Poll Everywhere

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Vibe Check: How are you feeling about C++ right now?

- You can keep this poll open and change your answer as the lecture goes on!

Systems Programming

C++ Classes, Constructors, and Copies

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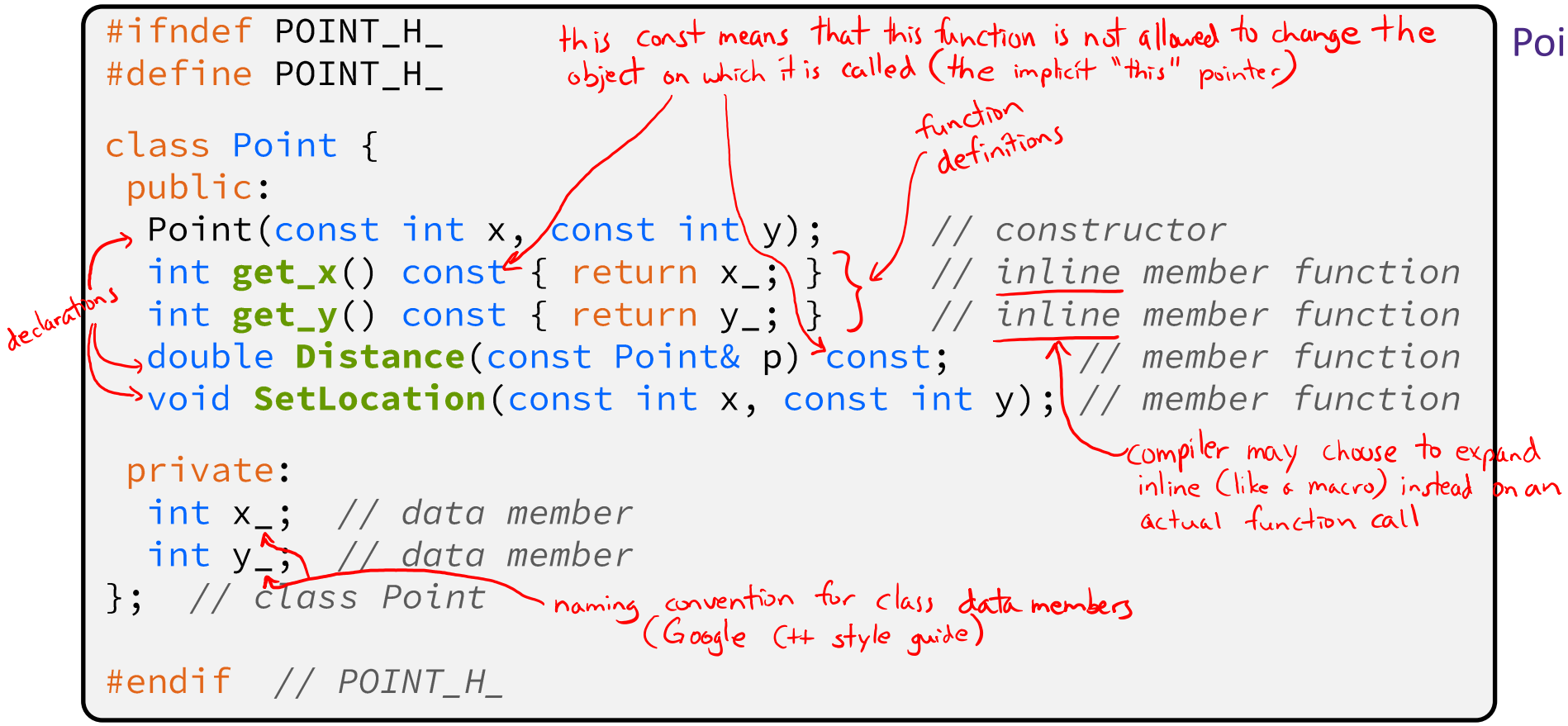
Relevant Course Information

