Introduction to C++: Part 2

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Tutorial Outline: Part 2

- References and Pointers
- Function Overloads
- Generic Functions
- Defining Classes
- Intro to the Standard Template Library

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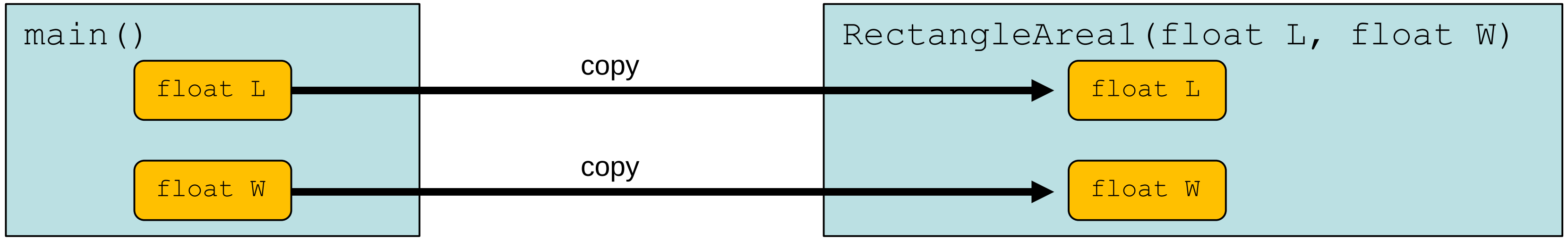
Pass by Value



- 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!

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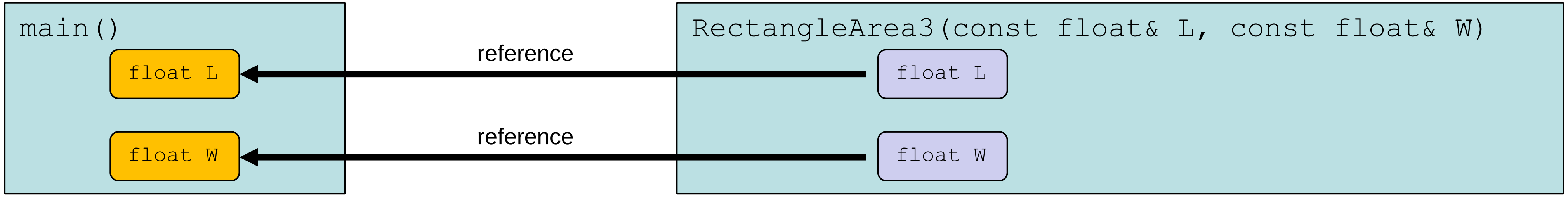
Pass by Reference



- *Pass by reference* behavior is triggered when the & character is used to modify the type of the argument.
- This is the type of behavior you see in Fortran, Matlab, Python, and others.
- 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().

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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…
  - 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.

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> "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

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Function overloading

- The same function can be implemented multiple times with different arguments.
- This allows for special cases to be handled, or specialized behavior for different types.
- cout and the << operator are an example of function overloading
  - << is just a function.

```
float sum(float a, float b) {
    return a+b ;
}

int sum(int a, int b) {
    return a+b ;
}
```

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Function overloading

- Overloaded functions are differentiated by their arguments and not the return type.
  - The number of arguments and their types can be varied.
- The compiler will decide which overload to use depending on the types of the arguments.
- If it can't decide a compile-time error will occur.

```
float sum(float a, float b) {
    return a+b ;
}

int sum(int a, int b) {
    return a+b ;
}
```

C++ Templates (aka generics)

- Generic code is code that works on multiple different data types but is only coded once.
- In C++ this is called a *template*.

- A C++ template is implemented entirely in a header file to define generic classes and functions.
- The actual code is generated **by the compiler** wherever the template is used in your code.
  - There is NO PENALTY when your code is running!
  - Function overloads are created automatically by the compiler.
- As a preview of how the C++ Standard Template Library works we'll walk thru some templates with NetBeans.

