CSE 333

Lecture 13 -- smart pointers

Hal Perkins

Department of Computer Science & Engineering

University of Washington

Administrivia

HW2 is due Tomorrow!

Midterm Monday

- Topic list posted later today
  - Everything in lectures (including basic C++), exercises, hw project
  - Study hint: do lecture exercises, make up sample problems — don't just "go over" the slides
- Review in sections tomorrow
- Additional review Q&A Sunday, 2 pm, CSE 403

Back to regular exercises and HW3 right after midterm

Last time

We learned about STL

- noticed that STL was doing an enormous amount of copying
- were tempted to use pointers instead of objects
  - but tricky to know who is responsible for delete'ing and when

C++ smart pointers

A **smart pointer** is an **object** that stores a pointer to a heap allocated object

- a smart pointer looks and behaves like a regular C++ pointer
  - how? by overloading ***** , **->** , **[ ]** , etc.
- a smart pointer can help you manage memory
  - the smart pointer will delete the pointed-to object at the right time
    - when that is depends on what kind of smart pointer you use
  - so, if you use a smart pointer correctly, you no longer have to remember when to delete new'd memory

C++’s auto_ptr

The auto_ptr class is part of C++’s standard library

- it’s useful, simple, but limited
    - gradually being replaced by alternatives in C++11 - but still used
- an auto_ptr object **takes ownership** of a pointer
    - when the auto_ptr object is *delete*’d or falls out of scope, its destructor is invoked, just like any C++ object
    - this destructor invokes delete on the owned pointer

Using an auto_ptr

```
#include <iostream>   // for std::cout, std::endl
#include <memory>     // for std::auto_ptr
#include <stdlib.h>   // for EXIT_SUCCESS

void Leaky() {
  int *x = new int(5);  // heap allocated
  (*x)++;
  std::cout << *x << std::endl;
}

void NotLeaky() {
  std::auto_ptr<int> x(new int(5));  // wrapped, heap-allocated
  (*x)++;
  std::cout << *x << std::endl;
}

int main(int argc, char **argv) {
  Leaky();
  NotLeaky();
  return EXIT_SUCCESS;
}
```

autoexample1.cc

Why are auto_ptrs useful?

If you have many potential exits out of a function, it's easy to forget to call *delete* on all of them

- auto_ptr will delete its pointer when it falls out of scope
- thus, an auto_ptr also helps with **exception safety**

```
int NotLeaky() {
  std::auto_ptr<int> x(new int(5));

  lots of code, including several returns
  lots of code, including a potential exception throw
  lots of code

  return 1;
}
```

auto_ptr operations

```
#include <memory>     // for std::auto_ptr
#include <stdlib.h>   // for EXIT_SUCCESS

using namespace std;
typedef struct { int a, b; } IntPair;

int main(int argc, char **argv) {
  auto_ptr<int> x(new int(5));

  // Return a pointer to the pointed-to object.
  int *ptr = x.get();

  // Return a reference to the value of the pointed-to object.
  int val = *x;

  // Access a field or function of a pointed-to object.
  auto_ptr<IntPair> ip(new IntPair);
  ip->a = 100;

  // Reset the auto_ptr with a new heap-allocated object.
  x.reset(new int(1));

  // Release responsibility for freeing the pointed-to object.
  ptr = x.release();
  delete ptr;
  return EXIT_SUCCESS;
}
```

autoexample2.cc

Transferring ownership

The copy and assignment operators **transfer ownership**

- the RHS auto_ptr's pointer is set to NULL
- the LHS auto_ptr's pointer now owns the pointer

```
int main(int argc, char **argv) {
  auto_ptr<int> x(new int(5));
  cout << "x: " << x.get() << endl;

  auto_ptr<int> y(x);  // y takes ownership, x abdicates it
  cout << "x: " << x.get() << endl;
  cout << "y: " << y.get() << endl;

  auto_ptr<int> z(new int(10));

  // z deletes its old pointer and takes ownership of y's pointer.
  // y abdicates its ownership.
  z = y;

  return EXIT_SUCCESS;
}
```

