Lecture Participation Poll #24

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Lecture 24: C++ Inheritance

CSE 374: Intermediate Programming Concepts and Tools

Administrivia

- HW 3 posted Friday -> Extra credit due date Wednesday Nov 25th @ 9pm
- HW 4 posted Tuesday -> Extra credit due date Wednesday
- End of quarter due date Wednesday December 16th @ 9pm

```cpp
#ifndef BANKACCOUNT_H
#define BANKACCOUNT_H

#include <iostream>

namespace bank {

class BankAccount {
 public:
  explicit BankAccount(const std::string& accountHolder);
  BankAccount(const BankAccount& other) = delete;

  // Accessors
  int getBalance() const;
  int getAccountId() const;
  const std::string& getAccountHolder() const;

  // Modifier - add money.
  void deposit(int amount);

  // different for every type of account,
  // require derived classes to implement
  virtual void withdraw(int amount) = 0;

 protected:
  // derived classes can modify the balance.
  void setBalance(int balance);

 private:
  const std::string accountHolder_;
  const int accountId_;
  int balance_;

  static int accountCount_;
};
}
#endif
```

BankAccount.cc

```cpp
#ifndef SAVINGSACCOUNT_H
#define SAVINGSACCOUNT_H

#include "BankAccount.h"

namespace bank {

class SavingsAccount : public BankAccount {
 public:
  SavingsAccount(double interestRate, std::string name);

  double getInterestRate() const;

  virtual void withdraw(int amount) override;

 private:
  bool isNewMonth(time_t* curTime);

  double interestRate_;
  time_t lastMonth_;
  int numTransactionsInMonth_;
};

}

#endif
```

SavingsAccount.cc

Self Check

b()

m1. a1

m2. a2
b2

m3.
b3

```
#include <iostream>

using namespace std;

class A {
public:
  A() { cout << "a()" << endl; }
  ~A() { cout << "~a" << endl; }
  void m1() { cout << "a1" << endl; }
  void m2() { cout << "a2" << endl; }
};

// class B inherits from class A
class B : public A {
public:
  B() { cout << "b()" << endl; }
  ~B() { cout << "~b" << endl; }
  void m2() { cout << A::m2();
                 << "b2" << endl; }
  void m3() { cout << "b3" << endl; }
};

int main() {
  //B* x = new B();
  A* x = new B();
  x->m1();
  x->m2();
  x->m3();
  delete x;
}
```

Suppose that…

- You want to write a function to compare two ints
- You want to write a function to compare two strings
  - Function overloading!
- The two implementations of **compare** are nearly identical!
  - What if we wanted a version of **compare** for *every* comparable type?
  - We could write (many) more functions, but that's obviously wasteful and redundant
- What we'd prefer to do is write "*generic code*"
  - Code that is type-independent
  - Code that is compile-type polymorphic across types

```
// returns 0 if equal, 1 if value1 is bigger, -1 otherwise
int compare(const int& value1, const int& value2) {
  if (value1 < value2) return -1;
  if (value2 < value1) return  1;
  return 0;
}

// returns 0 if equal, 1 if value1 is bigger, -1 otherwise
int compare(const string& value1, const string& value2) {
  if (value1 < value2) return -1;
  if (value2 < value1) return  1;
  return 0;
}
```

Polymorphism in C++

- In Java: `PromisedType var = new ActualType();`
  - var is a reference (different term than C++ reference) to an object of ActualType on the Heap
  - ActualType must be the same class or a subclass of PromisedType
- In C++: `PromisedType* var_p = new ActualType();`
  - var_p is a *pointer* to an object of ActualType on the Heap
  - ActualType must be the same or a derived class of PromisedType
  - (also works with references)
  - PromisedType defines the *interface* (*i.e.* what can be called on var_p), but ActualType may determine which *version* gets invoked
- polymorphism is the ability to access different objects through the same interface

