Lecture Participation Poll #22

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Lecture 22: C++ Inheritance

CSE 374: Intermediate Programming Concepts and Tools

Administrivia

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

Anatomy of C++ Class

Rectangle.h

```cpp
namespace mynamespace {

   class Rectangle {

      private:
         int width;
         int height;

      public:
         Rectangle();
         Rectangle(int, int);

      public:
         int getArea() {
             return  width * height ;
         }
         int getWidth() {
             return width;
         }
         int getHeight()  {
             return height;
         }
   };
}
```

A namespace name is mynamespace

Rectangle class in the mynamespace

Field — *Rectangle has two field width and height*

Constructor — *The default Constructor (No parameter)*; *Constructor with 2 parameters width and height*

Method: — *Method to calculate the area of this rectangle*; *Method returns the width of this rectangle*; *Method returns the height of this rectangle*

Access Control

- Access modifiers for members:
  - public: accessible to *all* parts of the program
  - private: accessible to the member functions of the class
    - Private to *class*, not object instances
  - protected: accessible to member functions of the class and any *derived* classes (subclasses – more to come, later)
- Reminders:
  - Access modifiers apply to *all* members that follow until another access modifier is reached
  - If no access modifier is specified, struct members default to public and class members default to private

Class Definition (Member declaration)

Point.h

```
#ifndef POINT_H_
#define POINT_H_

class Point {
 public:
  Point(const int x, const int y); // constructor
  int get_x() const { return x_; } // inline member function
  int get_y() const { return y_; } // inline member function
  double Distance(const Point& p) const; // member function
  void SetLocation(const int x, const int y); // member
function

 private:
  int x_;   // data member
  int y_;   // data member
};  // class Point

#endif  // POINT_H_
```

Class Member Definition

Point.cpp

```
#include <cmath>
#include "Point.h"

Point::Point(const int x, const int y) {
  x_ = x;
  this->y_ = y;   // "this->" is optional unless name conflicts
}

double Point::Distance(const Point& p) const {
  // We can access p’s x_ and y_ variables either through the
  // get_x(), get_y() accessor functions or the x_, y_ private
  // member variables directly, since we’re in a member
  // function of the same class.
  double distance = (x_ - p.get_x()) * (x_ - p.get_x());
  distance += (y_ - p.y_) * (y_ - p.y_);
  return sqrt(distance);
}

void Point::SetLocation(const int x, const int y) {
  x_ = x;
  y_ = y;
}
```

Class Usage

usePoint.cpp

```
#include <iostream>
#include "Point.h"

using namespace std;

int main(int argc, char** argv) {
  Point p1(1, 2);  // allocate a new Point on the Stack
  Point p2(4, 6);  // allocate a new Point on the Stack

  cout << "p1 is: (" << p1.get_x() << ", ";
  cout << p1.get_y() << ")" << endl;

  cout << "p2 is: (" << p2.get_x() << ", ";
  cout << p2.get_y() << ")" << endl;

  cout << "dist : " << p1.Distance(p2) << endl;
  return 0;
}
```

To allocate on the heap use the "new" keyword

```
Point* p1 = new Point(1, 2);
```

Constructors in C++

- A constructor (ctor) initializes a newly-instantiated object
  - A class can have multiple constructors that differ in parameters
    - Which one is invoked depends on *how* the object is instantiated
- Written with the class name as the method name:

```
Point(const int x, const int y);
```

  - C++ will automatically create a synthesized default constructor if you have *no* user-defined constructors
    - Takes no arguments and calls the default ctor on all non-"plain old data" (non-POD) member variables
    - Synthesized default ctor will fail if you have non-initialized const or reference data members
- 4 different types of constructors
  - <u>default constructor</u> – takes zero arguments. If you don't define any constructors the compiler will generate one of these for you (just like Java)
  - <u>copy constructor</u> – takes a single parameter which is a *const reference*(`const T&`) to another object of the same type, and initializes the fields of the new object as a *copy* of the fields in the referenced object
  - <u>user-defined constructors</u> – initialize fields and take whatever arguments you specify
  - <u>conversion constructors</u> – implicit, take a single argument. If you want a single argument constructor that is not implicit must use the keyword "explicit" like: `explicit String(const char* raw);`

Synthesized Default Constructor

SimplePoint.h

```
class SimplePoint {
 public:
  // no constructors declared!
  int get_x() const { return x_; }      // inline member function
  int get_y() const { return y_; }      // inline member function
  double Distance(const SimplePoint& p) const;
  void SetLocation(int x, int y);

 private:
  int x_;   // data member
  int y_;   // data member
};  // class SimplePoint
```

