CSE 333

Lecture 11 - constructor insanity

Hal Perkins

Department of Computer Science & Engineering

University of Washington
Administrivia

New exercise posted after class*, due before class Friday

*which one depends on how far we get today. 😊

Office hours moved to CSE 023

Discussion board — help us help you:

Please minimize posting of large images instead of text.

Context helps. It’s easier to work with a question if it doesn’t require a lot of searching to figure out what it’s about.

Reminder: Must use cse333-staff@cs for email to course staff. Otherwise we can’t keep track of questions/problems.

HW2 due a week from tomorrow. How’s it going?

Midterm two weeks from Friday.
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`
Constructors

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 (POD = “Plain Old Data”)

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

Optionally, 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;
}
```
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_
```
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_;  // private data members
};  // class Point

#endif  // _POINT_H_
```

next, constructor is executed
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 initialization to assignment

An object must already be initialized by a constructor before it can be (re-)assigned - initializer avoids two separate steps
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
assignment != construction

The “=” operator is the assignment operator
assigns values to an existing, already constructed object
you can overload the “=” operator

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/*
Rule of Three

If you define any of:

- Destructor
- Copy Constructor
- Assignment (operator=)

Then you should normally define all three
Dealing with the insanity

C++ style guide tip

if possible, disable the copy constr. and assignment operator

not possible if you want to store objects of your class in an STL container, unfortunately

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
Disabling copy ctr/= in C++11

C++11 adds new syntax to do this directly

better choice in C++11 code

class Point {
   public:
      Point(int x, int y) : x_(x), y_(y) { }

      // declare copy cons. and "=" as deleted (C++11)
      Point(Point &copyme) = delete;
      Point &operator=(Point &rhs) = delete;
   }

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 probably have an explicit “CopyFrom” function

class Point {
public:
    Point::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);
};

Point x(1,2);       // OK
Point y(3,4);       // OK
x.CopyFrom(y);      // OK
new

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 introduced 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 *) (needs a cast)</td>
<td>appropriate pointer type (doesn’t need a cast)</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>
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 foo_ptr_; }

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

Foo &Foo::operator=(const Foo& rhs) {
  // bug...we forgot our "if (self == &rhs) { ... }" guard
  delete foo_ptr_;  
  Init(* (rhs.foo_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’ed pointer!!
}
```
Overloading the “=” operator

Remember the rules we should follow?

This is yet another reason for disabling the assignment operator, when possible.
see str/*
Administrivia (2)

HW2 due Thursday night, 11 pm.

<panic>if not started yet</panic>

Exam a week later, Friday, in class

Closed book, no notes — exam questions can be more straightforward that way; reference info on test as needed

Topics: everything from lectures, exercises, project, etc. up to HW2 & basics of C++ (including references, classes, constructors, destructors, new/delete, templates & STL basics, maybe smart pointers, definitely nothing after that)

Old exams and topic list on the web now

New exercise today - due before class Wed. (rework today’s ex.)
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 Wednesday!