CSE 333
Lecture 11 - constructor insanity

Hal Perkins
Department of Computer Science & Engineering
University of Washington
Administrivia

HW2 out now, due a week from Tuesday

Midterm the following Friday

- Everything up to C++ basics (e.g., exercises)
- Old exams on the web now; topic list will be updated if needed by early next week

New exercise posted today, due Monday before class
Today’s goals

More details on constructors, destructors, operators

Walk through `complex_example/`

- pretty hairy and complex
- a lesson on why using a **subset of C++** is often better

`new / delete / delete[]`

- `str/` example
A constructor initializes a newly instantiated object

- a class can have multiple constructors
  - they differ in the arguments that they accept
  - which one is invoked depends on how the object is instantiated

You can write constructors for your object

- but if you don’t write any, C++ might automatically synthesize a default constructor for you
  - the default constructor is one that takes no arguments and that calls default constructors on all non-POD member variables
  - C++ does this iff your class has no const or reference data members, and no other user-defined constructors
Example of synthesis

see SimplePoint.cc, SimplePoint.h
Constructors, continued

You might choose to define multiple constructors:

```cpp
Point::Point() {  
    x_ = 0;  
    y_ = 0;  
}

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

void foo() {  
    Point x;  // invokes the default (argument-less) constructor  
    Point y(1,2);  // invokes the two-int-arguments constructor  
}
```
Constructors, continued

You might choose to define only one:

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

void foo() {
    // Compiler error; if you define any constructors, C++ will
    // not automatically synthesize a default constructor for you.
    Point x;

    // Works.
    Point y(1,2);  // invokes the two-int-arguments constructor
}
```
Initialization lists

As shorthand, C++ lets you declare an initialization list as part of your constructor declaration:

- initializes fields according to parameters in the list
- the following two are (nearly) equivalent:

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

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

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

```cpp
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

When a new object is created using some constructor:

- first, the initialization list is applied to members
  - in the order that those members appear within the class definition, not the order in the initialization list (!)
- next, the constructor is invoked, and any statements within it are executed

Prefer initializations to assignment

- Objects are already initialized by some constructor before they can be assigned - initializer avoids two separate steps
#ifndef _POINT_H_
define _POINT_H_

class Point {
  public:
    Point(const int x, const int y, const int z)
      : x_(x), y_(y) {
        z_ = z;
    }

  private:
    int x_, y_, z_;  // class Point
};

endif  // _POINT_H_
Initialization vs. construction

```cpp
#ifndef _POINT_H_
#define _POINT_H_

class Point {
  public:
    Point(const int x, const int y, const int z)
       : x_(x), y_(y) {
      z_ = z;
    }
  private:
    int x_, y_, z_;  
};  // class Point

#endif  // _POINT_H_
```

first, initialization list is applied
Initialization vs. construction

```cpp
#ifndef _POINT_H_
#define _POINT_H_

class Point {
  public:
    Point(const int x, const int y, const int z)
      : x_(x), y_(y) {
      z_ = z;
    }

  private:
    int x_, y_, z_;  
};  // class Point

#endif  // _POINT_H_
```

next, constructor is executed
Copy constructors

C++ has the notion of a **copy constructor**

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

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

  // invokes the copy constructor to construct y as a copy of x  
  Point y(x);  // could also write as “Point y = x;”
}
```
When do copies happen?

The copy constructor is invoked if:

- you pass an object as a parameter to a call-by-value function

```cpp
void foo(Point x) { ... }
Point y; // default cons.
foo(y); // copy cons.
```

- you return an object from a function

```cpp
Point foo() {
    Point y; // default cons.
    return y; // copy cons.
}
```

- you initialize an object from another object of the same type

```cpp
Point x; // default cons.
Point y(x); // copy cons.
Point z = y; // copy cons.
```
But...the compiler is smart...

It sometimes uses a “return by value optimization” to eliminate unnecessary copies

- sometimes you might not see a constructor get invoked when you expect it

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

see SimplePoint.cc, SimplePoint.h
The "=" operator is the assignment operator
- assigns values to an existing, already constructed object
- you can overload the "=" operator

```cpp
Point w;          // default constructor.
Point x(1,2);     // two-ints-argument constructor.
Point y = w;      // copy constructor.
y = x;            // assignment operator.
```
Overloading the “=” operator

You can choose to overload the “=” operator
- but there are some rules you should follow

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

Point a;       // default constructor
a = b = c;     // works because “=” returns *this
a = (b = c);   // equiv to above, as “=” is right-associative
(a = b) = c;   // works because “=” returns a non-const
```
Synthesized assignment oper.