Sample template function

- The template is started with the keyword *template* and is told it'll handle a type which is referred to as *T* in the code.
  - Templates can be created with multiple different types, not limited to just one.
  - You don't have to use *T*, any non-reserved word will do.

```
template <typename T>
T sum_template (T a, T b) {
    return a+b ;
}


// Then call the function:
float x=1.0 ;
float y=2.0 ;
float z=sum_template<float>(x,y) ;
```

- When the compiler sees the call to the template function it will automatically generate a function that takes and returns float types.

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An Example

- Open the project *Overloads_and_templates*
- This is an example of simple function overloads and a template function.
- Let’s walk through it with the debugger.

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When to use function overloading and templates?

- When it makes your code easier to use, maintain, write, or debug!
  - From an academic scientific computing point of view, that is.
- These are more advanced C++ features. Mis-use can cause a lot of misery and confusion.
- These are worthwhile parts of the language to become comfortable for more experienced C++ programmers.

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Stepping back a bit

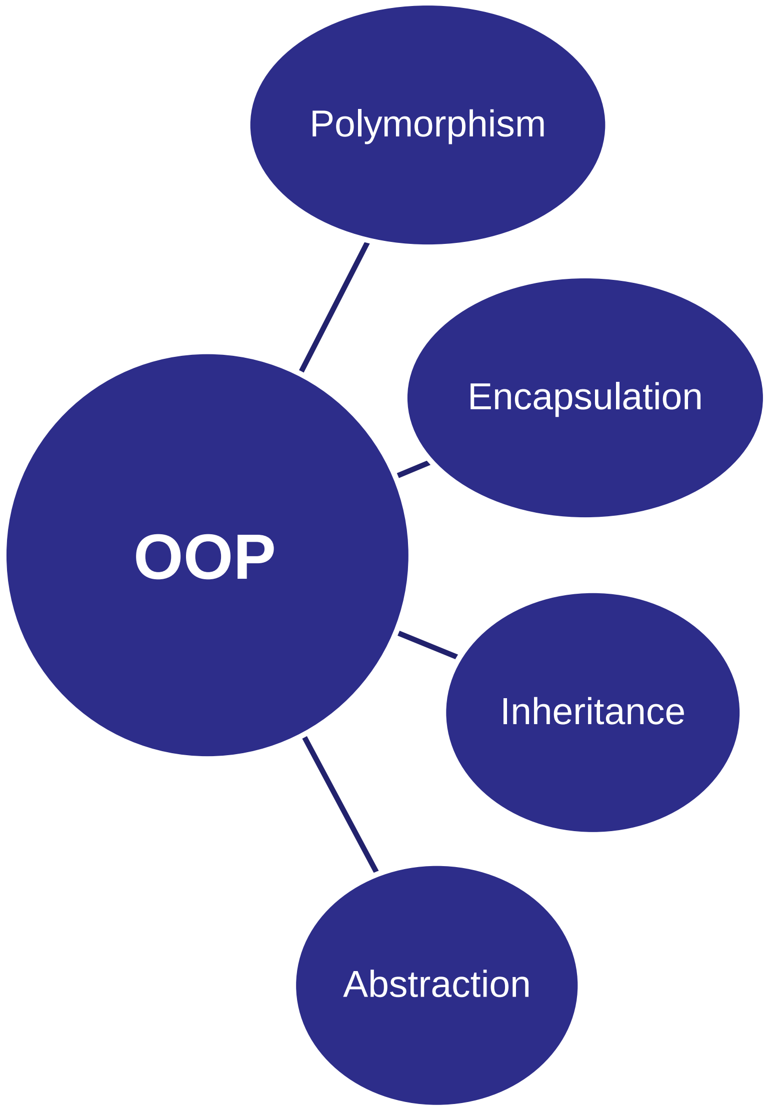
- Summary so far:
  - Basics of C++ syntax
  - Declaring variables
  - Defining functions
  - Using the IDE

- As an object-oriented language C++ supports a core set of OOP concepts.

- Knowing these concepts help with understanding some of the underlying design of the language and how it operates in your programs.

