CSE 333

Lecture 14 -- smart pointers

Hal Perkins

Department of Computer Science & Engineering

University of Washington

Administrivia 1 (Monday)

New exercise out this morning, due ~~Wednesday~~ next Monday

Exam 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, const, classes, constructors, destructors, new/delete, basic ideas behind templates/STL and smart pointers)
- Old exams and topic list on the web now
- Review in sections Thursday

Administrivia 2 (Monday)

Upcoming topics

- finishing up C++ (smart pointers then subclasses)
- rest of quarter: networking, tools, more systems topics, other good stuff

Administrivia (Wednesday)

HW3 out Friday right after exam; brief demo in class today

Exercise 13 (assigned Monday) due next Monday morning

Exam 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, const, classes, constructors, destructors, new/delete, nothing after that)
- Old exams and topic list on the web now
- Review in sections tomorrow

Last time

We learned about STL

- noticed that STL was doing an enormous amount of copying
- we 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**, including invoking the object's destructor
    - **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

A toy smart pointer

We can implement a simple one with:

- a constructor that accepts a pointer
- a destructor that frees the pointer
- overloaded * and -> operators that access the pointer

see toyptr/

What makes it a toy?

Can’t handle:

arrays

copying

reassignment

comparison

...plus many other subtleties...

Luckily, others have built non-toy smart pointers for us!

C++11's std::unique_ptr

The unique_ptr template is part of C++'s standard library

- available starting with the C++11 standard

A unique_ptr **takes ownership** of a pointer

- when the unique_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 a unique_ptr

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

void Leaky() {
  int *x = new int(5);  // heap allocated
  (*x)++;
  std::cout << *x << std::endl;
}  // never used delete, therefore leak

void NotLeaky() {
  std::unique_ptr<int> x(new int(5));  // wrapped, heap-allocated
  (*x)++;
  std::cout << *x << std::endl;
}  // never used delete, but no leak

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

unique1.cc

Why are unique_ptrs useful?

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

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

```
int NotLeaky() {
  std::unique_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;
}
```

unique_ptr operations

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

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

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

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

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

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

  // Deallocate the pointed-to object and reset the unique_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;
}
```

unique2.cc

unique_ptrs cannot be copied

std::unique_ptr disallows the use of its copy constructor and assignment operator

- therefore, you cannot copy a unique_ptr
- this is what it means for it to be “unique”

```
#include <memory>
#include <stdlib.h>

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

  // fail, no copy constructor
  std::unique_ptr<int> y(x);

  // succeed, z starts with NULL pointer
  std::unique_ptr<int> z;

  // fail, no assignment operator
  z = x;

  return EXIT_SUCCESS;
}
```

uniquefail.cc

Transferring ownership

You can use reset( ) and release( )

- release( ) returns the pointer, sets wrapper's pointer to NULL
- reset( ) delete's the current pointer, acquires a new one

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

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

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

  // z delete's its old pointer and takes ownership of y's pointer.
  // y abdicates its ownership.
  z.reset(y.release());

  return EXIT_SUCCESS;
}
```

unique3.cc

Copy semantics

Assigning values typically means making a copy

- sometimes this is what you want
  - assigning the value of one string to another makes a copy
- sometimes this is wasteful
  - returning a string and assigning it makes a copy, even though the returned string is ephemeral

```
#include <iostream>
#include <string>

std::string ReturnFoo(void) {
  std::string x("foo");
  // this return might copy
  return x;
}

int main(int argc,
         char **argv) {
  std::string a("hello");
  // copy a into b
  std::string b(a);

  // copy return value into b.
  b = ReturnFoo();

  return EXIT_SUCCESS;
}
```

copysemantics.cc

Move semantics

C++11 introduces "move semantics"