autoexample3.cc

auto_ptr and STL

auto_ptrs cannot be used with STL containers :(

- a container may make copies of contained objects
    - e.g., when you sort a vector, the quicksort pivot is a copy
- accessors will unwittingly NULL-ify the contained auto_ptr

```
void foo() {
  vector<auto_ptr<int> >  ivec;
  ivec.push_back(auto_ptr<int>(new int(5)));
  ivec.push_back(auto_ptr<int>(new int(6)));  // might make copies

  // Accessing a vector element makes a copy of it; therefore, this
  // transfers ownership out of the vector
  auto_ptr<int> z = ivec[0];  // ivec[0] now contains a NULL auto_ptr
}
```

auto_ptr and arrays

STL has no auto_ptr for arrays

- an auto_ptr always calls delete on its pointer, never delete[ ]

Boost

Community supported, peer-reviewed, portable C++ libraries

- more containers, asynchronous I/O support, statistics, math, graph algorithms, image processing, regular expressions, serialization/marshalling, threading, and more

Already installed on attu, ugrad workstations, CSE VMs

- or, you can download and install from:
  - http://www.boost.org/

Boost smart pointers

The Boost library contains six variations of smart pointers

- scoped_ptr: non-transferrable ownership of a single object
- scoped_array: non-transferrable ownership of an array
- shared_ptr: shared, reference-counted ownership
- shared_array: same as shared_ptr, but for an array
- weak_ptr: similar to shared_ptr, but doesn't count towards the reference count
- *intrusive_ptr: we won't discuss in 333*

Sidebar: C++11

In 2011, an updated standard for C++ was approved

- includes a number of enhancements to the language and to the standard library
- one of them is to incorporate into the standard libraries some of the smart pointers that Boost pioneered
    - another is to deprecate auto_ptr!

We'll stick to Boost for now

- the compilers are racing to adopt the new C++11 features
- should be in place any ~~month~~ year now?

boost::scoped_ptr

scoped_ptr is similar to auto_ptr

- but a scoped_ptr doesn't support copy or assignment
  - therefore, you cannot transfer ownership of a scoped_ptr
  - and therefore, you cannot use one with STL containers

Intended to be used to manage memory within a scope

- connotes that the managed resource is limited to some context

C++2011 has std::unique_ptr, which is very similar

scoped_ptr example

```
#include <boost/scoped_ptr.hpp>
#include <stdlib.h>

class MyClass {
 public:
  MyClass(int *p) { sptr_ = p; }

 private:
  // A MyClass object's sptr_ resource is freed when the object's
  // destructor fires.
  boost::scoped_ptr<int> sptr_;
};

int main(int argc, char **argv) {
  // x's resource is freed when main() exits.
  boost::scoped_ptr<int> x(new int(10));

  int *sevenptr = new int(7);
  MyClass mc(sevenptr);

  return EXIT_SUCCESS;
}
```

scopedexample.cc

scoped_array

Identical to scoped_ptr, but owns an **array**, not a pointer

```
#include <boost/scoped_array.hpp>
#include <stdlib.h>

int main(int argc, char **argv) {
  boost::scoped_array<int> x(new int[10]);
  x[0] = 1;
  x[1] = 2;

  return EXIT_SUCCESS;
}
```

scopedarray.cc

shared_ptr

A shared_ptr is similar to an auto_ptr

- but, the copy / assign operators increment a reference count rather than transferring ownership
    - after copy / assign, the two shared_ptr objects point to the same pointed-to object, and the (shared) reference count is 2
- when a shared_ptr is destroyed, the reference count is decremented
    - when the reference count hits zero, the pointed-to object is deleted

