6.088 Intro to C/C++

Day 6: Miscellaneous Topics

Eunsuk Kang & Jean Yang

In the last lecture...

Inheritance

Polymorphism

Abstract base classes

Today's topics

Polymorphism (again)

Namespaces

Standard Template Library

Copying objects

Integer overflow

Polymorphism revisited

Polymorphism revisited

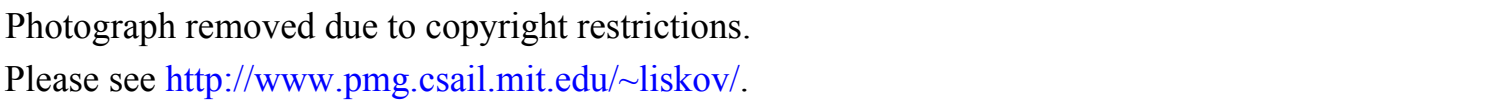
Recall: Ability of type A to appear as or be used like another type B.

Example:

```
Rectangle* r = new Square(5.0);  // length = 5.0
```

where Square is a subtype of Rectangle

Liskov Substitution Principle



Barbara Liskov
Winner, Turing Award 08'

If S is a subtype of T, then the behavior of a program P must remain unchanged when objects of type T are replaced with objects of type S.

Rectangle-Square example

```
class Rectangle {
 protected:
  float length;
  float width;
 public:
  Rectangle(float length, float width);
  void setLength();
  void setWidth();
  void getLength();
  void getWidth();
}

class Square : public Rectangle {
  // representation invariant: length = width
  public:
   Square(float length);
   void setLength();  // ensures length = width
   void setWidth();   // does nothing
}
```

Rectangle-Square example

```
class Rectangle {
 protected:
  float length;
  float width;
 public:
  Rectangle(float length, float width);
  void setLength();
  void setWidth();
  void getLength();
  void getWidth();
}

class Square : public Rectangle {
  // representation invariant: length = width
  public:
   Square(float length);
   void setLength();  // ensures length = width
   void setWidth();   // does nothing
}
```

Violates the Liskov Substitution Principle. Why?

Solutions

Ugly: Modify setWidth and setLength in Rectangle to return a boolean. Make them return "true" in Rectangle, and "false" in Square. Define a separate method "setDimension" in Square.

Better: Maybe Square shouldn't really be a subtype of Rectangle? Change the type hierarchy!

Think about behaviors, not just characteristics of an object!

Solutions

Ugly: Modify setWidth and setLength in Rectangle to return a boolean. They always return "true" in Rectangle, and "false" in Square. Define a separate method "setDimension" in Square.

Better: Maybe Square shouldn't really be a subtype of Rectangle? Re-think the type hierarchy!

Think about behaviors, not just characteristics of an object!

Solutions

Ugly: Modify setWidth and setLength in Rectangle to return a boolean. They always return "true" in Rectangle, and "false" in Square. Define a separate method "setDimension" in Square.

Better: Maybe Square shouldn't really be a subtype of Rectangle? Re-think the type hierarchy!

Think about behaviors, not just characteristics of an object!

Namespaces

Namespaces

- an abstract space that contains a set of names
- useful for resolving naming conflicts

```
namespace ford {
  class SUV {
    ...
  };
}
namespace dodge {
  class SUV {
    ...
  };
}

int main() {
  ford::SUV s1 = new ford::SUV();
  dodge::SUV s2 = new dodge::SUV();
  ...
}
```

Using namespaces

Use with caution!

```
namespace ford {
  class SUV {
    ...
  };
  class Compact {
    ...
  };
}

int main() {
  using namespace ford;    // exposes SUV and Compact
  SUV s1 = new SUV();
  ...
}
```

Using namespaces

Expose only the things that you need to use!

```
namespace ford {
  class SUV {
    ...
  };
  class Compact {
    ...
  };
}

int main() {
  //using namespace ford;
  using ford::SUV;
  SUV s1 = new SUV();
  ...
}
```

C++ standard library & namespace

C++ standard library includes:

- string (`std:string s = “Hello World!”`)
- vector (`std::vector<T> ...`)
- iostream (`std::cout << ...`)
- and many other things!

