --
  - Logical: && (AND) ||(OR) !(NOT)
  - Comparison: == > < >= <= !=

Built-in (aka primitive or intrinsic) Types

- “primitive” or “intrinsic” means these types are not objects
- Here are the most commonly used types.
- Note: The exact bit ranges here are **platform and compiler dependent**!
  - Typical usage with PCs, Macs, Linux, etc. use these values
  - Variations from this table are found in specialized applications like embedded system processors.

Name	Name	Value
char	unsigned char	8-bit integer
short	unsigned short	16-bit integer
int	unsigned int	32-bit integer
long	unsigned long	64-bit integer
bool		true or false

Name	Value
float	32-bit floating point
double	64-bit floating point
long long	128-bit integer
long double	128-bit floating point

http://www.cplusplus.com/doc/tutorial/variables/

Need to be sure of integer sizes?

- In the same spirit as using *integer(kind=8)* type notation in Fortran, there are type definitions that exactly specify exactly the bits used. These were added in C++11.
- These can be useful if you are planning to port code across CPU architectures (ex. Intel 64-bit CPUs to a 32-bit ARM on an embedded board) or when doing particular types of integer math.
- For a full list and description see: http://www.cplusplus.com/reference/cstdint/

#include <cstdint>

Name	Name	Value
int8_t	uint8_t	8-bit integer
int16_t	uint16_t	16-bit integer
int32_t	uint32_t	32-bit integer
int64_t	uint64_t	64-bit integer

Type Casting

- C++ is strongly typed. It will auto-convert a variable of one type to another in a limited fashion: if it will not change the value.

```
short x = 1 ;
int y = x ;    // OK
short z = y ; // NO!
```

- Conversions that don't change value: increasing precision (float double) or integer floating point of at least the same precision.
- C++ allows for C-style type casting with the syntax: (new type) expression

```
double x = 1.0 ;
int y = (int) x ;
float z = (float) (x / y) ;
```

- In addition to this C++ offers 4 different variations in a C++ style.

Type Casting

- `static_cast<new type>( expression )`
  - This is exactly equivalent to the C style cast.
  - This identifies a cast at compile time and the compiler inserts the CPU type conversion instructions for primitive types.
  - Can do casting that reduces precision (ex. double ⍰ float)
- `dynamic_cast<new type>( expression)`
  - Special version where type casting is performed at runtime, only works on reference or pointer type variables.
- `const_cast<new type>( expression )`
  - Variables labeled as *const* can't have their value changed.
  - const_cast lets the programmer remove or add *const* to reference or pointer type variables.
- `reinterpret_cast<new type>( expression )`
  - Takes the bits in the expression and re-uses them **unconverted** as a new type. Also only works on reference or pointer type variables.

"unsafe": the compiler will not protect you here.

Functions

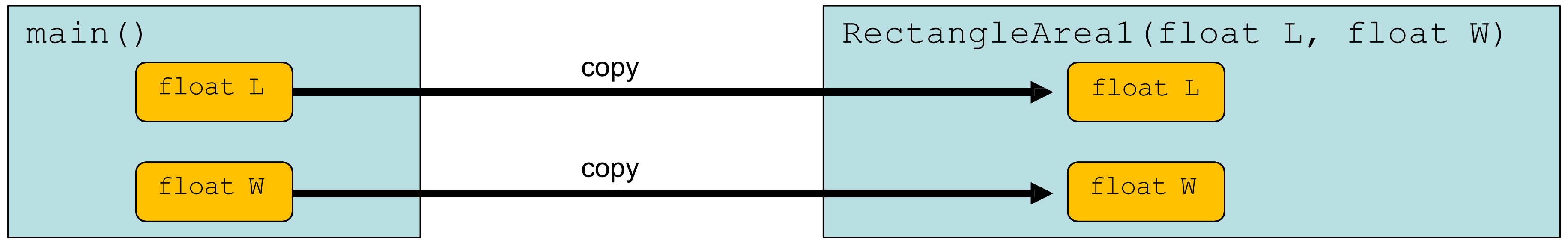
The return type is *float*.