- moves values from one object to another without copying ("steal")
- useful for optimizing away temporary copies
- complex topic
  - "rvalue references"
  - mostly beyond scope of 333 (this qtr anyway)

```
#include <iostream>
#include <string>

std::string ReturnFoo(void) {
  std::string x("foo");
  // this return might make a copy
  return x;
}

int main(int argc, char **argv) {
  std::string a("hello");

  // moves a to b
  std::string b = std::move(a);
  std::cout << "a: " << a << std::endl;
  std::cout << "b: " << b << std::endl;

  // moves the returned value into b.
  b = std::move(ReturnFoo());
  std::cout << "b: " << b << std::endl;

  return EXIT_SUCCESS;
}
```

movesemantics.cc

Move semantics and unique_ptr

unique_ptr supports move semantics

- can "move" ownership from one unique_ptr to another
- old owner:
  - post-move, its wrapped pointer is set to NULL
- new owner:
  - pre-move, its wrapped pointer is delete'd
  - post-move, its wrapped pointer is the moved pointer

Transferring ownership

Using move semantics

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

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

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

  // z delete's its old pointer and takes ownership of y's pointer.
  // y abdicates its ownership.
  z = std::move(y);

  return EXIT_SUCCESS;
}
```

unique4.cc

unique_ptr and STL

unique_ptrs can be stored in STL containers!!

- but, remember that STL containers like to make lots copies of stored objects
  - and, remember that unique_ptrs cannot be copied
  - how can this work??

Move semantics to the rescue

- when supported, STL containers will move rather than copy
  - luckily, unique_ptrs support move semantics

unique_ptr and STL

see uniquevec.cc

unique_ptr and “<”

a unique_ptr implements some comparison operators

- e.g., a unique_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)
- so, to use sort on vectors, you want to provide sort with a comparison function

unique_ptr and sorting with STL

see uniquevecsort.cc

unique_ptr, “<” and maps

Similarly, you can use unique_ptrs as keys in a map

- good news: a map internally stores keys in sorted order
  - so iterating through the map iterates through the keys in order
  - under the covers, by default, “<” is used to enforce ordering
- bad news: as before you can’t count on any meaningful sorted order using “<” of unique_ptrs
  - instead, you specify a comparator when constructing the map

unique_ptr, “<” and maps

see uniquemap.cc

unique_ptr and arrays

unique_ptr can store arrays as well

- will call delete[ ] on destruction

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

using namespace std;

int main(int argc, char **argv) {
  // x is a unique_ptr storing an array of 5 ints
  unique_ptr<int[]> x(new int[5]);

  x[0] = 1;
  x[2] = 2;

  return EXIT_SUCCESS;
}
```

unique5.cc

C++11 has more smart ptrs

shared_ptr

copyable, reference counted ownership of objects / arrays

multiple owners have pointers to a shared object

weak_ptr

similar to shared_ptr, but doesn’t count towards refcount

shared_ptr

A std::shared_ptr is similar to a std::unique_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 <cstdlib>
#include <iostream>
#include <memory>

int main(int argc, char **argv) {
  // x contains a pointer to an int and has reference count 1.
  std::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.
    std::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

