CS390-CPP
C++ programming

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General Information

- Web Page: http://www.cs.purdue.edu/homes/cs390lang/cpp
- Office: LWSN1185
- E-mail: grr@cs.purdue.edu
- Textbook:
  - C++ Programming with Design Patterns Revealed
    Tomasz Muldner
    Adison Wesley
    ISBN 0-201-72231-3
  - Buying the textbook is not required

Grading

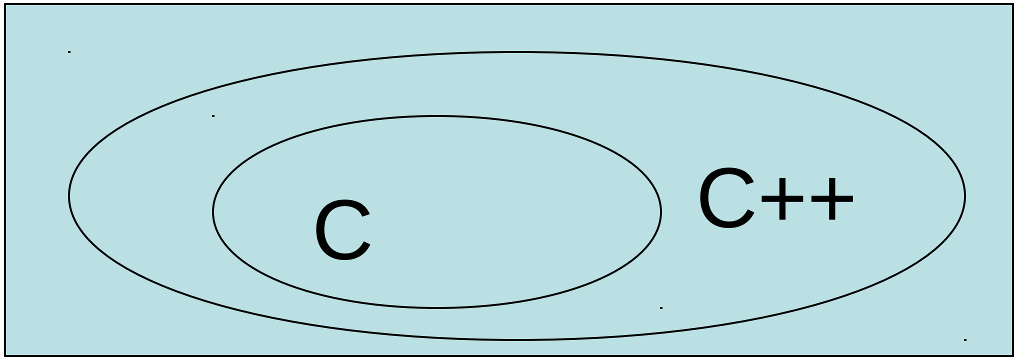
- Grade allocation
  - Final Exam: 30%
  - Final Project: 70%
- Exams also include questions about the projects.
- Please send your questions to cs390-ta@cs.purdue.edu

Course Organization

- Basic Types
- Simple I/O
- Reference Data Types
- Function Overloading,
- Default Arguments Constructors and Destructors
- Constant and Static Features
- Exception Handling
- Namespaces
- Inheritance
- Overloaded Operators
- Templates
- Standard Template Library

C++ Introduction

- C++ was designed by Bjarne Stroustrup of AT&T Bell Labs in the early 1980s
- Now C++ is widely accepted as an object-oriented low-level computer language.
- C++ is a superset of C, that is, code written in C can be compiled by a C++ compiler.



C++ and Java

- James Gosling created the Java Language
- He used C++ as base to design the Java syntax
- In this way it was easy for C++ programmers to learn Java.
- You will find Java and C++ to be very similar

Example of a C++ Program: Stack

- A C++ class is divided into two files:
  - The Header file
    - It ends with .h, or .hh
    - Example: Stack.h
  - An implementation file
    - It ends with .cc or .cpp
    - Example: Stack.cpp
- Programs that use the C++ class should include the header file
  - #include “Stack.h”

Stack.h

```
// Make sure that this file is included only once
#ifndef Stack_h
#define Stack_h

// Definition of a Stack class to store double values

class Stack {
 private:
   int maxStack;   // Max number of elements
   int top;        // Index to top of the stack
   double * stack; // Stack array
 public:
   // Constructor
   Stack(int maxStack);

   // Push a value into the stack.
   // Return false if max is reached.
   bool push(double value);
```

Stack.h (cont)

```
    // Pop a value from the stack.
    // Return false if stack is empty
    bool pop(double & value);

    // Return number of values in the stack
    int getTop() const;

    // Return max number of values in stack
    int getMaxStack() const;

    // Prints the stack contents
    void print() const;

   // Destructor
   ~Stack();
};

#endif
```

Stack.cpp

```
// Stack Implementation

// Used for cout << "string"
#include <iostream>

using namespace std;

#include "Stack.h"

// Constructor
Stack::Stack(int maxStack) {
  this->maxStack = maxStack;
  stack = new double[maxStack];
  top = 0;
}
```

Stack.cpp (cont.)

```
// Push a value into the stack.
// Return false if max is reached.
bool
Stack::push(double value) {
  if (top == maxStack) {
     return false;
  }

  stack[top]=value;
  top++;
  return true;
}
```

Stack.cpp (cont.)

```
// Pop a value from the stack.
// Return false if stack is empty
bool
Stack::pop(double & value) {
  if (top == 0) {
  return false;
  }

  top--;

  // Copy top of stack to variable value
  // passed by reference
  value = stack[top];
  return true;
}
```

Stack.cpp (cont.)

```
// Return number of values in the stack
int
Stack::getTop() const {
  return top;
}

// Return max number of values in stack
int
Stack::getMaxStack() const {
  return maxStack;
}
```

Stack.cpp (cont.)

```
// Prints the stack contents
void
Stack::print() const {
   cout << "Stack:" << endl;
   if (top==0) {
        cout << "Empty" << endl;
   }
   for (int i = 0; i < top; i++) {
        cout << i << ":" <<  stack[i] << endl;
   }
   cout << "------" << endl;
}
// Destructor
Stack::~Stack() {
  delete [] stack;
}
```

TestStack.cpp

```
// Example program to test Stack class
#include <iostream>
#include "Stack.h“

using namespace std;

int
main(int argc, char **argv) {
  Stack * stack = new Stack(10);
  stack->push(40);
  stack->push(50);
  stack->push(60);
  stack->push(70);
  stack->push(80);
```

TestStack.cpp (cont.)

```
  stack->print();

  double val;
  stack->pop(val);
  cout << "val=" << val << endl;

  stack->print();

  delete stack;
}
```

Makefile

```
all: TestStack

TestStack: TestStack.cpp Stack.cpp Stack.h
	g++ -o TestStack TestStack.cpp Stack.cpp

clean:
	rm -f TestStack core
```

Output

```
bash-4.1$ make
g++ -o TestStack TestStack.cpp Stack.cpp
.bash-4.1$ ./TestStack
Stack:
0:40
1:50
2:60
3:70
4:80
------
val=80
Stack:
0:40
1:50
2:60
3:70
------
```

Reference Data Types

- It is used to create aliases of variables and to pass by references in functions.

```
 int i = 1;
int & r = i; // Now r is an alias for i
r++;           // Increments i
```

- References have pointer semantics.

Passing by reference

- If a parameter type of a function is a reference and the parameter is modified, then it will modify the variable passed as parameter.

```
void swap(int & a, int & b) {
  int tmp = a;
  a = b;
  b = tmp;
}

main () {
  int x = 5;
  int y = 6;
  swap(x, y);
  // Now x ==6 and y ==5
}
```

- **Notice that no pointer operators * are not necessary so it looks simpler.**

Passing by Reference

- If we want a similar behavior using pure C we will need to write swap as follows:

```
void swap(int * pa, int * pb) {
  int tmp = *pa;
  *pa = *pb;
  *pb = tmp;
}

main () {
  int x = 5;
  int y = 6;
  swap(&x, &y);
  // Now x ==6 and y ==5
}
```

- References is a “syntax sugar” for pointers, that is, the code generated is the same in both cases.

Constants

- You can define variables as constant.
- If you try to modify them in your code, the compiler will generate an error.
- In this way the compiler will detect misuses of variables.
- Early detection of errors is important.
- Example:

```
const double pi = 3.14;
pi = 5; // Compiler Error!
```

Constant Parameters

- Also parameters to functions can be defined as constant.
- If the parameter is modified in the function then the compiler will generate an error.
- Example:

```
printInt(const int & i) {
   i = 9; // Compiler Error!
   . . .
}
```

Default Parameters

- You can set default parameters.
- The default parameters should be the last ones in a function declaration.
- Example:

```
void drawRect(int x, int y,
          int width=100, int height=100);

drawRect(45, 67); // Use defaults.
drawRect(78, 96, 45); // Use default height only.
```

- Only the declaration includes the default parameters and not the implementation.

Overloading Functions

- Also in C++ you can have multiple functions with the same name as long as the types of the arguments are different.
- When calling a function C++ will use the function that best matches the types.

Overloading Functions

- Example:

```
print(int a) { …}
print(const char * s) {… }
print(double d) {…}
…
int x = 9;
double y = 89.78;
const char * z =  “Hello world”;
print(x); // Uses print(int a);
print(y); // Uses print(double d)
print(z); // Uses print(const char * s)
```

Operator Overloading

- You can also define your own operators in C++.
- For example, if you have a class

```
class A {
  …
}
```

Then you can define an operator

```
A operator + (const A &s1, const A &s2) {
  …
}
```

And use it as:

```
A a;
A b;
A c = a + b;
```

We will see more of this later.