The formal concepts in OOP

- Object-oriented programming (OOP):
  - Defines *classes* to represent data and logic in a program. Classes can contain *members* (data) and *methods* (internal functions).
  - Creates *instances* of classes, aka *objects*, and builds the programs out of their interactions.
- The core concepts in addition to classes and objects are:
  - Encapsulation
  - Inheritance
  - Polymorphism
  - Abstraction



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Core Concepts

- Encapsulation
  - Bundles related data and functions into a class
- Inheritance
  - Builds a relationship between classes to share class members and methods
- Abstraction
  - The hiding of members, methods, and implementation details inside of a class.
- Polymorphism
  - The application of the same code to multiple data types

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Core Concepts in this tutorial

- Encapsulation
  - Demonstrated by writing some classes
- Inheritance
  - Write classes that inherit (re-use) the code from other classes.
- Abstraction
  - Design and setup of classes, discussion of the Standard Template Library (STL).
- Polymorphism
  - Function overloading, template code, and the STL

Tutorial Outline: Part 2

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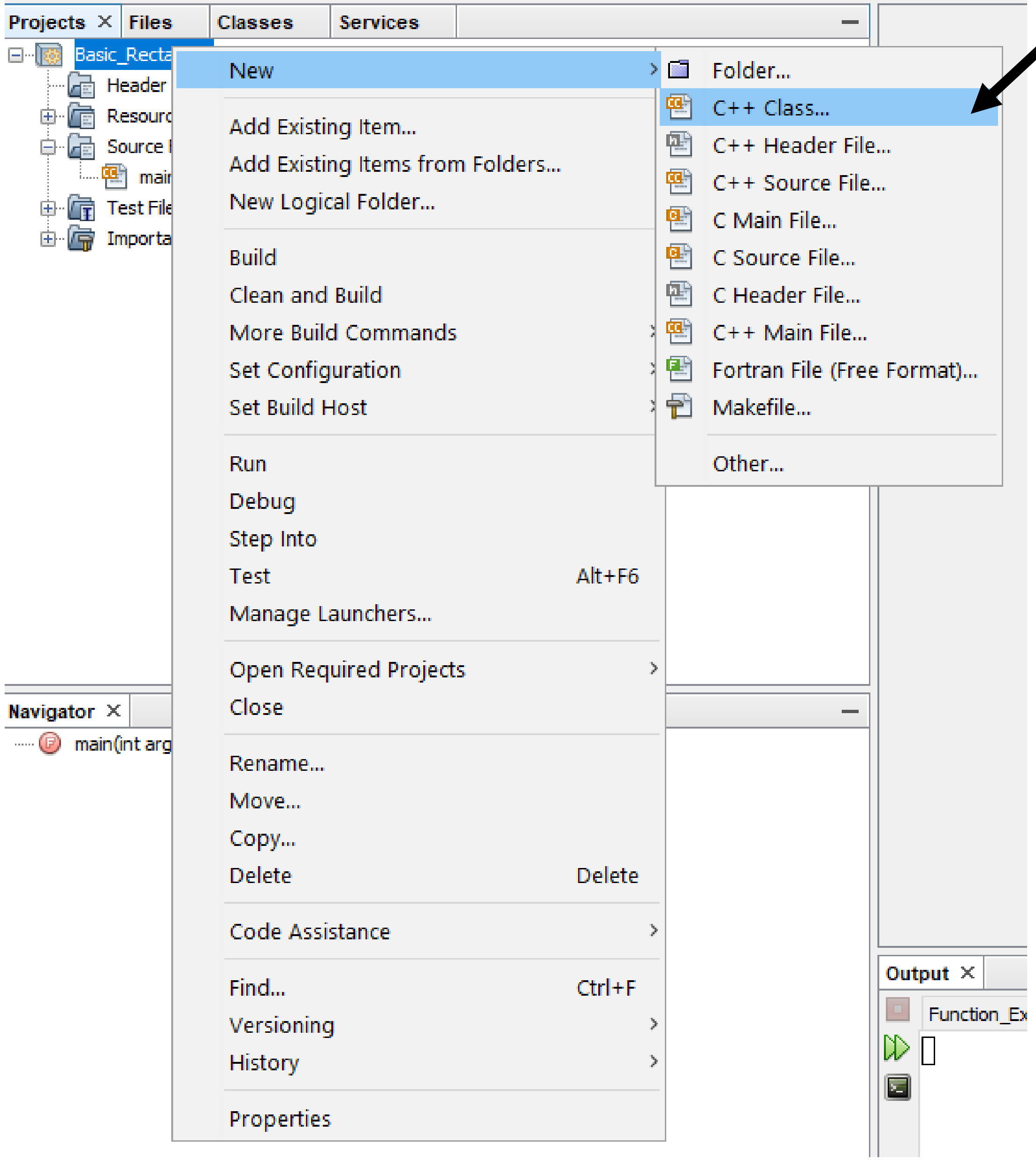
A first C++ class