shared_ptr example

```
#include <iostream>
#include <boost/shared_ptr.hpp>
#include <stdlib.h>

int main(int argc, char **argv) {
  // x contains a pointer to an int and has reference count 1.
  boost::shared_ptr<int> x(new int(10));

  {
    // x and y now share the same pointer to an int, and they
    // share the reference count; the count is 2.
    boost::shared_ptr<int> y = x;
    std::cout << *y << std::endl;
  }
  // y fell out of scope and was destroyed.  Therefore, the
  // reference count, which was previously seen by both x and y,
  // but now is seen only by x, is decremented to 1.
  std::cout << *x << std::endl;

 return EXIT_SUCCESS;
}
```

sharedexample.cc

shared_ptrs and STL containers

Finally, something that works!

- it is safe to store shared_ptrs in containers, since copy/assign maintain a shared reference count and pointer

but, what about ordering?

- a map is implemented as a binary tree
  - therefore, it needs to order elements
  - therefore, it needs elements to support the “<“ operator
- similarly, what about sorting a vector of shared_ptr<int>’s?

shared_ptr and “<“

a shared_ptr implements some comparison operators

- e.g., a shared_ptr implements the “<“ operator
- but, it doesn’t invoke “<“ on the pointed-to objects
    - instead, it just promises a stable, strict ordering (probably based on the pointer address, not the pointed-to value)
- this means you can use shared_ptrs as keys in maps
    - but you can’t count on any meaningful sorted order, unless you provide a comparison function in the constructor
- similarly, to use sort on vectors, you have to provide sort with a comparison function

Example

```
bool sortfunction(shared_ptr<int> x, shared_ptr<int> y) {
  return *x < *y;
}

bool printfunction(shared_ptr<int> x) {
  std::cout << *x << std::endl;
}

int main(int argc, char **argv) {
  vector<shared_ptr<int> > vec;

  vec.push_back(shared_ptr<int>(new int(9)));
  vec.push_back(shared_ptr<int>(new int(5)));
  vec.push_back(shared_ptr<int>(new int(7)));

  std::sort(vec.begin(), vec.end(), &sortfunction);
  std::for_each(vec.begin(), vec.end(), &printfunction);
  return EXIT_SUCCESS;
}
```

sharedsort.cc

Putting it all together

see alltogether/

weak_ptr

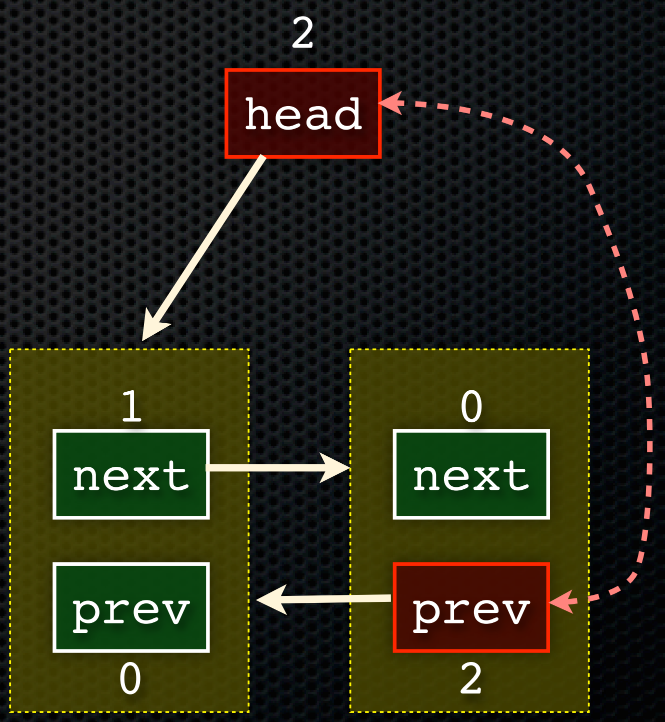
If you used shared_ptr and have a cycle in the sharing graph, the reference count will never hit zero

