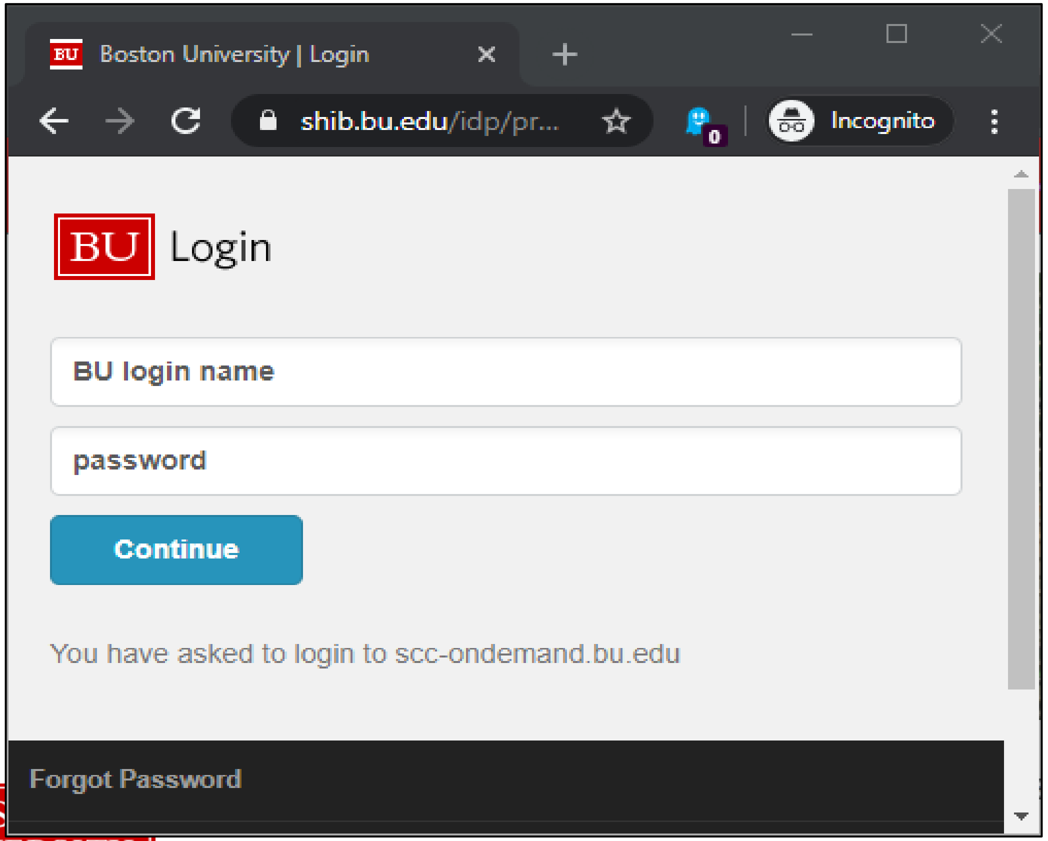
Introduction to C++: Part 3

Tutorial Outline: Part 3

- Defining Classes
- Class inheritance
- Public, private, and protected access
- Virtual functions

Existing SCC Account

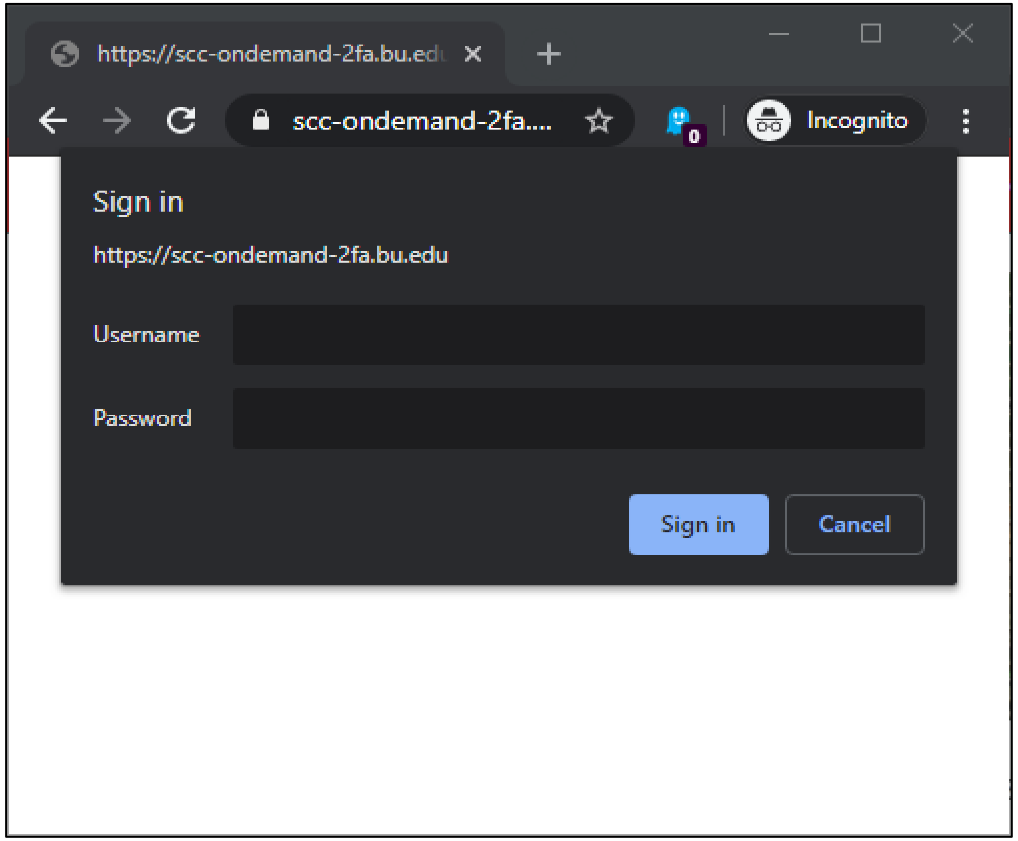
1. Open a web browser
2. Navigate to http://scc-ondemand.bu.edu
3. Log in with your BU Kerberos Credentials



You have asked to login to scc-ondemand.bu.edu

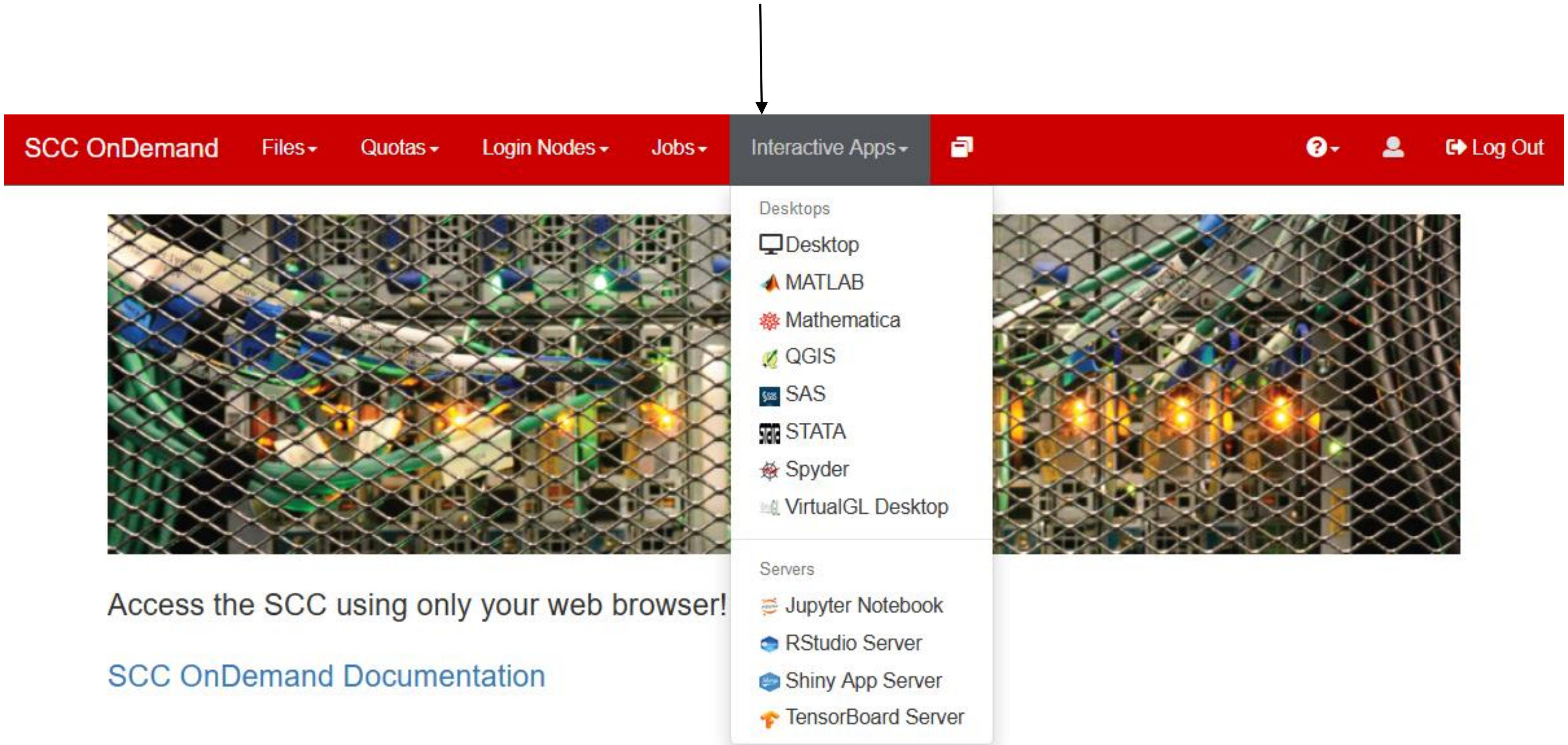
Temporary Tutorial Account

1. Open a web browser
2. Navigate to [http://scc-ondemand-**2fa**.bu.edu](http://scc-ondemand-2fa.bu.edu)
3. Log in with Tutorial Account