- 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 NetBeans

- 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→C++ Class*



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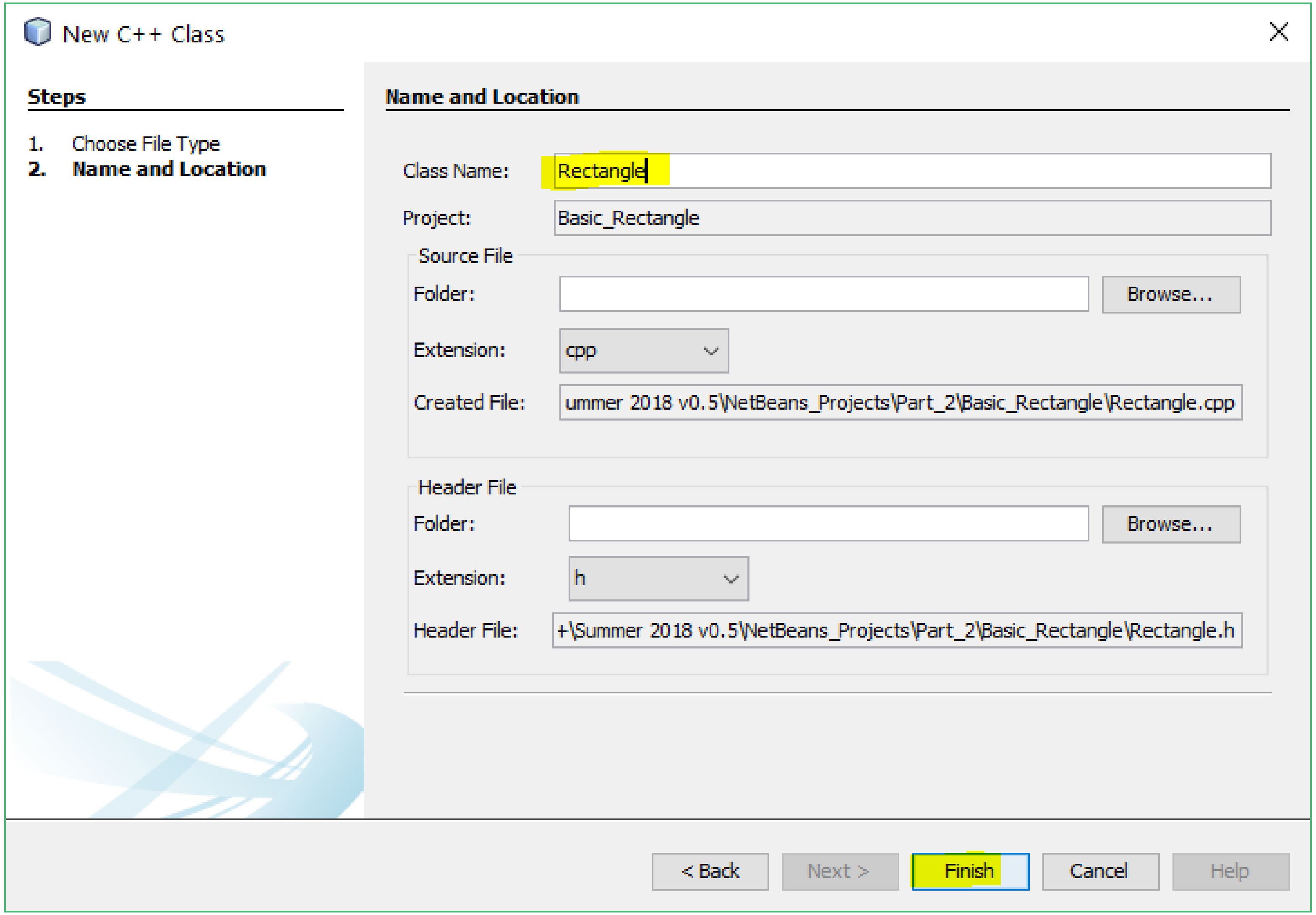
- Give it the name *Rectangle* and click the Finish button.