- Exercise 6 released today, due Wednesday
  - Write a class in C++ (today's topic!) and Makefile
- Homework 2 due this coming Thursday (10/29)
  - File system crawler, indexer, and search engine
  - "Check-In 1 (HW2)" activity due Tuesday (10/27)
- Midterm is Monday, November 2 from 5:30–6:40 PM
  - Located in GUG 220 or ARC 147, depending on your quiz section
  - Ed post with details forthcoming
  - Practice midterms and solutions on the course website
  - Midterm review (hybrid) on Friday (10/30) from 4:30–6:20 PM

Class Definition (.h file)



Point.h

Class Member Definitions (.cc file)

Point.cc

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

Point::Point(const int x, const int y) {
  // BAD STYLE to mix-and-match "this->var_" and "var_"
  x_ = x;
  this->y_ = y;  // "this->" is optional unless name conflicts
}

double Point::Distance(const Point& p) const {
  // In a member function of the same class, can access p's x_
  // and y_ members directly or using the get_x()/get_y()
  // accessor functions (BAD STYLE to mix-and-match, though).
  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 (`.cc` file)

usepoint.cc

```
#include "Point.h"

#include <iostream>
#include <cstdlib>

using std::cout;
using std::endl;

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 EXIT_SUCCESS;
}
```

calls defined constructor

"dot notation" used for member functions

`struct` vs. `class`

- 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`

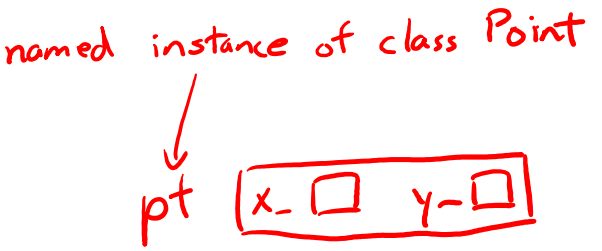
- Common style convention:
  - Use `struct` for simple bundles of data ← public data members with names like x, y
  - Use `class` for abstractions with data + functions ↑ private data members with names like x_, y_

Memory Diagrams for Objects

- An **object** is an instance of a class that maintains its *state* independently of other objects
  - This state is the collection of its data members
  - Conceptually, an object acts like a collection of data fields (plus class metadata)
    - Layout is *not* specified or guaranteed, unlike structs in C

- Drawn out as variables within variables:

```
class Point {
 ...

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



Lecture Outline (1/4)

- **Constructors**
- Copy Constructors
- Assignment
- Destructors

Constructors

- A constructor (ctor) initializes a newly-instantiated object
  - Written with the class name as the method name:
    e.g., `Point(const int x, const int y);`
  - A class can have multiple constructors that differ in parameters
  - A constructor *must* be invoked when creating a new instance of an object – which one depends on *how* the object is instantiated
- 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

created for you

zero-argument

Synthesized Default Constructor Example

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
```

default behavior → primitives: just allocate space (mystery data)
default behavior → objects: default construct

SimplePoint.cc

```
#include "SimplePoint.h"

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

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

(main) x [x_ ? y_ ?]

Synthesized Default Constructor

- If you define *any* constructors, C++ will *not* add a synthesized default constructor
  - This doesn't prevent it from synthesizing other methods (*e.g.*, copy constructor)

```
#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
}
```

added, so no synthesized def ctor

Multiple Constructors (overloading)

```
#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
}
```

added, so now there is a def. ctor

int: a [? | ? | ?]

SimplePoint: a [x_[0] y_[0] | x_[0] y_[0] | x_[0] y_[0]]

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;
}
```