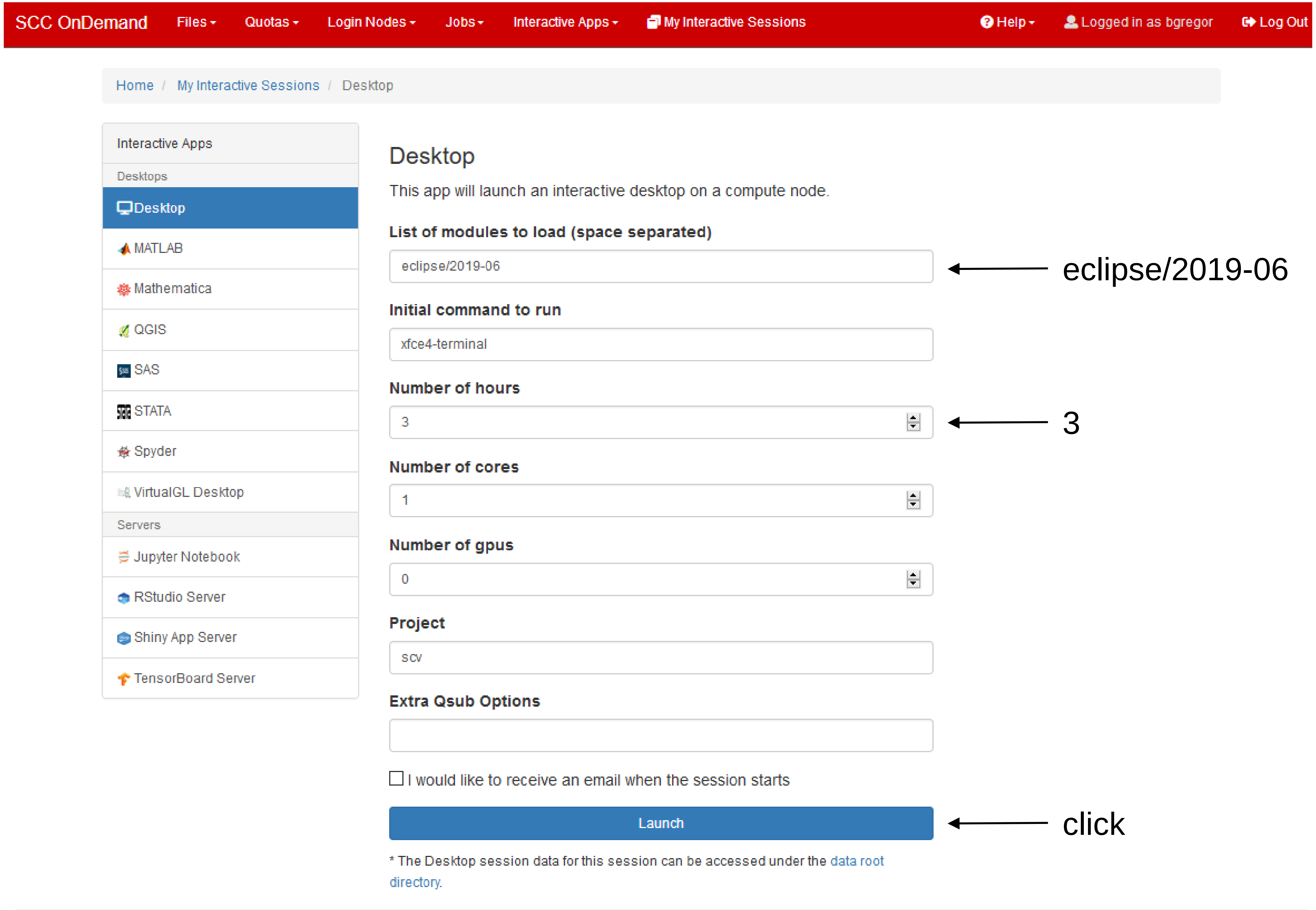
https://scc-ondemand-2fa.bu.edu

Click on Interactive Apps/Desktop



Access the SCC using only your web browser!

SCC OnDemand Documentation



Desktop

This app will launch an interactive desktop on a compute node.

List of modules to load (space separated)
eclipse/2019-06

Initial command to run
xfce4-terminal

Number of hours
3

Number of cores
1

Number of gpus
0

Project
scv

Extra Qsub Options

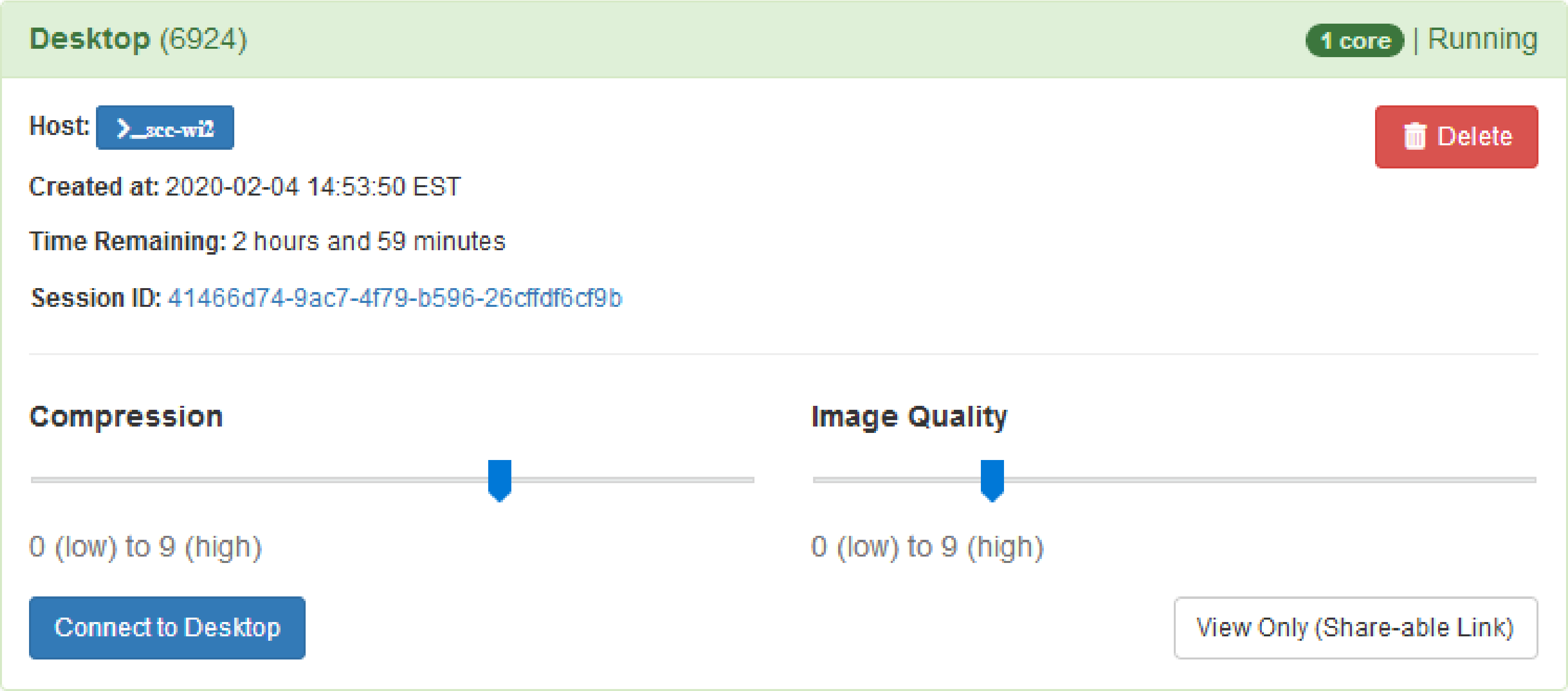
☐ I would like to receive an email when the session starts

* The Desktop session data for this session can be accessed under the data root directory.

eclipse/2019-06

3

click



Host: >_scc-wi2

Created at: 2020-02-04 14:53:50 EST

Time Remaining: 2 hours and 59 minutes

Session ID: 41466d74-9ac7-4f79-b596-26cffdf6cf9b

When your desktop is ready click *Connect to Desktop*

- Enter this command to create a directory in your home folder and to copy in tutorial files:

```
/net/scc2/scratch/intro_to_cpp_3.sh
```

- Also get the tutorial slides here:

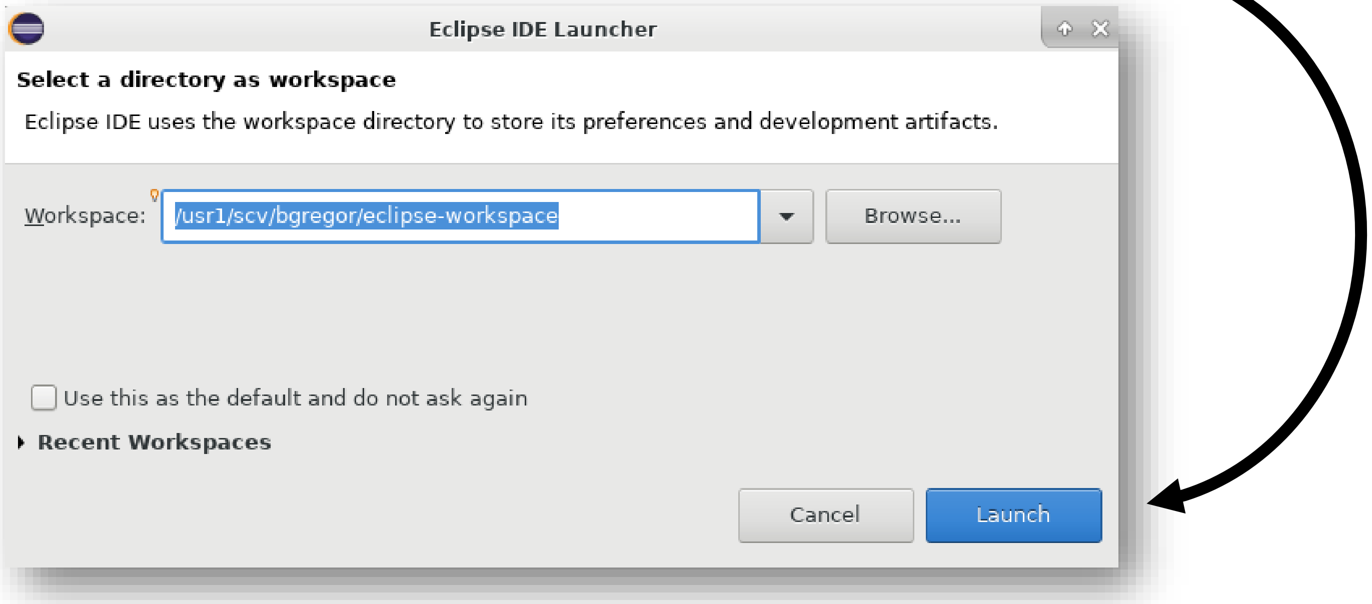
http://rcs.bu.edu/examples/cpp/tutorial/

Run the Eclipse software

- Enter this command to start up the Eclipse development environment.

```
eclipse &
```

- When this window appears just click the Launch button:



Eclipse IDE Launcher

Select a directory as workspace

Eclipse IDE uses the workspace directory to store its preferences and development artifacts.

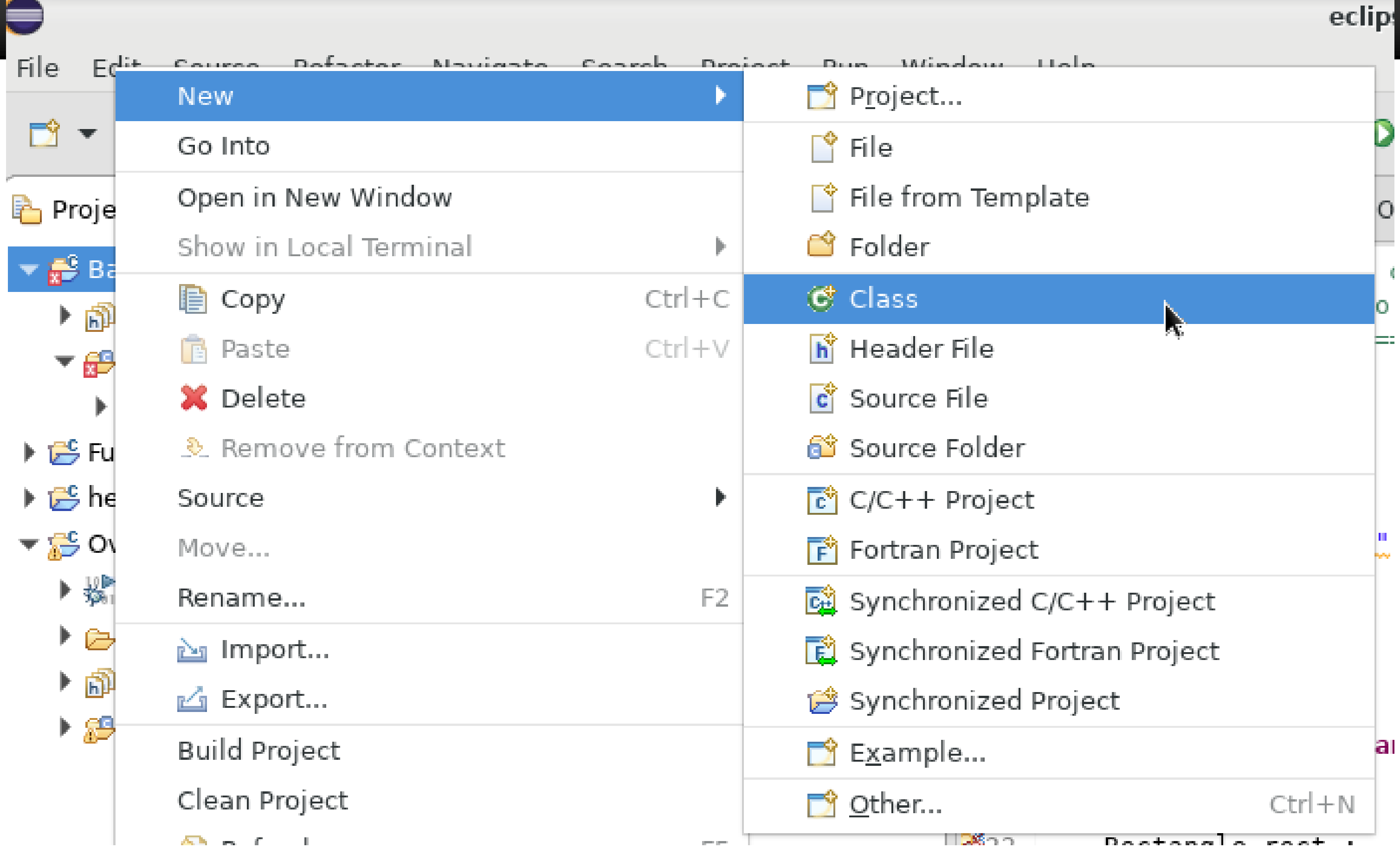
Workspace: /usr1/scv/bgregor/eclipse-workspace

☐ Use this as the default and do not ask again

A first C++ class

- Open project **Basic_Rectangle**.
- We’ll add our own custom class to this project.
- A C++ class consists of 2 files: a header file (.h) and a source file (.cpp)
- The header file contains the definitions for the types and names of members, methods, and how the class relates to other classes (if it does).
- The source file contains the code that implements the functionality of the class
- Sometimes there is a header file for a class but no source file.