Even simpler than unique_ptrs

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

see sharedvec.cc

weak_ptr

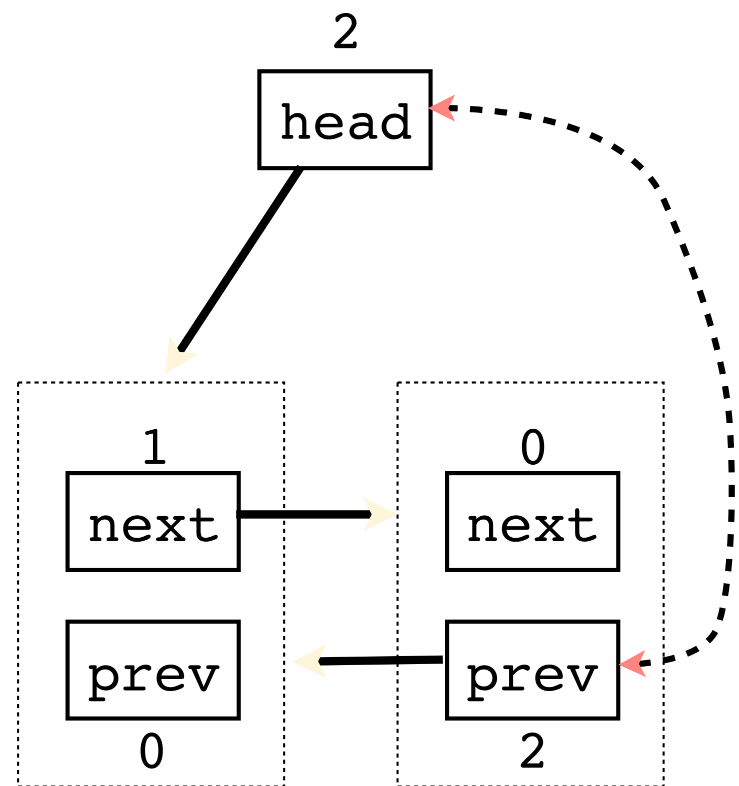
If you used shared_ptr and have a cycle in the sharing graph, the reference count will never hit zero

- 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 <memory>

using std:::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;
}
```

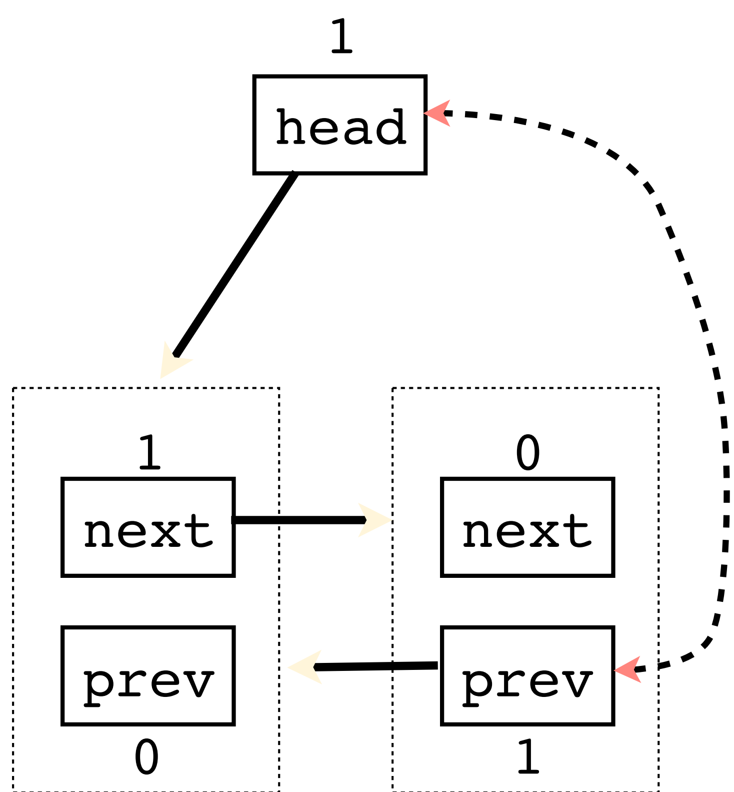
strongcycle.cc



breaking the cycle with weak_ptr

```
#include <memory>

using std::shared_ptr;
using std::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 <iostream>
#include <memory>

using std::shared_ptr;
using std::weak_ptr;

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

  {
    shared_ptr<int> x;
    {
      shared_ptr<int> y(new int(10));
      w = y;
      x = w.lock();
      std::cout << *x << std::endl;
    }
    std::cout << *x << std::endl;
  }
  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
  - (Feel free to wait until after we’ve talked about C++ subclasses)
- has a Derived class called “PhrasedQuery” that adds a list of phrases (a phrase is a set of strings within quotation marks)
- uses a 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!