



## Lecture Participation Poll #21

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# Lecture 21: C++ Continued...

CSE 374: Intermediate  
Programming Concepts and  
Tools

# Administrivia

- HW 3 posted Friday -> Extra credit due date Wednesday Nov 25th @ 9pm
- **End of quarter due date Wednesday December 16<sup>th</sup> @ 9pm**

# Stack vs Heap

- Java
  - Stack: cannot stack-allocate objects
  - Heap: can only directly allocate pointers to objects, all objects are dynamically allocated in the heap
    - `new Thing(...)` calls constructor, returns heap allocated pointer
    - garbage collector frees allocated memory, outside of programmer responsibility
- C
  - Stack: can stack-allocate a struct, then initialize individual variables within stack as well, does not persist beyond single function
  - Heap: use `malloc` to dynamically allocate memory on the heap, must initialize data explicitly afterwards.
    - Must free this memory exactly once later.
    - `Malloc` returns untyped pointers.
- C++
  - Stack: can directly stack-allocate or call a constructor that allocates a pointer in the stack to object constructed.
  - Heap: use of `new` keyword allocates space in heap for object, returns pointer to object which if stored in local variable will be saved in the stack. Can also simultaneously allocate and initialize heap data EG: `new int(42)`
    - Like C must deallocate dynamically allocated memory, but must use `delete` instead of `free`.

# Allocating memory in C++

- In C

```
int* arr = (int*) malloc(sizeof(int) * 100); // returns non-typed pointer  
free(arr);
```

- In C++, we have more modern syntax:

- Array allocation

```
int* arr = new int[100];  
delete [] arr; // [] required to free array memory
```

- Non-array allocation

```
int* x = new int(4); // x stores the value 4  
delete x;
```



# new / delete

- To allocate on the heap using C++, you use the `new` keyword instead of `malloc()` from `stdlib.h`
  - You can use `new` to allocate an object (e.g. `new Point`)
  - You can use `new` to allocate a primitive type (e.g. `new int`)
- To deallocate a heap-allocated object or primitive, use the `delete` keyword instead of `free()` from `stdlib.h`
  - Don't mix and match!
    - Never `free()` something allocated with `new`
    - Never delete something allocated with `malloc()`
    - Careful if you're using a legacy C code library or module in C++

```
int* AllocateInt(int x) {  
    int* heapy_int = new int;  
    *heapy_int = x;  
    return heapy_int;  
}
```

```
Point* AllocatePoint(int x, int y) {  
    Point* heapy_pt = new Point(x,y);  
    return heapy_pt;  
}
```

heappoint.cpp

```
#include "Point.h"  
  
// definitions of AllocateInt() and AllocatePoint()  
  
int main() {  
    Point* x = AllocatePoint(1, 2);  
    int* y = AllocateInt(3);  
  
    cout << "x's x_coord: " << x->get_x() << endl;  
    cout << "y: " << y << ", *y: " << *y << endl;  
  
    delete x;  
    delete y;  
    return EXIT_SUCCESS;  
}
```

# Malloc vs New

|                          | <code>malloc()</code>                           | <code>new</code>   |
|--------------------------|---|--|
| What is it?              | a function                                      | an operator or keyword                                   |
| How often used (in C)?   | often   | never  |
| How often used (in C++)? | rarely  | often  |
| Allocated memory for     | anything  | arrays, structs, objects, primitives                     |
| Returns                  | a <code>void*</code><br><i>(should be cast)</i> | appropriate pointer type<br><i>(doesn't need a cast)</i> |
| When out of memory       | returns <code>NULL</code>                       | throws an exception                                      |
| Deallocating             | <code>free()</code>                             | <code>delete</code> or <code>delete []</code>            |

# Dynamically Allocated Arrays

- To dynamically allocate an array:

```
type* name = new type[size];
```

- calls default (zero-argument) constructor for each element
- convenient if there's a good default for initialization

- To dynamically deallocate an array:

- Use `delete[] name;`

- It is an *incorrect* to use “delete name;” on an array

- The compiler probably won't catch this, though (!) because it can't always tell if `name*` was allocated with `new type[size];` or `new type;`
- Especially inside a function where a pointer parameter could point to a single item or an array and there's no way to tell which!
- Result of wrong delete is undefined behavior