Classes

- Remember that classes in C++ use two files.
- <class>.h (or .hh) has the class declaration with the names of the methods and variables.
- <class>.cpp (or .cc or .cxx) has the implementation.

private:/protected:/public:

- Variables inside a class can be defined private, protected or public.
- private:
  - It means that every method or variable after a ***private:*** declaration can be used only by the class that defines it.
- protected:
  - It means that every method or variable after a ***protected:*** declaration can be used only by the class or subclass that defines it.
- public:
  - It means that every method or variable after a ***public:*** declaration can be used by anybody.
- See Stack.h

friends

- In some cases you would like to allow some special classes to access the private method or variables of a class.
- For this you use friends.
- Example:

```
class ListNode {
  friend class List; // Class list can access
  char * val;        // anything in ListNode
  ListNode * next;
}
class List {
  …
}
```

Inline Functions

- You can define functions as inline.
- This will be a hint for the compiler to “inline” or expand the function instead of calling it.
- This may be faster in some cases.
- Example:

```
inline int min(int a, int b) {
  return (b<a)?b:a;
}
```

- The inline function may appear in a header file.

Creating an Instance of an Object

- You can create an instance of an object dynamically by calling “new”. Example:

```
Stack * stack = new Stack();
```

- There is no garbage collector in C++, therefore you need to “delete” an object when it is no longer needed. Example:

```
delete stack;
```

- Not calling delete may cause your program to use more and more memory. This is called a “memory leak”.
- Be careful not to delete an object while it is still in use. This is called a “premature free”.

Objects as Local Variables

- You may also create an object as a local variable. Example:

```
void pushMany() {
  Stack stack();
  stack.push(78.9);
  stack.push(89.7);
  stack.print();
}
```

- The object will be deleted automatically when the function returns. No explicit call to “delete” is needed.
- The destructor will be called before returning.
- Try to define objects as local variables when possible.

TestStackWithLocalVars.cpp

```
// Example program to test Stack class
#include <iostream>
#include "Stack.h“

using namespace std;

int
main(int argc, char **argv) {
  Stack stack(10);
  stack.push(40);
  stack.push(50);
  stack.push(60);
  stack.push(70);
  stack.push(80);
```

TestStackWithLocalVars.cpp(cont.)

```
    stack.print();

    double val;
    stack.pop(val);
    cout << "val=" << val << endl;

    stack.print();
}
```

Objects as Global Variables

- Alternatively, you can define an object as a global variable.
- The variable will be created and the constructor called before main() starts.
- These constructors called before main starts are called “static constructors”.

```
// Example program to test Stack class
#include <iostream>
#include "Stack.h“

using namespace std;

// Create stack before main starts
Stack stack(10);

int
main(int argc, char **argv) {
   stack.push(40);
   stack.push(50);
   stack.push(60);
   stack.push(70);
   stack.push(80);
```

Constructors and Destructors

- When an object is created, either with new or as a local variable, the constructor is called.
- The constructor is a method with the same name as the class of the object that contains initialization code.
- The destructor is a method in the class that starts with “~” and the name of the class that is called when the object is deleted.

Constructors and Destructors

Stack.h

```
class Stack {
 private:
  int maxStack;   // Max number of elements
  int top;        // Index to top of the stack
  double * stack; // Stack array
 public:
  // Constructor
  Stack(int maxStack);
  ~Stack();
…
}
```

Constructors and Destructors

Stack.cpp:

```
// Constructor
Stack::Stack(int maxStack) {
  this->maxStack = maxStack;
  stack = new double[maxStack];
  top = 0;
}

// Destructor
Stack::~Stack() {
  // delete the array
  delete [] stack;
}
```

Constructors and Destructors

```
int foo() {
  Stack * stack = new Stack(10);
   ...
   // Prevent memory leak
   delete stack;
}
```

Allocating Arrays Dynamically

- To allocate arrays dynamically you can use new.

```
double array = new double[100];
```

- To delete an array call “delete []”

```
delete [] array;
```

Copy Constructor

- Copy constructors are called when:
  1. Initializing an object from another

```
Stack s1(50);
s1.push(78);
Stack s2 = s1;
// Now s1 and s2 are two
// different objects where s1 and
// s2 have the same contents.
```

Copy Constructor (cont)

2. A parameter of a class type is passed as a value

```
Stack s1(50);
s1.push(78);
foo(s1);
…
void foo(Stack s) {
   // s and s1 are two different
   // objects with the same contents.
```

Copy Constructor (cont)

3. When a value of a class type is returned in a function.

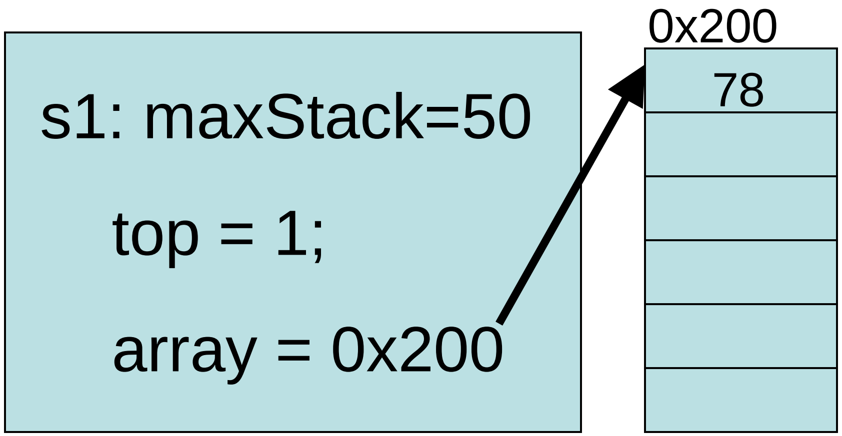
```
Stack s2 = getStack();
…
Stack getStack() {
  Stack s1(50);
  s1.push(78);
  return s1;
} // The content of s1 is copied into s2
```

Copy Constructor (cont.)

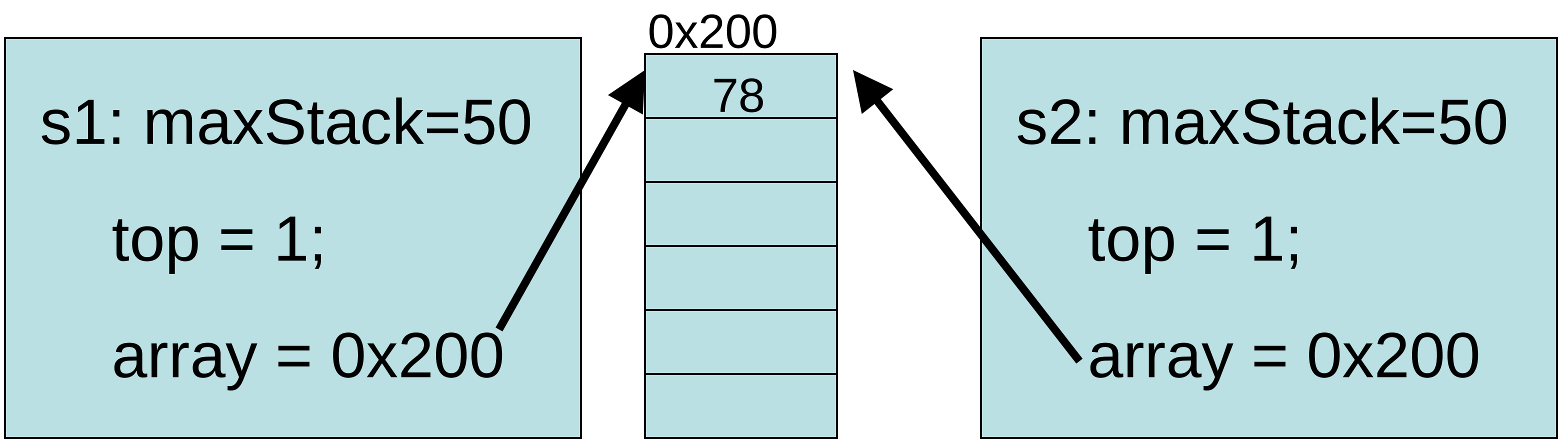
- By default the compiler will generate a copy constructor that will allocate a new instance and copy element member from the old to the new object (shallow copy).
- This is OK for simple classes but not for the classes that manage their own resources.
- Assume:

```
Stack s1(50);
s1.push(78);
Stack s2 = s1;
```

Copy Constructor (cont.)



Stack s2 = s1;



Copy Constructor (cont.)

- This is wrong because s2 should have its own copy of the stack array.
- This is solved by defining in the Stack class a “copy constructor” that will make a “deep copy” of the old object.

Copy Constructor (cont.)

Stack.h

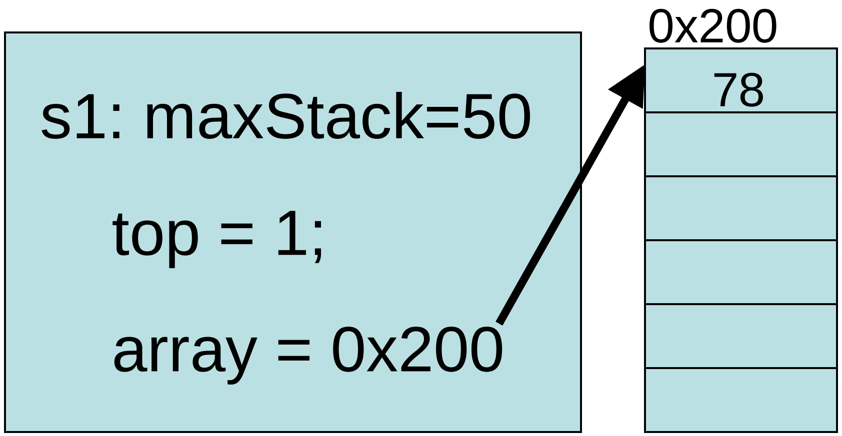
```
class Stack {
 …
 public:
    Stack();
    Stack(Stack &s); // Copy constructor
   …
};
```

Copy Constructor (cont.)

