Advanced C++

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Fun – and educational too

- http://www.symantec.com/theme.jsp?themeid=cyber-readiness-challenge
- This is (I hope) a public version of our just-completed employee cyberwar contest, where we compete to break into systems, which was a blast, and I learned more about security exploits in the last week than I did in my whole life up til then
- Obviously, no C++, but mentioning it in case anyone finds it interesting

Declaring vs Defining

- Declare (how to use)
  - int f();
- Define (actual implementation)
  - int f() { return 7; }
- Put declarations in headers
- Put definitions in
  - Headers if inline
  - Headers if template
  - .cpp files otherwise

Constructors

- `new Student_info()` leaves `midterm`, `final` with nonsense values. (Use the original version. The one with the "pure virtual" method can't be new'ed!)
- But not `homework`! We'll understand that momentarily
- Fix as follows:

```
struct Student_info {
  Student_info() : midterm(0), final(0) {}
};
```

Constructor Signatures

```
struct A {
   A(int _i = 0) : i(_i) {};
// Alternate
//    A(int _i = 0) { i = _i; }
  int i;
};
```

Non-virtual base classes

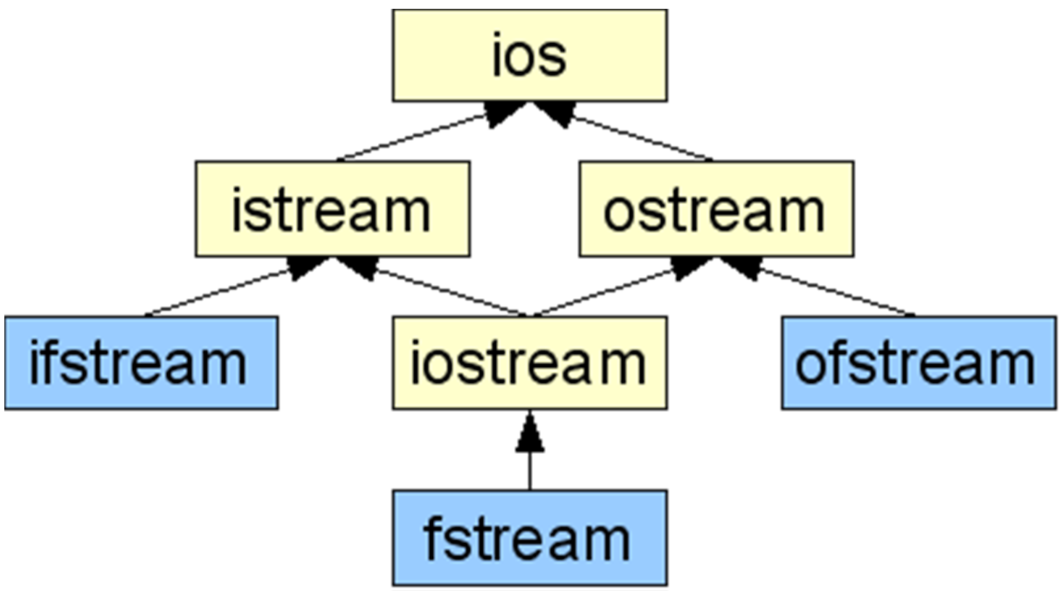
```
class B : public D {};
class C : public D {};
class A : public B, public C {
  // Has two D objects
};
```

Virtual base classes

```
struct B : virtual public D {
  B(int i) : D(i) {}
};
struct C : virtual public D {
  C() : D(5) {}
};
class A : public B, public C {
  // Has one D object
  A() : D(3), B(1){}
};
```

Multiple inheritance

- For a good discussion, see http://www.phpcompiler.org/doc/virtualinheritance.html



Implicit conversions

- Built-in
  - int i = 7;
    long l = i;
    char c = 7;
    char c = i; // No warning, but dangerous!
- Polymorphism
  - Animal *ap = new Dog;
  - Animal a = Dog(); // Legal but almost always wrong! Slicing
- User-defined
  - Constructors
  - Operator overloading
- “Standard Conversions”
  - Defined in clause 4 of the standard

Constructors and typecasts

```
struct A {
  A(int i);
  A(int i, string s);
  explicit A(double d);
};
A a0(1, "foo");
A a1(7); // Calls A(int)
A a2 = 7;// ok
A a3(5.4); // Calls A(double)
a3 = 5.5; // Calls A(int)!!
```

Type conversion operators

```
struct seven {
  operator int() { return 7; }
};
Struct A { A(int); }
int i = seven();
A a = 7;
A a = seven(); // Illegal, two user-
// defined conversions not allowed
```