# Arrays Example (Primitives)

arrays.cpp

```
#include "Point.h"

int main() {
    int stack_int;
    int* heap_int = new int;
    int* heap_int_init = new int(12);

    int stack_arr[3];
    int* heap_arr = new int[3];

    int* heap_arr_init_val = new int[3]();
    int* heap_arr_init_lst = new int[3]{4, 5}; // C++11

    ...

    delete heap_int; //
    delete heap_int_init; //
    delete heap_arr; //
    delete[] heap_arr_init_val; //

    return EXIT_SUCCESS;
}
```



# Arrays Example (Objects)

arrays.cpp

```
#include "Point.h"

int main() {
    ...

    Point stack_pt(1, 2);
    Point* heap_pt = new Point(1, 2);

    Point* heap_pt_arr_err = new Point[2];

    Point* heap_pt_arr_init_lst = new Point[2]{{1, 2},
{3, 4}};

    // C++11
    ...

    delete heap_pt;
    delete[] heap_pt_arr_init_lst;

    return EXIT_SUCCESS;
}
```

# Pointers in C++

- Work the same as in C, hooray!
- A **pointer** is a variable containing an address
  - Modifying the pointer *doesn't* modify what it points to, but you can access/modify what it points to by *dereferencing*

```
int main(int argc, char** argv) {  
    int x = 5, y = 10;  
    int* z = &x;  
  
    *z += 1; // sets x to 6  
    x += 1; // sets x (and *z) to 7  
  
    z = &y; // sets z to the address of y  
    *z += 1; // sets y (and *z) to 11  
  
    return EXIT_SUCCESS;  
}
```

# References in C++

- A **reference** is an alias for another variable
  - *Alias*: another name that is bound to the aliased variable
  - Mutating a reference *is* mutating the aliased variable
  - Introduced in C++ as part of the language

```
int main(int argc, char** argv) {
    int x = 5, y = 10;
    int& z = x; // binds the name "z" to x

    z += 1; // sets z (and x) to 6
    x += 1; // sets x (and z) to 7

    z = y; // sets z (and x) to the value of y
    z += 1; // sets z (and x) to 11

    return EXIT_SUCCESS;
}
```

# Pass by Reference

## C++ allows you to use real **pass-by-reference**

- Client passes in an argument with normal syntax
  - Function uses reference parameters with normal syntax
  - Modifying a reference parameter modifies the caller's argument!

```
void swap(int& x, int& y) {
    int tmp = x;
    x = y;
    y = tmp;
}

int main(int argc, char** argv) {
    int a = 5, b = 10;

    swap(a, b);
    cout << "a: " << a << "; b: " << b << endl;
    return EXIT_SUCCESS;
}
```

- In C all function arguments are copies
- pointer arguments pass a copy of the address value, original values will be unaffected by changes to parameter

- A stylistic choice, not mandated by the C++ language
- Google C++ style guide suggests:
  - Input parameters:
    - Either use values (for primitive types like int or small structs/objects)
    - Or use const references (for complex struct/object instances)
  - Output parameters:
    - Use unchangeable pointers referencing changeable data
  - Ordering:
    - List input parameters first, then output parameters last

# Structs in C vs Classes in C++

- In C, a struct can only contain data fields
  - No methods and all fields are always accessible
- In C++, struct and class are (nearly) the same!
  - Both can have methods and member visibility (public/private/protected)
  - Minor difference: members are **default *public*** in a struct and **default *private*** in a class
  - structs need to allocate heap memory so object will persist
- Common style convention:
  - Use struct for simple bundles of data
  - Use class for abstractions with data + functions

# Classes in C++

MyClass.h

## ■ Unlike C structs

- Class definition is part of interface and should go in .h file
  - Private members still must be included in definition (!)
- Typically put member function definitions into companion .cpp file with implementation details
  - Common exception: setter and getter methods
- These files can also include non-member functions that use the class

## ■ Like java

- Fields & methods, static vs instance, constructors
- method overloading (functions, operators and constructors)

## ■ Not quite like Java

- access-modifier (eg private) syntax
- declaration separate from implementation (like C)
- funny constructor syntax, default parameters (eg, ...=0)

## ■ Not at all like Java

- you can name files anything you want
  - Typically a combination of Name.cpp and Name.h for class Name
- destructors and copy constructors
- virtual vs non-virtual

```
namespace mynamespace {
    class MyClass {
        private:
            type fieldOne;
            type fieldTwo;

        public:
            MyClass();
            MyClass(type, type);

        public:
            type functionOne() {
                // function definition
            }
            type functionTwo() {
                // function definition
            }
    };
}
```