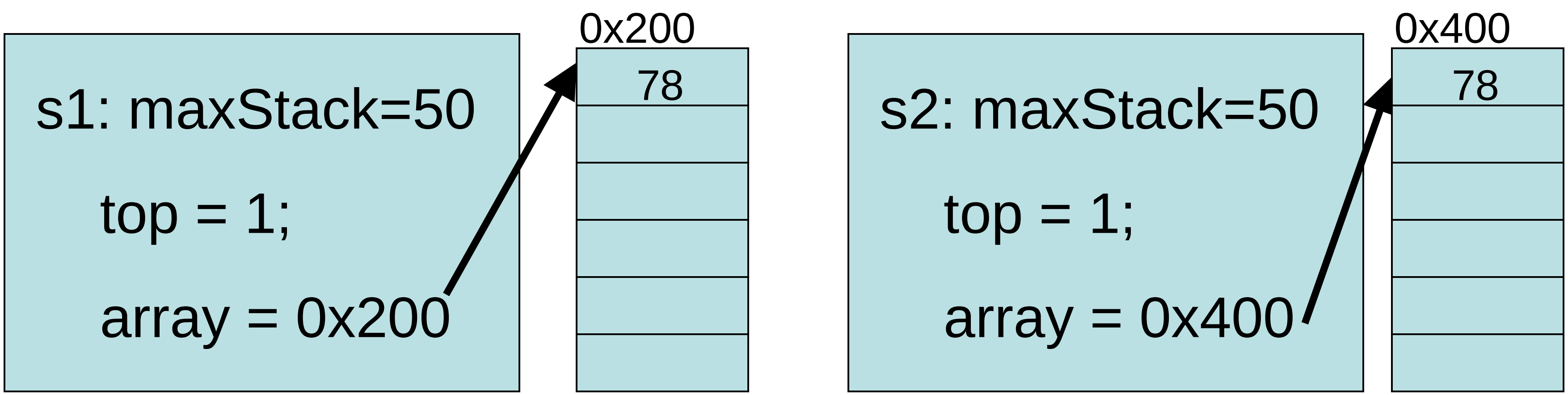
Stack.cpp

```
Stack::Stack(Stack &s) {
  top = s.top;
  maxStack = s.maxStack;

  // Create a new stack array
  stack = new double[maxStack];

  // Copy the entries in the array.
  for (int i = 0; i < top; i++) {
    stack[i] = s.stack[i];
  }
}
```

Copy Constructor (cont.)



Stack s2; s2 = s1;



Assignment Operator with Classes

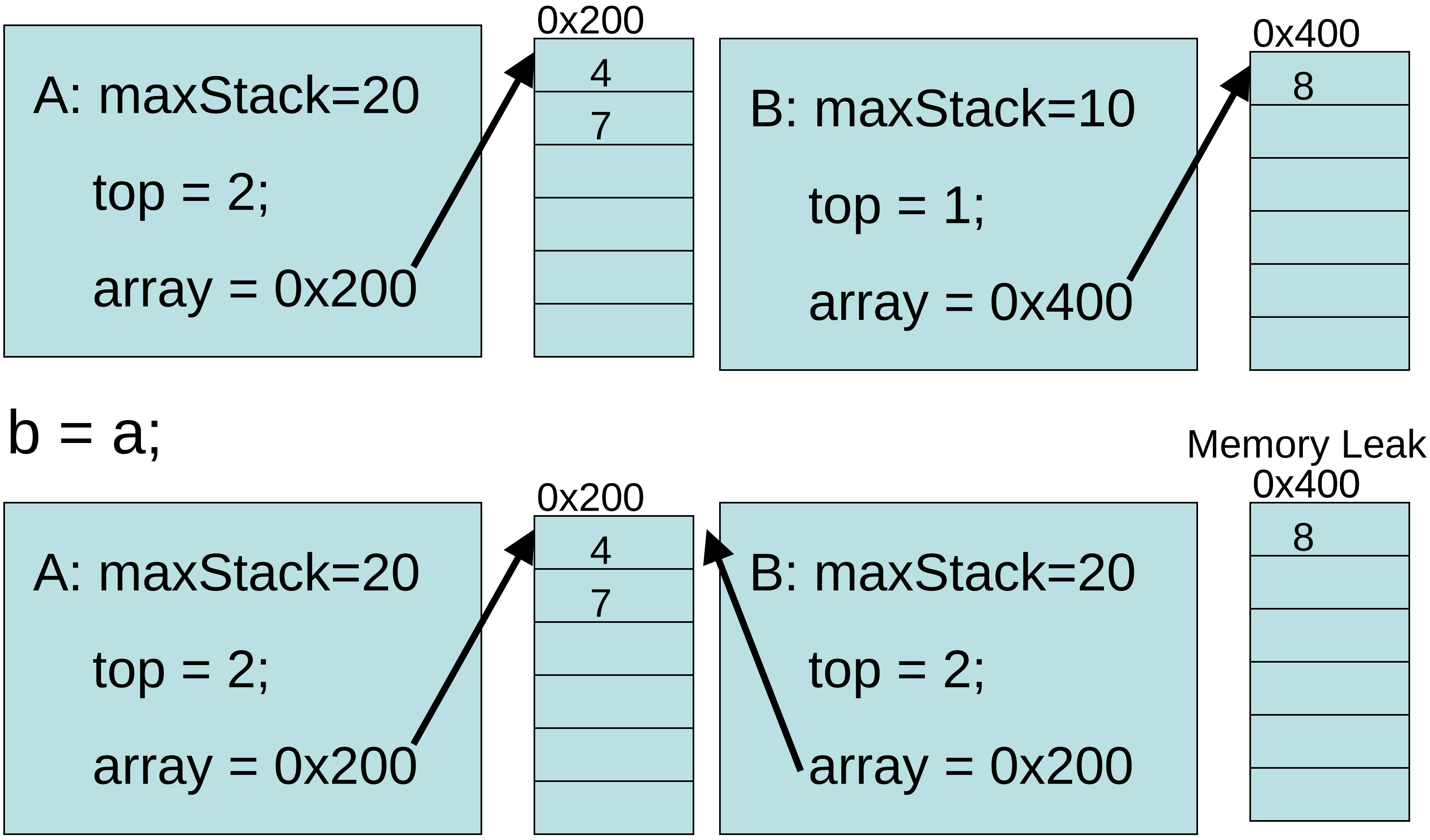
- By default assigning an object to another will copy the elements of one object to another (shallow copy)

```
Stack a(20); // Create stack a as a local var
a.push(4);
a.push(7);
Stack b(10); // Create stack b as a local var
b.push(8);
b = a; // Assign content of a to b
```

Assignment Operator with Classes

- This is wrong because the content of ***b*** will be exactly the same as ***a.***
- The member variable “stack” will point to the same array in both a and b.
- The array pointed by **b** will be overwritten and leaked.
- To fix this problem if you need to assign objects to objects you have to define your own assignment operator.

Assignment Operator with Classes



Assignment Operator with Classes

- The default assignment operator that implements a shallow copy is fine for most classes.
- However, it is not fine for classes that manage their own resources.
- For those classes we need to define an assignment operator.