Using Eclipse



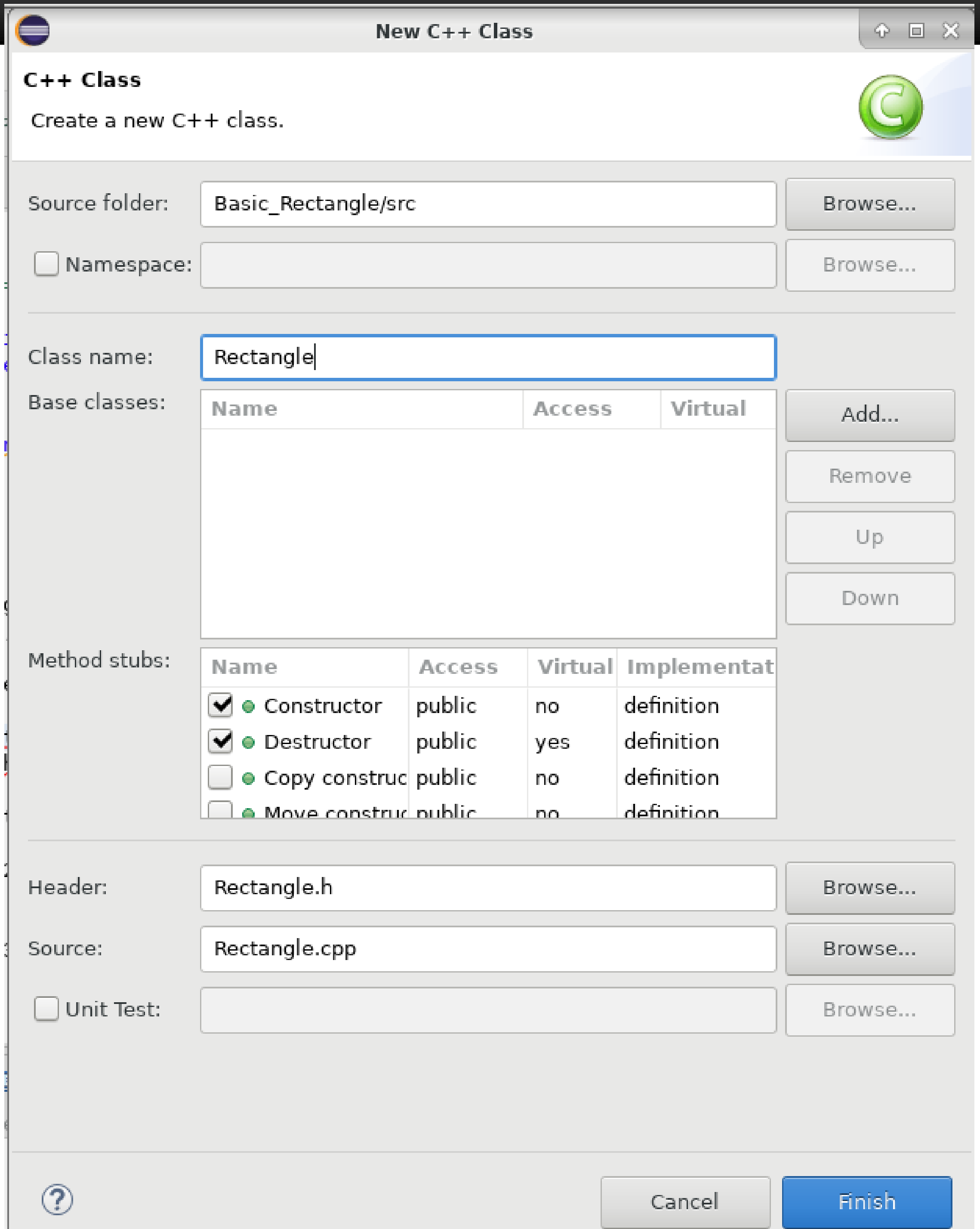
- An IDE is very useful for setting up code that follows patterns and configuring the build system to compile them.

- This saves time and effort for the programmer.

- Right-click on the Basic_Rectangle project and choose *New→Class*

- Give it the name *Rectangle* and click the Finish button.

- Open the new files *Rectangle.h* and *Rectangle.cpp*



New C++ Class

C++ Class

Create a new C++ class.

Source folder: Basic_Rectangle/src

☐ Namespace:

Class name: Rectangle

Base classes:

Name	Access	Virtual

Method stubs:

Name	Access	Virtual	Implementat
☑ Constructor	public	no	definition
☑ Destructor	public	yes	definition
☐ Copy construc	public	no	definition
☐ Move construc	public	no	definition

Header: Rectangle.h

Source: Rectangle.cpp

☐ Unit Test:

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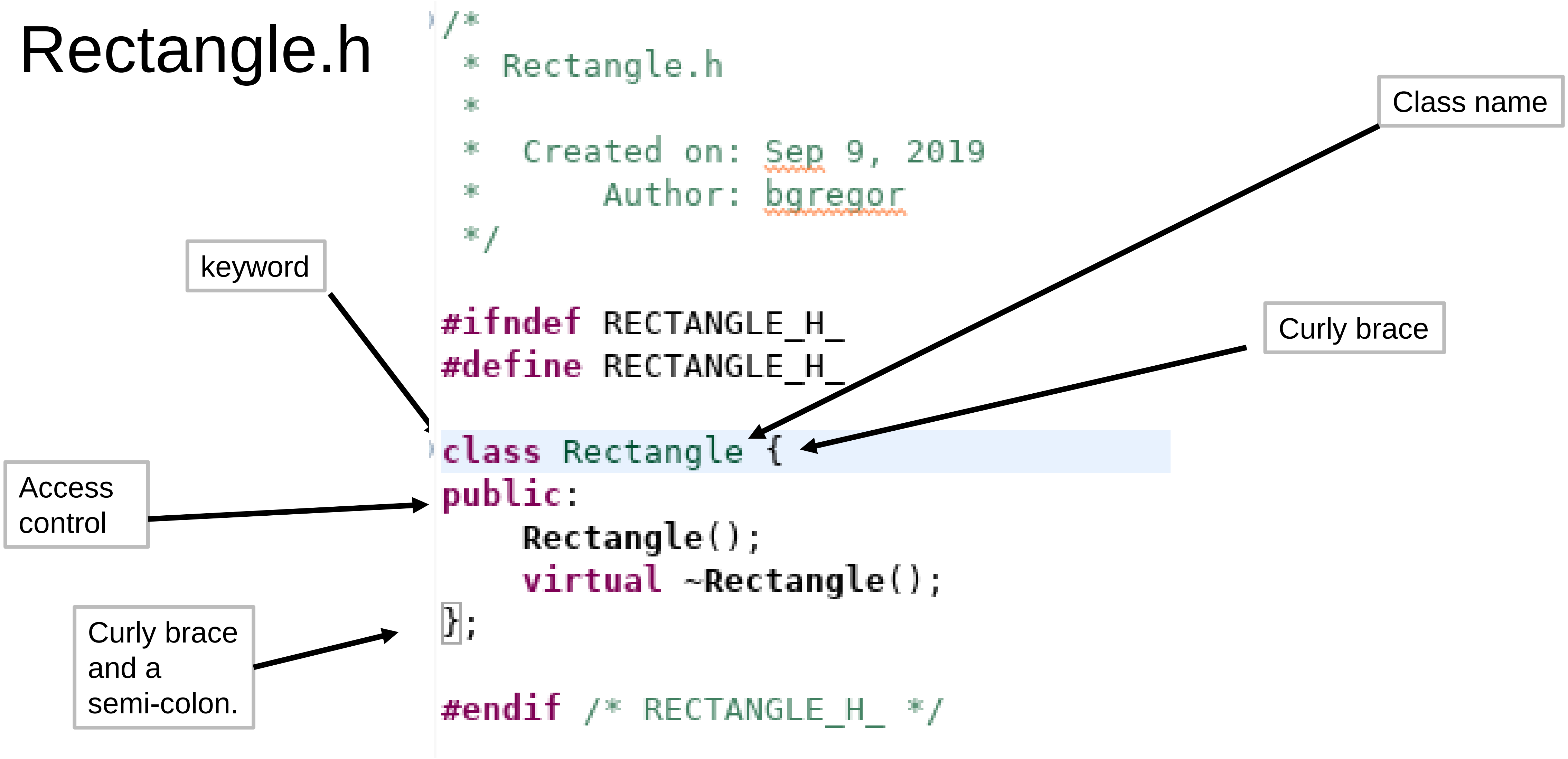
Rectangle.h



```
/*
 * Rectangle.h
 *
 *  Created on: Sep 9, 2019
 *      Author: bgregor
 */

#ifndef RECTANGLE_H_
#define RECTANGLE_H_

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

#endif /* RECTANGLE_H_ */
```

keyword

Class name

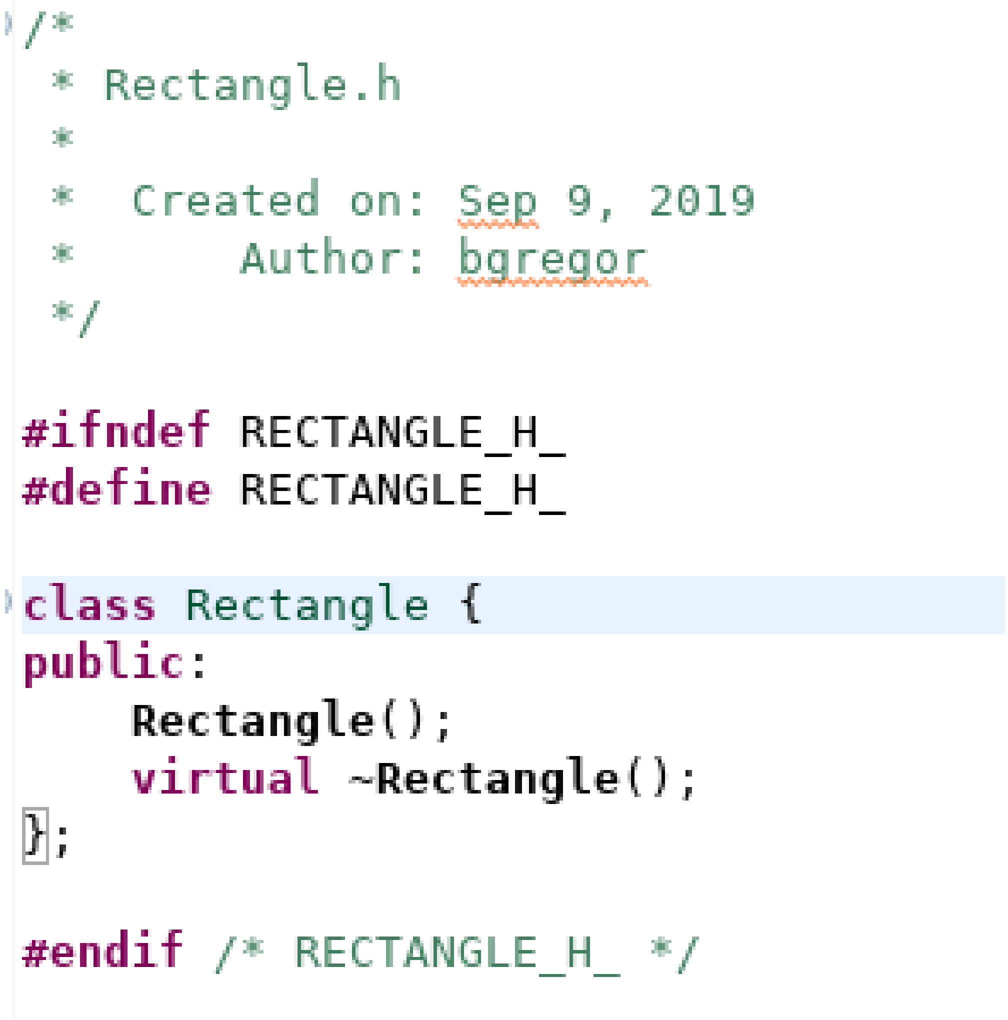
Curly brace

Access control

Curly brace and a semi-colon.