# Defining Classes in C++

- Class Definition (in a .h file)

**Name.h**

```
class Name {  
    public:  
        // public member definitions & declarations go here  
  
    private:  
        // private member definitions & declarations go here  
}; // close class Name
```

- Class Member Definition (in a .cpp file)

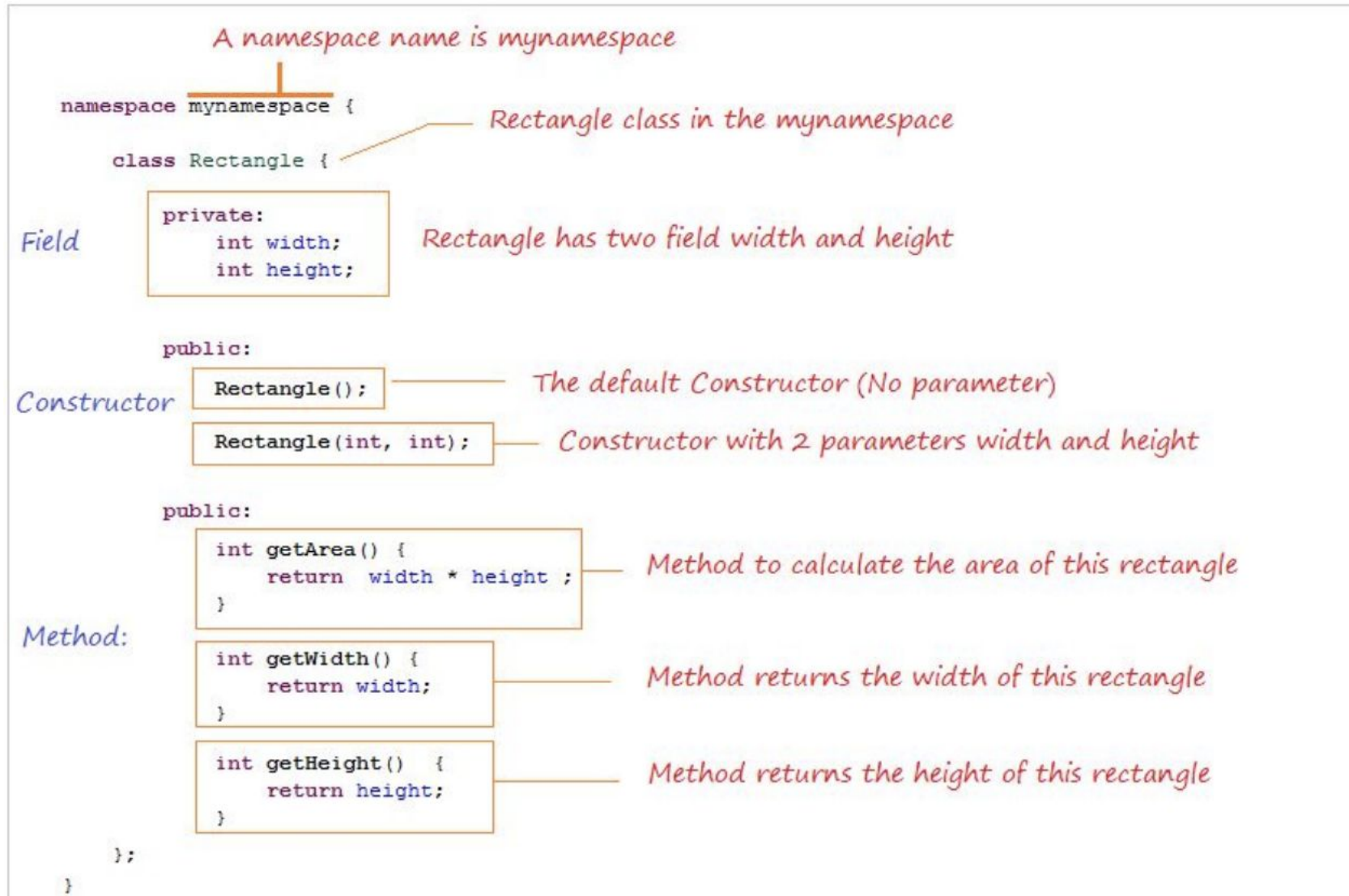
**Name.cpp**

```
returnType ClassName::MethodName(type1 param1, ..., typeN paramN) {  
    // body statements  
}
```