Explicit conversions

- Old-style C casts (Legal but bad!)
  - `char *cp f(void *vp) { return (char *)vp; }`
- New template casting operators
  - static_cast<T>
    - Like C casts, but only makes conversions that are always valid. E.g, convert one integral type to another (truncation may still occur).
  - dynamic_cast<T*>
    - Casts between pointer types. Can even cast a Base* to a Derived* but only does the cast if the target object really is a Derived*.
    - Only works when the base class has a vtable (because the compiler adds a secret virtual function that keeps track of the real run-time type of the object).
    - If the object is not really a T *, dynamic_cast<T*> returns 0;
  - reinterpret_cast<T*>
    - Does a bitwise reinterpretation between any two pointer types, even for unrelated types. Never changes the raw address stored in the pointer. Also can convert between integral and pointer types.
  - const_cast<T>
    - Can change constness or volatileness only

More on function overloading

- Recall the basics
  - Create list of candidate functions
  - Choose a fit that is best on each argument
- What template candidate functions are chosen?
  - Each argument is used to infer the template parameters
  - No automatic type conversions are allowed

Template candidate functions

```
const T &min(const T &x, const T &y)
  { return x < y ? x : y; }
```

- `min(3, 4)` infers `T` is `int`
- For `min(3, 4.5)`, the first argument suggests that `T` is `int`, but the second argument implies `T` is `double`. Ambiguous!

Explicit function template arguments

- We can specify by giving the template arguments explicitly: `min<double>(3, 4.5)`
- This is also useful for places where functions aren't so clear. For example, to take the min of all the elements of a vector, you can use:

```
accumulate
  (v.begin(),
   v.end(),
   numeric_limits<double>::max(),
   min<double>)
```

More on template overload resolution

- Sometimes surprising results:
- What does the following output?

```
double *dp = { 0.1, 0.2, 0.3 }
cout << accumulate(dp, dp + 3, 0);
```

- Answer: 0!

```
template<class _InIt, class _Ty> inline
  _Ty _Accumulate(_InIt _First, _InIt _Last, _Ty _Val)
```

- This implies that `_Ty` is `int`.
- Correct: `accumulate(dp, dp + 3, 0.0);yy`

Order of argument evaluation

```
int f(int x, int y)
  { return x * y * y; }
int i = 3;
```

- What is `f(i++, i++)`?
- Answer: Undefined!

Undefined vs. Implementation-defined

- Implementation-defined behavior is defined (Section 1.3.5) as "behavior, for a well-formed program construct and correct data, that depends on the implementation and that each implementation shall document.“
- By contrast for undefined behavior (1.3.12), the "...standard imposes no requirement." This is scary because it means your program might work during testing and not fail until you have a million copies in the field when some small C++ run-time patch is pushed out by your compiler vendor and the order gets changed.

Copy constructors

- Classes can have constructors that show how to make copies.
- Signature is `T(T const &)`
- A default copy constructor is almost always generated
  - Calls the copy constructors of all the base classes and members in the same order we discussed before
  - `T(T const &) = delete;`

Assignment vs. Initialization

- What if a class defines both a constructor and operator=?
- Consider

  ```
  struct A {
    A(int); // Constructor
    void operator=(int);
  };
  ```

- The statement `A a = 7;` works whichever is defined, but prefers the constructor
- The statement `A a(7);` works whichever is defined, but prefers the constructor
- Function arguments prefer construction
- We'll talk about Return Value Optimization later

Rule of three

- A class should define all or neither of the following
  - Destructor
  - Copy constructor
  - Assignment operator

Order of construction

- Virtual base classes first
  - Even if not immediate
- First base class constructors are run in the order they are declared
- Next, member constructors are run in the order of declaration
- This is defined, but very complicated
  - Best practice: Don’t rely on it
  - Good place for a reminder: Best practice: don’t use virtual functions in constructors

Constructor ordering

```
class A {
public:
  A(int i) : y(i++), x(i++) {}
  int x, y;
  int f() { return x*y*y; }
};
```

- What is `A(2).f()`?

Answer: 18! (x is initialized first, because it was declared first. Order in constructor initializer list doesn't matter)

Destructor ordering

- Reverse of constructor ordering
- Begin by calling total object destructor
- Then members in reverse order of declaration
- Then non-virtual base classes in reverse order
- Virtual base classes

Object duration

- Automatic storage duration
  - Local variables
  - Lifetime is the same as the lifetime of the function/method
- Static storage duration
  - Global and static variables
  - Lifetime is the lifetime of the program
- Dynamic storage duration
  - Lifetime is explicit
  - Created with “new” destroyed with “delete”
- In all cases, the constructor is called when the object is created and the destructor is called when the object isdestroyed

Static storage duration

- What orders are the constructors of static storage duration objects called?
- In each source file, they are constructed in order
- Static/global variables in different source files are constructed in undefined orders
- This creates interesting issues

Static storage duration

```
#include <iostream>
using std;
struct A {
A() { cout << "Creating an A object" << endl;}
};
A static_a;

int main()
{ ... }
```

- Prints "Creating an A object" before main is run because all global and static objects need to be constructed before starting the main program.