Templates in C++

- C++ has the notion of **templates**
  - A function or class that accepts a ***type*** as a parameter
    - You define the function or class once in a type-agnostic way
    - When you invoke the function or instantiate the class, you specify (one or more) types or values as arguments to it
  - At ***compile-time***, the compiler will generate the "specialized" code from your template using the types you provided
    - Your template definition is NOT runnable code
  - Code is *only* generated if you use your template

Function Template

```
// returns 0 if equal, 1 if value1 is bigger, -1 otherwise
int compare(const int& value1, const int& value2) {
  if (value1 < value2) return -1;
  if (value2 < value1) return  1;
  return 0;
}

// returns 0 if equal, 1 if value1 is bigger, -1 otherwise
int compare(const string& value1, const string& value2) {
  if (value1 < value2) return -1;
  if (value2 < value1) return  1;
  return 0;
}
```

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

// returns 0 if equal, 1 if value1 is bigger, -1 otherwise
template <typename T>    // <...> can also be written <class T>
int compare(const T &value1, const T &value2) {
  if (value1 < value2) return -1;
  if (value2 < value1) return  1;
  return 0;
}

int main(int argc, char **argv) {
  std::string h("hello"), w("world");
  std::cout << compare<int>(10, 20) << std::endl;
  std::cout << compare<std::string>(h, w) << std::endl;
  std::cout << compare<double>(50.5, 50.6) << std::endl;
  return EXIT_SUCCESS;
}
```

What's going on?

- The compiler doesn't generate any code when it sees the template function
  - It doesn't know what code to generate yet, since it doesn't know what types are involved
- When the compiler sees the function being used, then it understands what types are involved
  - It generates the ***instantiation*** of the template and compiles it (kind of like macro expansion)
    - The compiler generates template instantiations for *each* type used as a template parameter

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

// returns 0 if equal, 1 if value1 is bigger,
// -1 otherwise
template <typename T>
int compare(const T &value1, const T &value2) {
  if (value1 < value2) return -1;
  if (value2 < value1) return  1;
  return 0;
}

int main(int argc, char **argv) {
  std::string h("hello"), w("world");
  std::cout << compare(10, 20) << std::endl; // ok
  std::cout << compare(h, w) << std::endl;   // ok
  return EXIT_SUCCESS;
}
```

Class Templates

- Templates are useful for classes as well
  - (In fact, that was one of the main motivations for templates!)
- Imagine we want a class that holds a pair of things that we can set and get the value of, but we don't know what data type the things will be
- Thing is replaced with template argument when class is instantiated
  - The class template parameter name is in scope of the template class definition and can be freely used there
  - Class template member functions are template functions with template parameters that match those of the class template
    - These member functions must be defined as template function outside of the class template definition (if not written inline)
      - The template parameter name does *not* need to match that used in the template class definition, but really should
  - Only template methods that are actually called in your program are instantiated (but this is an implementation detail)

Pair.h

```
#ifndef PAIR_H_
#define PAIR_H_

template <typename Thing> class Pair {
 public:
  Pair() { };

  Thing get_first() const { return first_; }
  Thing get_second() const { return second_; }
  void  set_first(Thing &copyme);
  void  set_second(Thing &copyme);
  void  Swap();

 private:
  Thing first_, second_;
};

#include "Pair.cc"

#endif  // PAIR_H_
```

Pair Function Definition

Pair.cpp

```
template <typename Thing>
void Pair<Thing>::set_first(Thing &copyme) {
  first_ = copyme;
}

template <typename Thing>
void Pair<Thing>::set_second(Thing &copyme) {
  second_ = copyme;
}

template <typename Thing>
void Pair<Thing>::Swap() {
  Thing tmp = first_;
  first_ = second_;
  second_ = tmp;
}

template <typename T>
std::ostream &operator<<(std::ostream &out, const Pair<T>& p) {
  return out << "Pair(" << p.get_first() << ", "
          << p.get_second() << ")";
}
```