Assignment Operator with Classes

<u>Stack.h</u>

```
class Stack {
 …
 public:
    Stack();

    // Copy constructor
    Stack(Stack &s);

    // Assignment Operator
    Stack & operator=(const Stack & s);
  …
};
```

Assignment Operator with Classes

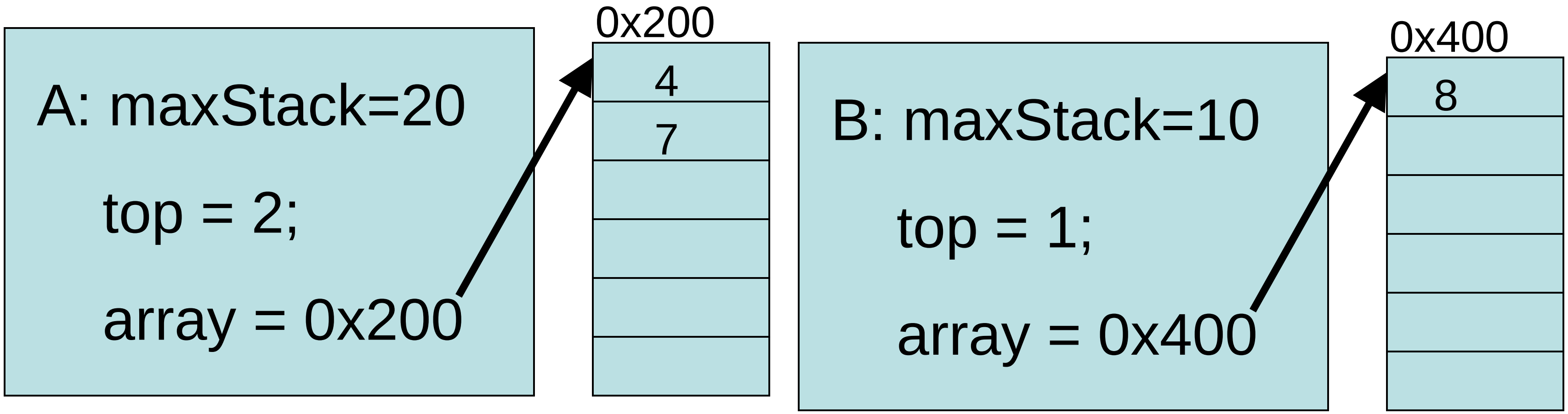
Stack.cpp

```
  // Assignment Operator
  Stack &
  Stack::operator=(const Stack & s){
   // Check for self assignment. E.g. a=a;
   if (this == &s) {
    return *this;
   }
   // deallocate old array
   delete [] stack;
```

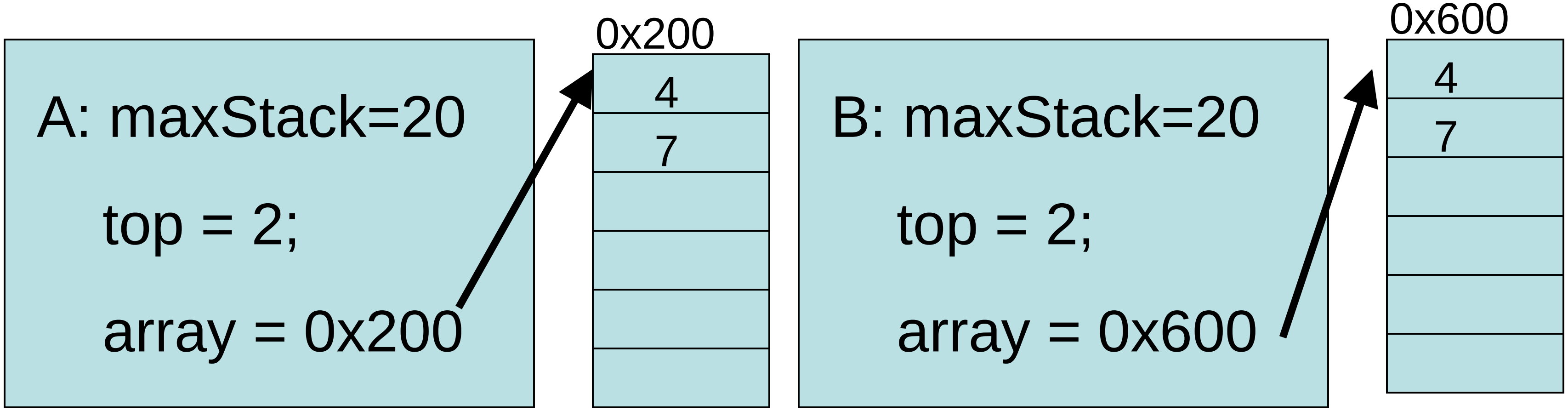
Assignment Operator with Classes

```
  // Copy members
  top = s.top;
   maxStack = s.maxStack;

   // Create a new stack array
   stack = new double[maxStack];

   // Copy the entries in the array.
   for (int i = 0; i < top; i++) {
     stack[i] = s.stack[i];
   }
   return *this;
}
```

Assignment Operator with Classes



b = a;



Exception Handling

- In C++ there are exceptions like in Java
- The exceptions thrown derive from the class “exception”.
- Other standard exceptions are defined in the include <stdexcept>.
- Exception types are:
  - exception, logic_error, invalid_argument, runtime_error, range_error, overflow_error, underflow_error, etc.

Exception Handling

```
Stack.h:
#include <stdexcept>
class Stack {
     double pop()
  throw(logic_error);
     ….
}
```

Exception Handling

```
Stack.cpp:
#include “Stack.h”
double Stack::pop() throw(logic_error)
{
  if (top==0) {
      throw logic_error(“Stack Empty”);
  }
  top--;
  return stack[top];
}
```

Exception Handling

```
int main() {
  Stack * stack = new Stack();
  try {
    stack->push();
  }
  catch (logic_error &e) {
    cout << e.what() << endl;
  }
}
```

Namespaces

- Namespaces are used to help encapsulation and modularity.
- They also are used to avoid name conflicts.
- In Java namespaces are called packages.
- The syntax is similar to the classes but without the public/protected/private.

Namespace Definition

```
Figure.h
namespace MyDraw {
  class Figure {
    …..
  };
}

Line.h
namespace MyDraw {
  class Line {
    …..
  };
}
```

Namespace Usage

- To refer to the classes in the namespace from outside the namespace you need to pre-append the namespace.
- Example:

```
MyClass.h
#include  “Figure.h”
class MyClass {
  MyDraw::Figure * figure;// Need to
                           //pre-append MyDraw
…
};
```

Namespace Usage

- If you want to avoid in your code pre-pending the namespace every time it is used, you can use “using namespace”.

```
MyClass.h
#include  “Figure.h”
using namespace MyDraw;
class MyClass {
   Figure * figure; // No need to
                    // pre-append MyDraw
…
};
```

Standard Namespaces

- The standard library that defines strings, streams etc. are in the name space “std”.
- To refer to the elements of “std” you need to pre-append std::.

```
std::cout << “Hello world”;
```

- If you don’t want to pre-append “std” every time you use the standard library use the “using” statement.

```
using namespace std;
…
cout << “Hello world”;
```

Public Inheritance

- It is used when you want a derived class to inherit all the public interface of the parent class.
- Assume the following Figure parent class.

<u>**Figure.h**</u>

```
class Figure {
 public:
    enum FigureType { Line, Rectangle,
                                  Circle, Text };

    Figure(FigureType figureType);

    FigureType getFigureType();
    void select(bool selected);
     bool isSelected();
    …
};
```

Public Inheritance

- Now assume the following Line class that is subclass of Figure. Notice the keywords “public Figure”.

Line.h

```
class Line : public Figure {
  public:
    Line(int x0, int y0,
              int x1, int y1);
    int getX0();
    …
}
```

- Line will inherit all the public methods of Figure, such as the select() and isSelected() methods.

Creating Objects of a Subclass

- The constructor of a subclass needs to take care first of constructing the attributes of the base class.
- In C++ there is no “super” like in Java, so the initialization of the base class is the same as the initialization of members.

```
 // Constructor/destructor for a line
Line::Line(int x0, int y0, int x1, int y1)
:Figure(Figure::FigureType::Line)
{
  controlPoints.push_back(
        new ControlPoint(this, x0,y0));
  controlPoints.push_back(
        new ControlPoint(this, x1,y1));
}
```

Dynamic Cast

- You can assign a pointer to Line to a variable that is a pointer to Figure.

```
Figure * figure = new Line(x0, y0, x1, y1);
```

- You can use ***figure*** to call any public method of Figure in the instance of the Line object.

```
bool selected = figure->isSelected();
```

- However you cannot call a method that only belongs to Line.

```
int x0 = figure->getX0();
        // Compiler error!! getX0() is
        // not a method of Figure.
```

Dynamic Cast

- You can use a dynamic cast to go from a pointer to a base class to a pointer to a subclass.

```
Line * line =
    dynamic_cast<Line>(figure);
  if (line != NULL) {
    // Yeah! figure was a line.
    int x0 = line->getX0();
  …
  }
```

- The dynamic cast will return NULL if the object ***figure*** points to is not a ***Line***.

Virtual Methods

- A virtual method is a method that can be overwritten by a subclass.

<u>Figure.h</u>

```
    class Figure {
     public:
        …
        Figure(FigureType figureType);

        FigureType getFigureType();

        virtual void draw(CDC * pDC);
        …
    };
```

Virtual Methods

- The subclass may overwrite the virtual method or may keep the definition of the parent class.

Line.h

```
class Line : public Figure {
  public:
    Line(int x0, int y0,
              int x1, int y1);
    void draw(CDC * pDC);
    …
};
```

- In this case Line overwrites the definition of the draw class.

Virtual Methods

- Other subclasses may also overwrite the draw method for other geometric shapes.