The library lives inside the namespace “std”

Using namespace std

```
#include <string>

class MITPerson {

 protected:
  int id;
  std::string name;
  std::string address;

 public:

  MITPerson(int id, std::string name, std::string address);

  void displayProfile();
  void changeAddress(std::string newAddress);

};
```

Using namespace std

```
#include <string>

class MITPerson {

 protected:
  int id;
  std::string name;
  std::string address;

 public:

  MITPerson(int id, std::string name, std::string address);

  void displayProfile();
  void changeAddress(std::string newAddress);

};
```

Using namespace std

```
#include <string>

class MITPerson {

 protected:
  int id;
  std::string name;
  std::string address;

 public:

  MITPerson(int id, std::string name, std::string address);

  void displayProfile();
  void changeAddress(std::string newAddress);

};
```

I am too lazy to type!

Using namespace std

```
#include <string>

using namespace std;

class MITPerson {

 protected:
  int id;
  string name;
  string address;

 public:

  MITPerson(int id, string name, string address);

  void displayProfile();
  void changeAddress(string newAddress);

};
```

Using namespace std - Be aware!

This is potentially dangerous. Why?

Rules of thumb:

- "using std::string" instead of "using namespace std"
- include "using..." only in the .cc file, not in the header (why?)

Simplest rule: Just type "std::". Sacrifice a few extra keystrokes in the name of good!

Standard Template Library

Standard Template Library (STL)

- a set of commonly used data structures & algorithms
- parameterized with types

Some useful ones include:

- vector
- map
- stack, queue, priority_queue
- sort

More available at:
http://www.cppreference.com/wiki/stl/start

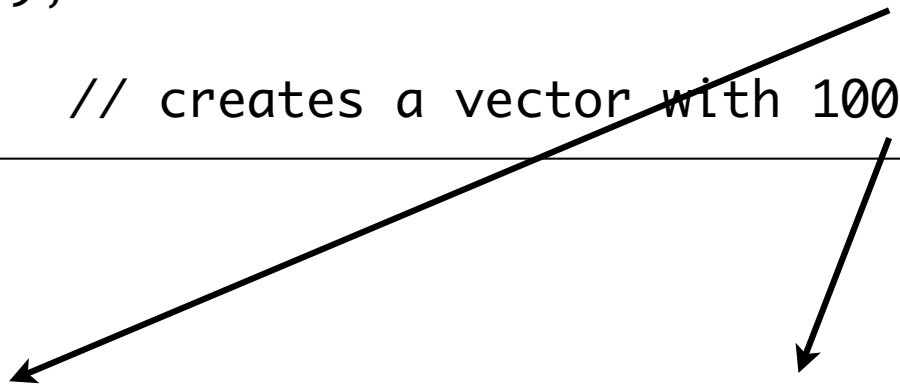
Example using vectors

- an array with automatic resizing

```
std::vector<T> v;  // creates an empty vector of type T elements

std::vector<int> v2(100);  // creates a vector with 100 ints

std::vector<T> v3(100);  // creates a vector with 100 elements
```



primitives initialized to some default value

objects created using default constructor

Student class from the last lecture

```
#include <iostream>
#include <vector>
#include "MITPerson.h"
#include "Class.h"

class Student : public MITPerson {

  int course;
  int year;      // 1 = freshman, 2 = sophomore, etc.
  std::vector<Class*> classesTaken;

 public:
  Student(int id, std::string name, std::string address,
          int course, int year);
  void displayProfile();
  void addClassTaken(Class* newClass);
  void changeCourse(int newCourse);

};
```

A list of classes as a vector

```
#include <iostream>
#include <vector>
#include "MITPerson.h"
#include "Class.h"

class Student : public MITPerson {

  int course;
  int year;      // 1 = freshman, 2 = sophomore, etc.
  std::vector<Class*> classesTaken;

 public:
  Student(int id, std::string name, std::string address,
          int course, int year);
  void displayProfile();
  void addClassTaken(Class* newClass);
  void changeCourse(int newCourse);

};
```

don't forget!