Default declared methods

- Rectangle();
  - A *constructor*. Called when an object of this class is created.
- ~Rectangle();
  - A *destructor*. Called when an object of this class is removed from memory, i.e. destroyed.
  - Ignore the *virtual* keyword for now.



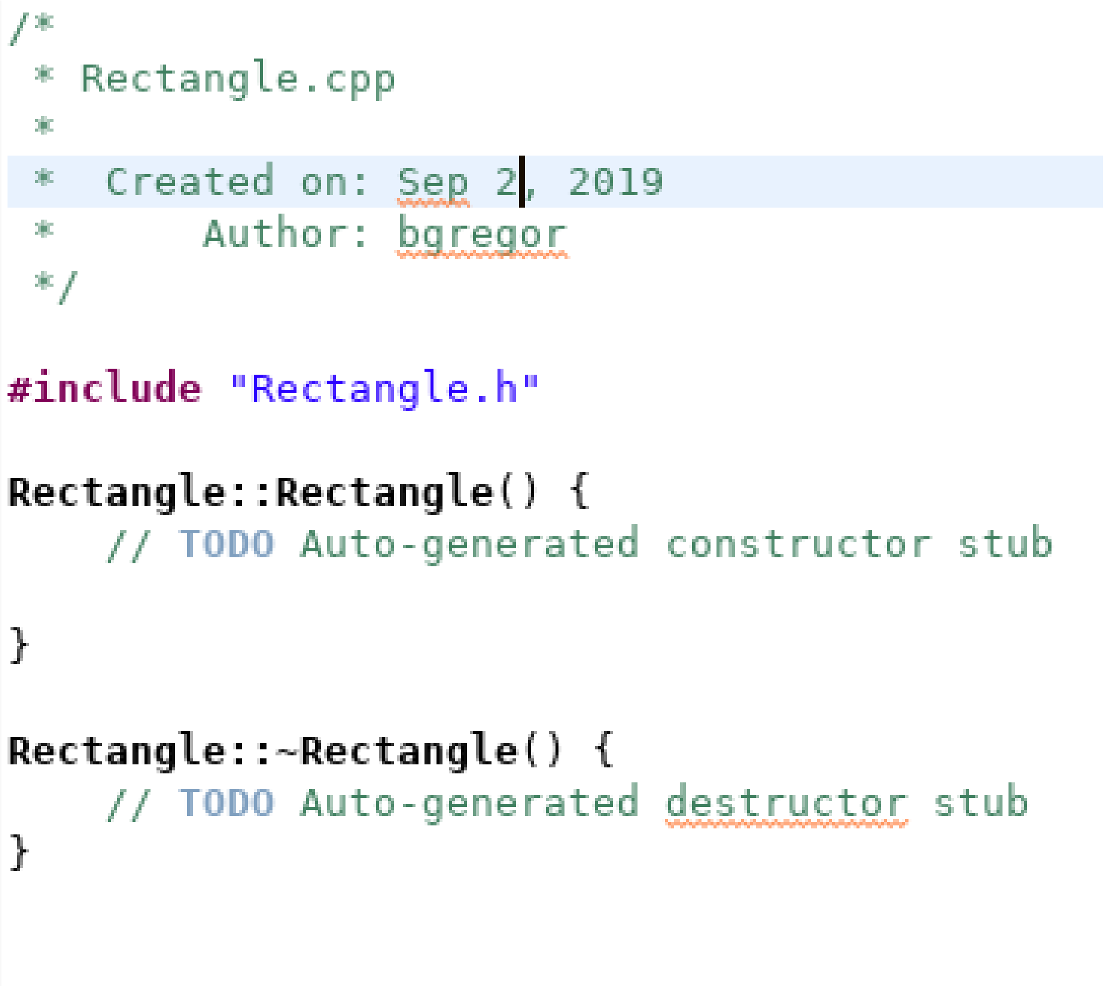
```
/*
 * Rectangle.h
 *
 *  Created on: Sep 9, 2019
 *      Author: bgregor
 */

#ifndef RECTANGLE_H_
#define RECTANGLE_H_

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

#endif /* RECTANGLE_H_ */
```

Rectangle.cpp

Header file included

Class_name:: pattern indicates the method declared in the header is being implemented in code here.

Methods are otherwise regular functions with arguments () and matched curly braces {}.

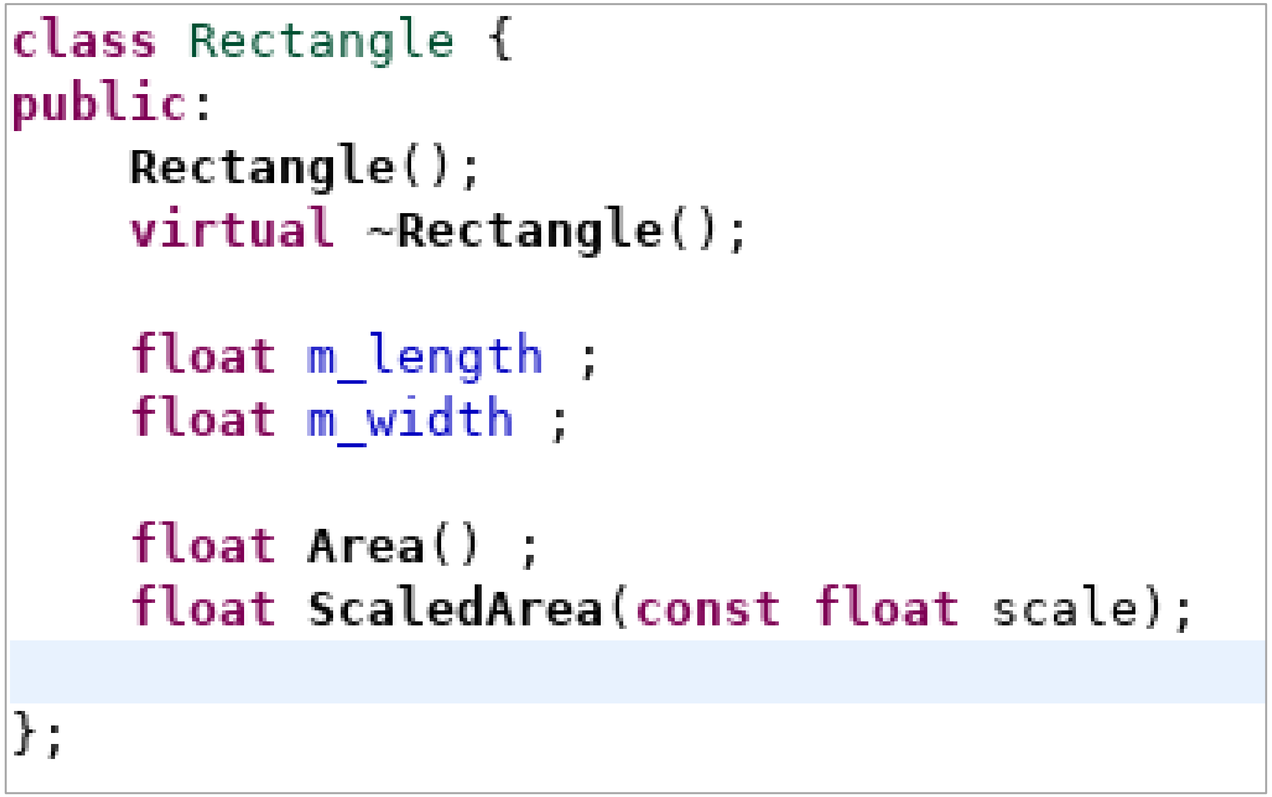


```
/*
 * Rectangle.cpp
 *
 *  Created on: Sep 2, 2019
 *      Author: bgregor
 */

#include "Rectangle.h"

Rectangle::Rectangle() {
	// TODO Auto-generated constructor stub

}

Rectangle::~Rectangle() {
	// TODO Auto-generated destructor stub
}
```

Let’s add some functionality

- A Rectangle class should store a length and a width.
- To make it useful, let’s have it supply an Area() method to compute its own area.

- Edit the header file to look like the code to the right.



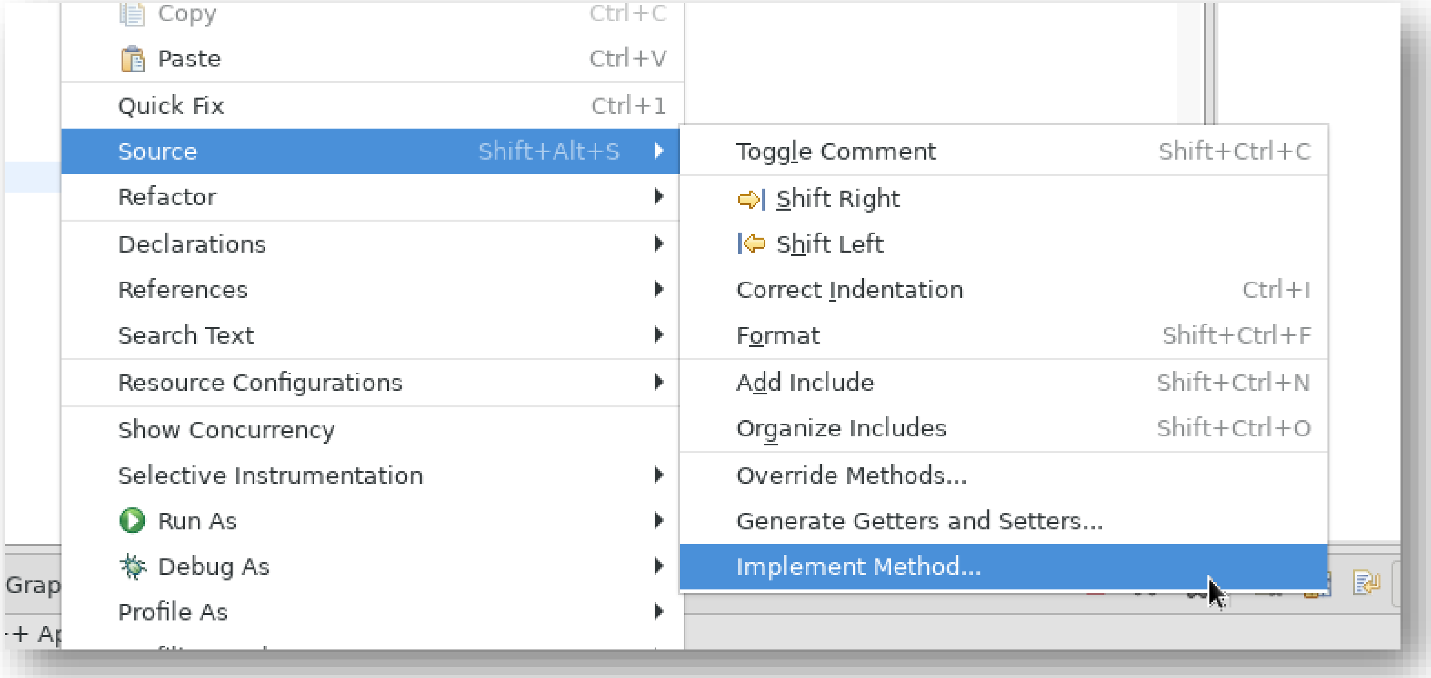
```
class Rectangle {
public:
    Rectangle();
    virtual ~Rectangle();

    float m_length ;
    float m_width ;

    float Area() ;
    float ScaledArea(const float scale);

};
```