SimplePoint.cpp

```
#include "SimplePoint.h"

... // definitions for Distance() and SetLocation()

int main(int argc, char** argv) {
  SimplePoint x;  // invokes synthesized default constructor
  return EXIT_SUCCESS;
}
```

Synthesized Default Constructor

- If you define *any* constructors, C++ assumes you have defined all the ones you intend to be available and will *not* add any others

```
#include "SimplePoint.h"

// defining a constructor with two arguments
SimplePoint::SimplePoint(const int x, const int y) {
  x_ = x;
  y_ = y;
}

void foo() {
  SimplePoint x;        // compiler error:  if you define any
                        // ctors, C++ will NOT synthesize a
                        // default constructor for you.

  SimplePoint y(1, 2);  // works:  invokes the 2-int-arguments
                        // constructor
}
```

Overloading Constructors

```
#include "SimplePoint.h"

// default constructor
SimplePoint::SimplePoint() {
  x_ = 0;
  y_ = 0;
}

// constructor with two arguments
SimplePoint::SimplePoint(const int x, const int y) {
  x_ = x;
  y_ = y;
}

void foo() {
  SimplePoint x;          // invokes the default constructor
  SimplePoint y(1, 2);    // invokes the 2-int-arguments ctor
  SimplePoint a[3];       // invokes the default ctor 3 times
}
```

Copy Constructors

- C++ has the notion of a copy constructor (cctor)
  - Used to create a new object as a copy of an existing object
  - Initializer lists can also be used in copy constructors
  - initializes a new bag of bits (new variable or parameter)
  - assignment (=) replaces an existing value with a new one
    - may need to clean up old state (free heap data?)

```
Point::Point(const int x, const int y) : x_(x), y_(y) { }

// copy constructor
Point::Point(const Point& copyme) {
  x_ = copyme.x_;
  y_ = copyme.y_;
}

void foo() {
  Point x(1, 2);  // invokes the 2-int-arguments constructor

  Point y(x);     // invokes the copy constructor
  Point z = y;    // also invokes the copy constructor
}
```

Synthesized Copy Constructor

- If you don't define your own copy constructor, C++ will synthesize one for you
  - It will do a *shallow* copy of all of the fields (*i.e.* member variables) of your class
  - Sometimes the right thing; sometimes the wrong thing

```
#include "SimplePoint.h"

... // definitions for Distance() and SetLocation()

int main(int argc, char** argv) {
  SimplePoint x;
  SimplePoint y(x);  // invokes synthesized copy constructor
  ...
  return EXIT_SUCCESS;
}
```

When Do Copies Happen?

- The copy constructor is invoked if:
  - You *initialize* an object from another object of the same type:

```
Point x;          // default ctor
Point y(x);       // copy ctor
Point z = y;      // copy ctor
```

  - You pass a non-reference object as a value parameter to a function:

```
void foo(Point x) { ... }

Point y;          // default ctor
foo(y);           // copy ctor
```

  - You return a non-reference object value from a function:

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

Initialization Lists

- C++ lets you *optionally* declare an initialization list as part of a constructor definition
  - Initializes fields according to parameters in the list
  - The following two are (nearly) identical:

```
Point::Point(const int x, const int y) {
  x_ = x;
  y_ = y;
  std::cout << "Point constructed: (" << x_ << ",";
  std::cout << y_<< ")" << std::endl;
}
```

```
// constructor with an initialization list
Point::Point(const int x, const int y) : x_(x), y_(y) {
  std::cout << "Point constructed: (" << x_ << ",";
  std::cout << y_<< ")" << std::endl;
}
```

Initialization vs Construction

- Data members in initializer list are initialized in the order they are defined in the class, not by the initialization list ordering
  - Data members that don't appear in the initialization list are *default initialized/constructed* before body is executed
- Initialization preferred to assignment to avoid extra steps
  - Never mix the two styles

```
class Point3D {
 public:
  // constructor with 3 int arguments
  Point3D(const int x, const int y, const int z) : y_(y), x_(x) {
    z_ = z;
  }

 private:
  int x_, y_, z_;  // data members
};  // class Point3D
```

First, initialization list is applied.

Next, constructor body is executed.