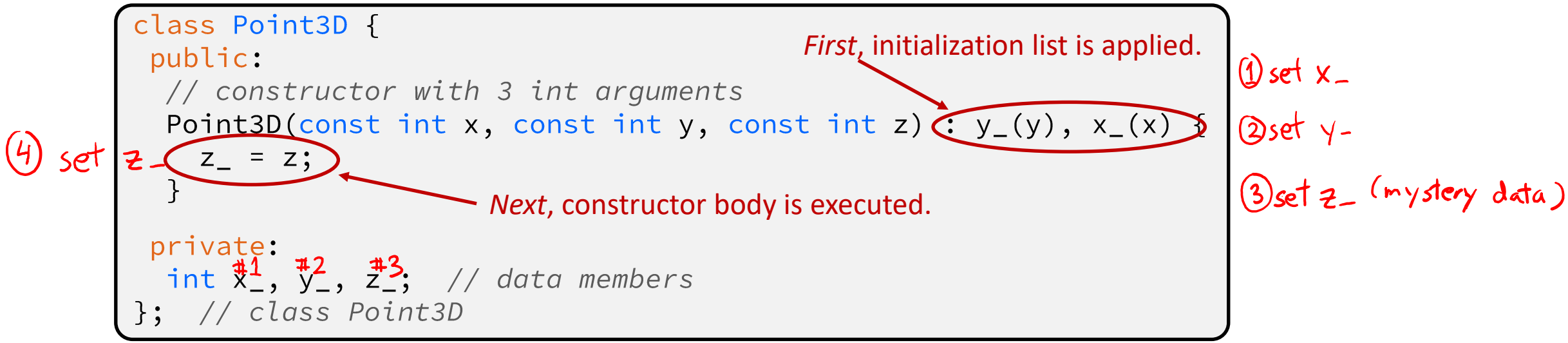
```
// constructor with an initialization list
Point::Point(const int x, const int y) : x_(x), y_(y) {
  std::cout << "Point constructed: (" << x_ << ",";
  std::cout << y_<< ")" << std::endl;
}
```

body can be empty { }

can be expressions

member names

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
  - Real code should never mix the two styles

Lecture Outline (2/4)

- Constructors
- **Copy Constructors**
- Assignment
- Destructors

Copy Constructors

- C++ has the notion of a copy constructor (cctor)
  - Used to initialize a new object "as a copy" of an existing object
  - Initializer lists can also be used in copy constructors (preferred)

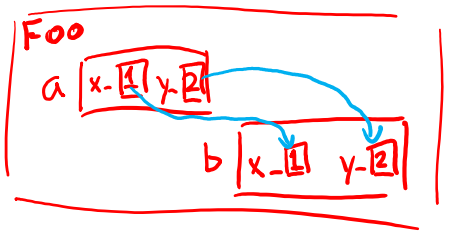
```
Point::Point(const int x, const int y) : x_(x), y_(y) { }

// copy constructor
Point::Point(const Point& orig) x_(orig.x_), y_(orig.y_) { }

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

  Point b(a);    // invokes the copy constructor
                 // could also be written as "Point b = a;"
}
```

reference to object of same class

alias binds to object

constructing from existing object, so we use the copy ctor

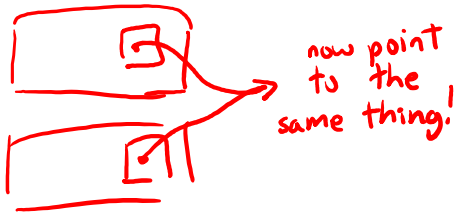
a ctor must be called because the object didn't exist previously



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 (can be problematic with pointers)
  - Sometimes the right thing; sometimes the wrong thing
  - This is separate from non-copy constructors

```
#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
```

pass-by-value of an object

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

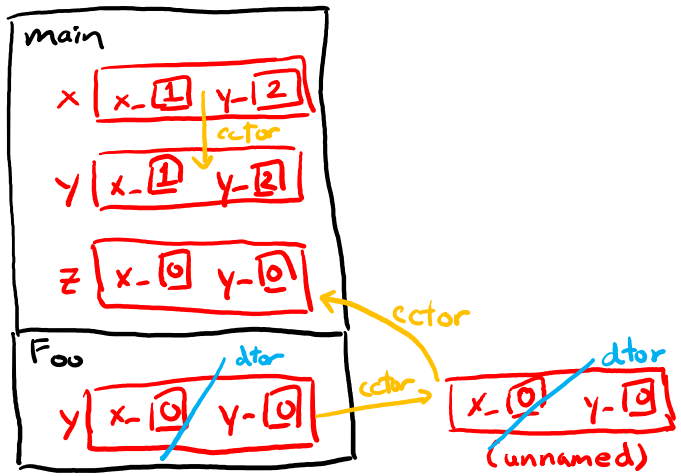
```
Point Foo() {
  Point y;     // default ctor
  return y;    // copy ctor
}
```