Will cout be safe to use?

- There's something a little worrisome here. cout is a global object defined in the C++ run-time libary. The <iostream> header declares it as:
  `extern ostream cout;`
- How do we know `cout` will be initialized before `static_a`?
- Remember, order of static initialization is undefined for global objects defined in different source files

When does the global variable cout get defined?

- If the standard library ignored the issue, it might or might not work, depending on whether `cout` or `static_a` is initialized first.
  - Unacceptable for static constructors not to be allowed to write to `cout`.
- Fortunately, there is a static method `ios_base::init()` that initializes the standard streams.

Can we force cout to be initialized before `static_a`?

- Sure, use a static constructor ourselves

```
#include <iostream>
using namespace std;
struct ForceInitialization {
  ForceInitialization() { ios_base::Init(); }
};
ForceInitialization forceInitialization;
struct A {
  A() { cout << "Creating an A object" << endl; }
};
A static_a;
...
```

Abstracting into a header

- We will need to include ForceInit in any file that might use cout during static initialization, so extract it into a header ForceInit.

```
#ifndef FORCE_INIT_H
#define FORCE_INIT_H
#include <iostream>
struct ForceInit {
 ForceInit() { ios_base::Init(); }
};
static ForceInit forceInit;
#endif
```

Static vs. Global

- In the file above, we needed to make forceInit static, so multiple files didn't define the same global variable.
- However, the previous file still isn't right because ios_base::Init() will be called once for each source file, and we only want to call it once.

Preventing multiple initialization

```
#include <iostream>
namespace cspp51044 {
struct ForceInit {
  ForceInit() {
    if(count == 0) {
      count = 1;
      ios_base::Init();
    }
  }
private:
  static int count;
};
 static ForceInit forceInit;
}
```

So useful, it’s already there

- This idiom is extremely useful, and is actually part of the iostream header, so as long as you include iostream above where you use cout, you’re (almost) OK

Almost OK?

- Suppose A::A() didn't use cout, but called a function defined in another file.
- That function might use cout before it is initialized when it is called by static_a's constructor
- Just to be safe, you might want to include the <iostream> header in any file that creates static or global objects with non-trivial constructors.

Tear down

- Automatic and static duration objects are destroyed at the end of their scope in the reverse order they were created:

```
struct A {
  A() { cout << "A() "; }
  ~A() { cout << "~A()"; }
};
struct B {
  B() { cout << "B()"; }
  ~B() { cout << "~B()"; }
};
void f() {
  A a;
  B b;
}
int main() { f(); return 0; }
// Prints A() B() ~B() ~A()
```

HW3.1

- Write a program that prints “Hello, world!” with the following main function:

```
int
main()
{
  return 0;
}
```

- Extra credit: Give a solution that depends on constructor ordering. The more intricate the dependence, the greater the extra credit.

HW 3.2

- An object of a class that implements operator() is called a functor. For a simple (but useless) example of the syntax, you can look at http://www.devx.com/tips/Tip/13197 (free registration).

- More usefully, define a class Nth_Power so that code like the following prints the first 10 cubes.

```
int main()
{
  Nth_Power cube(3);
  for(int i = 1; i < 10; i++) {
    cout << cube(i) << endl;
  }
}
```

HW 3-3

- Combining functors with the standard library is very powerful, but sometimes gives unexpected results.
- The following code (next slide) to find the maximum length of a collection of strings unexpectedly always returns 0. Why doesn’t it work? How can you fix it?

HW 3.3 (Code)

```
#include<algorithm>
#include<iostream>
#include<string>
#include<vector>
using namespace std;

struct maxlenftn {
     maxlenftn() { maxlen = 0; }
    void operator()(string s) {
            maxlen = max(maxlen,s.size());
     }
     string::size_type maxlen;
};

int main() {
    const char *na[] = {
        "Spertus", "Lemon", "Golden", "Melhus"
    };
     vector<string> names(na, na + sizeof(na)/sizeof(const char *));
     maxlenftn maxf;
     for_each(names.begin(),names.end(),maxf);
     cout << maxf.maxlen << endl;
    return 0;
}
```

HW 3.4—Extra Credit

- Define classes D and B such that D inherits from B and create a B `*b`, such that `dynamic_cast<D*>(b)` and the c-style cast `(D*)b` give different results.
- You can demonstrate they give different results simply by printing them as pointers:

```
cout << dynamic_cast<D*>(b) << endl;
cout << (D*)b;
```

- Which one is better?
- For extra credit, solve this problem in two or more different ways
- If you wanted to get the C-style behavior but still don't want to use "bad" C++ casts, what C++ cast would you use?

HW3.5—Extra credit

- The const modifier can appear on either side of most types.
  - “int const” and “const int” mean exactly the same thing
- Which do you think is better?
- Hint: Think about pointer types