- Members can be functions (methods) or data (variables)
- (1) *define* within the class definition OR (2) *declare* within the class definition and then *define* elsewhere

# Anatomy of C++ Class

Rectangle.h



# Access Control

- Access modifiers for members:

- public: accessible to *all* parts of the program
- private: accessible to the member functions of the class
  - Private to *class*, not object instances
- protected: accessible to member functions of the class and any *derived* classes (subclasses – more to come, later)

- Reminders:

- Access modifiers apply to *all* members that follow until another access modifier is reached
- If no access modifier is specified, struct members default to public and class members default to private

# Class Definition (Member declaration)

## Point.h

```
#ifndef POINT_H_
#define POINT_H_

class Point {
public:
    Point(const int x, const int y); // constructor
    int get_x() const { return x_; } // inline member function
    int get_y() const { return y_; } // inline member function
    double Distance(const Point& p) const; // member function
    void SetLocation(const int x, const int y); // member
function

private:
    int x_; // data member
    int y_; // data member
}; // class Point

#endif // POINT_H_
```

# Class Member Definition

## Point.cpp

```
#include <cmath>
#include "Point.h"

Point::Point(const int x, const int y) {
    x_ = x;
    this->y_ = y; // "this->" is optional unless name conflicts
}

double Point::Distance(const Point& p) const {
    // We can access p's x_ and y_ variables either through the
    // get_x(), get_y() accessor functions or the x_, y_ private
    // member variables directly, since we're in a member
    // function of the same class.
    double distance = (x_ - p.get_x()) * (x_ - p.get_x());
    distance += (y_ - p.y_) * (y_ - p.y_);
    return sqrt(distance);
}

void Point::SetLocation(const int x, const int y) {
    x_ = x;
    y_ = y;
}
```

# Class Usage

## usePoint.cpp

```
#include <iostream>
#include "Point.h"

using namespace std;

int main(int argc, char** argv) {
    Point p1(1, 2); // allocate a new Point on the Stack
    Point p2(4, 6); // allocate a new Point on the Stack

    cout << "p1 is: (" << p1.get_x() << ", ";
    cout << p1.get_y() << ")" << endl;

    cout << "p2 is: (" << p2.get_x() << ", ";
    cout << p2.get_y() << ")" << endl;

    cout << "dist : " << p1.Distance(p2) << endl;
    return 0;
}
```

To allocate on the heap use the “new” keyword  
`Point* p1 = new Point(1, 2);`



# Constructors in C++

- A constructor (ctor) initializes a newly-instantiated object

- A class can have multiple constructors that differ in parameters
  - Which one is invoked depends on *how* the object is instantiated

- Written with the class name as the method name:

```
Point(const int x, const int y);
```

- C++ will automatically create a synthesized default constructor if you have *no* user-defined constructors
  - Takes no arguments and calls the default ctor on all non-“plain old data” (non-POD) member variables
  - Synthesized default ctor will fail if you have non-initialized const or reference data members

- 4 different types of constructors

- default constructor – takes zero arguments. If you don't define any constructors the compiler will generate one of these for you (just like Java)
- copy constructor – takes a single parameter which is a *const reference* (`const T&`) to another object of the same type, and initializes the fields of the new object as a *copy* of the fields in the referenced object
- user-defined constructors – initialize fields and take whatever arguments you specify
- conversion constructors – implicit, take a single argument. If you want a single argument constructor that is not implicit must use the keyword “explicit” like: `explicit String(const char* raw);`

# Synthesized Default Constructor

## SimplePoint.h

```
class SimplePoint {
public:
    // no constructors declared!
    int get_x() const { return x_; } // inline member function
    int get_y() const { return y_; } // inline member function
    double Distance(const SimplePoint& p) const;
    void SetLocation(int x, int y);

private:
    int x_; // data member
    int y_; // data member
}; // class SimplePoint
```

## SimplePoint.cpp

```
#include "SimplePoint.h"

... // definitions for Distance() and SetLocation()

int main(int argc, char** argv) {
    SimplePoint x; // invokes synthesized default constructor
    return EXIT_SUCCESS;
}
```