Destructors

- C++ has the notion of a destructor (dtor)
  - Like "free" in c. In fact, invokes free under the hood to clean up when freeing memory
  - Invoked automatically when a class instance is deleted, goes out of scope, etc. (even via exceptions or other causes!)
    - Do not need to call destructors explicitly
  - Place to put your cleanup code – free any dynamic storage or other resources owned by the object
  - Standard C++ idiom for managing dynamic resources
    - Slogan: "*Resource Acquisition Is Initialization*" (RAII)

```
Point::~Point() {    // destructor
  // do any cleanup needed when a Point object goes away
  // (nothing to do here since we have no dynamic resources)
}
```

Nonmember Functions

- "Nonmember functions" are just normal functions that happen to use some class
  - Called like a regular function instead of as a member of a class object instance
  - These do *not* have access to the class' private members
- Useful nonmember functions often included as part of interface to a class
  - Declaration goes in header file, but *outside* of class definition
- A class can give a nonmember function (or class) access to its non-public members by declaring it as a **friend** within its definition
  - Not a class member, but has access privileges as if it were
  - friend functions are usually unnecessary if your class includes appropriate "getter" public functions

```
class Complex {
  ...
  friend std::istream& operator>>(std::istream& in, Complex&
a);
  ...
}; // class Complex
```

Complex.h

Complex.cpp

```
std::istream& operator>>(std::istream& in, Complex& a)
{
  ...
}
```

