SECTION 03
Smart pointers

Problems with 'raw' pointers

```
class X
{
};

void func(X& theX)
{
  theX = *(new X);
}


int main()
{
  X& x = *(new X);
  func(x);
}
```

Raw pointer types do not perform any management of their resource. This can lead to all sorts of nasty problems.

Smart pointer types

`std::shared_ptr`

`std::unique_ptr`

`std::weak_ptr`

C++11 has three managed pointer types:

`std::shared_ptr`

A reference-counted pointer, introduced in C++98 TR1

`std::unique_ptr`

Single-owner managed pointer which replaces (the now deprecated) auto_ptr

`std::weak_ptr`

Works with shared_ptr in situations where circular references could be a problem

Single ownership pointer

```
#include <memory>

class X
{
public:
  void op();
};

int main()
{
  std::unique_ptr<X> p1(new X);    // NB: You can't do:
                                   // std::unique_ptr<X> p1 = new X;
  p1->op();

  std::unique_ptr<X> p2(p1);            // ERROR - Copy construction
  std::unique_ptr<X> p3(std::move(p1)); // OK - move constructor called

}
```

`unique_ptr` allows single ownership of a resource. That is, only one `unique_ptr` can ever be pointing at the resource

`unique_ptr` supports move semantics but not copying; unlike `auto_ptr`.

Custom delete functor

```
class SpecialDeleter
{
public:
  void operator() (SpecialCase* pObj)
  {
    cout << "Custom deleter for SpecialCase objects" << endl;
    delete pObj;
  }
};


int main()
{
  std::unique_ptr<SpecialCase, SpecialDeleter> p(new SpecialCase);
}
```

`unique_ptr` allows a custom delete functor; for situations requiring special cleanup (for example, files)

The deletor functor `operator()` must take a pointer to the type referenced by the `unique_ptr`

Reference-counted pointer

```
#include <memory>

class X
{
public:
  X(int val);
  void op();
};

void func(std::shared_ptr<X> p)         // Pass-by-value; copy made on call
                                        // ref count incremented
  p->op();
}                                       // temp object deleted;
                                        // ref count decremented

int main()
{
  auto ptr = std::make_shared<X>(100);  // Creates a new shared_ptr<X>.

  ptr -> op();
  func(ptr);
}                                       // Last shared_ptr goes out of
                                        // scope; delete memory.
```

`std::shared_ptr` is a reference-counted smart pointer.

Each time a shared pointer is copied the reference count is incremented. Each time one of the pointers goes out of scope the reference count on the resource is decremented. When the reference count is zero (that is, the last shared_ptr referencing the resource goes out of scope) the resource is deleted.

The standard library also provides a helper function, `std::make_shared`, that constructs a new resource (on the free store) and returns a `shared_ptr` to it. `std::make_shared` is a tempate function that takes as many parameters as required by the type being constructed

Problems with circular references

```
class A;
class B;
void bind (std::shared_ptr<A>& a, std::shared_ptr<B>& b);

class A
{
public:
  void opA() { cout << "A::opA()" << endl; }

private:
  friend void bind (shared_ptr<A>& a, shared_ptr<B>& b);
  std::shared_ptr<B> pB;
};
```

```
class B
{
  public:
  void opB() { cout << "B::opB()" << endl; }
  void go();

private:
  friend void bind (shared_ptr<A>& a, shared_ptr<B>&
b);
  std::shared_ptr<A> pA;
};
```

Note the circular reference

Here we have a common situation: Two classes with a bi-directional association. We have modelled the association this time using `shared_ptr`s rather than raw pointers.

The `bind` function allows us to connect objects together at construction time. Note in this case the `bind()` function takes `shared_ptr`s as parameters, rather than references to objects.

Constructing the objects

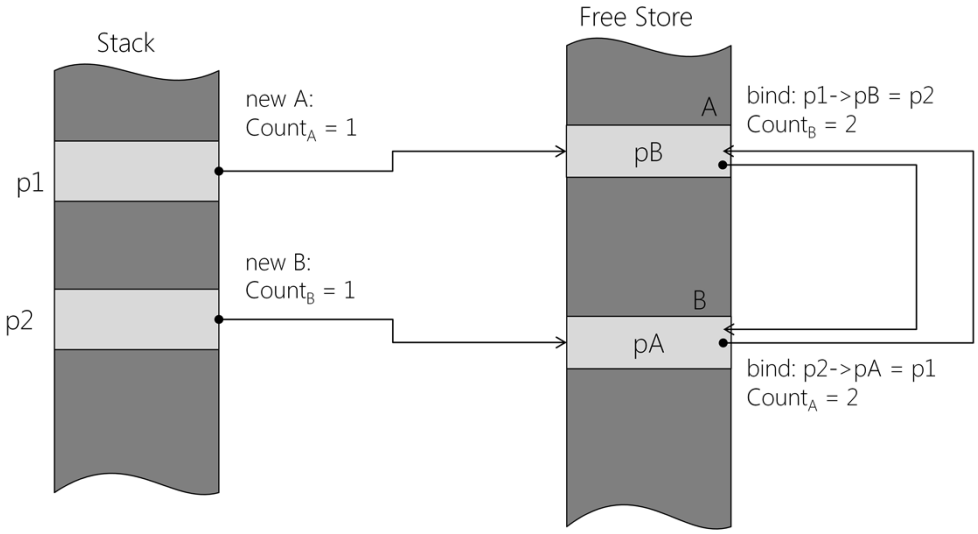
```
void bind(std::shared_ptr<A>& a,
std::shared_ptr<B>& b)
{
  a->pB = b;
  b->pA = a;
}

int main()
{
  auto p1 = std::make_shared<A>();
  auto p2 = std::make_shared<B>();

  bind(p1, p2);

  p2->go();
}
```

What's the problem with this code?