UsePair.cpp

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

#include "Pair.h"

int main(int argc, char** argv) {
  Pair<std::string> ps;
  std::string x("foo"), y("bar");

  ps.set_first(x);
  ps.set_second(y);
  ps.Swap();
  std::cout << ps << std::endl;

  return EXIT_SUCCESS;
}
```

Abstract Methods & Classes

- Sometimes we want to include a function in a class but *only* implement it in derived classes
  - In Java, we would use an abstract method
  - In C++, we use a "pure virtual" function
    - Example: virtual string **noise**() = 0;
- virtual string **noise**() = 0;
- A class containing *any* pure virtual methods is abstract
  - You can't create instances of an abstract class
  - Extend abstract classes and override methods to use them
- A class containing *only* pure virtual methods is the same as a Java interface
  - Pure type specification without implementations

Virtual Functions

- A virtual function is a member function that is declared within a base class and is overridden by a derived class,
  - Ensures correct function is called for object regardless of reference type (facilitate polymorphism)
  - A method-call is virtual if the method called is market virtual or overrides a virtual method
  - a non-virtual method call is resolved using the compile-time type of the receiver expression
  - a virtual method call is resolved using the run-time class of the receiver object (what the expression evaluates to) AKA: dynamic dispatch
- pure virtual functions
  - to maximize code sharing sometimes you will need "theoretical" objects or functions that will be shared across more specific implementations. (EX: "bank account" is too general to exist, instead you use it to share code across "checking account" and "business account")
  - When defining abstract classes sometimes you want to declare a function that must be implemented by all derived classes, you can create a virtual function:
  - `virtual void withdraw(int amount) = 0 ;`

```
class C {
    virtual t0 m(t1, t2,…,tn) = 0;
    …
};
```

Dynamic Dispatch

- Dynamic dispatch is the process of selecting which implementation of a polymorphic operation to call at runtime
- Usually, when a derived function is available for an object, we want the derived function to be invoked
  - This requires a _run time_ decision of what code to invoke
- A member function invoked on an object should be the *most-derived function* accessible to the object's visible type
  - Can determine what to invoke from the *object* itself
- Example:
  - `void PrintStock(Stock* s) { s->Print(); }`
- Calls the appropriate `Print()` without knowing the actual type of `*s`, other than it is some sort of `Stock`
- Functions just like Java
- Unlike Java: Prefix the member function declaration with the virtual keyword
  - Derived/child functions don't need to repeat virtual, but was traditionally good style to do so
  - This is how method calls work in Java (no virtual keyword needed)
  - You almost always want functions to be virtual

Dynamic Dispatch

Stock.cc

```
double Stock::GetMarketValue() const {
  return get_shares() * get_share_price();
}

double Stock::GetProfit() const {
  return GetMarketValue() - GetCost();
}
```

```
double DividendStock::GetMarketValue() const {
  return get_shares() * get_share_price() + dividends_;
}

double "DividendStock"::GetProfit() const {   // inherited
  return GetMarketValue() - GetCost();
}
```

DividendStock.cc

```
#include "Stock.h"
#include "DividendStock.h"

DividendStock dividend();
DividendStock* ds = &dividend;
Stock* s = &dividend;    // why is this allowed?

// Invokes DividendStock::GetMarketValue()
ds->GetMarketValue();

// Invokes DividendStock::GetMarketValue()
s->GetMarketValue();

// invokes Stock::GetProfit(),
//   since that method is inherited.
// Stock::GetProfit() invokes
//   DividendStock::GetMarketValue(),
//   since that is the most-derived accessible
function.
s->GetProfit();
```

Most-Derived Self-Check

```
class A {
 public:
  virtual void Foo();
};

class B : public A {
 public:
  virtual void Foo();
};

class C : public B {
};

class D : public C {
 public:
  virtual void Foo();
};

class E : public C {
};
```

```
void Bar() {
  A* a_ptr;
  C c;
  E e;

  // Q1:
  a_ptr = &c;
  a_ptr->Foo();

  // Q2:
  a_ptr = &e;
  a_ptr->Foo();
}
```

	Q1	Q2
A.	A	B
B.	A	D
C.	B	B
D.	B	D

How does dynamic dispatch work?

- The compiler produces Stock.o from *just* Stock.cc
  - It doesn't know that DividendStock exists during this process
  - So then how does the emitted code know to call Stock::**GetMarketValue**() or DividendStock::**GetMarketValue**() or something else that might not exist yet?
    - *Function pointers!!!*

Stock.h