# Synthesized Default Constructor

- If you define *any* constructors, C++ assumes you have defined all the ones you intend to be available and will *not* add any others

```
#include "SimplePoint.h"

// defining a constructor with two arguments
SimplePoint::SimplePoint(const int x, const int y) {
    x_ = x;
    y_ = y;
}

void foo() {
    SimplePoint x;           // compiler error: if you define any
                           // ctors, C++ will NOT synthesize a
                           // default constructor for you.

    SimplePoint y(1, 2);    // works: invokes the 2-int-arguments
                           // constructor
}
```

# Overloading Constructors

```
#include "SimplePoint.h"

// default constructor
SimplePoint::SimplePoint() {
    x_ = 0;
    y_ = 0;
}

// constructor with two arguments
SimplePoint::SimplePoint(const int x, const int y) {
    x_ = x;
    y_ = y;
}

void foo() {
    SimplePoint x;           // invokes the default constructor
    SimplePoint y(1, 2);    // invokes the 2-int-arguments ctor
    SimplePoint a[3];       // invokes the default ctor 3 times
}
```

# Copy Constructors

- C++ has the notion of a copy constructor (cctor)
  - Used to create a new object as a copy of an existing object
  - Initializer lists can also be used in copy constructors
  - initializes a new bag of bits (new variable or parameter)
  - assignment (=) replaces an existing value with a new one
    - may need to clean up old state (free heap data?)

```
Point::Point(const int x, const int y) : x_(x), y_(y) { }

// copy constructor
Point::Point(const Point& copyme) {
    x_ = copyme.x_;
    y_ = copyme.y_;
}

void foo() {
    Point x(1, 2); // invokes the 2-int-arguments constructor

    Point y(x); // invokes the copy constructor
    Point z = y; // also invokes the copy constructor
}
```

# Synthesized Copy Constructor

- If you don't define your own copy constructor, C++ will synthesize one for you
  - It will do a *shallow* copy of all of the fields (*i.e.* member variables) of your class
  - Sometimes the right thing; sometimes the wrong thing

```
#include "SimplePoint.h"

... // definitions for Distance() and SetLocation()

int main(int argc, char** argv) {
    SimplePoint x;
    SimplePoint y(x); // invokes synthesized copy constructor
    ...
    return EXIT_SUCCESS;
}
```



# When Do Copies Happen?

- The copy constructor is invoked if:

- You *initialize* an object from another object of the same type:

```
Point x;           // default ctor
Point y(x);       // copy ctor
Point z = y;      // copy ctor
```

- You pass a non-reference object as a value parameter to a function:

```
void foo(Point x) { ... }

Point y;           // default ctor
foo(y);           // copy ctor
```

- You return a non-reference object value from a function:

```
Point foo() {
    Point y;       // default ctor
    return y;     // copy ctor
}
```

# Initialization Lists

- C++ lets you *optionally* declare an initialization list as part of a constructor definition
  - Initializes fields according to parameters in the list
  - The following two are (nearly) identical:

```
Point::Point(const int x, const int y) {  
    x_ = x;  
    y_ = y;  
    std::cout << "Point constructed: (" << x_ << ", ";  
    std::cout << y_ << ")" << std::endl;  
}
```

```
// constructor with an initialization list  
Point::Point(const int x, const int y) : x_(x), y_(y) {  
    std::cout << "Point constructed: (" << x_ << ", ";  
    std::cout << y_ << ")" << std::endl;  
}
```

# Initialization vs Construction

- Data members in initializer list are initialized in the order they are defined in the class, not by the initialization list ordering
  - Data members that don't appear in the initialization list are *default initialized/constructed* before body is executed
- Initialization preferred to assignment to avoid extra steps
  - Never mix the two styles

```
class Point3D {
public:
    // constructor with 3 int arguments
    Point3D(const int x, const int y, const int z) : y_(y), x_(x) {
        z_ = z;
    }

private:
    int x_, y_, z_; // data members
}; // class Point3D
```

*First, initialization list is applied.*

*Next, constructor body is executed.*

# Destructors

- C++ has the notion of a destructor (dtor)
  - Like “free” in c. In fact, invokes free under the hood to clean up when freeing memory
  - Invoked automatically when a class instance is deleted, goes out of scope, etc. (even via exceptions or other causes!)
    - Do not need to call destructors explicitly
  - Place to put your cleanup code – free any dynamic storage or other resources owned by the object
  - Standard C++ idiom for managing dynamic resources
    - Slogan: “*Resource Acquisition Is Initialization*” (RAII)

```
Point::~~Point() { // destructor
    // do any cleanup needed when a Point object goes away
    // (nothing to do here since we have no dynamic resources)
}
```

