About how long did Exercise 4 & 5 take you?

A. [0, 2) hours
B. [2, 4) hours
C. [4, 6) hours
D. [6, 8) hours
E. 8+ Hours
F. I didn’t submit / I prefer not to say
C++ Constructor Insanity
CSE 333 Winter 2023

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Relevant Course Information

❖ Exercise 6 released today, due Wednesday
  ▪ Write a substantive class in C++ (uses a lot of what we will talk about in lecture today)

❖ Homework 2 due next Thursday (2/2)
  ▪ File system crawler, indexer, and search engine
  ▪ **Note:** libhw1.a (yours or ours) and the .h files from hw1 need to be in right directory (~yourgit/hw1/)
  ▪ **Note:** use Ctrl-D to exit searchshell
  ▪ **Tip:** test on directory of small self-made files
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
  ▪ Use class for abstractions with data + functions
Memory Diagrams for Objects

- An **object** is an instance of a class that maintains its *state* independent from 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:

```cpp
class Point {
    ...

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

❖ Constructors
❖ Copy Constructors
❖ Assignment
❖ Destructors
Constructors

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

- **Written with the class name as the method name:**
  ```cpp
  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


### Synthesized Default Constructor Example

```cpp
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
```

```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

```cpp
#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
}
```
#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
}
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:

```cpp
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
  - Real code should never mix the two styles

```cpp
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
```
Lecture Outline

❖ Constructors
❖ Copy Constructors
❖ Assignment
❖ Destructors
Copy Constructors

- C++ has the notion of a **copy constructor** (**cctor**)
  - Used to create a new object as a copy of an existing object

```cpp
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
    // could also be written as "Point y = x;"
}
```

- Initializer lists can also be used in copy constructors (preferred)
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

```c++
#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
    }
    ```
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

```cpp
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

- Constructors
- Copy Constructors
- Assignment
- Destructors
Assignment != 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
y = x;        // assignment operator
```
Overloading the "=" Operator

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

```cpp
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
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

```cpp
#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

❖ 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 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)

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

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

#include "FileDescriptor.h"

int main(int argc, char** argv) {
    FileDescriptor fd("foo.txt");
    return EXIT_SUCCESS;
}
How many times does the destructor get invoked?

- Assume `Point` with everything defined (ctor, cctor, =, dtor)
- Assume no compiler optimizations

A. 1
B. 2
C. 3
D. 4
E. We’re lost...

```cpp
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;
}
```
Class Definition (from last lecture)

```cpp
#ifndef POINT_H_
define POINT_H_

class Point {
public:
    Point(int x, 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(int x, int y); // member function

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

#endif // POINT_H_
```

- `#ifndef` and `#define` are used to prevent redefinition.
- `class Point` defines a class named `Point`.
- `public` section contains public methods.
- `private` section contains private data members.
- `int x_, y_` are data members.
- `Point(int x, int y);` is the constructor, allowing object creation.
- `int get_x() const` and `int get_y() const` are inline member functions for accessing `x_` and `y_`.
- `double Distance(const Point& p) const;` is a member function to calculate the distance between two points.
- `void setLocation(int x, int y);` sets the location of the point.

This `const` means that this function is not allowed to change the object on which it is called (the implicit "this" pointer).
How many times does the destructor get invoked?

<table>
<thead>
<tr>
<th>ctor</th>
<th>cctor</th>
<th>op=</th>
<th>dtor</th>
</tr>
</thead>
</table>

```cpp
test.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;
}
```
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

#include "FileDescriptor.h"

int main(int argc, char** argv) {
    FileDescriptor fd1(foo.txt);
    FileDescriptor fd2(fd); // Invokes synthesized cctor
    return EXIT_SUCCESS; // What happens when we return and destruct our objects?
}

(This won’t crash the program, but what if we were using heap allocation instead of file descriptors?)
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

- Modify your Point3D class from Extra Exercise #1
  - Disable the copy constructor and assignment operator
  - Attempt to use copy & assignment in code and see what error the compiler generates
  - Write a `CopyFrom()` member function and try using it instead
    - (See details about `CopyFrom()` in next lecture)
Extra Exercise #4

❖ 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