```
virtual double Stock::GetMarketValue() const;
virtual double Stock::GetProfit() const;
```

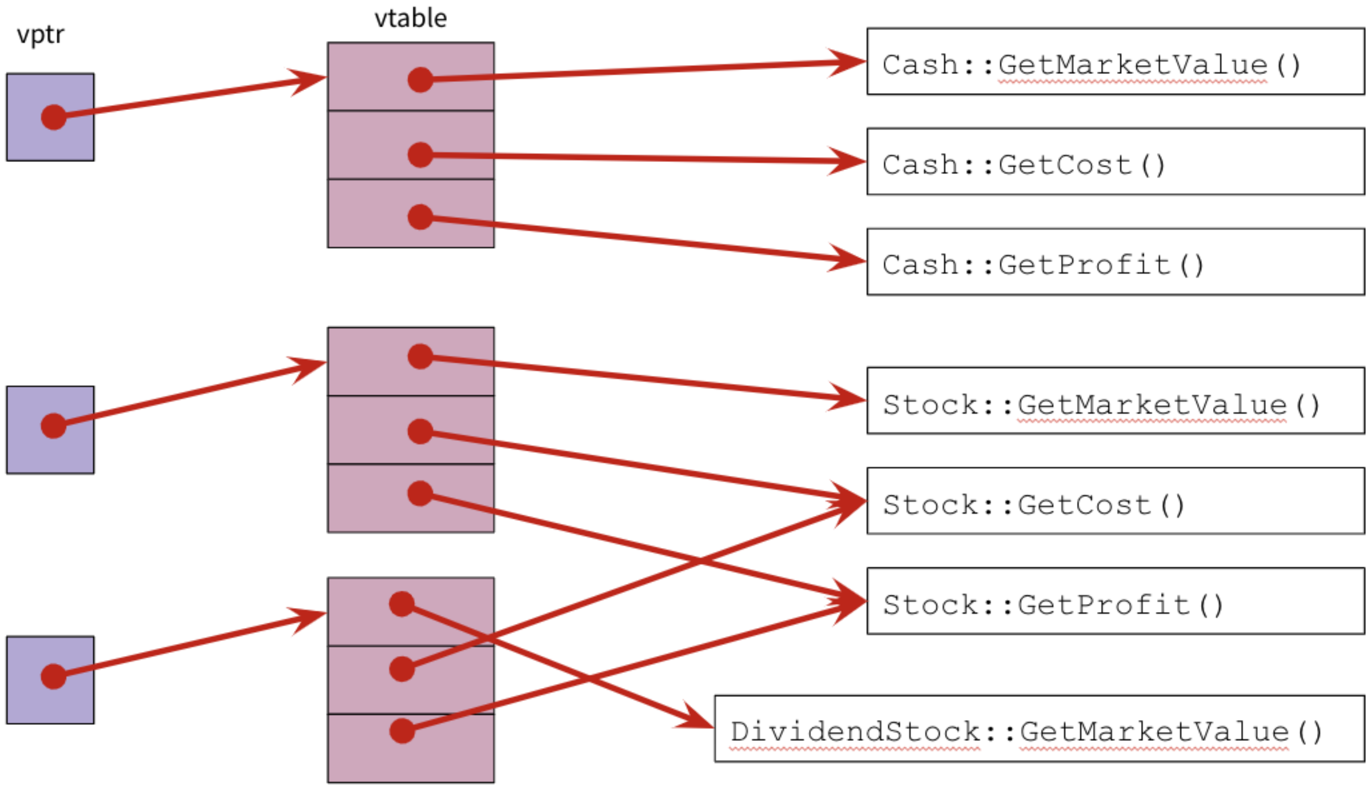
Stock.cpp

