

CSE 333

Lecture 14 -- smart pointers

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Administrivia

HW2 due tomorrow night (+ late days if you need them)

Exam next Monday, 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, projects up to HW2 + basics of C++ (incl. references, const, classes, constructors, destructors, new/delete, basic STL, but not smart pointers)

Old exams and topic list on the web now

Review in section + review Q&A Sunday, 1 pm, EEB 045

Administrivia (Friday)

Exam Monday, 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 yesterday, review Q&A Sun. 1 pm, here

Unique pointer exercise out Mon., due next Wed. morning

HW3 out Mon. right after exam; brief demo in class today

Administrivia

Upcoming topics

finishing up C++ (smart pointers then subclasses)

rest of quarter: networking, tools, more systems topics, other good stuff

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;
}
```

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;
}
```

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”)

Source object likely modified to “remove” old data

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 something like a shared_ptr, but it doesn't count towards the reference count and doesn't support *, ->

a weak_ptr breaks the cycle

but, a weak_ptr can become dangling

but, can check weak_ptr to see if dangling

and, if weak_ptr's object still exists (not dangling), can construct a regular shared_ptr from it to access the object

cycle of shared_ptr's

```
#include <memory>

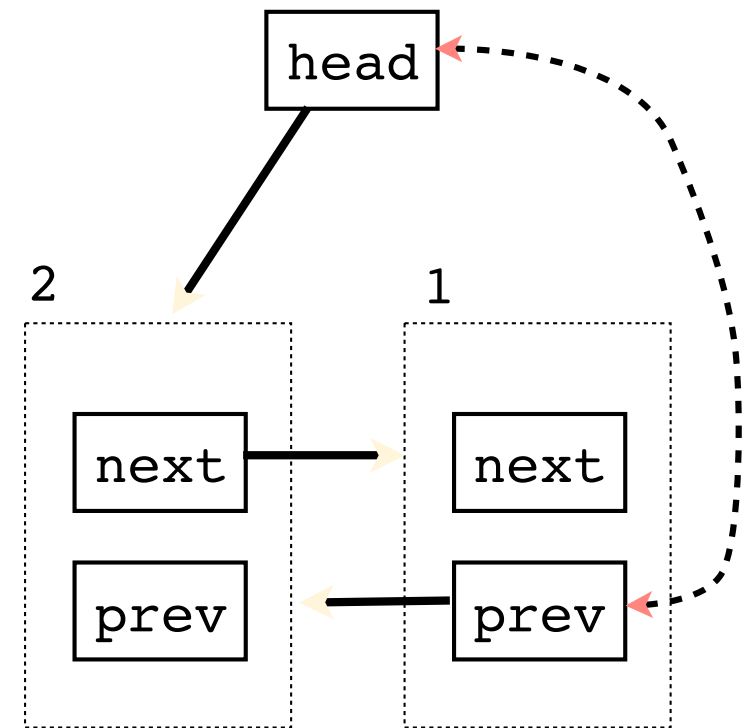
using std::shared_ptr;

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>

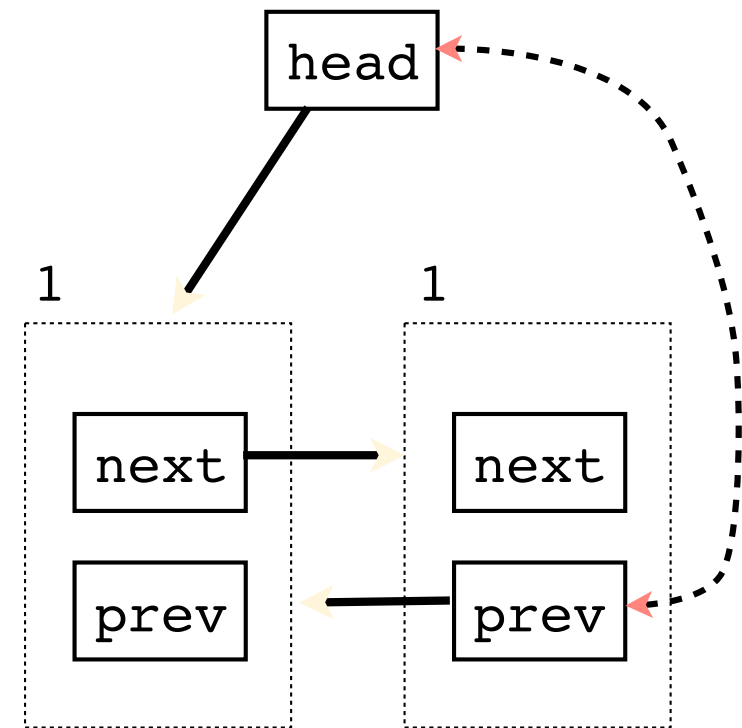
using std::shared_ptr;
using std::weak_ptr;

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 Monday!