If you don’t overload 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

see SimplePoint.cc, SimplePoint.h
Destructors

C++ has the notion of a **destructor**

- invoked automatically when a class instance is deleted / goes out of scope, etc., even via exceptions or other causes

- place to put 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)
}
```
see complex_example/*
Dealing with the insanity

C++ style guide tip

- if possible, disable the copy const. and assignment operator
  ‣ not possible if you want to store objects of your class in an STL container, unfortunately

```cpp
class Point {
public:
    Point(int x, int y) : x_(x), y_(y) { }
private:
    // disable copy cons. and "=" by declaring but not defining
    Point(Point &copyme);
    Point &operator=(Point &rhs);
};
Point w;       // compiler error
Point x(1,2);  // OK
Point y = x;   // compiler error
x = w;         // compiler error
```
Dealing with the insanity

C++ style guide tip

- if you disable them, then you should instead have an explicit “CopyFrom” function

```cpp
class Point {
public:
    Point(int x, int y) : x_(x), y_(y) { }
    void CopyFrom(const Point &copy_from_me);

private:
    // disable copy cons. and "=" by declaring but not defining
    Point(const Point &copyme);
    Point &operator=(const Point &rhs);
};
```

```cpp
Point x(1,2);         // OK
Point y(3,4);         // OK
x.CopyFrom(y);        // OK
```
To allocate on the heap using C++, you use the “new” keyword instead of the “malloc( )” stdlib.h function

- you can use new to allocate an object
- you can use new to allocate a primitive type

To deallocate a heap-allocated object or primitive, use the “delete” keyword instead of the “free( )” stdlib.h function

- if you’re using a legacy C code library or module in C++
  ‣ if C code returns you a malloc( )’d pointer, use free( ) to deallocate it
  ‣ **never** free( ) something allocated with new
  ‣ **never** delete something allocated with malloc( )
new / delete

see heappoint.cc
C++11 nullptr

C and C++ have long used NULL as a pointer value that references nothing.

C++11 introduces a new literal for this: nullptr

- New reserved word
- Interchangeable with NULL for all practical purposes
  - But it has type T* for any/every T, and is not an integer value
    - Avoids funny edge cases (see C++ references for details)
    - Still can convert to/from integer 0 for tests, assignment, etc.
- Advice: prefer nullptr in C++11 code, but NULL will also
  be around for a long, long time.
Dynamically allocated arrays

To dynamically allocate an array
- use "type *name = new type[size];"

To dynamically deallocate an array
- use "delete[] name;"
- it is an error to use "delete name;" on an array
  ‣ the compiler probably won’t catch this, though!!!
  ‣ it can’t tell if it was allocated with "new type[size];" or "new type;"

see arrays.cc
### malloc vs. new

<table>
<thead>
<tr>
<th></th>
<th>malloc( )</th>
<th>new</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>what is it</strong></td>
<td>a function</td>
<td>an operator and keyword</td>
</tr>
<tr>
<td><strong>how often used in C</strong></td>
<td>often</td>
<td>never</td>
</tr>
<tr>
<td><strong>how often used in C++</strong></td>
<td>rarely</td>
<td>often</td>
</tr>
<tr>
<td><strong>allocates memory for</strong></td>
<td>anything</td>
<td>arrays, structs, objects, primitives</td>
</tr>
<tr>
<td><strong>returns</strong></td>
<td>a (void *) <em>(needs a cast)</em></td>
<td>appropriate pointer type <em>(doesn’t need a cast)</em></td>
</tr>
<tr>
<td><strong>when out of memory</strong></td>
<td>returns NULL</td>
<td>throws an exception</td>
</tr>
<tr>
<td><strong>deallocating</strong></td>
<td>free</td>
<td>delete or delete[ ]</td>
</tr>
</tbody>
</table>
see str/*
Overloading the "=" operator

Remember the rules we should follow?
- here's why; hugely subtle bug

```cpp
Foo::Foo(int val) { Init(val); }
Foo::~Foo() { delete my_ptr_; }

void Foo::Init(int val) { my_ptr_ = new int; *my_ptr_ = val; }

Foo &Foo::operator=(const Foo& rhs) {
    // bug...we forgot our "if (self == &rhs) { ... }" guard
    delete my_ptr_; 
    Init(*(rhs.my_ptr_));  // might crash here (see below)
    return *this; // always return *this from =
}

void bar() {
    Foo a(10); // default constructor
    Foo b(20); // default constructor
    a = a;     // crash above; dereference delete'd pointer!!
}
```
Overloading the “=” operator

Remember the rules we should follow?

*This is yet another reason for disabling the assignment operator, when possible*
Exercise 1

Modify your 3D Point class from lec10 exercise 1

- disable the copy constructor and assignment operator
- attempt to use copy & assign in code, and see what error the compiler generates
- write a CopyFrom( ) member function, and try using it instead
Exercise 2

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-separate 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
Exercise 3

Write a C++ function that:

- uses new to dynamically allocate an array of strings
  ‣ and uses delete[ ] to free it
- uses new to dynamically allocate an array of pointers to strings
  ‣ and then iterates through the array to use new to allocate a string for each array entry and to assign to each array element a pointer to the associated allocated string
  ‣ and then uses delete to delete each allocated string
  ‣ and then uses delete[ ] to delete the string pointer array
  ‣ (whew!)
See you on Monday!