The function arguments L and W are sent as type *float*.

Product is computed

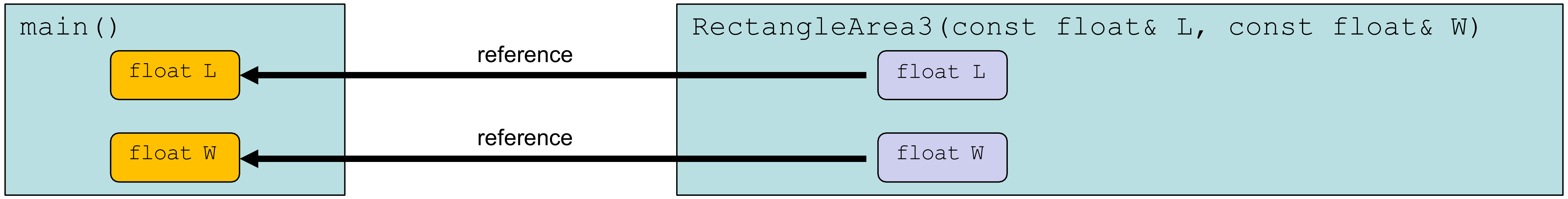
```
float RectangleArea1(float L, float W) {
    return L*W ;
}


float RectangleArea2(const float L, const float W) {
    // L=2.0 ;
    return L*W ;
}


float RectangleArea3(const float& L, const float& W) {
    return L*W ;
}


void RectangleArea4(const float& L, const float& W, float& area) {
    area= L*W ;
}
```

Pass by Value



- C++ defaults to *pass by value* behavior when calling a function.
- The function arguments are **copied** when used in the function.
- Changing the value of L or W in the RectangleArea1 function does **not** effect their original values in the main() function
- When passing objects as function arguments it is important to be aware that potentially large data structures are automatically copied!

Pass by Reference



- *Pass by reference* behavior is triggered when the & character is used to modify the type of the argument.
- Pass by reference function arguments are **NOT** copied. Instead the compiler sends a *pointer* to the function that references the memory location of the original variable. The syntax of using the argument in the function does not change.
- Pass by reference arguments almost always act just like a pass by value argument when writing code **EXCEPT** that changing their value changes the value of the original variable!!
- The *const* modifier can be used to prevent changes to the original variable in main().

void does not return a value.

```
void RectangleArea4(const float& L, const float& W, float& area) {
    area= L*W ;
}
```

- In RectangleArea4 the pass by reference behavior is used as a way to return the result without the function returning a value.
- The value of the *area* argument is modified in the main() routine by the function.
- This can be a useful way for a function to return multiple values in the calling routine.

- In C++ arguments to functions can be objects…which can contain any quantity of data you've defined!
  - Example: Consider a string variable containing 1 million characters (approx. 1 MB of RAM).
    - Pass by value requires a copy – 1 MB.
    - Pass by reference requires 8 bytes!
- Pass by value could potentially mean the accidental copying of large amounts of memory which can greatly impact program memory usage and performance.
- When passing by reference, use the *const* modifier whenever appropriate to protect yourself from coding errors.
  - Generally speaking – use *const* anytime you don't want to modify function arguments in a function.

"C makes it easy to shoot yourself in the foot; C++ makes it harder, but when you do it blows your whole leg off." – Bjarne Stroustrop

A first C++ class

- In the main.cpp, we'll define a class called BasicRectangle
- First, just the basics: length and width
- Enter the code on the right before the main() function in the main.cpp file (copy & paste is fine) and create a BasicRectangle object in main.cpp:

```
#include <iostream>

using namespace std;

class BasicRectangle
{
public:
    // width ;
    float W ;
    // length
    float L ;
};

int main()
{
    cout << "Hello world!" << endl;

    BasicRectangle rectangle ;
    rectangle.W = 1.0 ;
    rectangle.L = 2.0 ;

    return 0;
}
```

