Exceptions

CMSC 202

Outline

- Dynamic memory and classes
- Destructors
- Call by reference
- Exceptions

Dynamic Memory and Classes

Types of memory from Operating System

- Stack – local variables and pass-by-value parameters are allocated here
- Heap – dynamic memory is allocated here

C

- malloc() – memory allocation
- free() – free memory

C++

- new – create space for a new object (allocate)
- delete – delete this object (free)

New Objects

new
- Works with primitives
- Works with class-types

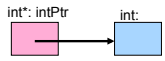
Syntax:

```
type* ptrName = new type;
type* ptrName = new type( params );
```

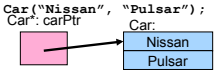
Constructor!

New Examples

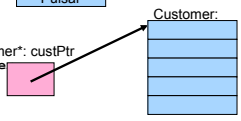
```
int* intPtr = new int;
```




```
Car* carPtr = new Car("Nissan", "Pulsar");
```




```
Customer* custPtr = new Customer;
```



Notice:

These are unnamed objects! The only way we can get to them is through the pointer!

Pointers are the same size no matter how big the data is!

Deletion of Objects

delete
- Called on the pointer to an object
- Works with primitives & class-types

Syntax:
- delete ptrName;

Example:

```
delete intPtr;
intPtr = NULL;

delete carPtr;
carPtr = NULL;

delete custPtr;
custPtr = NULL;
```

Set to NULL so that you can use it later – protect yourself from accidentally using that object!

Video!

Pointer Fun with Binky
http://cslibrary.stanford.edu/104/

Practice

Assume you have a Shoe class:

- Create a pointer to a Shoe
- Connect the pointer to a new Shoe object
- Delete your Shoe object
- Set pointer to null

```
Shoe* shoePtr;

shoePtr = new Shoe;

delete shoePtr;

shoePtr = NULL;
```

Destructors

Constructors
- Construct or create the object
- Called when you use `new`

Destructors
- Destroy the object
- Called when you use `delete`
- Why is this needed?
  - Dynamic memory WITHIN the class!

Syntax:

```
class ClassName
{
public:
   ClassName();     // Constructor
   ~ClassName();    // Destructor
   // other stuff…
};
```

Destructor Example

```
class Car
{
public:
    Car(const string& make,
            int year);

    ~Car(); // Destructor

private:
    string* m_make;
    int* m_year;
};
```

```
Car::Car( const string& make,
    int year)
{
    m_make = new string(make);
    m_year = new int(year);
}

Car::~Car()
{
    delete m_make;
    m_make = NULL;   // cleanup

    delete m_year;
    m_year = NULL;   // cleanup
}
```

Dynamic Memory Rules

- Classes
  - If dynamic data
    - MUST have constructor
    - MUST have destructor
- Delete
  - After delete – always set pointer to NULL
    - Security

"For every `new`, there must be a `delete`."

Practice

Dynamically create an array of 50 Shoes
Delete your array of shoes
"Clear" the pointer

```
Shoe* shoeArray = new Shoe[ 50 ];

delete [] shoeArray;
shoeArray = NULL;
```

Call by Reference

"Call by reference" is a parameter-passing scheme where a reference to the original caller's argument is passed to a function
- This allows caller's variable to be modified by called function

Originally, C (and earliest versions of C++) implemented this with pointers
- So we pass in the address of, i.e., a usable reference to, the caller's variable

1-13

Call by Reference

C++ has true *call by reference*
- Changes to the parameter change the argument
  - Function declares that it will change argument
- Share memory
  - Essentially a pointer
- Syntax:

```
retType funcName( type &varName, … ){ … }
```

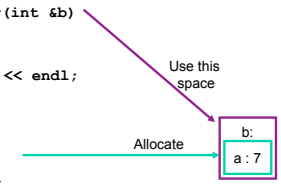
Look familiar?

Call by Reference Example

```
void mystery(int &b)
{
  b++;
  cout << b << endl;
}

int main()
{
  int a = 7;
  mystery(a);

  cout << a << endl;
  return 0;
}
```



Value versus Reference?

Why choose value or reference?

- Value
  - Data going in, nothing coming out
  - Only one piece of data coming out (return it!)
- Reference
  - Need to modify a value
  - Need to return more than one piece of data
  - Pass an array (by default are by reference, no '&' needed)
  - Pass a large object (efficiency); use const to protect from modification

Call-by-Reference – Issue!