Encapsulation

- Bundling the data and area calculation for a rectangle into a single class is an example of the concept of *encapsulation.*

The code for the two methods is needed

- Right-click in the Rectangle.h window and choose Source→Implement Methods



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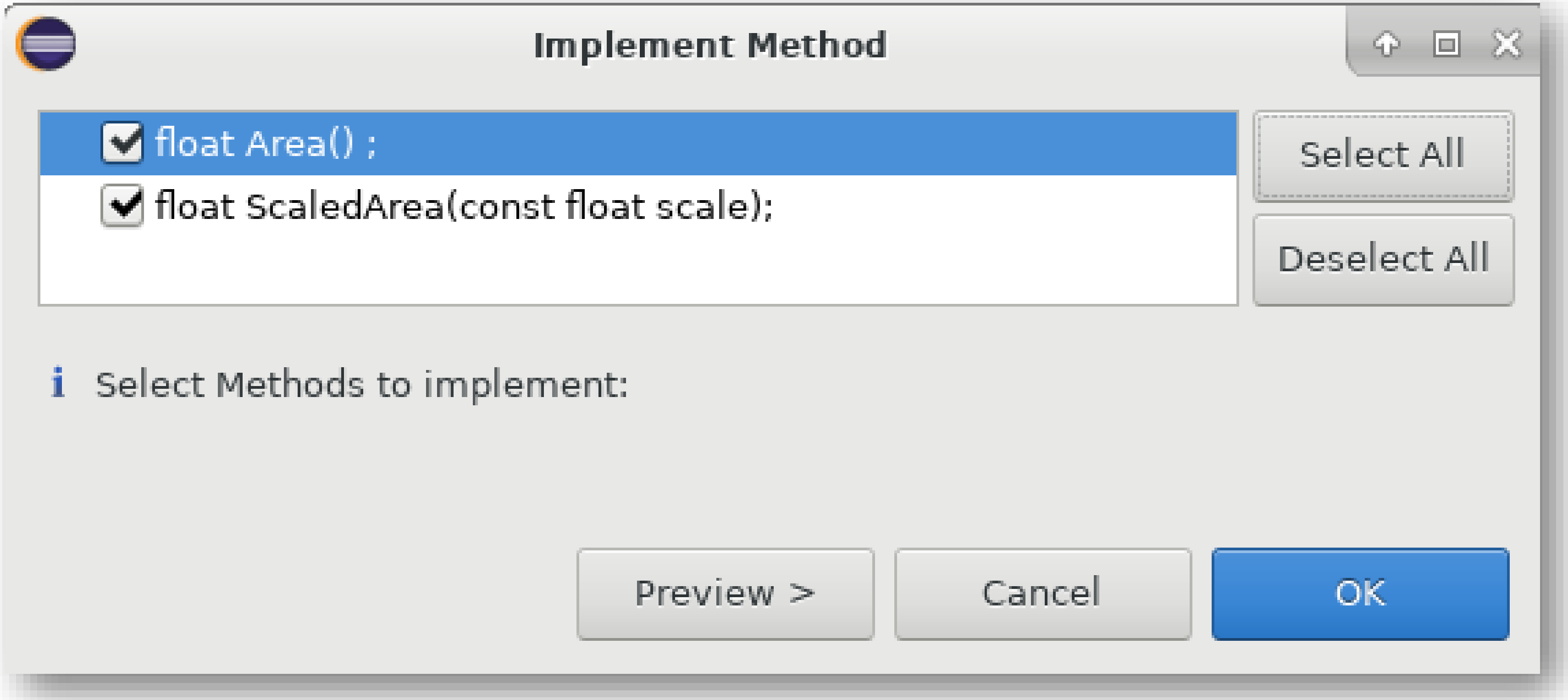
- Click *Select All* then click OK.



Implement Method

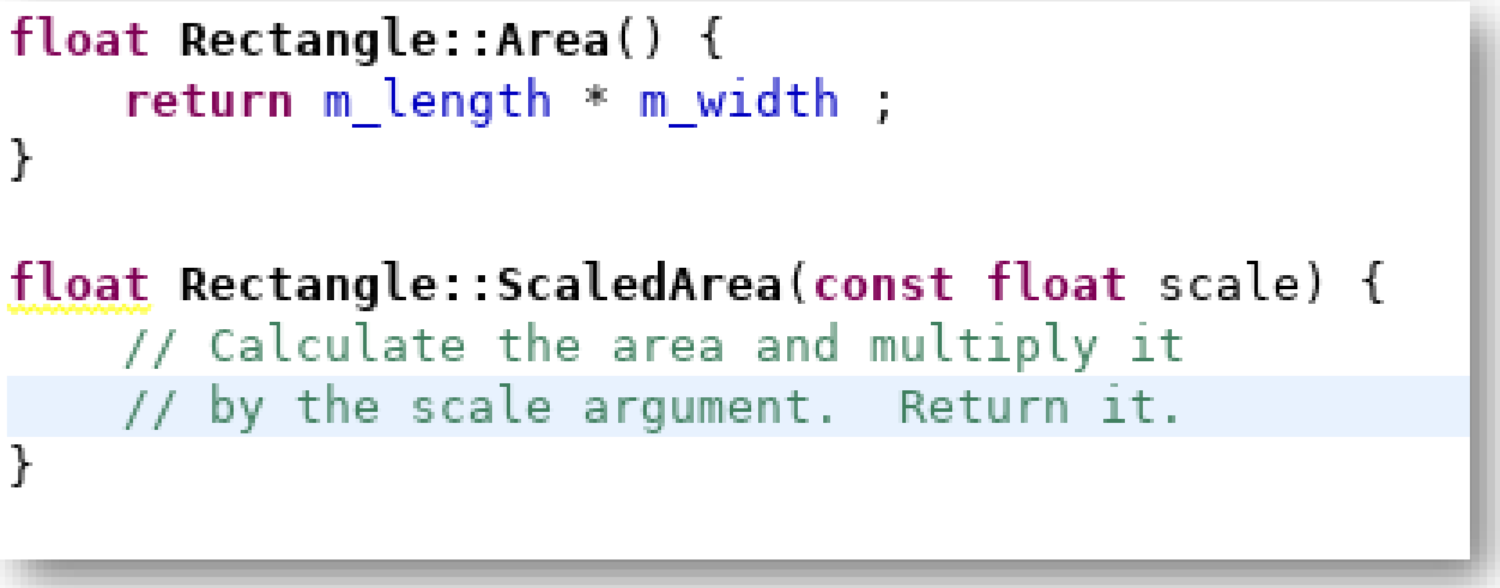
☑ float Area() ;

☑ float ScaledArea(const float scale);

Select Methods to implement:

Fill in the methods

- Step 1: add some comments.
- Step 2: add some code.



```
float Rectangle::Area() {
    return m_length * m_width ;
}

float Rectangle::ScaledArea(const float scale) {
    // Calculate the area and multiply it
    // by the scale argument.  Return it.
}
```

- **Member variables can be accessed as though they were passed to the method.**
- Methods can also call each other.
- Fill in the Area() method and then **write your own** ScaledArea(). Don’t forget to compile!

Using the new class

- Open *Basic_Rectangle.cpp*
- Add an include statement for the new Rectangle.h

- Create a Rectangle object and call its methods.

- We'll do this together…

Special methods

- There are several methods that deal with creating and destroying objects.

- These include:
  - *Constructors* – called when an object is created. Can have many defined per class.
  - *Destructor* – one per class, called when an object is destroyed
  - *Copy* – called when an object is created by copying an existing object
  - *Move* – a feature of C++11 that is used in certain circumstances to avoid copies.

Construction and Destruction

- The *constructor* is called when an object is created.
- This is used to initialize an object:
  - Load values into member variables
  - Open files
  - Connect to hardware, databases, networks, etc.

- The *destructor* is called when an object goes *out of scope*.
- Example:

```
void function() {
        ClassOne c1 ;
}
```

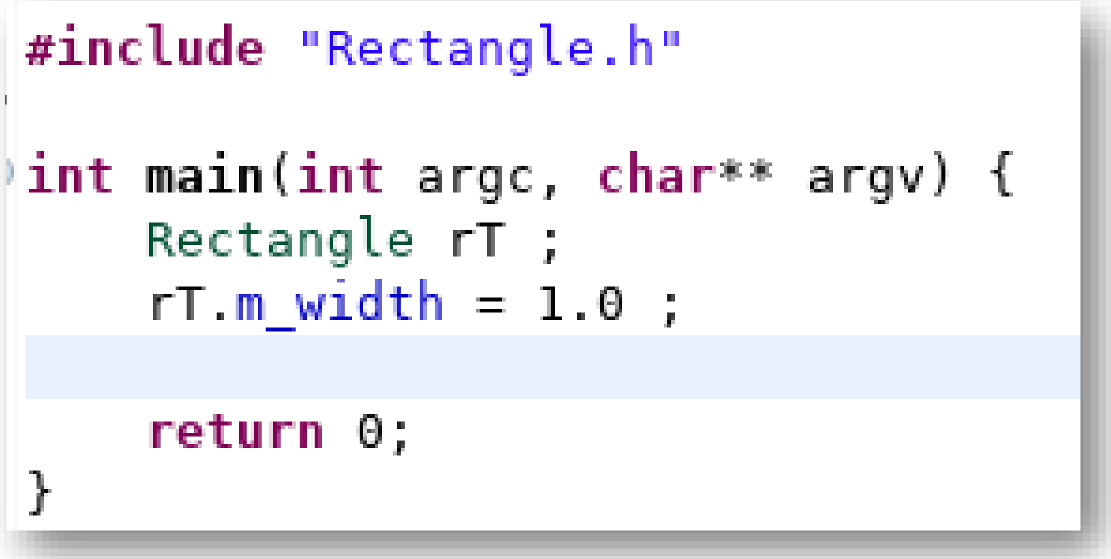
- Object c1 is created when the program reaches the first line of the function, and destroyed when the program leaves the function.

When an object is instantiated…

- The rT object is created in memory.
- When it is created its *constructor* is called to do any necessary initialization.

- The constructor can take any number of arguments like any other function but it *cannot* return any values.

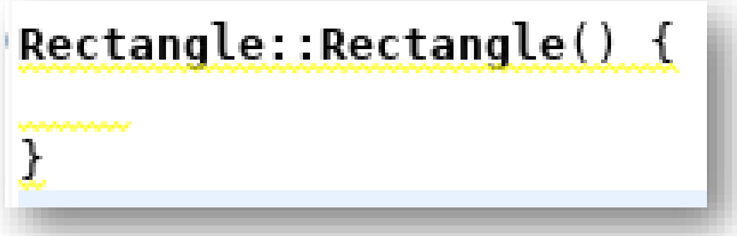
- What if there are multiple constructors?
  - The compiler follows standard function overload rules.



```
#include "Rectangle.h"

int main(int argc, char** argv) {
    Rectangle rT ;
    rT.m_width = 1.0 ;

    return 0;
}
```



```
Rectangle::Rectangle() {

}
```

Note the constructor
has no return type!