Basic C++ Class Syntax

class keyword

Name of class

Curly braces at the beginning and end followed by a semi-colon

public keyword indicates everything following the keyword is accessible by any other code outside of this class.

```
class BasicRectangle
{
public:
     // width ;
     float W ;
     // length
     float L ;
};
```

Internal variables are called *members*

The class can now be used to declare an object named *rectangle*. The width and length of the rectangle can be set.

```
BasicRectangle rectangle ;
rectangle.W = 1.0 ;
rectangle.L = 2.0 ;
```

Accessing data in the class

- Public members in an object can be accessed (for reading or writing) with the syntax:

  object.member

```
int main()
{
    cout << "Hello world!" << endl;

    BasicRectangle rectangle ;
    rectangle.W = 1.0 ;
    rectangle.L = 2.0 ;

    return 0;
}
```

- Next let's add a function inside the object (called a *method*) to calculate the area.

method Area does not take any arguments, it just returns the calculation based on the object members.

Methods are accessed just like members:

object.method(arguments)

```
class BasicRectangle
{
public:
    // width ;
    float W ;
    // length
    float L ;
    float Area() {
        return W * L ;
    }

};

int main()
{
    cout << "Hello world!" << endl;

    BasicRectangle rectangle ;
    rectangle.W = 21.0 ;
    rectangle.L = 2.0 ;

    cout << rectangle.Area() << endl ;

    return 0;
}
```

Basic C++ Class Summary

- C++ classes are defined with the keyword *class* and must be enclosed in a pair of curly braces **plus a semi-colon**:

  class ClassName { …. } **;**
- The *public* keyword is used to mark members (variables) and methods (functions) as accessible to code outside the class.
- The combination of data and the functions that operate on it is the OOP concept of *encapsulation.*

Encapsulation in Action

- In C – calculate the area of a few shapes…

```
/* assume radius and width_square are assigned
   already ; */
float a1 = AreaOfCircle(radius) ;   // ok
float a2 = AreaOfSquare(width_square) ; // ok
float a3 = AreaOfCircle(width_square) ; // !! OOPS
```

- In C++ with Circle and Rectangle classes…not possible to miscalculate.
  - Well, provided the respective Area() methods are implemented correctly!

```
Circle c1 ;
Rectangle r1 ;
// ... assign radius and width ...
float a1 = c1.Area() ;
float a2 = r1.Area() ;
```

Now for a “real” class

- Defining a class in the main.cpp file is not typical.
- Two parts to a C++ class:
  - Header file (my_class.h)
    - Contains the interface (definition) of the class – members, methods, etc.
    - The interface is used by the compiler for type checking, enforcing access to private or protected data, and so on.
    - Also useful for programmers when *using* a class – no need to read the source code, just rely on the interface.
  - Source file (my_class.cc)
    - Compiled by the compiler.
    - Contains implementation of methods, initialization of members.
  - In some circumstances there is no source file to go with a header file.

rectangle.h

```
#ifndef RECTANGLE_H
#define RECTANGLE_H


class Rectangle
{
    public:
        Rectangle();
        virtual ~Rectangle();

    protected:

    private:
};

#endif // RECTANGLE_H
```

rectangle.cpp

```
#include "rectangle.h"

Rectangle::Rectangle()
{
    //ctor
}

Rectangle::~Rectangle()
{
    //dtor
}
```

- 2 files are automatically generated: rectangle.h and rectangle.h.cpp

Modify rectangle.h

- As in the sample *BasicRectangle*, add storage for the length and width to the header file. Add a *declaration* for the Area method.

- The *protected* keyword will be discussed later.
- The *private* keyword declares anything following it (members, methods) to be visible only to code **in this class**.

```
#ifndef RECTANGLE_H
#define RECTANGLE_H


class Rectangle
{
    public:
        Rectangle();
        virtual ~Rectangle();

        float m_length ;
        float m_width ;

        float Area() ;
    protected:

    private:
};
#endif // RECTANGLE_H
```

rectangle.cpp

- The Area() method now has a basic definition added.
- The syntax:

  class::method

tells the compiler that this is the code for the Area() method declared in rectangle.h