Rectangle.h

```
class Rectangle : public Figure {
  public:
    Rectangle(int x0, int y0,
              int x1, int y1);
    void draw(CDC * pDC);
    …
};
```

Calling Virtual Functions

- Another class like ***Drawing*** may have a vector of pointer to ***Figure*** to represent a collection of shapes.
- To draw all the figures in the vector it just needs to iterate over all the pointers and call draw().

```
void
Drawing::draw(CDC* pDC)
{
  // For each figure in vector "figures" draw the figure with
  control points.
  for (unsigned i = 0; i < this->figures.size(); i++) {
   Figure * f = figures.at(i);
   f->draw(pDC);
  }
}
```

- The draw() method called will be the one redefined by the subclasses and not the one defined by Figure.

Abstract Classes

- An abstract class is one that can serve as a base class but that cannot be directly instantiated.
- It can be instantiated only through a subclass.
- An abstract class may declare methods without implementing them.

Abstract Classes

- Example

Figure.h

```
    class Figure {
     public:
        …
        Figure(FigureType figureType);

        FigureType getFigureType();

        virtual void draw(CDC * pDC) = 0;
        …
    };
```

- The “=0” means that the base class Figure does not implement this method but subclasses should implement it.
- Trying to create an object of type Figure will give a compiler error.

```
Figure * f = new Figure(Figure::FigureType::Line);
                                                     // Compiler error
Figure * l = new Line(x0, y0, x1, y1); // OK
```

Virtual Destructors

- When calling delete on a subclass, the destructor of the subclass is called before the destructor of the base class.

A.h

```
class A {
  X * x;
public:
  A();
  ~A();
};
```

A.cpp

```
  A() {
    x = new X;
  }
  ~A() {
    delete x;
  }
```

Virtual Destructors

B.h

```
class B : public A {
  Y * y;
public:
  B();
  ~B();
};
```

B.cpp

```
B::B() {
  y = new Y;
}
B::~B() {
  delete y;
}
```

Virtual Destructors

```
B * b = new B();
…
delete b; // It will call ~B() and then ~A()

A * a = new A();
..
delete a; // It will call ~A()
```

However,

```
A* a = new B();
..
delete a; // It will call ~A() only!!!
```

Virtual Destructors

- To make sure that ~B destructor is called, you need to define the destructor in A as virtual.

  A.h

  ```
  class A {
    X * x;
  public:
    A();
    virtual ~A();
  };
  ```

- Now

  ```
  A* a = new B();
  ..
  delete a; // It will call ~B() and ~A() that is what we want.
  ```

Private Inheritance

- We have seen public inheritance where all the public methods of the parent class are public in the subclass.
- In private inheritance, the public methods of the parent class are private in the subclass.

```
class A {
 public:
    void xx();
    void yy();
};
class B : private A {
  public:
    using A::xx(); // Makes xx() public.
                   // Only xx() is accessible in B.
                   // yy() is private.
};
```

Protected Inheritance

- In protected inheritance, the public methods of the parent class are protected in the subclass.

```
class A {
 public:
    void xx();
    void yy();
};
class B : protected A {
  public:
    using A::xx(); // Makes xx() made public.
                    // Only xx() is public in B.
                   // yy() is protected so it
                   //can be inherited in a subclass.
};
```

Multiple Inheritance

- In C++ you have multiple inheritance, that is a subclass can inherit from two or more parent classes.

```
class A {
 public:
   void xx();
 }
 class B {
 public:
   void yy();
 }
 class C: public A, public B {
  }; // C inherits from both A and B so xx() and yy() are
  public.
```

- Multiple inheritance is discouraged since adds extra complexity that is not needed.
- Java uses single inheritance but a class may implement multiple interfaces.

Parameterized Types

- In C++ we have three kind of types:
  - Concrete Type:
    - It is a user defined class that is tied to a unique implementation. Example: an int or a simple class.
  - Abstract Type:
    - It is user-defined class that is not tied to a particular implementation. Example Figure is an abstract class where draw can be Line::draw, Rectangle::draw(). It uses virtual methods and subclassing.
  - Parameterized type:
    - It is a type that takes as parameter another type. Example: Stack<int> creates a stack of type int, Stack<Figure *> will build a stack of entries of type Figure *. This is the base for “Templates”.

Templates

- They are parameterized types.
- They allow to implement data structures for different types using the same code, for example :
  - Stack<int> - Stack of type int
  - Stack<double>, Stack of type double
  - Stack<Figure>, Stack of type Figure.

Templates

- A generic class starts with the template definiton:

  template <typename T>

- typename T indicates that T is a type parameter.
- There can be also compile time constants or functions

  template <typename T, int SIZE>

Writing a Template

- Before writing a template it is recommended to write the code of the class without the parameters using a concrete type.
- For example, if you want to write a List template for any type, write first a List class for “int”s (ListInt).
- Once that you compile, test and debug ListInt, then write the template by substituting the “int” by “Data” (the parameter type).
- Also add template <typename Data> before every class, function, and struct.

A ListInt Class

```
ListInt.h
// Each list entry stores int
struct ListEntryInt {
  int _data;
  ListEntryInt * _next;
};
```

A ListInt Class

```
class ListInt {
 public:
  ListEntryInt * _head;

  ListInt();
  void insert(int data);
  bool remove(int &data);
};
```

A ListInt Class

```
ListInt::ListInt()
{
  _head = NULL;
}
```

A ListInt Class

```
void ListInt::insert(int data)
{
  ListEntryInt * e = new ListEntryInt;
  e->_data = data;
  e->_next = _head;
  _head = e;
}
```

A ListInt Class

```
bool ListInt::remove(int &data)
{
  if (_head==NULL) {
    return false;
  }

  ListEntryInt * e = _head;
  data = e->_data;
  _head = e->_next;
  delete e;
  return true;
}
```

A ListGeneric Template

- To implement the ListGeneric Template that can be used for any type we start with ListInt.
- Copy ListInt.h to ListGeneric.h.
- Add “template <typename Data> “ before any class, struct or function.
- Substitute “int” by ”Data”
- Where “ListEntryInt” is used, use “ListEntry<Data>” instead.
- Where “ListInt” is used, use “ListGeneric<Data>” instead.

A ListGeneric Template

<u>ListGeneric.h</u>

```
// Each list entry stores data
template <typename Data>
struct ListEntry {
  Data _data;
  ListEntry * _next;
};
```

A ListGeneric Template

```
template <typename Data>
class ListGeneric {
 public:
  ListEntry<Data> * _head;

  ListGeneric();
  void insert(Data data);
  bool remove(Data &data);
};
```

A ListGeneric Template

```
template <typename Data>
ListGeneric<Data>::ListGeneric()
{
  _head = NULL;
}
```

A ListGeneric Template

```
template <typename Data>
void ListGeneric<Data>::insert(Data data)
{
  ListEntry<Data> * e = new ListEntry<Data>;
  e->_data = data;
  e->_next = _head;
  _head = e;
}
```

A ListGeneric Template

```
template <typename Data>
bool ListGeneric<Data>::remove(Data &data)
{
  if (_head==NULL) {
    return false;
  }

  ListEntry<Data> * e = _head;
  data = e->_data;
  _head = e->_next;
  delete e;
  return true;
}
```

Using the Template

- To use the template include “ListGeneric.h”
  #include “ListGeneric .h”

- To instantiate the ListGeneric :

```
//List of int’s
ListGeneric<int> * listInt =
   new ListGeneric<int>();

//List of strings
ListGeneric<const char *> * listString =
        new ListGeneric<const char *>();

Or as local/global vars
ListGeneric<int> listInt; // List of int’s
ListGeneric<const char *> listString; // list of strings
```

A test for GenericList

```
#include <stdio.h>
#include <assert.h>
#include " ListGeneric.h"

int
main(int argc, char **argv)
{
  //////////////////////////////////////
  // testing lists for ints

  ListGeneric<int> * listInt = new ListGeneric<int>();

  listInt->insert(8);
  listInt->insert(9);

  int val;
  bool e;
  e = listInt->remove(val);
  assert(e); assert(val==9);

  e = listInt->remove(val);
  assert(e);
  assert(val==8);
```

Using the Template

```
///////////////////////////
  // testing lists for strings

  ListGeneric<const char *> * listString = new ListGeneric<const char *>();

  listString->insert("hello");
  listString->insert("world");

  const char * s;
  e = listString->remove(s);
  assert(e);
  assert(!strcmp(s,"world"));

  e = listString->remove(s);
  assert(e);
  assert(!strcmp(s,"hello"));
}
```

Iterator Template

- An iterator is a class that allows us to iterate over a data structure.
- It keeps the state of the position of the current element in the iteration.

```
template <typename Data>
class ListGenericIterator {
  ListEntry<Data> *_currentEntry; // Points to the
   current node
  ListGeneric<Data> * _list;
 public:
  ListGenericIterator(ListGeneric<Data> * list);
  bool next(Data & data);
};
```

Iterator Template

```
template <typename Data>
ListGenericIterator<Data>::ListGenericIterator(ListGeneric<Data> * list)
{
  _list = list;
  _currentEntry = _list->_head;
}

template <typename Data>
bool ListGenericIterator<Data>::next(Data & data)
{
  if (_currentEntry == NULL) {
    return false;
  }

  data = _currentEntry->_data;
  _currentEntry = _currentEntry->_next;

  return true;
}
```