```
double Stock::GetMarketValue() const {
  return get_shares() * get_share_price();
}

double Stock::GetProfit() const {
  return GetMarketValue() - GetCost();
}
```

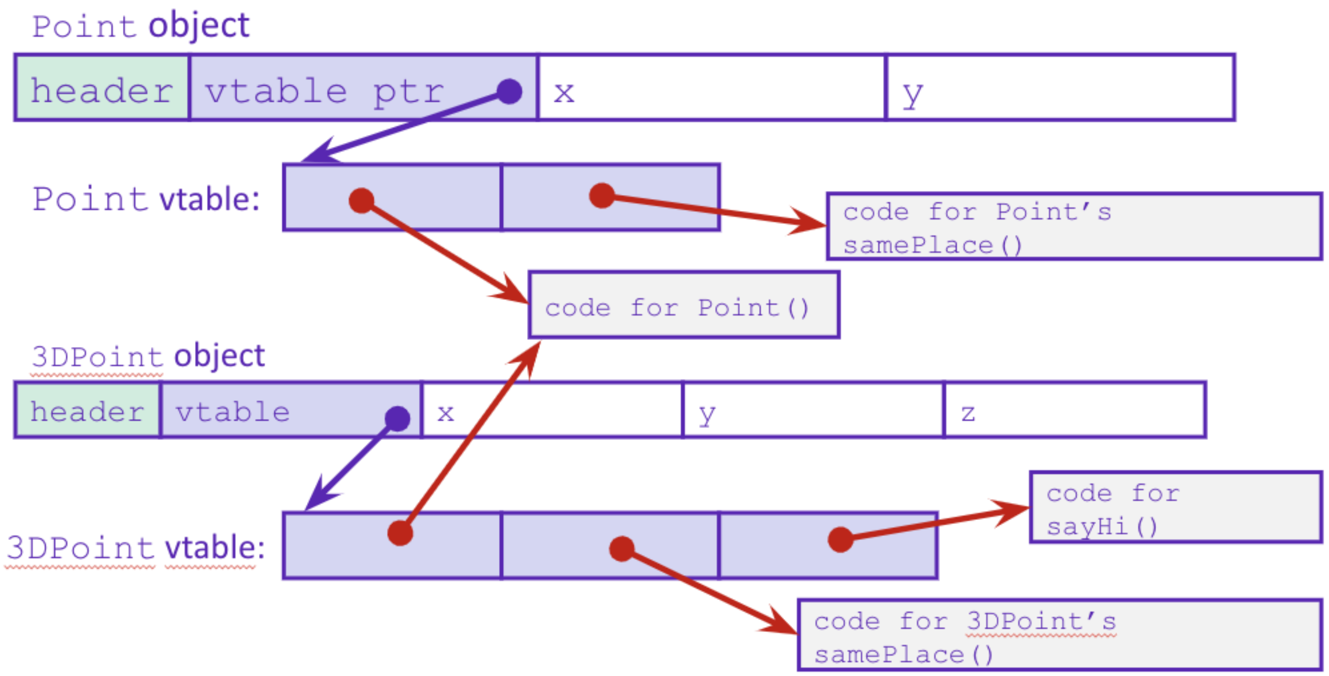
vtables and vptrs

- If a class contains *any* virtual methods, the compiler emits:
  - A (single) virtual function table (vtable) for *the class*
    - Contains a function pointer for each virtual method in the class
    - The pointers in the vtable point to the most-derived function for that class
  - A virtual table pointer (vptr) for *each object instance*
    - A pointer to a virtual table as a "hidden" member variable
    - When the object's constructor is invoked, the vptr is initialized to point to the vtable for the object's class
    - Thus, the vptr "remembers" what class the object is



Dynamic Dispatch Visual

Dynamic Dispatch



Java:

```
Point p = ???;
return p.samePlace(q);
```

C pseudo-translation:

```
// works regardless of what p is
return p->vtable[1](p, q);
```

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C++ Smart Pointers

- Wouldn't it be nice if pointers just got delete'd for us?
- 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
    - By overloading *, ->, [], etc.
  - These 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
    - With correct use of smart pointers, you no longer have to remember when to delete new'd memory!

C++ Standard Libraries

- C++'s Standard Library consists of four major pieces:
  - The entire C standard library
  - C++'s input/output stream library
    - std::cin, std::cout, stringstreams, fstreams, etc.
  - C++'s standard template library (**STL**)
    - Containers, iterators, algorithms (sort, find, etc.), numerics
  - C+'+'s miscellaneous library
    - Strings, exceptions, memory allocation, localization

Standard Template Library(STL) Containers

- A container is an object that stores (in memory) a collection of other objects (elements)
  - Implemented as class templates, so hugely flexible
- Several different classes of container
  - Sequence containers (vector, deque, list, ...)
  - Associative containers (set, map, multiset, multimap, bitset, ...)
  - Differ in algorithmic cost and supported operations
- STL containers store by *value*, not by *reference*
  - When you insert an object, the container makes a *copy*
  - If the container needs to rearrange objects, it makes copies
    - *e.g.* if you sort a vector, it will make many, many copies
    - *e.g.* if you insert into a map, that may trigger several copies
  - What if you don't want this (disabled copy constructor or copying is expensive)?
    - Use smart pointers!

STL Vector

- A generic, dynamically resizable array
  - http://www.cplusplus.com/reference/stl/vector/vector/
  - Elements are store in *contiguous* memory locations
    - Elements can be accessed using pointer arithmetic if you'd like
    - Random access is O(1) time
  - Adding/removing from the end is cheap (amortized constant time)
  - Inserting/deleting from the middle or start is expensive (linear time)

```
#include <iostream>
#include <vector>
#include "Tracer.h"

using namespace std;

int main(int argc, char** argv) {
  Tracer a, b, c;
  vector<Tracer> vec;

  cout << "vec.push_back " << a << endl;
  vec.push_back(a);
  cout << "vec.push_back " << b << endl;
  vec.push_back(b);
  cout << "vec.push_back " << c << endl;
  vec.push_back(c);

  cout << "vec[0]" << endl << vec[0] << endl;
  cout << "vec[2]" << endl << vec[2] << endl;

  return EXIT_SUCCESS;
}
```

STL iterator

- Each container class has an associated iterator class (*e.g.* vector<int>::iterator) used to iterate through elements of the container
  - http://www.cplusplus.com/reference/std/iterator/
  - Iterator range is from begin up to end i.e., [begin , end)
    - end is one past the last container element!
  - Some container iterators support more operations than others
    - All can be incremented (++), copied, copy-constructed
    - Some can be dereferenced on RHS (*e.g.* x = *it;)
    - Some can be dereferenced on LHS (*e.g.* *it = x;)
    - Some can be decremented (--)
    - Some support random access ([], +, -, +=, -=, <, > operators)

```
#include <vector>

#include "Tracer.h"

using namespace std;

int main(int argc, char** argv) {
  Tracer a, b, c;
  vector<Tracer> vec;

  vec.push_back(a);
  vec.push_back(b);
  vec.push_back(c);

  cout << "Iterating:" << endl;
  vector<Tracer>::iterator it;
  for (it = vec.begin(); it < vec.end(); it++) {
    cout << *it << endl;
  }
  cout << "Done iterating!" << endl;
  return EXIT_SUCCESS;
}
```

STL Algorithms

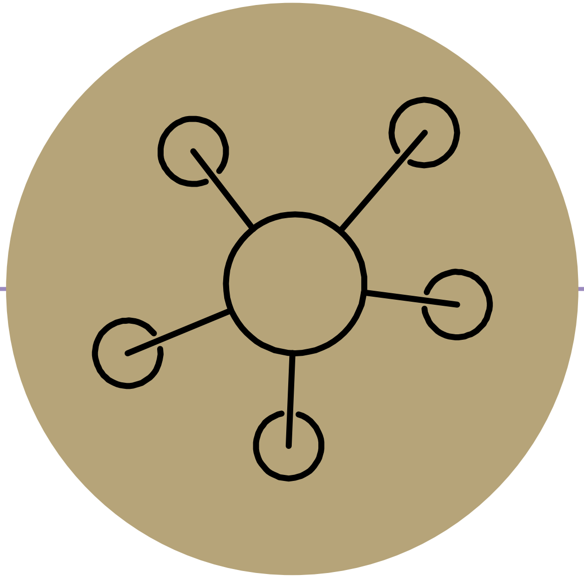
- A set of functions to be used on ranges of elements
  - Range: any sequence that can be accessed through *iterators* or *pointers*, like arrays or some of the containers
- General form: **algorithm**(*begin*, *end*, ...);
- Algorithms operate directly on range *elements* rather than the containers they live in
  - Make use of elements' copy ctor, =, ==, !=, <
  - Some do not modify elements
    - *e.g.* find, count, for_each, min_element, binary_search
  - Some do modify elements
    - *e.g.* sort, transform, copy, swap