The bind function builds the association between the objects. The copy of the `shared_ptr`s inside the `bind()` is what causes the problem: this code will cause a memory leak!

But how?...

Construction



Let's examine the problem.

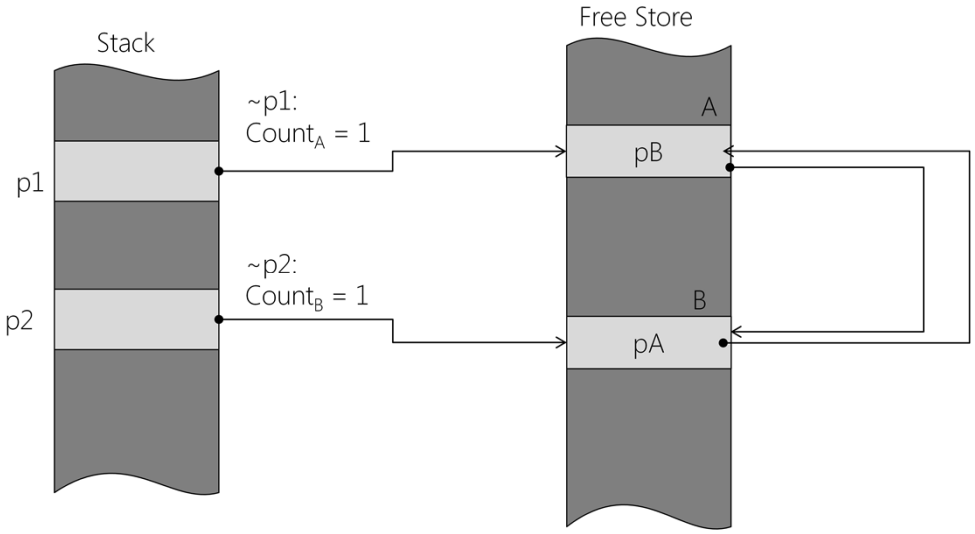
When we construct the A and B objects we get two `shared_ptr`s: `p1` and `p2`. Their reference counts are set to 1.

The `bind` function makes copies of `p1` and `p2`, in `p2->pA` and `p1->pB` respectively. This increments the reference counts on the `shared_ptr`s.

There are now two shared pointers referencing each A or B object.

So far, there is no problem.

Destruction…



When `p1` goes out of scope its reference count is decremented. However, since there is another `shared_ptr` referencing the resource (`B::pA`) the A object is not deleted.

Similarly, when `p2` goes out of scope its reference count is decremented, but the B object cannot be deleted since `A::pB` still references it.

Now we have a problem: memory for A and B cannot be deleted since `pA` and `pB` reference it; but they cannot be accessed any more (because `p1` and `p2` are no longer in scope!)

The solution is to use a `std::weak_ptr`

std::weak_ptr

```
#include <memory>
void func(std::weak_ptr<int> p);

int main()
{
  auto shared = std::make_shared<int>(100);   // shared ctor: count = 1
  std::weak_ptr<int> weak(shared);            // weak ctor:   count = 1

  *weak = 200;                                // ERROR!

  func(weak);                                 // weak copy:   count = 1

}                                             // weak dtor:   count = 1
                                              // shared dtor: count = 0

void func(std::weak_ptr<int> p)               // p:  count = 1
{
  if(!p.expired())                            // Is p valid?
  {
    std::shared_ptr<int> temp(p);             // temp ctor:   count = 2
    *temp = 200;
  }                                           // temp dtor:   count = 1
}                                             // p dtor:      count = 1
```

A `std::weak_ptr` is related to a `shared_ptr`. A `std::weak_ptr` can be assigned to a `std::shared_ptr`; but doing so does not increment the reference count on the resource.

Since `weak_ptr`s can have a different lifetime to their associated `shared_ptr` there is a chance the `shared_ptr` could go out of scope (and delete its resource) before the `weak_ptr` is destroyed. A `weak_ptr` can therefore be *invalid* - that is, referencing a resource that is no longer viable. You should use the `expired()` method on the `weak_ptr` to see if it is still valid, before attempting to access it.

You cannot directly use a `weak_ptr`. You must convert it back to a `shared_ptr` first.