declares an empty vector of pointers to Class objects

Vector operations

```
Class* c1 = new Class("6.01");
Class* c2 = new Class("6.005");

// inserting a new element at the back of the vector
classesTaken.push_back(c1);
classesTaken.push_back(c2);

// accessing an element
Class* c3 = classesTaken[0];
Class* c4 = classesTaken.at(1);
std::cout << c3.getName() << "\n";  // prints "6.01"
std::cout << c4.getName() << "\n";  // prints "6.005"

// removing elements from the back of the vector
classesTaken.pop_back();
classesTaken.pop_back();

// checking whether the vector is empty
if (classesTaken.empty()) std::cout << "Vector is empty!\n";
```

Vector operations

```
Class* c1 = new Class("6.01");
Class* c2 = new Class("6.005");

// inserting a new element at the back of the vector
classesTaken.push_back(c1);
classesTaken.push_back(c2);

// accessing an element
Class* c3 = classesTaken[0];
Class* c4 = classesTaken.at(1);
std::cout << c3.getName() << "\n";  // prints "6.01"
std::cout << c4.getName() << "\n";  // prints "6.005"

// removing elements from the back of the vector
classesTaken.pop_back();
classesTaken.pop_back();

// checking whether the vector is empty
if (classesTaken.empty()) std::cout << "Vector is empty!\n";
```

Vector operations

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Class* c1 = new Class("6.01");
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// inserting a new element at the back of the vector
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std::cout << c4.getName() << "\n";  // prints "6.005"

// removing elements from the back of the vector
classesTaken.pop_back();
classesTaken.pop_back();

// checking whether the vector is empty
if (classesTaken.empty()) std::cout << "Vector is empty!\n";
```

Vector operations

```
Class* c1 = new Class("6.01");
Class* c2 = new Class("6.005");

// inserting a new element at the back of the vector
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std::cout << c4.getName() << "\n";  // prints "6.005"

// removing elements from the back of the vector
classesTaken.pop_back();
classesTaken.pop_back();

// checking whether the vector is empty
if (classesTaken.empty()) std::cout << "Vector is empty!\n";
```

Traversing a vector using an iterator

```
// display a list of classes taken by the student

// create an iterator
std::vector<Class*>::iterator it;

std::cout << "Classes taken:\n";

// step through every element in the vector
for (it = classesTaken.begin(); it != classesTaken.end(); it++){
  Class* c = *it;
  std::cout << c->getName() << "\n";
}
```

```
Classes taken:
6.01
6.005
```

Traversing a vector using an iterator

```
// display a list of classes taken by the student

// create an iterator
std::vector<Class*>::iterator it;

std::cout << "Classes taken:\n";

// step through every element in the vector
for (it = classesTaken.begin(); it != classesTaken.end(); it++){
  Class* c = *it;
  std::cout << c->getName() << "\n";
}
```

type for the iterator

increment iterator

iterator to the beginning of the vector

iterator to the end of the vector

Traversing a vector using an iterator

```
// display a list of classes taken by the student

// create an iterator
std::vector<Class*>::iterator it;

std::cout << "Classes taken:\n";

// step through every element in the vector
for (it = classesTaken.begin(); it != classesTaken.end(); it++){
  Class* c = *it;
  std::cout << c->getName() << "\n";
}
```

it a pointer to an element

*it the element

There are many other functions

Constructors	create vectors and initialize them with some data
Operators	compare, assign, and access elements of a vector
assign	assign elements to a vector
at	return a reference to an element at a specific location
back	returns a reference to last element of a vector
begin	returns an iterator to the beginning of the vector
capacity	returns the number of elements that the vector can hold
clear	removes all elements from the vector
empty	true if the vector has no elements
end	returns an iterator just past the last element of a vector
erase	removes elements from a vector
front	returns a reference to the first element of a vector
insert	inserts elements into the vector
max_size	returns the maximum number of elements that the vector can hold
pop_back	removes the last element of a vector
push_back	add an element to the end of the vector
rbegin	returns a reverse_iterator to the end of the vector
rend	returns a reverse_iterator to the beginning of the vector
reserve	sets the minimum capacity of the vector
resize	change the size of the vector
size	returns the number of items in the vector
swap	swap the contents of this vector with another

http://www.cppreference.com/wiki/stl/vector/start

Copying objects

Objects as values

So far we've dealt mostly with pointers to objects.

What if you want to pass around objects by value? For example,

```
void print(MITPerson p){
  p.displayProfile();
}

int main() {
  MITPerson p1(921172, “James Lee”, “32 Vassar St.”);
  MITPerson p2 = p1;
  print(p2);
}
```

Creating an object from another

1. initialization by value, so make a copy