- a weak_ptr is just like a shared_ptr, but it doesn't count towards the reference count
- a weak_ptr breaks the cycle
  - but, a weak_ptr can become dangling

cycle of shared_ptr's

```
#include <boost/shared_ptr.hpp>

using boost::shared_ptr;

class A {
 public:
  shared_ptr<A> next;
  shared_ptr<A> prev;
};

int main(int argc, char **argv) {
  shared_ptr<A> head(new A());
  head->next = shared_ptr<A>(new A());
  head->next->prev = head;

  return 0;
}
```

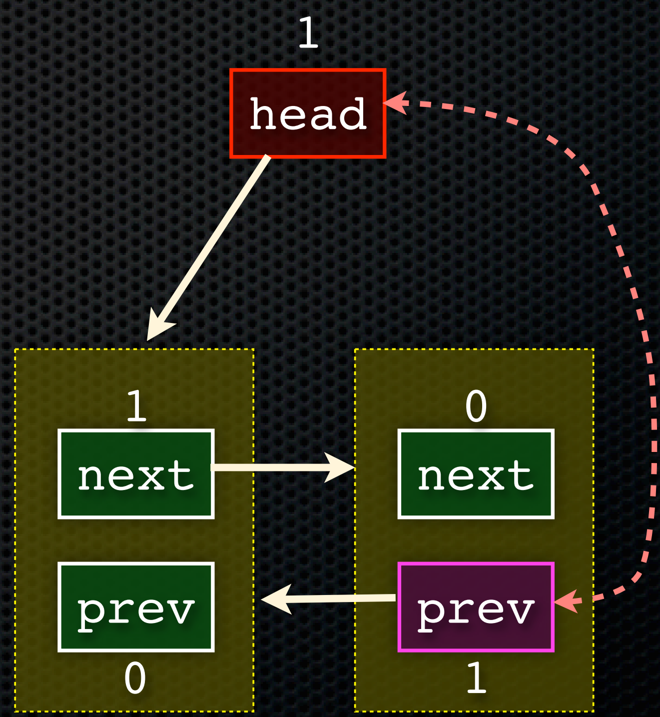
strongcycle.cc



breaking the cycle with weak_ptr

```
#include <boost/shared_ptr.hpp>
#include <boost/weak_ptr.hpp>

using boost::shared_ptr;
using boost::weak_ptr;

class A {
 public:
  shared_ptr<A> next;
  weak_ptr<A> prev;
};

int main(int argc, char **argv) {
  shared_ptr<A> head(new A());
  head->next = shared_ptr<A>(new A());
  head->next->prev = head;

  return 0;
}
```

weakcycle.cc



using a weak_ptr

```
#include <boost/shared_ptr.hpp>
#include <boost/weak_ptr.hpp>
#include <iostream>

int main(int argc, char **argv) {
  boost::weak_ptr<int> w;

  {
    boost::shared_ptr<int> x;
    {
      boost::shared_ptr<int> y(new int(10));
      w = y;
      x = w.lock();
      std::cout << *x << std::endl;
    }
    std::cout << *x << std::endl;
  }
  boost::shared_ptr<int> a = w.lock();
  std::cout << a << std::endl;
  return 0;
}
```

usingweak.cc

Exercise 1

Write a C++ program that:

- has a Base class called “Query” that contains a list of strings
- has a Derived class called “PhrasedQuery” that adds a list of phrases (a phrase is a set of strings within quotation marks)
- uses a Boost shared_ptr to create a list of Queries
- populates the list with a mixture of Query and PhrasedQuery objects
- prints all of the queries in the list

Exercise 2

Implement Triple, a templated class that contains three "things." In other words, it should behave like std::pair, but it should hold three objects instead of two.

- instantiate several Triple that contains shared_ptr<int>'s
- insert the Triples into a vector
- reverse the vector

See you on ~~Friday~~ Monday!