- Under the *Header Files* in the project open the new *Rectangle.h* file.



Rectangle.h

```cpp
#ifndef RECTANGLE_H
#define RECTANGLE_H

class Rectangle {
public:
    Rectangle();
    Rectangle(const Rectangle& orig);
    virtual ~Rectangle();
private:

};

#endif /* RECTANGLE_H */
```

Class name

Curly brace

keyword

Access restrictions

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(const Rectangle& orig);
  - A *copy* constructor. Used to create a new object that's a copy of another.

```
#ifndef RECTANGLE_H
#define RECTANGLE_H

class Rectangle {
public:
    Rectangle();
    Rectangle(const Rectangle& orig);
    virtual ~Rectangle();
private:

};

#endif /* RECTANGLE_H */
```

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Rectangle.cpp

Header file included

```
#include "Rectangle.h"

Rectangle::Rectangle() {
}

Rectangle::Rectangle(const Rectangle& orig) {
}

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

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 {}.

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

    float m_length ;
    float m_width ;

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

private:

};
```

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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

- Click on Rectangle.cpp and put the cursor at the end of the file.
- Type Ctrl-Space
- Select the Area() method.
- Repeat for ScaledArea().

- This creates a stub with necessary stuff filled in.

```
float Rectangle::Area() {

}

float Rectangle::ScaledArea(const float scale) {

}
```

Fill in the methods

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

```
float Rectangle::Area() {
    // Return the rectangle area
    return m_length * m_width ;
}

float Rectangle::ScaledArea(const float scale) {
    // Return the rectangle area multiplied by
    // parameter scale
}
```

- 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!

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Using the new class

- Open *main.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()
{
    Rectangle rT ;
    rT.m_width = 1.0 ;
}
```

```
#include "rectangle.h"

Rectangle::Rectangle()
{
    //ctor
}
```

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.

```cpp
#include <iostream>

using namespace std;

#include "rectangle.h"

int main()
{

    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 constructors.
- If members with default values get their value set in 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 NetBeans 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.