```
#include <vector>
#include <algorithm>
#include "Tracer.h"
using namespace std;

void PrintOut(const Tracer& p) {
  cout << " printout: " << p << endl;
}

int main(int argc, char** argv) {
  Tracer a, b, c;
  vector<Tracer> vec;

  vec.push_back(c);
  vec.push_back(a);
  vec.push_back(b);
  cout << "sort:" << endl;
  sort(vec.begin(), vec.end());
  cout << "done sort!" << endl;
  for_each(vec.begin(), vec.end(),
&PrintOut);
  return 0;
}
```



Questions

RAII

- "Resource Acquisition is Initialization"
- Design pattern at the core of C++
- When you create an object, acquire resources
  - Create = constructor
  - Acquire = allocate (e.g. memory, files)
- When the object is destroyed, release resources
  - Destroy = destructor
  - Release = deallocate
- When used correctly, makes code safer and easier to read

```
char* return_msg_c() {
  int size = strlen("hello") + 1;
  char* str = malloc(size);
  strncpy(str, "hello", size);
  return str;
}
```

```
std::string return_msg_cpp() {
  std::string str("hello");
  return str;
}
```

```
using namespace std;
char* s1 = return_msg_c();
cout << s1 << endl;
string s2 = return_msg_cpp();
cout << s2 << endl;
```

RAII Example

- Which do you prefer?
- Where is the bug?

```
char* return_msg_c() {
  int size = strlen("hello") + 1;
  char* str = malloc(size);
  strncpy(str, "hello", size);
  return str;
}
```

```
std::string return_msg_cpp() {
  std::string str("hello");
  return str;
}
```

```
using namespace std;
char* s1 = return_msg_c();
cout << s1 << endl;
string s2 = return_msg_cpp();
cout << s2 << endl;
```

Compiler Optimization

- The compiler sometimes uses a "return by value optimization" or "move semantics" to eliminate unnecessary copies
  - Sometimes you might not see a constructor get invoked when you might expect it

```
Point foo() {
  Point y;              // default ctor
  return y;             // copy ctor? optimized?
}

Point x(1, 2);          // two-ints-argument ctor
Point y = x;            // copy ctor
Point z = foo();        // copy ctor? optimized?
```

Namespaces

- Each namespace is a separate scope
  - Useful for avoiding symbol collisions!
- Namespace definition:
  - ```
    namespace name {
      // declarations go here
    }
    ```
  - Doesn't end with a semi-colon and doesn't add to the indentation of its contents
  - Creates a new namespace name if it did not exist, otherwise *adds to the existing namespace* (**!**)
    - This means that components (*e.g.* classes, functions) of a namespace can be defined in multiple source files
- Namespaces vs classes
  - They seems somewhat similar, but classes are *not* namespaces:
  - There are no instances/objects of a namespace; a namespace is just a group of logically-related things (classes, functions, etc.)
  - To access a member of a namespace, you must use the fully qualified name (*i.e.* nsp_name::member)
    - Unless you are using that namespace
    - You only used the fully qualified name of a class member when you are defining it outside of the scope of the class definition
    ```

Const

- C++ introduces the “const” keyword which declares a value that cannot change
- const int CURRENT_YEAR = 2020;