Resolving circular dependencies

```
class B
{
  public:
  void opB() { cout << "B::opB()" << endl; }
  void go();

private:
  friend void bind (shared_ptr<A>& a, shared_ptr<B>& b);
  std::weak_ptr<A> pA;
};
```

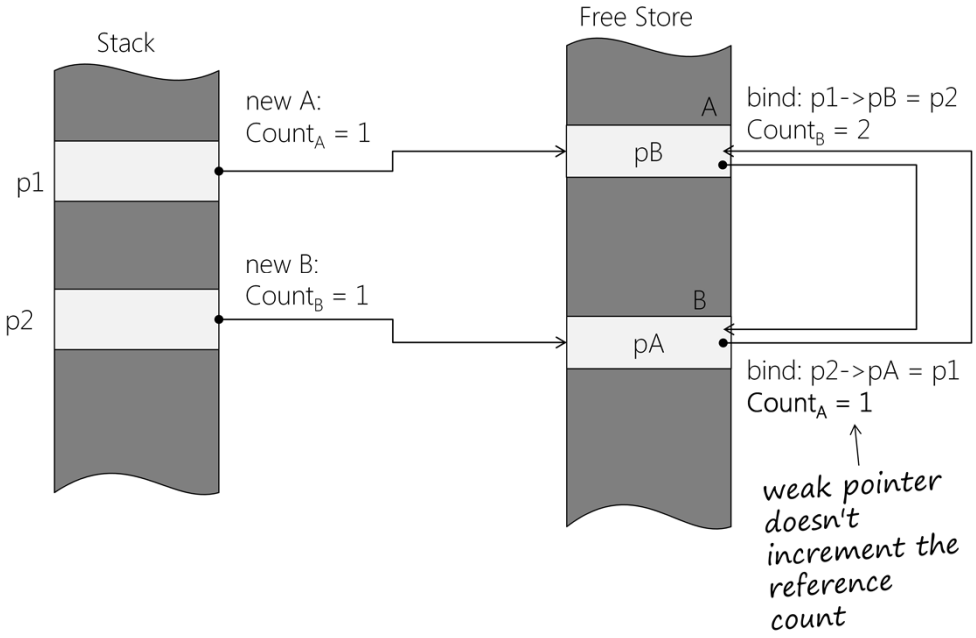
```
void B::go()
  {
    if (!pA.expired())            // Check to see if pA
  {                               // is valid.
      std::shared_ptr<A> ptr(pA); // Construct a temporary
                                  // shared_ptr to access
      ptr->opA();
    }
  }
```

Either A or B (or both) could use weak_ptrs

Using weak pointers solves our previous problem.

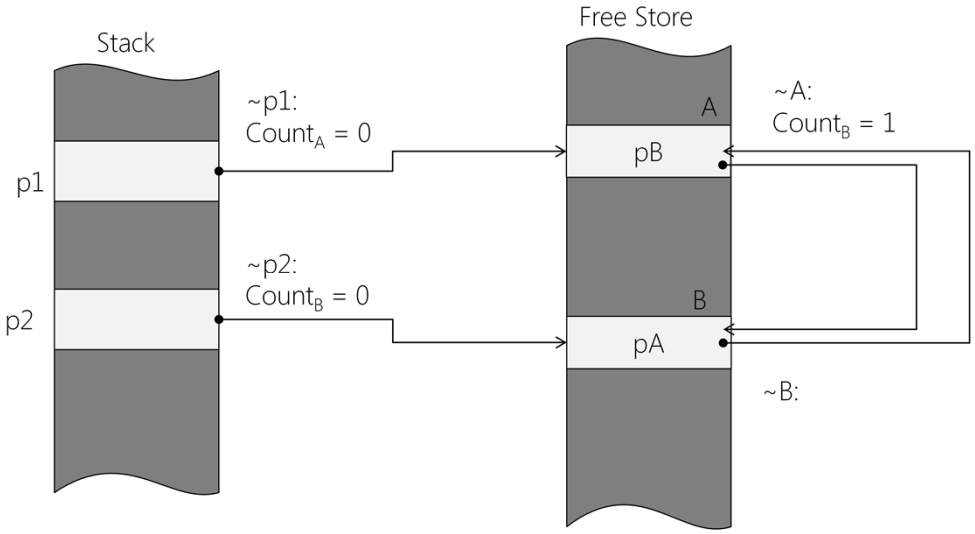
In this example you could make either, or both, pointers weak if you wish.

Construction with weak_ptr



Since B uses a `weak_ptr` to associate with `A`, when the objects are bound together the reference count for the A object remains a 1.

Destruction with weak_ptr...



When `p1` is destroyed it decrements its reference count. Since B uses a `weak_ptr` to refer to A, `p1`'s reference count is decremented to zero; and the A object is deleted.

As the A object is destroyed its `shared_ptr` (`pB`) goes out of scope, decrementing the reference count (down to 1)

Now, when `p2` is destroyed its reference count is decremented to zero; and its resource is deleted.

Key points

Raw pointers in C++ require careful (manual) management from the programmer.

Using 'smart' pointers uses RAII / RDID to allow automatic management of resource handling.

std::unique_ptr should be used for management of a resource within a single scope (block).

std::shared_ptr should be used for managing resources across scopes

std::weak_ptr resolves problems with circular references on shared_ptrs