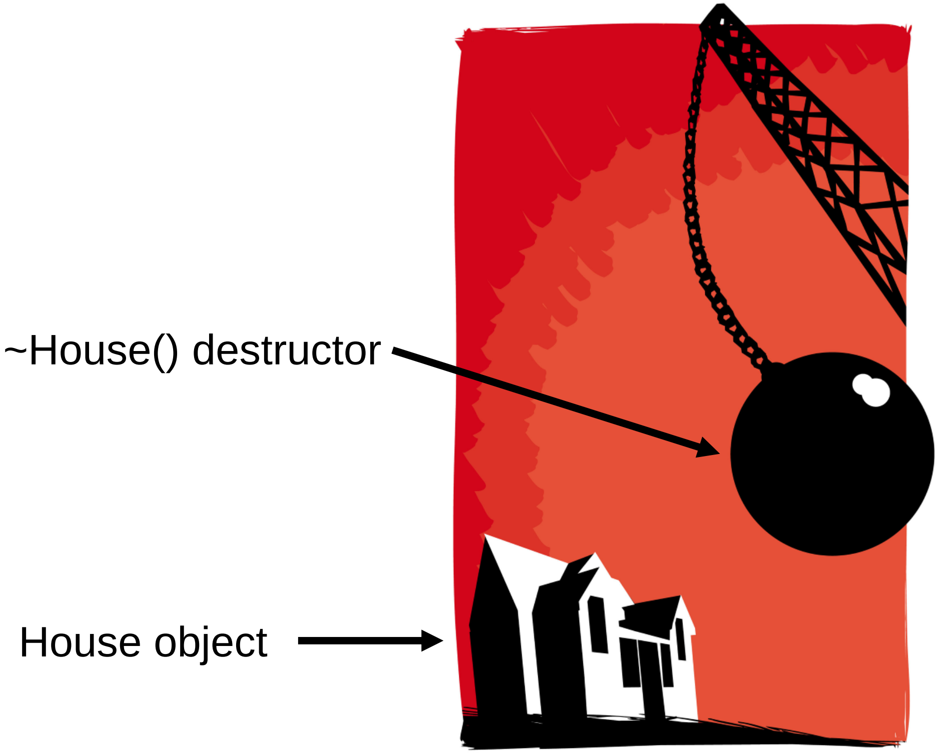
- A custom destructor is **always** needed when internal members in the class need special handling.
  - Examples: manually allocated memory, open files, hardware drivers, database or network connections, custom data structures, etc.

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.

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

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



Destructors

- Example:

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

        virtual ~Example() ;

        // A pointer to some memory
       // that will be allocated.
        float *values = nullptr ;
};
```

```
Example::Example(int count) {
        // Allocate memory to store "count"
        // floats.
        values = new float[count];
}

Example::~Example() {
        // The destructor must free this
        // memory. Only do so if values is not
       // null.
        if (values) {
                delete[] values ;
        }
}
```

Scope

- Scope is the region where a variable is valid.
- Constructors are called when an object is created.
- Destructors are only ever called implicitly.

```
int main() { // Start of a code block
        // in main function scope
        float x ;  // No constructors for built-in types
        ClassOne c1 ;    // c1 constructor ClassOne() is called.
        if (1){  // Start of an inner code block
              // scope of c2 is this inner code block
                ClassOne c2 ; //c2 constructor ClassOne() is called.
        }   // c2 destructor ~ClassOne() is called.
        ClassOne c3 ;  // c3 constructor ClassOne() is called.
}   // leaving program, call destructors for c3 and c1 ~ClassOne()
    // variable x: no destructor for built-in type
```

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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 ;
```

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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!

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The Standard Template Library

- The STL is a large collection of containers and algorithms that are part of C++.
  - It provides many of the basic algorithms and data structures used in computer science.

- As the name implies, it consists of generic code that you specialize as needed.

- The STL is:
  - Well-vetted and tested.
  - Well-documented with lots of resources available for help.

Containers

- There are 16 types of containers in the STL:

Container	Description
array	1D list of elements.
vector	1D list of elements
deque	Double ended queue
forward_list	Linked list
list	Double-linked list
stack	Last-in, first-out list.
queue	First-in, first-out list.
priority_queue	1st element is always the largest in the container

Container	Description
set	Unique collection in a specific order
multiset	Elements stored in a specific order, can have duplicates.
map	Key-value storage in a specific order
multimap	Like a map but values can have the same key.
unordered_set	Same as set, sans ordering
unordered_multiset	Same as multisetset, sans ordering
unordered_map	Same as map, sans ordering
unordered_multimap	Same as multimap, sans ordering

Algorithms

- There are 85+ of these.
  - Example: find, count, replace, sort, is_sorted, max, min, binary_search, reverse
- Algorithms manipulate the data stored in containers but is not tied to STL containers
  - These can be applied to your own collections or containers of data
- Example:

```
vector<int> v(3);                 // Declare a vector of 3 elements.
v[0] = 7;
v[1] = 3;
v[2] = v[0] + v[1];               // v[0] == 7, v[1] == 3, v[2] == 10
reverse(v.begin(), v.end()) ;  // v[0] == 10, v[1] == 3, v[2] == 7
```

- The implementation is hidden and the necessary code for reverse() is generated from templates at compile time.