Iterator Template

```
void testIterator() {
  ListGeneric<const char *> * listString = new ListGeneric<const char *>();
  const char * (array[]) = {"one","two","three","four","five","six"};
  int n = sizeof(array)/sizeof(const char*);

  int i;
  for (i=0;i<n;i++) {
    listString->insert(array[i]);
  }

  const char * s;
  ListGenericIterator<const char *> iterator(listString);
  while (iterator.next(s)) {
    printf(">>%s\n",s);
    i--;
    assert(!strcmp(s,array[i]));
  }

  printf("Tests passed!\n");
}
```

Default Template Parameters

- You can provide default values to templates. Example:

Stack.h

```
  template <typename T = int, int n = 20>
class Stack {
   T array[n];
     …
 };
```

- At instantiation time:

```
Stack stack1; // Stack of type int of size 20 (default)
Stack<double> stack2; // Stack of type double of size 20
Stack<Figure, 100> stack3; // Stack f type Figure of size 100
```

Function Templates

- Also functions can be parameterized.

```
template <typename T>
void swap(T &a, T &b) {
   T tmp = a;
   a = b;
   b = tmp;
}
…
 int x = 3; int y = 4;
 swap(x,y); // Swaps int vars x, y
 double z1 = 3.567; double z2 = 56;
 swap(z1, z2); // Swaps double vars z1, z2
```

- The compiler will generate instances of the swap function for double and int.

C++ Input/Output Library

- Three tyes of I/O
  - Interactive I/O
  - File I/O
  - Stream I/O
- Use istream for input and ostream for output.
- We have the following predefined streams:

```
istream cin;     // Standard input
ostream cout;  // Standard output
```

Output Operations

- To output a variable use the << operator.

  cout << 7; // Prints a 7 in standard output.

- Also you can use modifiers like:

  flush – Flush output buffer

  endl - Sends end-of-line and the flush.

  dec - Display ints in base 10

  hex - Displays ints in hex format

  oct - Displays ints in octal format.

  setw(i) – Specify field width.

  left - Specify left justification

  right – Specify right justification

  setprecision(i) – Set total number of digits in a real value.

Examples

```
cout << setw(6) << left << 45;
  // Prints “45bbbb” where b is space char
cout << setw(6) << right << 45;
  // Print “bbbb45”
cout << setprecision(3) << 45.68;
  // Prints 46.7
```

Input Operations

- By default input operator >> skips whitespace chars.

```
int i;
double f;
  cin >> i; // Read an int value i
  cin >> f; // Read double f
```

- To check error conditions

```
If (!cin) {
   // operation failed
}
```

- You can also read a whole line

```
char line[200];
cin.getline(line, 200);
```

Input state

- To check the state of the input you can use:

  cin.eof() – EOF

  cin.bad() – In error state

  cin.fail() – Return true if last operation failed.

File Streams

- To write to a file you use <fstream>

  ifstream – input stream

  ofstream – output stream

For example:

```
 ifstream myinput(“file.txt”); // Open file for reading.
 int i;
 myinput >> i;  // Read integer i.
 if (! myinput) {
   // Error
 }
myinput.close(); // Close file.
```

File Streams

```
#include <fstream>
…
// Open file for writing.
 ofstream myoutput(“file.txt”);
 int i;
 myoutput << i;  // Write integer i.
 if (! myoutput) {
   // Error
 }
 myoutput.close(); // Close file.
```

Standard Template Library (STL)

- Created by Alex Stepanov in 1997.
- Intended to provide standard tool for programmers for vectors, lists, sorting, strings, numerical algorithms etc.
- It is part of the ANSI/ISO C++ standard.
- It has three components:
  - Containers: Contain collections of values.
  - Algorithms: Perform operations on the containers.
  - Iterators: Iterate over the containers.

Containers

- Containers store elements of the same type.
- There exist two kind of containers: Sequential and associative.
  - Sequential Containers:
    - used to represent sequences

vector<ElementType> - vectors

deque<ElementType> - queues with operations at either end.

list<ElementType> - Lists

Containers

- Associative Containers:
  - Used to represent sorting collections.
  - They associate a key to a data value.

set<KeyType> - Sets with unique keys.

map<KeyType,ElementType> - Maps with unique keys.

multiset<KeyType> - Sets with duplicate keys.

multimaps<KeyType, ElementType> - Maps with duplicate keys.

Iterators

- Iterators are used to refer to a value in a container.
- Every container provides its own iterator. Example:

```
vector<int> v;

. . .

for (vector<int>::iterator it = v.begin();
                              it!=v.end(); ++it) {
   cout << *it << endl;
}
```

Iterators

- An iterator supports at least the following operations:

  ***iter**   refers to the value the iterator points to.

  ++iter increments iter to point to the next value in the container.

  iter1 == iter2 Used to compare two iterators.

- Also a container like vector<int> v; provides the functions:

  v.begin() – Returns an iterator that points to the beginning of the container.

  v.end() – Returns an iterator that points to the end of the container.

Vectors

- Use

```
#include <vector>
```

- Represents a resizable array.

```
vector<int> v; // Vector of ints.
vector<Figure *> figures; // Vector of pointer to Figures.
```

- ***v.capacity()*** represents the maximum number of elements before resizing.
- ***v.size()*** represents the number of elements used.
- ***v.push_back(e)*** adds an element to the end.
- ***e=v.pop_back()*** Remove last element.
- ***e=v[i] or e=v.at(i)*** Get a reference to the ith element

Vectors and Iterators

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

using namespace std;
main()
 {
      vector<string> table;
      table.push_back(“Hello”);
      table.push_back(“World”);
      table.push_back(“cs390cpp”);

      // Iterating with i
      for (int i = 0; i < table.size(); i++) {
        cout << table[i] << endl;
      }
```

Vectors and Iterators

```
  // Iterating with an iterator
  vector<string>::iterator it;

  for (it=table.begin(); it<table.end(); it++) {
    cout << *it << endl;
  }

  // Reverse iterator
  vector<string>::reverse_iterator rit;
  for (rit=table.rbegin(); rit<table.rend(); rit++)
  {
    cout << *rit << endl;
  }
}
```

Lists

- Use

  #include <list>
- Represents a list.

  list<int> l; // List of ints.

  list<Figure *> figures; // List of pointer to Figures.
- Optimized for insertions and deletions. No random access operators such as [] or at() are provided.
- ***l.size()*** represents the number of elements used.
- ***l.push_back(e)*** adds an element to the end.
- ***e=v.pop_back()*** Remove last element.
- ***l.sort()*** sorts list.

Maps

- They are templates that represent a table that relate a key to its data.
- Std::map <*key_type*, *data_type*, [*comparison_function*]>
- Example:

```
map <string, int> grades;
grades[“Peter”] = 99;
grades[“Mary”] = 100;
grades[“John”] = 98;
cout<<“Mary’s grade is "<<grades[“Mary”] << endl;
grades[“Peter”] = 100; // Change grade
```

Maps

- Checking if an element is not in the map

```
if(grades.find(“Luke") == grades.end()) {
   cout<<“Luke is not in the grades list.“ << endl;
}
else {
   cout<<“Luke’s grade is “<< grades[“Luke”] << endl;
}
```

- **Iterating over a map**

```
for (map<string,int>::iterator it = grades.begin();
     it != grades.end(); ++it) {
    cout << “Name: " << it.first;
    cout << “Grade: " << it.second << endl;

}
```

- Erasing a key

  grades.erase(“Peter”);

STL Strings

- The STL strings provide Java like string manipulation

```
#include<string>
…
string str1 = “Hello”;
string str2 = “world.”
string str3 = str1 + “ “ + str2;
cout << str3 << endl;
```

- **`You do not need to allocate or deallocate memory. Everything is done by the methods themselves.`**
- **`You can create a STL string from a C string: string s(“c string”);`**

Some STL Strings Functions

- str.length()
  - Length of string
- str[i] or str.at(i)
  - Get ith character in the string.
- size_t str1.find (const string& str2, size_t pos = 0)
  - Find the position of a str2 in str1. -1 if not found.
- str.substr (size_t pos = 0, size_t n = npos)
  - Returns a substring starting at pos with up to n chars.
- You can use str.c_str() to get the corresponding const char * string.

Memory Allocation Errors

- Explicit Memory Allocation (calling free) uses less memory and is faster than Implicit Memory Allocation (GC)
- However, Explicit Memory Allocation is Error Prone
  1. Memory Leaks
  2. Premature Free
  3. Double Free
  4. Wild Frees
  5. Memory Smashing

Memory Leaks

- Memory leaks are objects in memory that are no longer in use by the program but that ***are not freed***.
- This causes the application to use excessive amount of heap until it runs out of physical memory and the application starts to swap slowing down the system.
- If the problem continues, the system may run out of swap space.
- Often server programs (24/7) need to be “rebounced” (shutdown and restarted) because they become so slow due to memory leaks.

Memory Leaks

- Memory leaks is a problem for long lived applications (24/7).
- Short lived applications may suffer memory leaks but that is not a problem since memory is freed when the program goes away.
- Memory leaks is a “slow but persistent disease”. There are other more serious problems in memory allocation like premature frees.

Memory Leaks

Example:

```
int * i;
while (1) {
  ptr = new int;
}
```

Premature Frees

- A premature free is caused when an object that is still in use by the program is freed.
- The freed object is added to the free list modifying the next/previous pointer.
- If the object is modified, the next and previous pointers may be overwritten, causing further calls to malloc/free to crash.
- Premature frees are difficult to debug because the crash may happen far away from the source of the error.

Premature Frees

Example:

```
int * p = new int;
* p = 8;
delete p; // delete adds object to free list
         // updating header info
…
*p = 9;  // next ptr will be modified.
int *q = new int;
 // this call or other future malloc/free
 // calls will crash because the free
 // list is corrupted.
 // It is a good practice to set p = NULL
// after delete so you get a SEGV if
// the object is used after delete.
```

Double Free

- Double free is caused by freeing an object that is already free.
- This can cause the object to be added to the free list twice corrupting the free list.
- After a double free, future calls to malloc/free may crash.

Double Free

Example:

```
int * p = new int;

delete p; // delete adds object to free
  list
delete p; // deleting the object again
         // overwrites the next/prev ptr
         // corrupting the free list
         // future calls to free/malloc
         // will crash
```

Wild Frees

- Wild frees happen when a program attempts to free a pointer in memory that was not returned by malloc.
- Since the memory was not returned by malloc, it does not have a header.
- When attempting to free this non-heap object, the free may crash.
- Also if it succeeds, the free list will be corrupted so future malloc/free calls may crash.

Wild Frees

- Also memory allocated with *malloc()* should only be deallocated with *free()* and memory allocated with new should only be deallocated with delete.
- Wild frees are also called “free of non-heap objects”.

Wild Frees

Example:

```
int q;
int * p = &q;

delete p;
 // p points to an object without
 // header. Free will crash or
 // it will corrupt the free list.
```

Wild Frees

Example:

```
char * p = new char[100];
p=p+10;

delete [] p;
 // p points to an object without
 // header. Free will crash or
 // it will corrupt the free list.
```

Memory Smashing

- Memory Smashing happens when less memory is allocated than the memory that will be used.
- This causes overwriting the header of the object that immediately follows, corrupting the free list.
- Subsequent calls to malloc/free may crash
- Sometimes the smashing happens in the unused portion of the object causing no damage.

Memory Smashing

Example:

```
 char * s = new char[8];
strcpy(s, “hello world”);

 // We are allocating less memory for
 // the string than the memory being
 // used. Strcpy will overwrite the
 // header and maybe next/prev of the
 // object that comes after s causing
 // future calls to malloc/free to crash.
 // Special care should be taken to also
 // allocate space for the null character
 // at the end of strings.
```

Debugging Memory Allocation Errors

- Memory allocation errors are difficult to debug since the effect may happen farther away from the cause.
- Memory leaks is the least important of the problems since the effect take longer to show up.
- As a first step to debug premature free, double frees, wild frees, you may comment out free calls and see if the problem goes away.
- If the problem goes away, you may uncomment the free calls one by one until the bug shows up again and you find the offending free.

Debugging Memory Allocation Errors

- There are tools that help you detect memory allocation errors.
  - IBM Rational Purify
  - Bounds Checker
  - Insure++

Garbage Collection

- Garbage collection is a subsystem that deletes objects once they are not reachable by the program.
- There is no garbage collection native in C++.
- However, there exist libraries such as Boehm's Conservative GC that can be used in C++: http://www.hpl.hp.com/personal/Hans_Boehm/gc/
- Even with this library you have to follow certain rules, and there is no guarantee that a 3rd party library will follow these rules.
- A more realistic approach for GC in C++ is to use reference counting using "Smart Pointers".

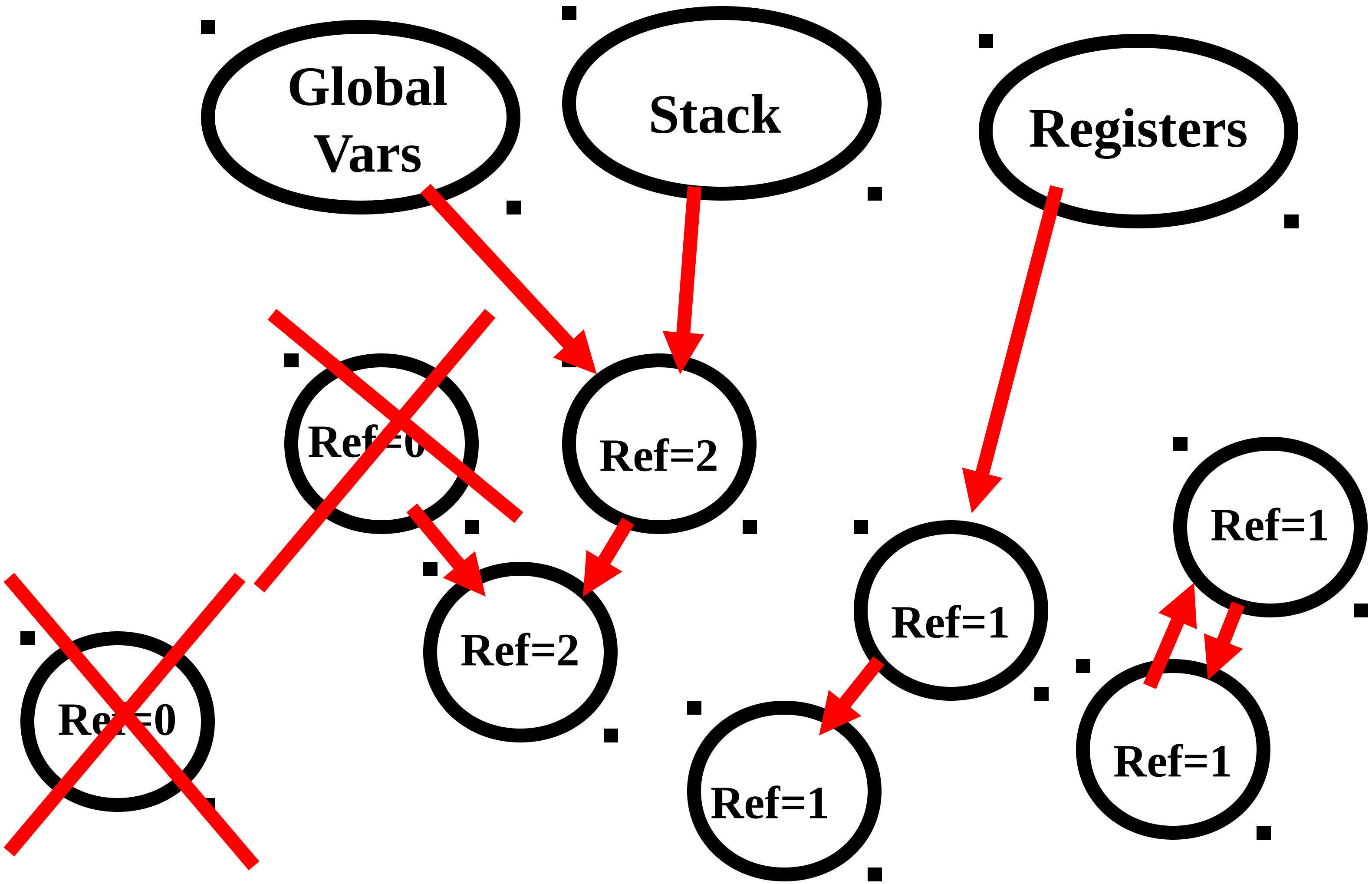
Reference Counting

- Reference counting is a garbage collection technique where an object has a reference counter that keeps track of the number of references to the object.
- Every time a new pointer points to the object, the reference counter is increased.
- When a pointer no longer points to the object, the reference is decreased.
- When the reference counter reaches 0, the object is removed.

Reference Counting

- In reference counting every object has a counter with the number of reference pointing to the object,
- When the reference count reaches 0 the object is removed.
- This is the approach used by languages such as Perl and Phyton or C++ with “Smart Pointers”.
- Advantage:
  - Easy to implement. Incremental (objects are freed while program is running)
- Disadvantage:
  - Slow. Every pointer assignment needs to increase/decreased a reference count.
  - Unable to free cycles
- In Multithreaded environments a mutex lock is necessary when incrementing/decrementing reference counter.

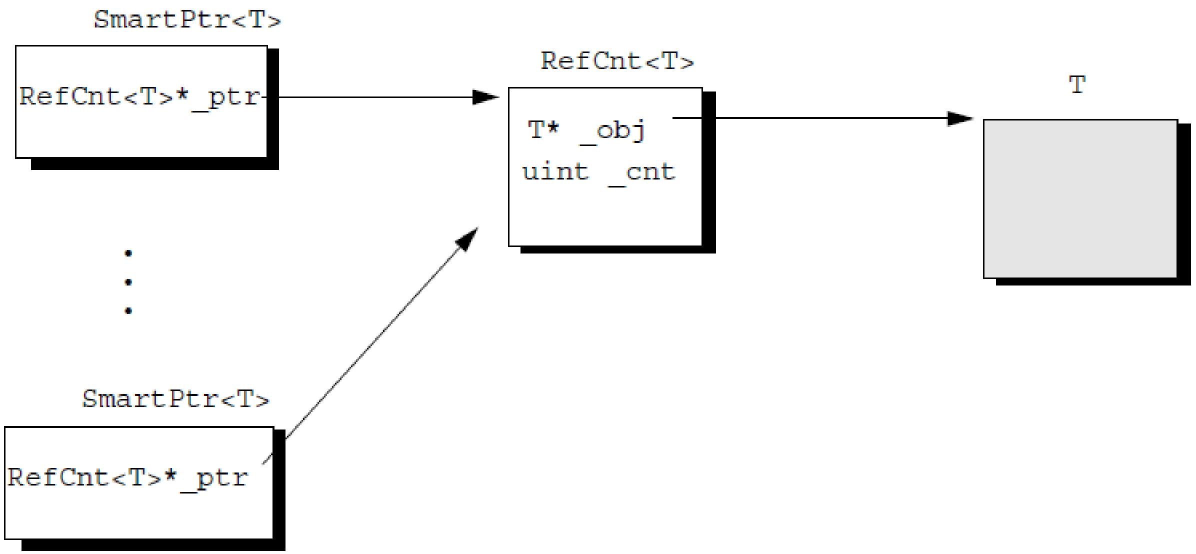
Reference Counting



Smart Pointers

- Based on Dr. Lavender Class notes at http://www.cs.utexas.edu/~lavender/courses/cs371/lectures/lecture-15.pdf
- Using operator overloading in C++ we can wrap the pointer operations such as “*” and “&” as well as “=“ to increment/decrement a reference counter.
- Also we can wrap an object around a Reference Count wrapper.
- Multiple SmartPtr<T> template instances point to a single RefCnt<T> instance, which holds a pointer and a reference count to an instance of a class T (e.g., String).
- The SmartPtr<T> template is a *handle* that is used to access a reference counted object and which updates the reference count.
  - On construction of a SmartPtr<T> instance, the count in incremented
  - On destruction the count is decremented.
  - When the last SmartPtr<T> object is destructed, the RefCnt<T> is deleted, which in turn deletes the object of type T.

Smart Pointers



Smart Pointers

SmartPtr.h