```
void print(MITPerson p){
  p.displayProfile();
}

int main() {
  MITPerson p1(921172, “James Lee”, “32 Vassar St.”);
  MITPerson p2 = p1;
  print(p2);
}
```

2. pass by value, so make a copy

(3. could also return an object as a return value)

Copying objects using constructors

```
void print(MITPerson p){
  p.displayProfile();
}

int main() {
  MITPerson p1(921172, “James Lee”, “32 Vassar St.”);
  MITPerson p2 = p1;
  print(p2);
}
```

So how do objects get copied?

Copy constructors are called.

```
Object::Object(const Object& other) {
  ...
}
```

Copy constructor in MITPerson

```
#include <string>

class MITPerson {

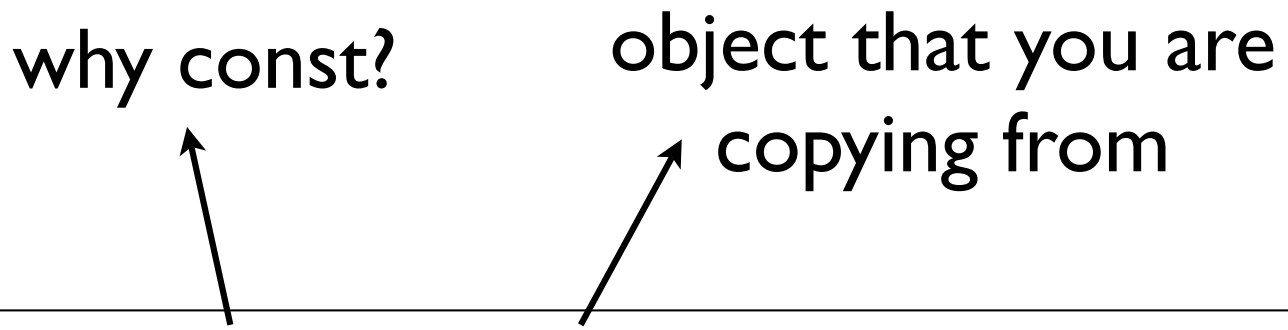
 protected:
  int id;
  std::string name;
  std::string address;

 public:

  MITPerson(int id, std::string name, std::string address);
  MITPerson(const MITPerson& other);

  void displayProfile();
  void changeAddress(std::string newAddress);
};
```

Defining the copy constructor




```
MITPerson::MITPerson(const MITPerson& other){
  name = other.name;
  id = other.id;
  address = other.address;
}
```

Default copy constructor

- automatically generated by the compiler
- copies all non-static members (primitives & objects)
- invokes the copy constructor of member objects

```
MITPerson::MITPerson(const MITPerson& other){
  name = other.name;
  id = other.id;
  address = other.address;
}
```

Assigning an object to another

```
MITPerson p1(921172, “James Lee”, “32 Vassar St.”);
MITPerson p2(978123, “Alice Smith”, “121 Ames St.”);
p2 = p1;  // assigns p2 to p1, does NOT create a new object
```

So how do objects get assigned to each other?

Copy assignment operator is called.

```
Object& Object::operator=(const Object& other) {
  ...
}
```

Copy assignment operator in MITPerson

```
#include <string>

class MITPerson {

 protected:
  int id;
  std::string name;
  std::string address;

 public:

  MITPerson(int id, std::string name, std::string address);
  MITPerson(const MITPerson& other);

  MITPerson& operator=(const MITPerson& other);
  void displayProfile();
  void changeAddress(std::string newAddress);
};
```

Defining the copy assignment operator

```
MITPerson& MITPerson::operator=(const MITPerson& other){
  name = other.name;
  id = other.id;
  address = other.address;

  return *this;  // returns a newly assigned MITPerson
}
```

```
MITPerson p1(921172, “James Lee”, “32 Vassar St.”);
MITPerson p2(978123, “Alice Smith”, “121 Ames St.”);
p2 = p1;
```

Defining the copy assignment operator

```
MITPerson& MITPerson::operator=(const MITPerson& other){
  name = other.name;
  id = other.id;
  address = other.address;

  return *this;
}
```

Again, if you don't define one, the compiler will automatically generate a copy assignment operator

So why do we ever need to define copy constructors & copy assignment operators ourselves?

Default copy constructor - caution!