A second constructor

rectangle.h

```
class Rectangle
{
    public:
        Rectangle() ;
        Rectangle(const float width,
              const float length) ;

   /* etc */
};
```

rectangle.cpp

```
#include "rectangle.h“

/* C++11 style */
Rectangle::Rectangle(const float width,
                     const float length):
                     m_width(width),
                     m_length(length)
{
   /* extra code could go here */

}
```

- Adding a second constructor is similar to overloading a function.
- Here the modern C++11 style is used to set the member values – this is called a *member initialization list*

Member Initialization Lists

- Syntax:

Colon goes here

```
MyClass(int A, OtherClass &B, float C):
       m_A(A),
       m_B(B),
       m_C(C)  {
              /* other code can go here */
       }
```

Members assigned and separated with commas. The order doesn't matter.

Additional code can be added in the code block.

And now use both constructors

- Both constructors are now used. The new constructor initializes the values when the object is created.
- Constructors are used to:
  - Initialize members
  - Open files
  - Connect to databases
  - Etc.

```
#include <iostream>

using namespace std;

#include "Rectangle.h‟

int main(int  argc, char** argv)
{

    Rectangle rT ;
    rT.m_width = 1.0 ;
    rT.m_length = 2.0 ;

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

    Rectangle rT_2(2.0,2.0) ;
    cout << rT_2.Area() << endl ;

    return 0;
}
```

Default values

- C++11 added the ability to define default values in headers in an intuitive way.
- Pre-C++11 default values would have been coded into source files.
- If members with default values get their value set in the constructor than the default value is ignored.
    - i.e. no “double setting” of the value.

```
class Rectangle {
public:
    Rectangle();
    Rectangle(const float width,
              const float length) ;

    Rectangle(const Rectangle& orig);
    virtual ~Rectangle();

    float m_length = 0.0 ;
    float m_width = 0.0 ;

    float Area() ;
    float ScaledArea(const float scale);

private:

};
```

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Default constructors and destructors

- The two methods created by Eclipse automatically are explicit versions of the **default** C++ constructors and destructors.

- Every class has them – if you don't define them then empty ones that do nothing will be created for you by the compiler.
  - If you really don't want the default constructor you can delete it with the *delete* keyword.
  - Also in the header file you can use the *default* keyword if you like to be clear that you are using the default.

```
class Foo {
    public:
        Foo() = delete ;
        // Another constructor
        // must be defined!
        Foo(int x) ;
};

class Bar {
    public:
        Bar() = default ;
};
```

Custom constructors and destructors

- You must define your own constructor when you want to initialize an object with arguments.
- A custom destructor is **always** needed when internal members in the class need special handling.
    - Examples: manually allocated memory, open files, hardware drivers, database or network connections, custom data structures, etc.

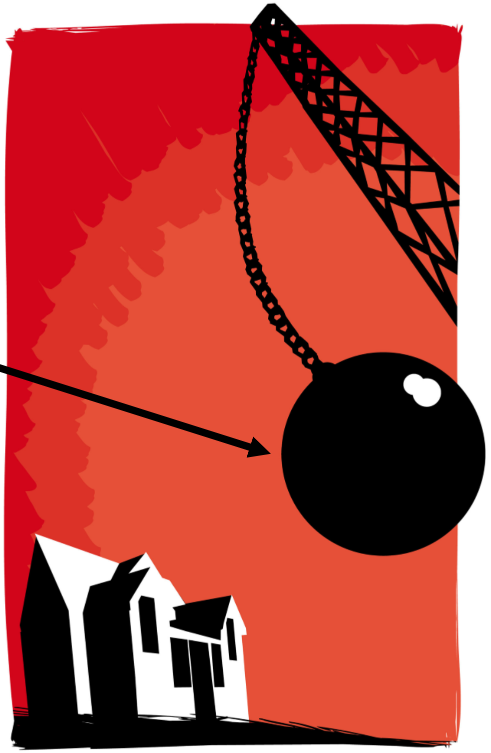
Destructors

- Destructors are called when an object is destroyed.
- Destructors have no return type.
- There is only **one** destructor allowed per class.
- Objects are destroyed when they go out of *scope*.
- Destructors are never called explicitly by the programmer. Calls to destructors are inserted automatically by the compiler.
- The destructor will automatically call the destructor for every member in the object where the members are themselves objects.

This class just has 2 floats as members which are automatically removed from memory by the compiler.

```
Rectangle::~Rectangle()
{

}
```



~House() destructor

House object

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A Custom Destructor

```
class Example {
  public:
        Example() = delete ;
        Example(int count) ;

        virtual ~Example() ;

        // A pointer to some memory
    // that will be allocated manually.
        float *m_values = nullptr ;

        // A vector of strings.
        vector<string> m_lines ;
};
```

```
Example::Example(int count) {
        // Allocate memory to store "count"
        // floats.
        values = new float[count];
        // And size the string vector to
        // hold the same number of strings.
        m_lines.reserve(count) ;
}

Example::~Example() {
        // The destructor MUST free this
        // memory. Only do so if values is not
    // null. - deleting a null pointer will
        // crash your program.
        if (values) {
                delete[] values ;
        }
        // m_lines gets its destructor called and
        // it cleans up after itself.
}
```

Manual Allocations

- C code: Use malloc() and free()
- C++: use **new** and **delete**
    - **delete[]** must be used for array allocations.

```
// Dynamically allocate a double value.
double *dbl = new double ;
// Dynamically allocate a vector.
vector<int> *dyn_vec = new vector<int>() ;
// And an array of strings
string *str_arr = new string[6] ;
*dbl = 2.0;
// Pointer access to a method use ->
dyn_vec->push_back(11) ;
str_arr[0] = "blarf" ;

// Always delete your allocations!
delete dbl ;
delete dyn_vec ;
delete[] str_arr ;
```

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Copy, Assignment, and Move Constructors

- The compiler will automatically create constructors to deal with copying, assignment, and moving. NetBeans filled in an empty default copy constructor for us.

- How do you know if you need to write one?
  - When the code won't compile and the error message says you need one!
  - OR unexpected things happen when running.

- You may require custom code when...
  - dealing with open files inside an object
  - The class manually allocated memory
  - Hardware resources (a serial port) opened inside an object
  - Etc.

```
Rectangle rT_1(1.0,2.0) ;
// Now use the copy constructor
Rectangle rT_2(rT_1) ;
// Do an assignment, with the
// default assignment operator
rT_2 = rT_1 ;
```

Templates and classes

- Classes can also be created via templates in C++

- Templates can be used for type definitions with:
  - Entire class definitions
  - Members of the class
  - Methods of the class

- Templates can be used with class inheritance as well.

- This topic is way beyond the scope of this tutorial!

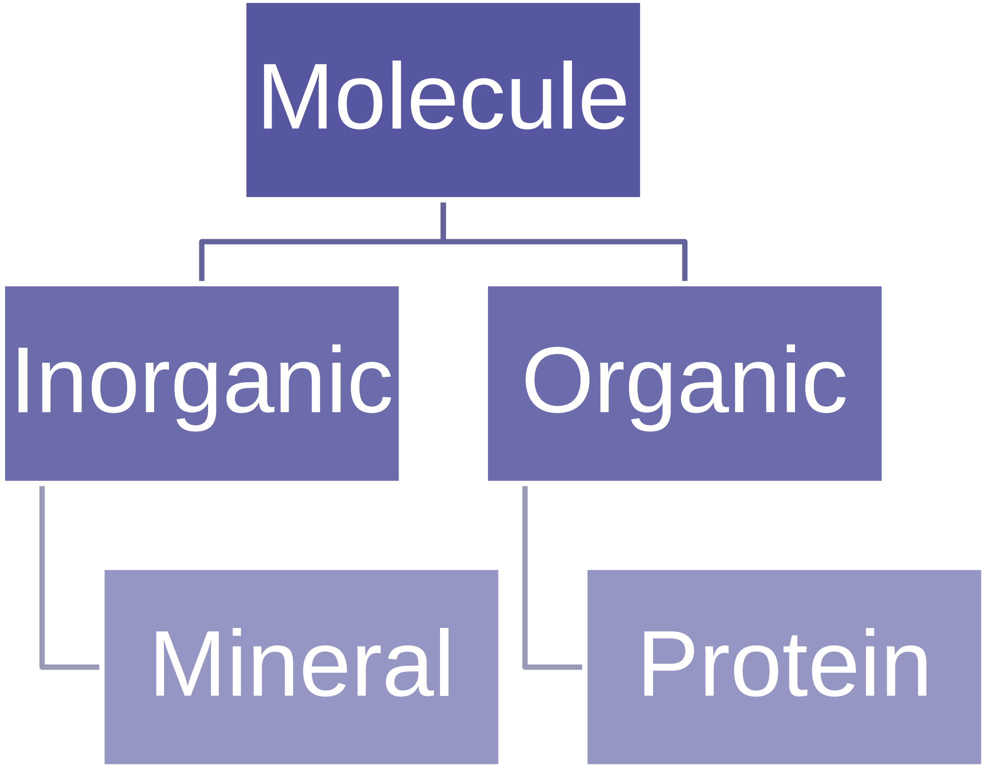
Tutorial Outline: Part 3

- Defining Classes
- Class inheritance
- Public, private, and protected access
- Virtual functions

Inheritance

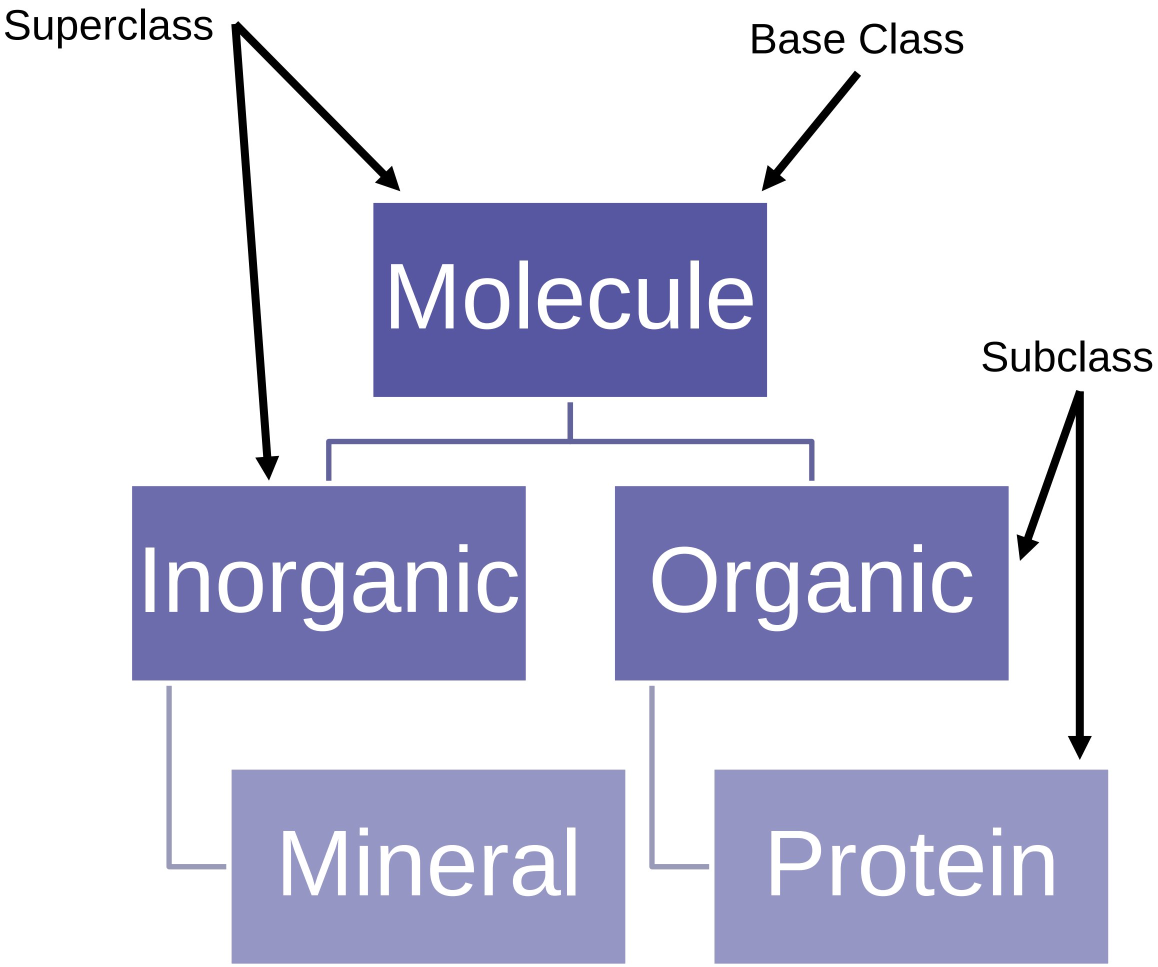
- Inheritance is the ability to form a hierarchy of classes where they share common members and methods.
    - Helps with: code re-use, consistent programming, program organization

- This is a powerful concept!