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vector<T>

- A very common and useful class in C++ is the vector class. Access it with:

```
#include <vector>
```

- Vector has many methods:
  - Various constructors
  - Ways to iterate or loop through its contents
  - Copy or assign to another vector
  - Query vector for the number of elements it contains or its backing storage size.
- Example usage: `vector<float> my_vec ;`
- Or: `vector<float> my_vec(50) ;`

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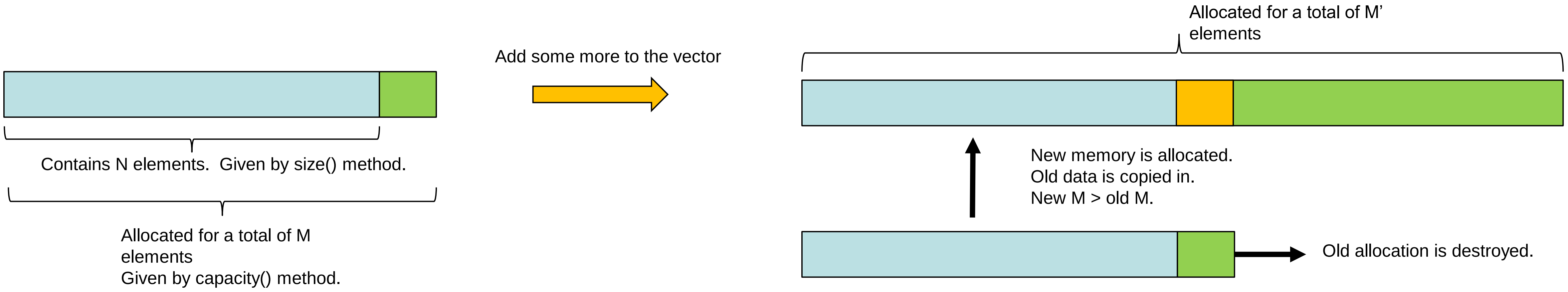
vector<T>

- Hidden from the programmer is the *backing store*
- Object oriented design in action!

- This is how the vector stores its data internally.



Destructors

- vector<t> can hold objects of any type:
  - Primitive (aka basic) types: int, float, char, etc.
  - Objects: string, your own classes, file stream objects (ex. ostream), etc.
  - Pointers: int*, string*, etc.
  - But NOT references!
- When a vector is destroyed:
  - If it holds primitive types or pointers it just deallocates its backing store.
  - If it holds objects it will call each object's destructor before freeing its backing store.

vector<t> with objects

- Select an object in a vector.
- The members and methods can be accessed directly.

- Elements can be accessed with brackets and an integer starting from 0.

```
// a vector with memory preallocated to
// hold 1000 objects.
vector<MyClass> my_vec(1000);

// Now make a vector with 1000 MyClass objects
// that are initialized using the MyClass constructor
vector<MyClass> my_vec2(1000,MyClass(arg1,arg2));

// Access an object's method.
my_vec2[100].some_method() ;
// Or a member
my_vec2[10].member_integer = 100 ;


// Clear out the entire vector
my_vec2.clear()
// but that might not re-set the backing store…
// Let's check the docs:
// http://www.cplusplus.com/reference/vector/vector/clear/
```