- Now take a few minutes to fill in the code for Area().
  - Hint – look at the code used in BasicRectangle...

```
#include "rectangle.h"

Rectangle::Rectangle()
{
    //ctor
}

Rectangle::~Rectangle()
{
    //dtor
}

float Rectangle::Area()
{

}
```

Program ExitCode

```cpp
  // success.cpp
int main()
{
    return 0;
}
```

```cpp
  // failed.cpp
int main()
{
    return 1;
}
```

Example Session

```
$ g++ -o success -Wall -Wextra success.cpp
$ ./success
$ echo $?
0
$ g++ -o failed -Wall -Wextra failed.cpp
$ ./failed
$ echo $?
1
```

Tips: For Windows, checkfor **ERRORLEVEL**.

Improving the FrameProgram

Overall structure (starting from previous version):

```cpp
#include <iostream>
#include <string>

int main()
{
    // ask for a person's name
    std::cout << "Please enter your first name: ";

    // read the name
    std::string name;
    std::cin >> name;

    // build the message that we intend to write
    const std::string greeting = "Hello, " + name + "!";

    // we have to rewrite this part ...

    return 0;
}
```

Compute the Number of Rows

```
  // the number of blanks
  // surrounding the greeting
const int pad = 1;

  // the number of rows and columns to write
const int rows = pad * 2 + 3;
```

```
  // constexpr is also `const`
constexpr int pad = 2;
constexpr int rows = pad * 2 + 3;
```

```
*****   | top border
*   *->| top pad
* x *
*   *--->| bottom pad
*****    | bottom border

Rows = (1 * 2) + 3 = 5
```

```
*******
*     *->| top pad
*     *  |
* xxx *
*     *--->|
*     *    | bottom pad
*******

Rows = (2 * 2) + 3 = 7
```

The `while` Statement

Print rows of output

```
constexpr int pad = 1;
constexpr int rows = pad * 2 + 3;

// separate the output from the input
cout << endl;

// write `rows' rows of output
int r = 0;

// invariant: we have written `r' rows so far
while (r != rows) {
    // write a row of output
    std::cout << std::endl;
    ++r;
}
```

```
while (condition)
    statement
```

```
while (condition) statement
```

See "Accelerated C++, section 2.3" for a reference

The `if` Statement

Print a row

```
// invariant: we have written `c' characters
//              so far in the current row
while (c != cols) {
    // is it time to write the greeting?
    if (r == pad + 1 && c == pad + 1) {
        cout << greeting;
        c += greeting.size();
    }
    else {
        // are we on the border?
        if (r == 0 || r == rows - 1 ||
            c == 0 || c == cols - 1)
            cout << "*";
        else
            cout << " ";
        ++c;
    }
}
```

```
if (condition)
    statement
```

```
if (condition)
    statement1
else
    statement2
```

The `for` Statement

```
for (init-statement condition; expression)
    statement
```

```
{
    init-statement
    while (condition) {
        statement
        expression;
    }
}
```

```
  // `r' takes on the values in [0, rows)
for (int r = 0; r != rows; ++r) {
    // stuff that doesn't change
    // the value of `r'
}
```

```
{
    int r = 0;
    while (r != rows) {
        // ...
        ++r;
    }
}
```

`for` statements is used as a shorthand way of writing a loop

The Complete Framing Program (1)

```cpp
#include <iostream>
#include <string>

  // say what standard-library names we
  use
using std::cin;           using std::endl;
using std::cout;          using std::string;

int main()
{
    // ask for the person's name
    cout << "Please enter your first name: ";

    // read the name
    string name;
    cin >> name;

    // build the message that we intend to write
    const string greeting = "Hello, " + name + "!";

    // the number of blanks surrounding the greeting
    constexpr int pad = 1;

    // the number of rows and columns to write
    constexpr int rows = pad * 2 + 3;
    const string::size_type cols = greeting.size() + pad * 2 +
    2;

    // write a blank line to separate the output from the input
    cout << endl;

    // ...
```