What happens in the following?

```
void mystery(int &b)
{
   b++;
   cout << b << endl;
}

int main()
{
    mystery(6);

    return 0;
}
```

Exceptions

Common runtime errors:

- Memory allocation error when using **new**
- File open error
- Out of bounds array subscript
- Division by zero
- Function PreConditions not met

Error Handling Techniques

assert (condition)
- if the condition is false, the program terminates

Ignore the error or try to handle the error internally
- devastating for real products, but maybe okay for your own software

Set an indicator for other code to detect (e.g., return a flag)

Issue an error message and exit

Error Handling, Currently

Commonly, error handling is interspersed
- Advantage
  - Error processing close to error
- Disadvantage
  - Code cluttered from error processing
  - Application cannot handle error as it wants to

Layering, Encapsulation
- Low-level code should ***not*** process errors
- Low-level code ***should*** alert high-level code
- High-level code ***should*** handle errors

Fundamental Issue

Class user may handle error in any way
- Exit program
- Output message & continue
- Retry function
- Ask user what to do
- …

Class implementer can't know which the user of class wants

Exception Handling

New Strategy
- Low-level code detects error
- "Throws" error to higher level code
- High-level code processes error

Positives
- Code that caused error loses control
- Catch all kinds of errors
- Usually used in recoverable situations

Exception Syntax

Three primary components:

Try/catch block

```
try {
   // some code to try
}
catch (ObjectType& obj) {
   // handle the error, if any
}
```

Throwing an exception

```
throw ObjectType(parameters);
```

Specifying which exceptions a function throws

```
void funcName(parameter) throw ObjectType { }
```

Simple Throw

```
double quotient(int num, int den) {
   if (den == 0)
     throw "Error: Divide by Zero";
   return static_cast<double>(num) / den;
}

int main() {
  try {
    cout << quotient(7, 0) << endl;
  }
  catch (string& e) {
    cout << e << endl;
  }
  return 0;
}
```

Throwing an Exception

```
class DivByZeroEx
{
public:

    DivByZeroEx ( ) : m_message ("divide by 0") { /* no code */ }

    const string& what ( ) const { return m_message; }

private:
    const string m_message;
};

double quotient(int num, int den)
{
    if (den == 0)
       throw DivByZeroEx();

    return static_cast<double>(num) / den;
}
```

Catching an Exception

```
int main()
{
    int numerator, denominator;
    double result;

    cout << "Input numerator and denominator" << endl;
    cin  >> numerator >> denominator;

    try {
         result = quotient(numerator, denominator);
         cout << "The quotient is: " << result << endl;
    }
    catch (DivByZeroEx& ex) {      // exception handler
         cerr << "Exception occurred: " << ex.what() << endl;
    }

    // code continues here

   return 0;
}
```

Exception Classes

Name?
- Reflects error, ***not*** code that throws error

Data?
- Basic information or a message
  - Parameter value
  - Name of function that detected error
  - Description of error

Methods?
- Constructor (one or more)
- Accessor (one or more)

Exception Examples

```
// Good example of an Exception Class
class NegativeParameter
{
    public:
        NegativeParameter(  const string& parameter,
              int value );
        int GetValue ( ) const;
        const string& GetParameter( ) const;
    private:
        int m_value;
        string m_paramName;
};

// Trivial example of an Exception Class
class MyException { };
```

Code that catches this exception gets the parameter name and its value

Code that catches this exception gets no other information – just the "type" of exception thrown

Exception Specification

Functions/Methods can specify which exceptions they throw (or that they don't throw any)

Syntax:

```
// Throws only 1 type of exception
retType funcName( params ) throw (exception);

// Throws 2 types of exceptions (comma separated list)
retType funcName( params ) throw (exception1, exception2);

// Promises not to throw any exceptions
retType funcName( params ) throw ( );

// Can throw any exceptions [backwards compatibility]
retType funcName( params );
```

Specification Example

```
// Divide() throws only the DivideByZero exception
void Divide (int dividend, int divisor ) throw (DivideByZero);


// Throws either DivideByZero or AnotherException
void Divide (int dividend, int divisor ) throw (DivideByZero,
                              AnotherException);

// Promises not to throw any exception
void Divide (int dividend, int divisor ) throw ( );

// This function may throw any exception it wants
void Divide (int dividend, int divisor );
```

Multiple Catch Blocks…Yes!

```
try
{
     // code that might throw an exception
}
catch (ExceptionObject1& ex1)
{
     // exception handler code
}
     . . .
catch (ExceptionObject2& ex2)
{
     // exception handler code
}
catch (ExceptionObjectN& exN)
{
     // exception handler code
}
catch (...)
{
     // default exception handler code
}
```

Most Specific

Multiple catch blocks – catch different types of exceptions!

What's this?

"Catch Everything Else"

Least Specific

Nested Functions?

```
// function2 throws an exception
void function2( )
{
     cout << "function2" << endl;
     throw int(42);
}

// function1 calls function2,
// but with no try/catch
void function1( )
{
     function2( );
     cout << "function1" << endl;
}
```

```
// main calls function1,
// with try/catch
int main( )
{
     try {
        function1( );
     }
     catch (int)
     {
        cout << "Exception "
             << "occurred"
             << endl;
     }

     return 0;
}
```

Stack is unwound until something catches the exception OR until unwinding passes main

What happens then?