# Nonmember Functions

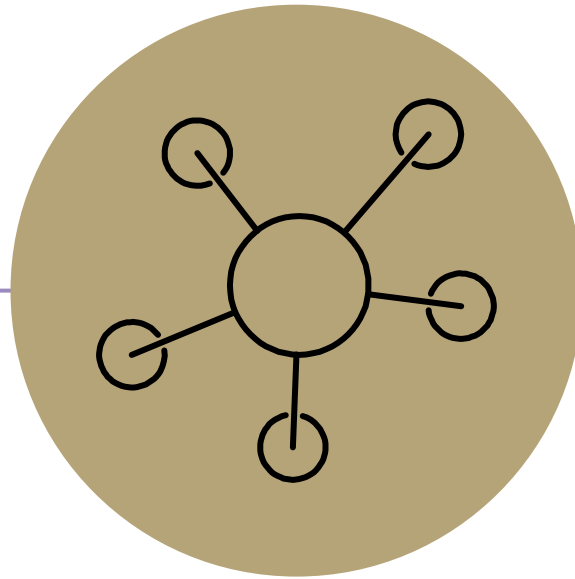
- “Nonmember functions” are just normal functions that happen to use some class
  - Called like a regular function instead of as a member of a class object instance
  - These do *not* have access to the class’ private members
- Useful nonmember functions often included as part of interface to a class
  - Declaration goes in header file, but *outside* of class definition
- A class can give a nonmember function (or class) access to its non-public members by declaring it as a **friend** within its definition
  - Not a class member, but has access privileges as if it were
  - friend functions are usually unnecessary if your class includes appropriate “getter” public functions

```
class Complex {  
    ...  
    friend std::istream& operator>>(std::istream& in, Complex&  
a);  
    ...  
}; // class Complex
```

**Complex.h**

**Complex.cpp**

```
std::istream& operator>>(std::istream& in, Complex& a)  
{  
    ...  
}
```



# Questions



# RAII

- "Resource Acquisition is Initialization"
- Design pattern at the core of C++
- When you create an object, acquire resources
  - Create = constructor
  - Acquire = allocate (e.g. memory, files)
- When the object is destroyed, release resources
  - Destroy = destructor
  - Release = deallocate
- When used correctly, makes code safer and easier to read

```
char* return_msg_c() {  
    int size = strlen("hello") + 1;  
    char* str = malloc(size);  
    strncpy(str, "hello", size);  
    return str;  
}
```

```
std::string return_msg_cpp() {  
    std::string str("hello");  
    return str;  
}
```

```
using namespace std;  
char* s1 = return_msg_c();  
cout << s1 << endl;  
string s2 = return_msg_cpp();  
cout << s2 << endl;
```

# Compiler Optimization

- The compiler sometimes uses a “return by value optimization” or “move semantics” to eliminate unnecessary copies
  - Sometimes you might not see a constructor get invoked when you might expect it

```
Point foo() {  
    Point y;           // default ctor  
    return y;         // copy ctor? optimized?  
}  
  
Point x(1, 2);        // two-ints-argument ctor  
Point y = x;         // copy ctor  
Point z = foo();     // copy ctor? optimized?
```

# Namespaces

- Each namespace is a separate scope

- Useful for avoiding symbol collisions!

- Namespace definition:

```
- namespace name {  
    // declarations go here  
}
```

- Doesn't end with a semi-colon and doesn't add to the indentation of its contents

- Creates a new namespace name if it did not exist, otherwise *adds to the existing namespace (!)*

- This means that components (e.g. classes, functions) of a namespace can be defined in multiple source files

- Namespaces vs classes

- They seems somewhat similar, but classes are *not* namespaces:

- There are no instances/objects of a namespace; a namespace is just a group of logically-related things (classes, functions, etc.)

- To access a member of a namespace, you must use the fully qualified name (i.e. `nsp_name::member`)

- Unless you are using that namespace

- You only used the fully qualified name of a class member when you are defining it outside of the scope of the class definition

# Const

- C++ introduces the “const” keyword which declares a value that cannot change
- `const int CURRENT_YEAR = 2020;`