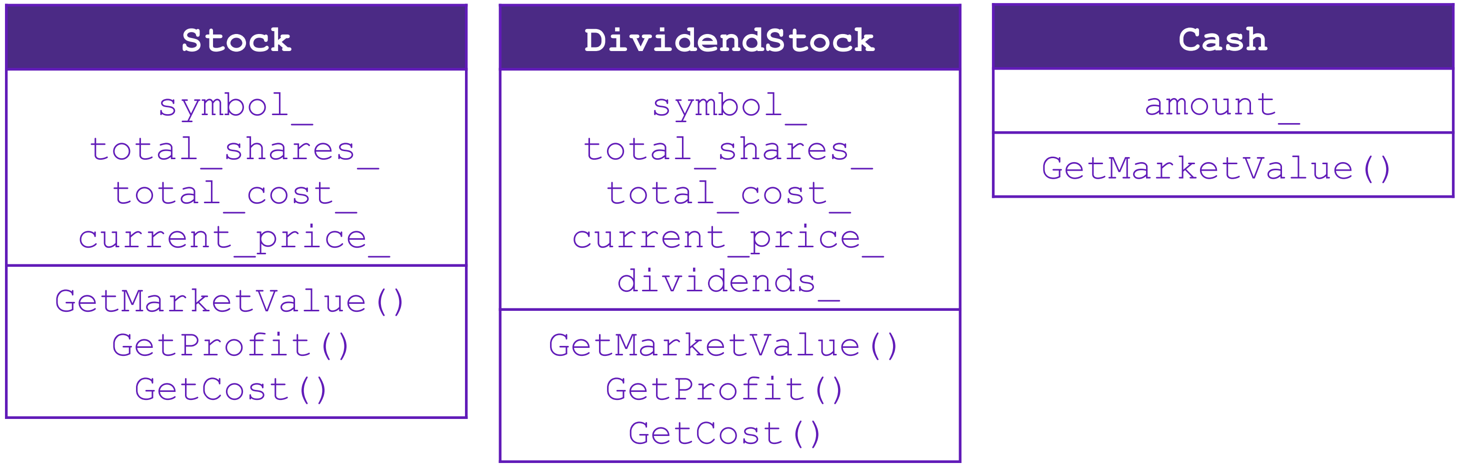
Inheritance in C++

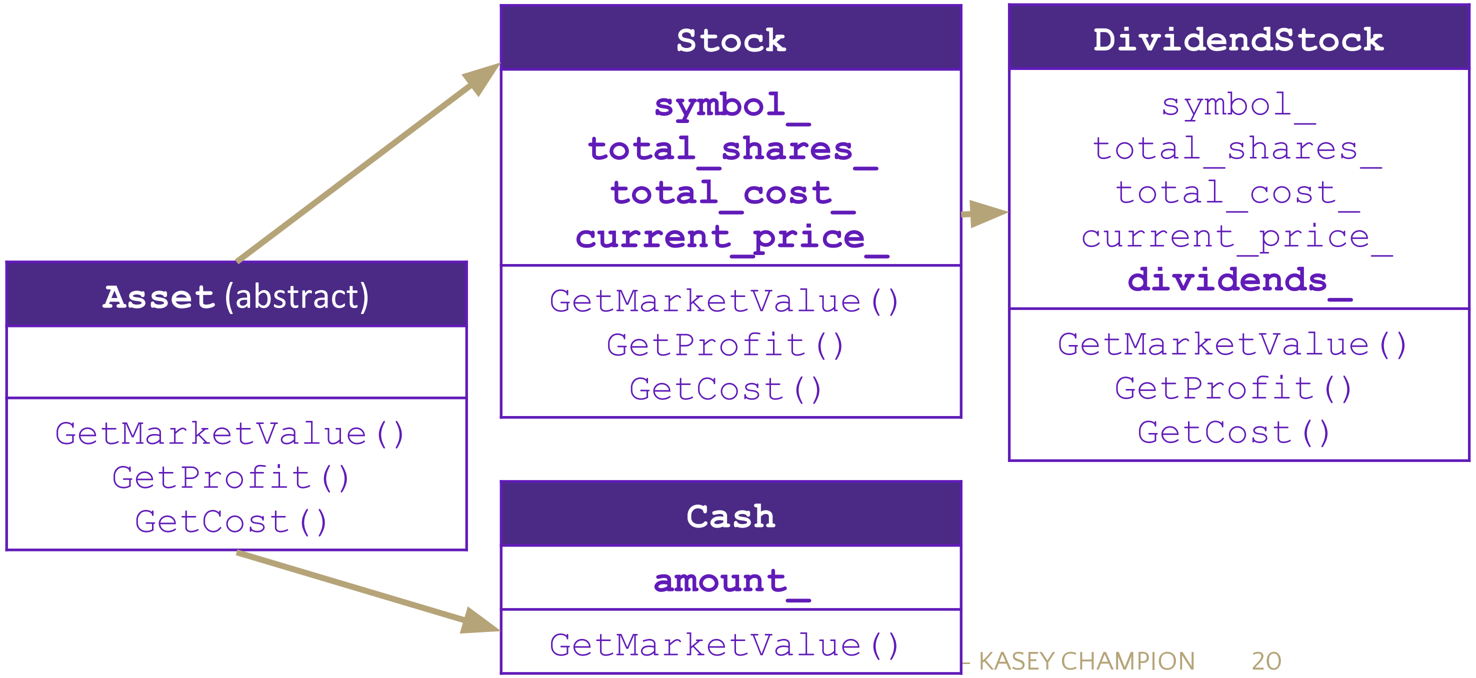
- Inheritance is the formal establishment of hierarchical relationships between classes in order to facilitate the sharing of behaviors
- A parent-child "is-a" relationship between classes
  - A child (**derived class**) extends a parent (**base class**)
- Benefits:
  - Code reuse
    - Children can automatically inherit code from parents
  - Polymorphism
    - Ability to redefine existing behavior but preserve the interface
    - Children can override the behavior of the parent
    - Others can make calls on objects without knowing which part of the inheritance tree it is in
  - Extensibility
    - Children can add behavior

Java	C++
Superclass	Base Class
Subclass	Derived Class

Inheritance Design Example: Stock Portfolio

- A portfolio represents a person's financial investments
  - Each *asset* has a cost (*i.e.* how much was paid for it) and a market value (*i.e.* how much it is worth)
    - The difference between the cost and market value is the *profit* (or loss)
  - Different assets compute market value in different ways
    - A **stock** that you own has a ticker symbol (*e.g.* "GOOG"), a number of shares, share price paid, and current share price
    - A **dividend stock** is a stock that also has dividend payments
    - **Cash** is an asset that never incurs a profit or loss





Class Derivation List

- Comma-separated list of classes to inherit from:

```
#include "BaseClass.h"

class Name : public BaseClass {
  ...
};
```

  - Focus on single inheritance, but *multiple inheritance* possible

```
#include "BaseClass.h"
#include "BaseClass2.h"
class Name : public BaseClass, public BaseClass2 {
  ...
};
```

- Almost always use “public” inheritance
  - Acts like extends does in Java
  - Any member that is non-private in the base class is the same in the derived class; both *interface and implementation inheritance*
    - Except that constructors, destructors, copy constructor, and assignment operator are *never* inherited

- `public`: visible to all other classes
- `protected`: visible to current class and its derived classes
- `private`: visible only to the current class
- Use `protected` for class members only when:
  - Class is designed to be extended by derived classes
  - Derived classes must have access but clients should not be allowed

Inheritance Design Example: Stock Portfolio

Stock
symbol_ total_shares_ total_cost_ current_price_
GetMarketValue() GetProfit() GetCost()

	DividendStock
Stock	dividends_
symbol_ total_shares_ total_cost_ current_price_	GetMarketValue() GetProfit() GetCost() PayDividend()
GetMarketValue() GetProfit() GetCost()	

A derived class:

- **Inherits** the behavior and state (specification) of the base class
- **Overrides** some of the base class' member functions (opt.)
- **Extends** the base class with new member functions, variables (opt.)

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

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;
```

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;