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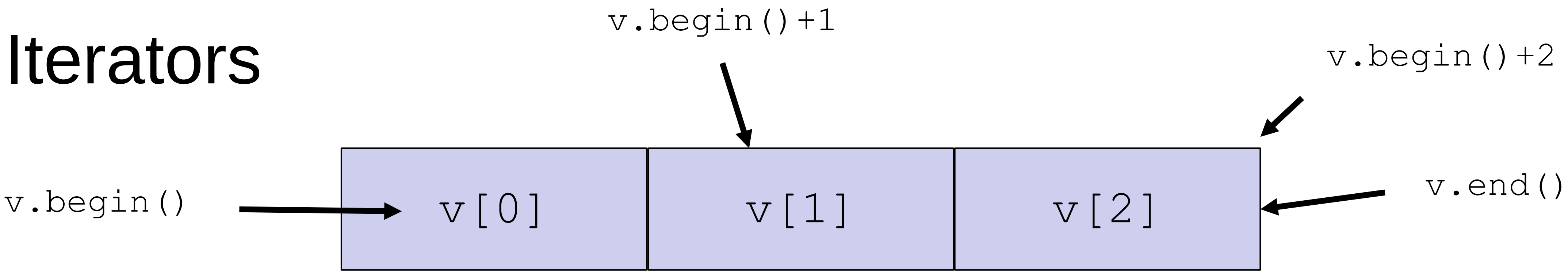
Looping

```
for (int index = 0 ; index < vec.size() ; ++index)
{
        // ++index means "add 1 to the value of index"
        cout << vec[index] << " " ;
}
```

- Loop with a “for” loop, referencing the value of vec using brackets.
- 1st time through:
  - index = 0
  - Print value at vec[0]
  - index gets incremented by 1
- 2nd time through:
  - Index = 1
  - Etc
- After last time through
  - Index now equal to vec.size()
  - Loop exits
- Careful! Using an out of range index will likely cause a memory error that crashes your program.
- Note we call the size() method on every iteration.

Iterators



- Iterators are generalized ways of keeping track of positions in a container.
- 3 types: forward iterators, bidirectional, random access
- Forward iterators can only be incremented (as seen here)
- Bidirectional can be added or subtracted to move both directions
- Random access can be used to access the container at any location

```
for (vector<int>::iterator itr = vec.begin(); itr != vec.end() ; ++itr)
{
      cout << *itr << " " ;
      // iterators are pointers!
}
```

Looping

- Loop with a “for” loop, referencing the value of vec using an **iterator** type.
- `vector<int>::iterator` is a type that iterates through a vector of int’s.
- 1st time through:
  - itr points at 1st element in vec
  - Print value pointed at by itr: *itr
  - itr is incremented to the next element in the vector
- Iterators are very useful C++ concepts. They work on any STL container!
  - **No need to worry about the # of elements!**
  - Exact iterator behavior depends on the type of container but they are guaranteed to always reach every value.

- Note we are now retrieving the end iterator at every loop to see if we’ve reached it: vec.end()

Looping

```
for (auto itr = vec.begin(), auto vec_end = vec.end() ; itr != vec_end ; ++itr)
{
        cout << *itr << " " ;
}
```

- Let the *auto* type asks the C++ compiler to figure out the iterator type automatically.

- An extra modification: Assigning the vec_end variable avoids calling vec.end() on every loop.

```
for(const auto &element : vec)
{
        cout << element << " " ;
}
```

Looping

- Another iterator-based loop: iterator behavior and accessing an element are handled automatically by the compiler
- Uses a reference so the element is not copied.
- The ***const auto &*** prevents changes to the element in the vector.
- Less typing == less chance for program bugs.

Iterator notes

- There is small performance penalty for using iterators…but are they safer to use.
- They allow substitution of one container for another (list<> for vector<>, etc.)
- With templates you can write a function that accepts any STL container type.

```
template<class T>
void dump_string(T &t)
{
    for( auto itr=t.begin() ; itr!=t.end() ; itr++) {
        cout<<*itr<<endl;
    }
}
```

```
list<float> lst ;
lst.push_back(-5.0) ;
lst.push_back(12.0) ;
vector<double> vec(2) ;
vec[0] = 1.0 ;
vec[1] = 2.0 ;

dump_string<list<float> >(lst) ;
dump_string<vector<double> >(lst) ;
```

BOSTON UNIVERSITY

STL Demo

- Open project *STL_Demo*

- Let’s walk through the functions with the debugger and see some vectors in action.