```
class B {
 public:
  void print() { std::cout << "Hello World!\n”; }
};

class A {
  B* pb;
  int x;
 public:
  A(int y) : x (y) { pb = new B(); }
  ~A() { delete pb; }  // destructor
  void printB() { pb->print(); }
};

void foo(A a) {
  a.printB();
}

int main() {
  A a1(5);
  a1.printB();
  foo(a1);
  return 0;
}
```

Default copy constructor - caution!

```
class B {
 public:
  void print() { std::cout << "Hello World!\n”; }
};

class A {
  B* pb;
  int x;
 public:
  A(int y) : x (y) { pb = new B(); }
  ~A() { delete pb; }  // destructor
  void printB() { pb->print(); }
};

void foo(A a) {
  a.printB();
}

int main() {
  A a1(5);
  a1.printB();
  foo(a1);
  return 0;
}
```

Double free!

How do we fix this?

Default copy constructor - caution!

```
class B {
 public:
  void print() { std::cout << "Hello World!\n”; }
};

class A {
  B* pb;
  int x;
 public:
  A(int y) : x (y) { pb = new B(); }
  A(const A& other) {  // copy constructor
    x = other.x;
    pb = new B();
  }
  ~A() { delete pb; }  // destructor
  A& operator=(const A& other) {  // copy assignment operator
    x = other.x;
    delete pb;                    // clean up the junk in the existing object!
    pb = new B();
    return *this;
  }
  void printB() { pb->print(); }
};
```

Rule of three in C++

If you define any one of the three in a class, then you should define all three (you will probably need them!)

- destructor
- copy constructor
- copy assignment operator

Integer overflow

Binary search algorithm

```
int binarySearch(int a[], int key, int length) {
  int low = 0;
  int high = length - 1;

  while (low <= high) {
    int mid = (low + high) / 2;
    int midVal = a[mid];

    if (midVal < key)
      low = mid + 1
    else if (midVal > key)
      high = mid - 1;
    else
      return mid;      // key found
  }
  return -(low + 1);  // key not found
}
```


based on from Joshua Bloch's implementation in java.util

Binary search bug

```
int binarySearch(int a[], int key, int length) {
  int low = 0;
  int high = length - 1;

  while (low <= high) {
    int mid = (low + high) / 2;
    int midVal = a[mid];

    if (midVal < key)
      low = mid + 1
    else if (midVal > key)
      high = mid - 1;
    else
      return mid;      // key found
  }
  return -(low + 1);  // key not found
}
```

Can you find the bug?

Courtesy of Joshua Bloch. Used with permission.

Binary search bug

```
int binarySearch(int a[], int key, int length) {
  int low = 0;
  int high = length - 1;

  while (low <= high) {
    int mid = (low + high) / 2;
    int midVal = a[mid];

    if (midVal < key)
      low = mid + 1
    else if (midVal > key)
      high = mid - 1;
    else
      return mid;     // key found
  }
  return -(low + 1);  // key not found
}
```

if (low + high) > MAX_INTEGER, it will overflow!

dangerous array access! (Java will at least throw an exception)

One solution

Instead of:

```
int mid = (low + high) / 2;
```

use:

```
int mid = low + (high - low) / 2;
```

Surprisingly, most implementations of the binary search tree had this bug! (including java.util)

http://googleresearch.blogspot.com/2006/06/extra-extra-read-all-about-it-nearly.html

Conclusion

Useful links

Google C++ style guideline

http://google-styleguide.googlecode.com/svn/trunk/cppguide.xml

C++ FAQ

http://www.parashift.com/c++-faq-lite/index.html

There are many things we haven't told you!

Thinking in C++ (B. Eckel) Free online edition!

Essential C++ (S. Lippman)

Effective C++ (S. Meyers)

C++ Programming Language (B. Stroustrup)

Design Patterns (Gamma, Helm, Johnson, Vlissides)

Object-Oriented Analysis and Design with Applications (G. Booch, et. al)

Congratulations!

Now you know enough about C/C++ to embark on your own journey!

6.088 Introduction to C Memory Management and C++ Object-Oriented Programming

January IAP 2010