Compiler Optimization: "Copy Elision"

"Eliminate" → "elide" → "elision"

- The compiler may eliminate unnecessary copies
  - You might not see a constructor get invoked when you expect it
- Most common is when an object is returned by value (*i.e.*, copied) and passed into *another* copy constructor
  - Since C++17, this kind of copy elision is **guaranteed**

```
Point Foo() {
  Point y;          // default ctor
  return y;         // copy ctor? optimized?
}

int main(int argc, char* argv[]) {
  Point x(1, 2);    // two-ints-argument ctor
  Point y = x;      // copy ctor
  Point z = Foo();  // copy ctor? optimized?
}
```



Lecture Outline (3/4)

- Constructors
- Copy Constructors
- **Assignment**
- Destructors

Assignment Isn't Construction

- "=" is the assignment operator
  - Assigns values to an *existing, already constructed* object

```
Point w;          // default ctor
Point x(1, 2);    // two-ints-argument ctor
Point y(x);       // copy ctor
Point z = w;      // copy ctor (z did not exist)
y = x;            // assignment operator (y exists)
```

method operator=( )

Overloading the "=" Operator

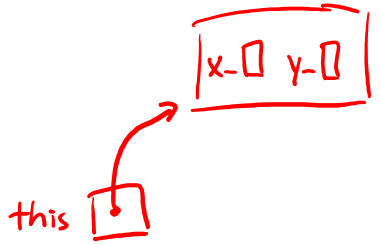
- You can choose to define the "=" operator
  - But there are some rules you should follow:

```
Point& Point::operator=(const Point& rhs) {
  if (this != &rhs) {  // (1) always check against this
    x_ = rhs.x_;
    y_ = rhs.y_;
  }
  return *this;        // (2) always return *this from op=
}

Point a;          // default constructor
a = b = c;        // works because = return *this
a = (b = c);      // equiv. to above (= is right-associative)
(a = b) = c;      // "works" because = returns a non-const
```

more important when dealing with dynamically allocated memory

returns reference to class object (allows for chaining)

a.operator=(b.operator=(c))



Synthesized Assignment Operator

- If you don't define the assignment operator, 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

Usually wrong whenever class owns a resource (e.g., dynamically allocated data)

```
#include "SimplePoint.h"

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

int main(int argc, char* argv[]) {
  SimplePoint x;
  SimplePoint y(x);
  y = x;           // invokes synthesized assignment operator
  return EXIT_SUCCESS;
}
```

Lecture Outline (4/4)

- Constructors
- Copy Constructors
- Assignment
- **Destructors**

Destructors

- C++ has the notion of a destructor (dtor)
  - Invoked automatically when a class instance is deleted, goes out of scope, etc. (even via exceptions or other causes!)
  - Place for your cleanup code – free any resources owned by the object
    - Standard C++ idiom for managing dynamic resources: "*Resource Acquisition Is Initialization*" (**RAII**)
  - After destructor body finishes, destruct members in reverse order of declaration (*i.e.*, reverse of initialization list)

tilde — no parameters

```
Point::~Point() {   // destructor
  // Do any cleanup needed when a Point object goes away.
  // Nothing to do here, but what if we had dynamic resources?
}
```

executed in reverse order as ctor: ① body of dtor
② destruct members in reverse order of declaration

Destructor Example

FileDescriptor.h

```
class FileDescriptor {
 public:
  FileDescriptor(char* file) {          // Constructor
    fd_ = open(file, O_RDONLY);
    // Error checking omitted
  }
  ~FileDescriptor() { close(fd_); }     // Destructor
  int get_fd() const { return fd_; }    // inline member function
 private:
  int fd_;  // data member
};  // class FileDescriptor
```

dtor automatically closes file for the user!

use_fd.cc

```
#include "FileDescriptor.h"

int main(int argc, char* argv[]) {
  FileDescriptor fd1("foo.txt");
  return EXIT_SUCCESS;
}
```

destruct object when it falls out of scope (here, when we return)

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How many times does the *destructor* get invoked?