```
#include <iostream>
using namespace std;template<class T> class RefCnt {
 private:
       T* _obj;
       unsigned long _cnt;
 public:
       RefCnt(T* p) : _obj(p), _cnt(0) {
       cout << "New object " << (void *) _obj << endl;
       }
       ~RefCnt() {
       cout << "Delete object " << (void *) _obj << endl;
       assert(_cnt == 0); delete _obj;
       }
       T* object() const { return _obj; }
       int inc() {
       _cnt++;
       cout <<" increment:" << _obj << " _cnt=" << _cnt << "\n";
       return _cnt;
       }
       int dec() {
       _cnt--;
       cout <<" decrement:" << _obj << " _cnt=" << _cnt << "\n";
       return _cnt;
       }
 };
```

Smart Pointers

```
/* A ``smart pointer to a reference counted object */
template<class T> class SmartPtr {
	RefCnt<T>* _ptr; // pointer to a reference counted object of type T

	/* hide new/delete to disallow allocating a SmartPtr<T> from the heap */
	static void* operator new(size_t) {}
	static void operator delete(void*) {}
 public:
	SmartPtr(T* p) {
	_ptr = new RefCnt<T>(p);
	_ptr->inc();
	}
	SmartPtr(const SmartPtr<T>& p) {
	_ptr = p._ptr;
	_ptr->inc();
	}

	~SmartPtr() { if (_ptr->dec() == 0) { delete _ptr; } }

	void operator=(const SmartPtr<T>& p) {
	if (this != &p) {
	if (_ptr->dec() == 0) delete _ptr;
	_ptr = p._ptr;
	_ptr->inc();
	}
	}

	T* operator->() const { return _ptr->object(); }
	T& operator*() const { return *(_ptr->object()); }
};
```

Smart Pointers

testSmartPtr.cpp:

```
#include <string>
#include "SmartPtr.h"

typedef SmartPtr<string> StringPtr;

int main()
{
	cout << "StringPtr p = new string(\"Hello, world\")" << endl;
	StringPtr p = new string("Hello, world");

	cout << "StringPtr s = p" << endl;
	StringPtr s = p; // invokes copy constructor incrementing reference counter

	cout << "Invoke a String method on a StringPtr " << endl;
	cout << "Length of " << *s << " is "  << s->length() << endl;

	cout << "s = new string(\"s\");" << endl;
	s = new string("s");

	cout << "p = new string(\"p\");" << endl;
	p = new string("p");

	cout << "Before Return"<< endl;

	return 0;
};
```

Smart Pointers

Makefile:

```
goal: TestSmartPtr

TestSmartPtr: TestSmartPtr.cpp SmartPtr.h
	g++ -o TestSmartPtr TestSmartPtr.cpp

clean:
	rm -f TestSmartPtr core
```

Smart Pointers

Output:

```
lore 228 $ ./TestSmartPtr
StringPtr p = new string("Hello, world")
New object 0x22878
 increment:0x22878 _cnt=1
StringPtr s = p
 increment:0x22878 _cnt=2
Invoke a String method on a StringPtr
Length of Hello, world is 12
s = new string("s");
New object 0x22898
 increment:0x22898 _cnt=1
 decrement:0x22878 _cnt=1
 increment:0x22898 _cnt=2
 decrement:0x22898 _cnt=1
p = new string("p");
New object 0x228b8
 increment:0x228b8 _cnt=1
 decrement:0x22878 _cnt=0
Delete object 0x22878
 increment:0x228b8 _cnt=2
 decrement:0x228b8 _cnt=1
Before Return
 decrement:0x22898 _cnt=0
Delete object 0x22898
 decrement:0x228b8 _cnt=0
Delete object 0x228b8
```

Lock Guards

- Lock Guards is a wrapper that automatically locks a mutex lock when entering a function and unlock the mutex when exiting the function.
- Assume the following code:

```
pthread_mutex_t mutex;
void mt_function() {
   mutex_lock( &mutex);
   // Synchronized code
   ...
   if (error) {
      return;  // Oops. Forgot to unlock mutex
   }
   mutex_unlock(&mutex);
}
```

Lock Guards

- Mutex locks may be prone to errors. The user may forget to unlock the mutex before returning, or an exception may be thrown while holding the mutex.
- Lock Guards are objects that wrap a mutex lock to lock it during construction at the beginning of the method and unlock it during desruction at the end of the method.

Lock Guards

```
class LockGuard {
    pthread_mutex_t & mutex;
public:
    LockGuard( pthread_mutex_t & mutex) {
      this->mutex = mutex;
      pthread_mutex_lock(&mutex);
    }
    ~LockGuard() {
        pthread_mutex_unlock(&mutex);
    }
};
```

Lock Guards

```
void mt_function() {
    LockGuard( &mutex)
    // Synchronized code
     ...
     if (error) {
        return;
        // Oops. Forgot to unlock mutex
        // No problem!
        // Destructor of LockGuard will unlock it at return.
     }
     // No need to call pthread_mutex_unlock() at return.
     // Destructor of LockGuard will unlock it at return.
  }
```

Final Review

- Java and C++
- Example of a C++ program. Stack.h and Stack.cpp
- Reference Data Types
- Passing by Reference and by Value
- Constant Parameters
- Default Parameters.
- Function Overloading
- Operator Overloading

Final Review

- Classes
- private:, protected: public:
- friends
- Inline functions
- new and delete
- Objects as local variables
- Constructors and Destructors
- Copy constructor
- Assignment operator in classes
- Exception Handling

Final Review

- Namespaces “using namespace std”
- Standard namespaces. “using namespace std;”.
- Public inheritance
- Constructor in a subclass
- Dynamic cast
- Virtual Methods
- Abstract classes

Final Review

- Virtual Destructors
- Private and Protected Inheritance
- Multiple Inheritance
- Parameterized Types and Templates
- Writing a Template: A ListInt class and a ListGeneric template.
- Using a Template
- Iterator Templates
- Default Template Parameters
- Function Templates

Final Review

- C++ Input/Output Library
- File Streams
- Standard Template Library (STL)
- Containers and Iterators
- Vectors
- Lists
- Maps
- STL Strings
- Memory Allocation Errors
- Smart Pointers
- Lock Guards

To Study

- Class slides
- Study Guide Homework
- Projects
- Textbook
- Final grade distribution
  - Projects - 70%
  - Exam – 30%