The Complete Framing Program (2)

```
    // ...

    // write `rows' rows of output
    // invariant: we have written `r' rows so far
    for (int r = 0; r != rows; ++r) {
        string::size_type c = 0;

        // invariant: we have written `c'
        characters
        //             so far in the current row
        while (c != cols) {
            // is it time to write the greeting?
            if (r == pad + 1 && c == pad + 1) {
                cout << greeting;
                c += greeting.size();
            }
            else {
                // are we on the border?
                if (r == 0 || r == rows - 1 ||
                    c == 0 || c == cols - 1)
                    cout << "*";
                else
                    cout << " ";
                ++c;
            }
        }

        cout << endl;
    }
    return 0;
}
```

Loop Counter

r takes on the values in **[0, rows)**

```
for (int r = 0; r != rows; ++r) {
    // write a row
}
```

r takes on the values in **[1, rows]**

```
for (int r = 1; r <= rows; ++r) {
    // write a row
}
```

The number of iterations is the same in both cases.

Tips: In C++, we often **prefer** to count from **0** and use the half-open range **[0, n)** to control the loop. We also **prefer** **++r** over **r++** whenever we have a choice.

Computing StudentGrades (1)

```
#include <iomanip>
#include <ios>
#include <iostream>
#include <string>

using std::cin;                     using std::setprecision;
using std::cout;                    using std::string;
using std::endl;                    using std::streamsize;

int main()
{
    // ask for and read the student's name
    cout << "Please enter your first name: ";
    string name;
    cin >> name;
    cout << "Hello, " << name << "!" << endl;

    // ask for and read the midterm and final grades
    cout << "Please enter your midterm and final exam grades:
    ";  double midterm, final;
    cin >> midterm >> final;

    // ask for the homework grades
    cout << "Enter all your homework grades, "
            "followed by end-of-file: ";

    // ...
```

Computing StudentGrades (2)

```
    // ...

    // the number and sum of grades read so far
    int count = 0;
    double sum = 0;

    // a variable into which to read
    double x;

    // invariant:
    //     we have read `count' grades so far, and
    //     `sum' is the sum of the first `count' grades
    while (cin >> x) {
        ++count;
        sum += x;
    }

    // write the result
    streamsize prec = cout.precision();
    cout << "Your final grade is " << setprecision(3)
         << 0.2 * midterm + 0.4 * final + 0.4 * sum /
         count
         << setprecision(prec) << endl;
    return 0;
}
```

Using Medians to Compute Grades (1)

```
#include <algorithm>
#include <iomanip>
#include <ios>
#include <iostream>
#include <string>
#include <vector>

using std::cin;              using std::sort;
using std::cout;             using std::streamsize;
using std::endl;             using std::string;
using std::setprecision;     using std::vector;

int main()
{
    // ask for and read the student's name
    cout << "Please enter your first name:
    ";  string name;
    cin >> name;
    cout << "Hello, " << name << "!" << endl;

    // ask for and read the midterm and final grades
    cout << "Please enter your midterm and final exam grades:
    ";  double midterm, final;
    cin >> midterm >> final;

    // ask for and read the homework grades
    cout << "Enter all your homework grades,
            "  "followed by end-of-file: ";

    // ...
```

Using Medians to Compute Grades (2)

```
    // ...

    vector<double> homework;
    double x;
    // invariant: `homework' contains all the homework grades read so
    far
    while (cin >> x)
        homework.push_back(x)
        ;

    // check that the student entered some homework grades
    typedef vector<double>::size_type vec_sz;
    vec_sz size = homework.size();
    if (size == 0) {
        cout << endl << "You must enter your grades.  "
                        "Please try again." << endl;
        return 1;
    }

    // sort the grades
    sort(homework.begin(), homework.end());

    // compute the median homework grade
    auto mid = size / 2;
    double median;
    median = size % 2 == 0 ? (homework[mid] + homework[mid-1]) / 2
                           : homework[mid];

    // compute and write the final grade
    auto prec = cout.precision();
    cout << "Your final grade is " << setprecision(3)
         << 0.2 * midterm + 0.4 * final + 0.4 * median
         << setprecision(prec) << endl;
    return 0;
}
```

Q & A