Rethrowing Exceptions

What if current scope shouldn't or can't handle error?

Re-throw error to next scope up the stack

```
try {
     // code that could throw an exception
}
catch (someException &e){
     throw;       // rethrow the exception to the next
}                 // enclosing try block
```

Rethrow Example

Application program
// handles exception if full

Add item to inventory
// rethrows exception if full

Insert item in list
// rethrows exception if full

Is list full?
// throws exception if full

How might we have used this in one of our past projects?

Exceptions in Constructors

Best way to handle Constructor failure
Replaces Zombie objects!
Any sub-objects that were successfully created are destroyed (destructor is ***not*** called!)

Example:

```
// MyClass constructor
MyClass::MyClass ( int value )
{
   m_pValue = new int(value);

   // pretend something bad happened
   throw NotConstructed( );
}
```

Exceptions in Destructors

Bad, bad idea…
What if your object is being destroyed in response to another exception?
Should runtime start handling your exception or the previous one?

General Rule…
Do not throw exceptions in destructor

Standard Library Exceptions

#include <stdexcept>

- **bad_alloc**
  - Thrown by new when a memory allocation error occurs
- **out_of_range**
  - Thrown by vector's at( ) function for an bad index parameter.
- **invalid_argument**
  - Thrown when the value of an argument (as in vector< int > intVector(-30);) is invalid

Derive from `std::exception`

- Define own classes that derive…

Exceptions and Pointers

```
void myNewIstFunction( )
{
     // dynamically allocate a Fred object
     Fred *pFred = new Fred;

     try {
         // call some function of Fred
     }
     catch( ... )              // for all exceptions
     {
        throw;                // rethrow to higher level
     }

     // destroy the Fred object
     // if no exception and normal termination
     delete pFred;
}
```

What happens to the Fred object?

One Solution…

```
void myNewIstFunction( )
{
     // dynamically allocate a Fred object
     Fred *pFred = new Fred;

     try {
         // call some function of Fred
     }
     catch( ... )              // for all exceptions
     {
         delete pFred;         // delete the object
         throw;                // rethrow to higher level
     }

     // destroy the Fred object
     // if no exception and normal termination
     delete pFred;
}
```

What's not so good about this solution?

Duplicated Code!

Exception-Safe Code

Fundamentals

- Exception-safe code
  - Leaves the object (or program) in a consistent and valid state
- Hard to do well
- Think through even simple code thoroughly…

Exception-UNsafe Example

```
// unsafe assignment operator implementation
FredArray& FredArray::operator=( const FredArray& rhs)
{
   if ( this != &rhs )  // this points to current object
   {
      // free existing Freds
      delete [] m_data;                    // 1

      // now make a deep copy of the right-hand object
      m_size = rhs.m_size;                 // 2
      m_data = new Fred [ m_size ];        // 3

      for (int j = 0; j < m_size; j++ )    // 4
          m_data[ j ] = rhs.m_data [ j ];  // 5
    }
    return *this;
}
```

Exception-safe Example

```
// Better assignment operator implementation
FredArray& FredArray::operator=( const FredArray& rhs)
{
   if ( this != &rhs )
   {
      // code that may throw an exception first
      // make a local temporary deep copy
      Fred *tempArray = new Fred[rhs.m_size];
      for ( int j = 0; j < rhs.m_size; j++ )
          tempArray[ j ] = rhs.m_data [ j ];

      // now code that does not throw exceptions
      delete [] m_data;
      m_size = rhs.m_size;
      m_data = tempArray;
    }
    return *this;
}
```

How could we improve this?

Rule of Thumb:

Do any work that may throw an exception off "to the side" using local variables

THEN change the object's state using methods that DON'T throw exceptions

Exception Guarantees

Each function/method can guarantee one of the following when an exception occurs:

- **Weak Guarantee**
  - Program/Object will not be corrupt
  - No memory is leaked
  - Object is usable, destructible
- **Strong Guarantee**
  - Function has no effect
  - Program/Object state is same as before
- **NoThrow Guarantee**
  - Function ensures no exceptions will be thrown
    - Usually: destructors, delete and delete[ ]

Which should you follow?

- C++ library:
  - A function should always support the ***strictest*** guarantee that it can support without ***penalizing*** users who don't need it

Practice

Write a function to Sort a vector of integers

- If the vector has no elements
  - Throw an exception
    - Use the message "Error: The vector is empty"

Write a main function that will:

- Create a vector
- Catch the error