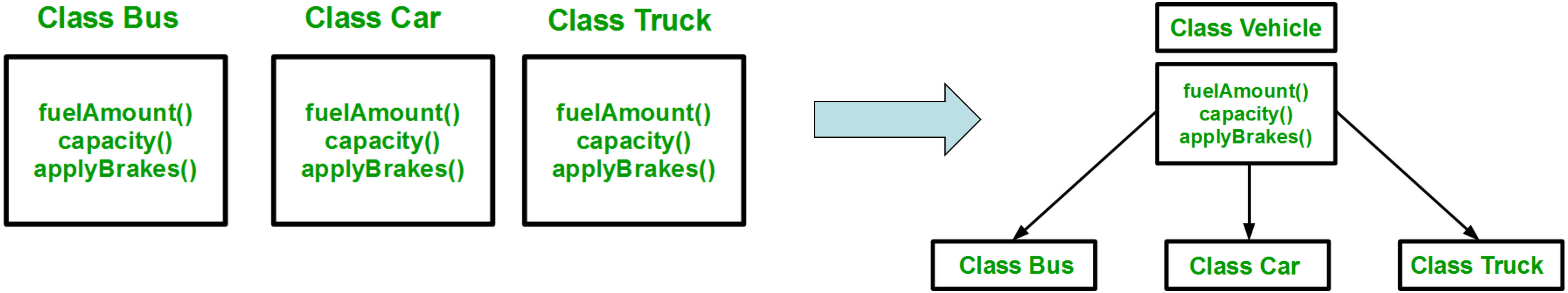


Inheritance

- The class being derived *from* is referred to as the **base**, **parent**, or **super** class.
- The class being derived is the **derived**, **child**, or **sub** class.
- For consistency, we'll use superclass and subclass in this tutorial. A base class is the one at the top of the hierarchy.



Why inherit?



Class Bus

fuelAmount()
capacity()
applyBrakes()

Class Car

fuelAmount()
capacity()
applyBrakes()

Class Truck

fuelAmount()
capacity()
applyBrakes()

Class Vehicle

fuelAmount()
capacity()
applyBrakes()

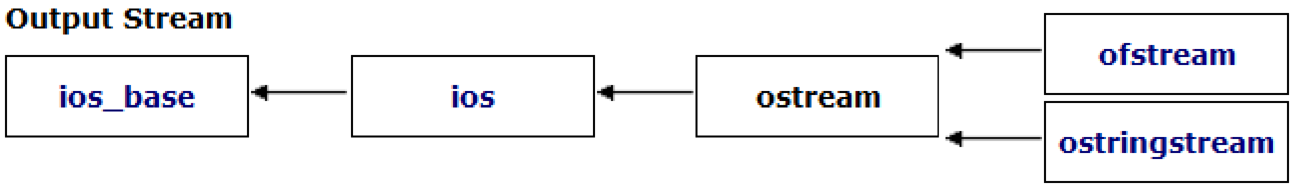
Class Bus **Class Car** **Class Truck**

OO programming helps you to model the problem you’re solving in your program.

Inheritance allows for class hierarchies to be built to organize your program – and share code.

https://www.geeksforgeeks.org/inheritance-in-c/

Inheritance in Action

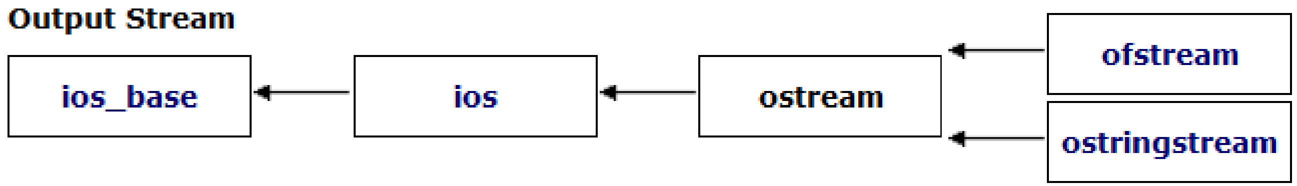


- Streams in C++ are series of characters – the C+ I/O system is based on this concept.
- **cout** is an object of the class *ostream*. It is a write-only series of characters that prints to the terminal.
- There are two subclasses of ostream:
  - *ofstream* – write characters to a file
  - *ostringstream* – write characters to a string
- Writing to the terminal is straightforward:

```
cout  << some_variable ;
```

- How might an object of class *ofstream* or *ostringstream* be used if we want to write characters to a file or to a string?

Inheritance in Action



- For *ofstream* and *ofstringstream* the << operator is inherited from *ostream* and behaves the same way for each from the programmer’s point of view.

- The *ofstream class* adds a constructor to open a file and a close() method.
- *ofstringstream* adds a method to retrieve the underlying string, str()

- If you wanted a class to write to something else, like a USB port…
  - Maybe look into inheriting from ostream!
    - Or *its* underlying class, *basic_ostream* which handles types other than characters…

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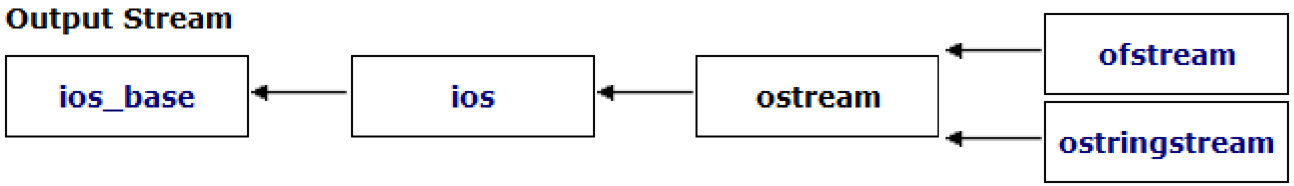
Inheritance in Action



```
#include <iostream>  // cout
#include <fstream>  // ofstream
#include <sstream> // ostringstream

using namespace std ;
void some_func(string msg) {
        cout << msg ; // to the terminal
        // The constructor opens a file for writing
        ofstream my_file("filename.txt") ;
        // Write to the file.
        my_file << msg ;
        // close the file.
        my_file.close() ;
        ostringstream oss ;
        // Write to the stringstream
        oss << msg ;
        // Get the string from stringstream
        cout << oss.str()  ;
}
```

Tutorial Outline: Part 3

- Defining Classes
- Class inheritance
- Public, private, and protected access
- Virtual functions

> “There are only two things wrong with C++: The initial concept and the implementation.”
> – Bertrand Meyer (inventor of the Eiffel OOP language)

Public, protected, private

- We can have public, private, and protected modifiers in the class definition.
- These are used to control access to parts of the class with inheritance and when using the class.

```
class Rectangle
{
    public:
        Rectangle();
        Rectangle(float width, float length) ;
        virtual ~Rectangle();

        float m_width ;
        float m_length ;

        float Area() ;

    protected:

    private:
};
```

C++ Access Control and Inheritance

Access	public	protected	private
Same class	Yes	Yes	Yes
Subclass	Yes	Yes	No
Outside classes	Yes	No	No

i.e. using the class in your program

```
class Super {
public:
     int i;
protected:
     int j ;
private:
     int k ;
};
```

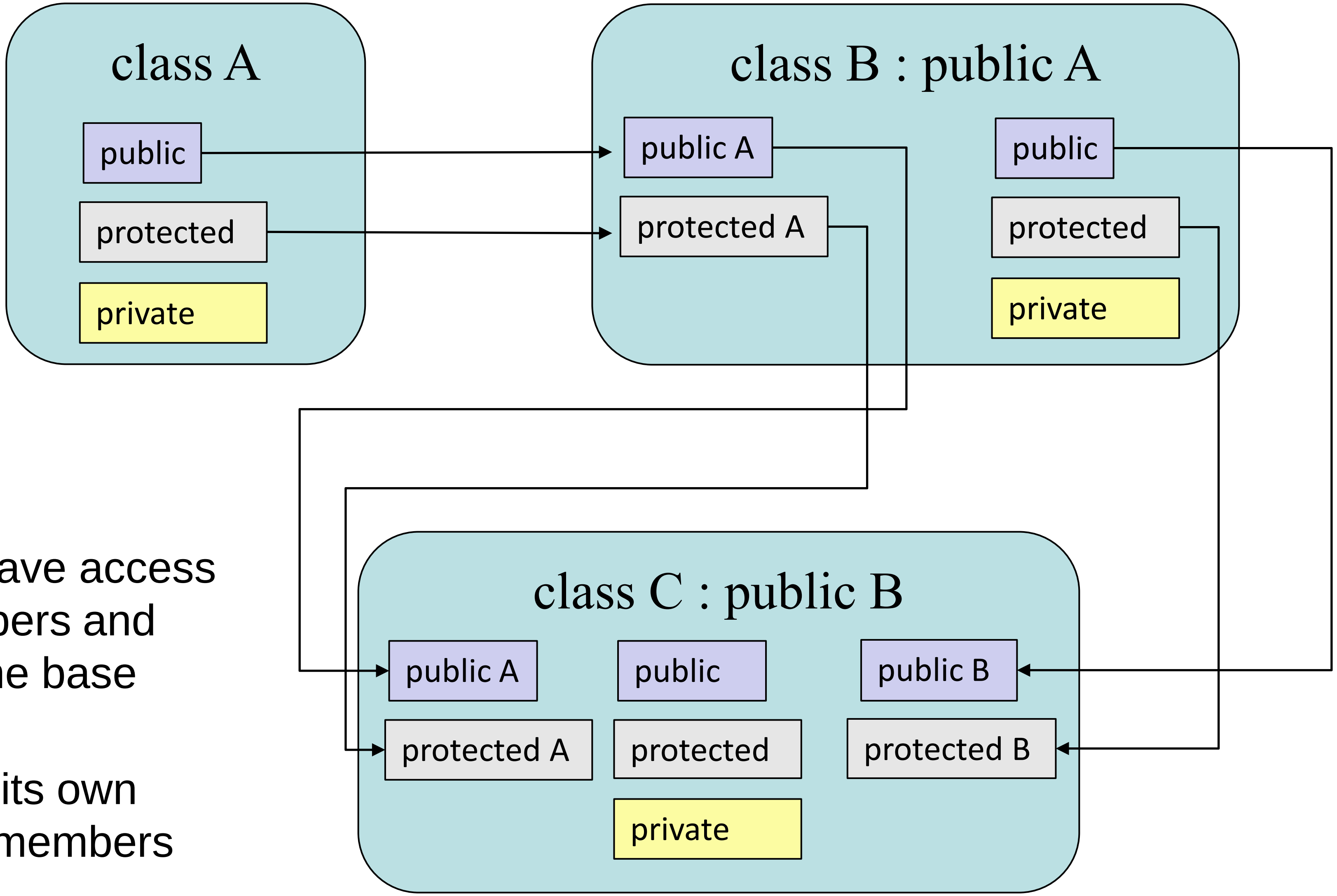
Inheritance

```
class Sub : public Super {
// in methods, could access
// i and j from Parent only.
};
```

Outside code

```
Sub myobj ;
Myobj.i = 10 ; // public - ok
Myobj.j = 3 ; // protected - Compiler error
Myobj.k = 1 ; // private - Compiler error
```

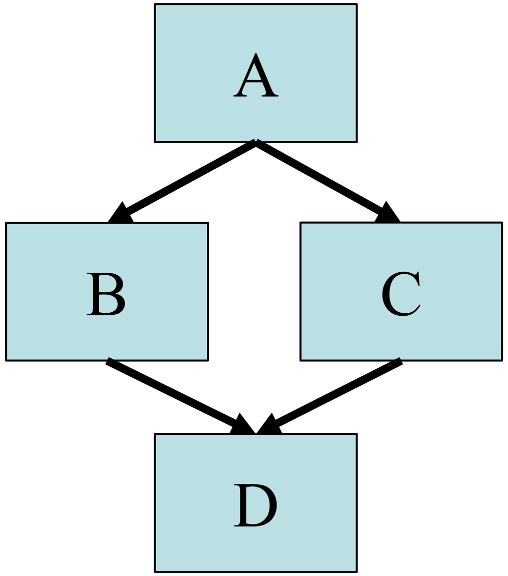
Inheritance



- With inheritance subclasses have access to private and protected members and methods all the way back to the base class.
- Each subclass can still define its own public, protected, and private members and methods along the way.