- Assume `Point` with ctor, cctor, =, dtor, and member function
  `double Distance(const Point& p) const;`
- Assume no optimizations

ctor	cctor	op=	dtor

A. 1 B. 2 C. 3 D. 4

E. We're lost…

poll.cc

```
Point PrintRad(Point& pt) {
  Point origin(0, 0);
  double r = origin.Distance(pt);
  double theta = atan2(pt.get_y(), pt.get_x());
  cout << "r = " << r << endl;
  cout << "theta = " << theta << " rad" << endl;
  return pt;
}

int main(int argc, char* argv[]) {
  Point pt(3, 4);
  PrintRad(pt);
  return EXIT_SUCCESS;
}
```

Polling Solution

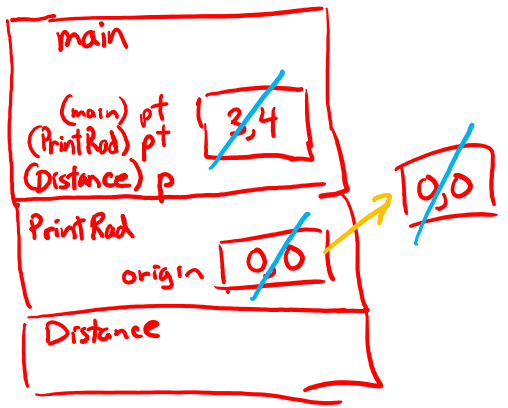
ctor	cctor	op=	dtor
2	1	0	3

- How many times does the ***destructor*** get invoked?
  - Assume `Point` with ctor, cctor, =, dtor, and member function `double Distance(const Point& p) const;`
  - Assume no optimizations

poll.cc

```
Point PrintRad(Point& pt) {
  Point origin(0, 0);          // ② ctor called
  double r = origin.Distance(pt);   // Distance takes ref, so object NOT copied
  double theta = atan2(pt.get_y(), pt.get_x());
  cout << "r = " << r << endl;
  cout << "theta = " << theta << " rad" << endl;
  return pt;                   // ③ PrintRad returns an object, so cctor is called to create a temp
}                              // ④ while cleaning up, origin is destructed

int main(int argc, char* argv[]) {
  Point pt(3, 4);              // ① ctor called
  PrintRad(pt);                // PrintRad takes ref, so pt is NOT copied
  return EXIT_SUCCESS;         // ⑤ return value of PrintRad ignored; temp is destructed
}                              // ⑥ while cleaning up, pt is destructed
```



Extra Exercise #1

- Write a C++ program that:
  - Has a class representing a 3-dimensional point
  - Has the following methods:
    - Return the inner product of two 3D points
    - Return the distance between two 3D points
    - Accessors and mutators for the `x`, `y`, and `z` coordinates

Extra Exercise #2

- Write a C++ program that:
  - Has a class representing a 3-dimensional box
    - Use your Extra Exercise #1 class to store the coordinates of the vertices that define the box
    - Assume the box has right-angles only and its faces are parallel to the axes, so you only need 2 vertices to define it
  - Has the following methods:
    - Test if one box is inside another box
    - Return the volume of a box
    - Handles `<<`, `=`, and a copy constructor
    - Uses `const` in all the right places

Extra Exercise #3

- Write a C++ class that:
  - Is given the name of a file as a constructor argument
  - Has a `GetNextWord()` method that returns the next whitespace- or newline-separated word from the file as a copy of a `string` object, or an empty string once you hit EOF
  - Has a destructor that cleans up anything that needs cleaning up