Single vs Multiple Inheritance

- C++ supports creating relationships where a subclass inherits data members and methods from a single superclass: single inheritance
- C++ also support inheriting from multiple classes simultaneously: Multiple inheritance
- **This tutorial will only cover single inheritance.**
- Generally speaking…
  - Multiple inheritance requires a **large** amount of design effort
  - It's an easy way to end up with overly complex, fragile code
  - Java and C# (both came after C++) exclude multiple inheritance *on purpose* to avoid problems with it.



- With multiple inheritance a hierarchy like this is possible to create…this is nicknamed the **Deadly Diamond of Death.**

C++ Inheritance Syntax

- Inheritance syntax pattern:

```
class SubclassName : public SuperclassName
```

- Here the *public* keyword is used.
    - Methods implemented in class Sub can access any public or protected members and methods in Super but cannot access anything that is private.

- Other inheritance types are *protected* and *private.*

```
class Super {
public:
    int i;
protected:
    int j ;
private:
    int k ;
};

class Sub : public Super {
// ...
};
```

Square

- Let’s make a subclass of Rectangle called Square.
- Open the Eclipse project *Shapes*
- This has the Rectangle class from Part 2 implemented.
- Add a class named *Square.*
- Make it inherit from Rectangle.

Square.h

```
#ifndef SQUARE_H
#define SQUARE_H

#include "Rectangle.h"


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

    protected:

    private:
};

#endif // SQUARE_H
```

Square.cpp

```
#include “Square.h"

Square::Square()
{}

Square::~Square()
{}
```

- Note that subclasses are free to add any number of new methods or members, they are not limited to those in the superclass.

- Class Square inherits from class Rectangle

A new Square constructor is needed.

- A square is, of course, just a rectangle with equal length and width.
- The area can be calculated the same way as a rectangle.
- Our Square class therefore needs just one value to initialize it and it can re-use the Rectangle.Area() method for its area.

- Go ahead and try it:
  - Add an argument to the default constructor in Square.h
  - Update the constructor in Square.cpp to do…?
  - Remember Square can access the public members and methods in its superclass

Solution 1

```
#ifndef SQUARE_H
#define SQUARE_H

#include “Rectangle.h"


class Square : public Rectangle
{
    public:
        Square(float width);
        virtual ~Square();

    protected:

    private:
};

#endif // SQUARE_H
```

```
#include “Square.h"

Square::Square(float length):
m_width (length), m_length(length)
{

}
```

- Square can access the public members in its superclass.
- Its constructor can then just assign the length of the side to the Rectangle m_width and m_length.
- This is unsatisfying – while there is nothing *wrong* with this it’s not the OOP way to do things.
- Why re-code the perfectly good constructor in Rectangle?

The delegating constructor

- C++11 added a new constructor type called the delegating constructor.
- Using member initialization lists you can call one constructor from another.
- Even better: with member initialization lists C++ can call superclass constructors!

```
class class_c {
public:
    int max;
    int min;
    int middle;

    class_c(int my_max) {
        max = my_max > 0 ? my_max : 10;
    }
    class_c(int my_max, int my_min) : class_c(my_max) {
        min = my_min > 0 && my_min < max ? my_min : 1;
    }
    class_c(int my_max, int my_min, int my_middle) :
               class_c (my_max, my_min){
        middle = my_middle < max &&
                 my_middle > min ? my_middle : 5;
}
};
```

```
Square::Square(float length) :
      Rectangle(length,length)
{
  // other code could go here.
}
```

Reference:

https://msdn.microsoft.com/en-us/library/dn387583.aspx

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Solution 2

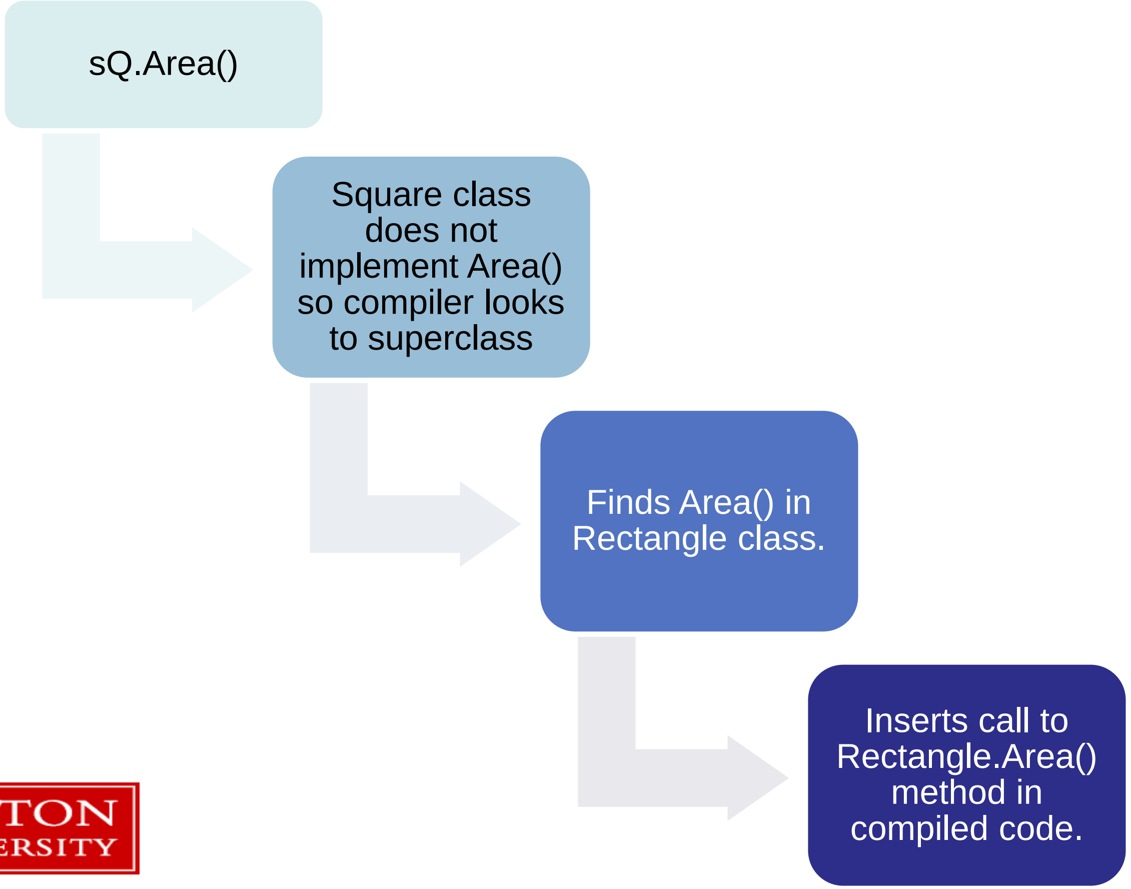
```
#ifndef SQUARE_H
#define SQUARE_H

#include "Rectangle.h"


class Square : public Rectangle
{
    public:
        Square(float width);
        virtual ~Square();

    protected:

    private:
};

#endif // SQUARE_H
```

```
#include "Square.h"

Square::Square(float length) :
     Rectangle(length, length) {}
```

- Square can directly call its superclass constructor and let the Rectangle constructor make the assignment to m_width and m_length.
- This saves typing, time, and **reduces the chance of adding bugs to your code**.
  - The more complex your code, the more compelling this statement is.
- Code re-use is one of the prime reasons to use OOP.

Trying it out in main()

- What happens behind the scenes when this is compiled….



sQ.Area()

Square class does not implement Area() so compiler looks to superclass

Finds Area() in Rectangle class.

Inserts call to Rectangle.Area() method in compiled code.

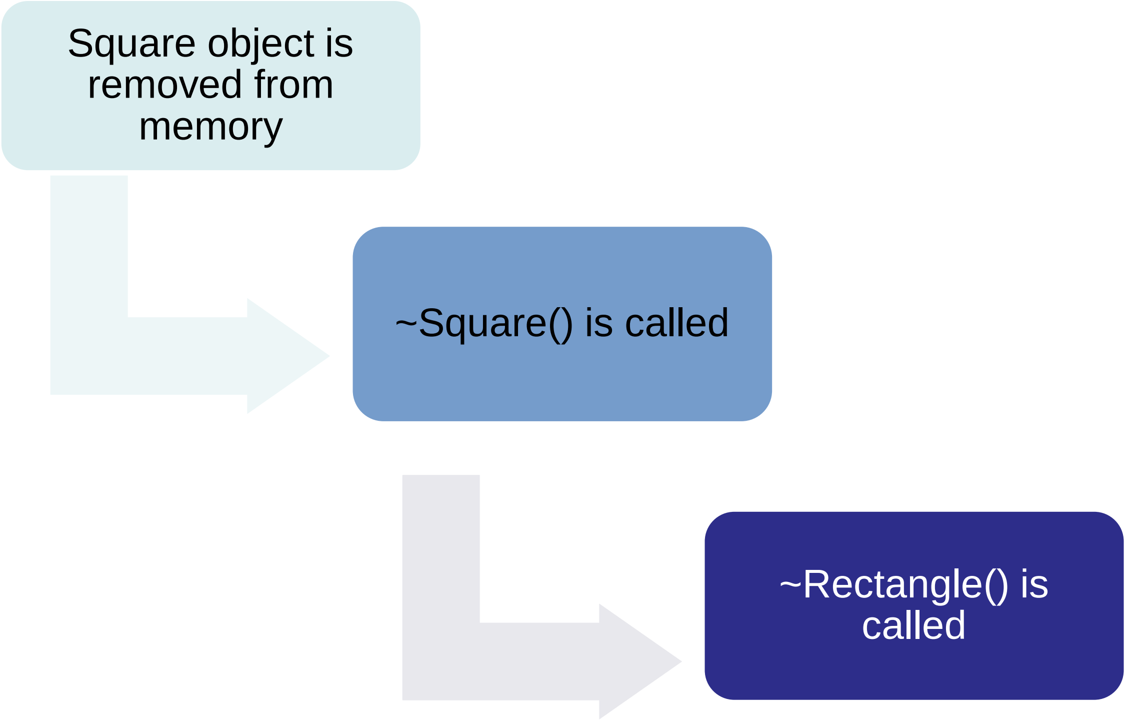
```
#include <iostream>

using namespace std;

#include “Square.h"

int main()
{
    Square sQ(4) ;

    // Uses the Rectangle Area() method!
    cout << sQ.Area() << endl ;

    return 0;
}
```

More on Destructors

- When a subclass object is removed from memory, its destructor is called as it is for any object.

- Its superclass destructor is than *also* called .

- Each subclass should only clean up its own problems and let superclasses clean up theirs.



Square object is removed from memory

~Square() is called

~Rectangle() is called

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