# 9 EXCEPTION

# Program Errors

- Kinds of errors with programs
  - Poor logic - bad algorithm
  - Improper syntax - bad implementation
  - Exceptions - Unusual, but predictable problems
- The earlier you find an error, the less it costs to fix it
- Modern compilers find errors early

# Paradigm Shift from C

- In C, the default response to an error is to continue, possibly generating a message
- In C++, the default response to an error is to terminate the program
- C++ programs are more “brittle”, and you have to strive to get them to work correctly
- Can catch all errors and continue as C does

# assert()

- a macro (processed by the precompiler)
  - Returns TRUE if its parameter is TRUE
  - Takes an action if it is FALSE
    - abort the program
    - throw an exception
- If DEBUG is not defined, asserts are collapsed so that they generate no code

# assert() (cont'd)

- When writing your program, if you know something is true, you can use an assert
- If you have a function which is passed a pointer, you can do
  - assert(pTruck);
    - if pTruck is 0, the assertion will fail
- Use of assert can provide the code reader with insight to your train of thought

# assert() (cont'd)

- Assert is only used to find programming errors
- Runtime errors are handled with exceptions
  - DEBUG false => no code generated for assert
  - Animal *pCat = new Cat;
  - assert(pCat); // bad use of assert
  - pCat ->memberFunction();

# assert() (cont'd)

- assert() can be helpful
- Don't overuse it
- Don't forget that it "instruments" your code
  - invalidates unit test when you turn DEBUG off
- Use the debugger to find errors

# Exceptions

- You can fix poor logic (code reviews, debugger)
- You can fix improper syntax (asserts, debugger)
- You have to live with exceptions
  - Run out of resources (memory, disk space)
  - User enters bad data
  - Floppy disk goes bad

# Why are Exceptions Needed?

- The types of problems which cause exceptions (running out of resources, bad disk drive) are found at a low level (say in a device driver)
- The low level code implementer does not know what your application wants to do when the problem occurs, so s/he “throws” the problem “up” to you

# How To Deal With Exceptions

- Crash the program
- Display a message and exit
- Display a message and allow the user to continue
- Correct the problem and continue without disturbing the user

Steinbach's Corollary to Murphy's Law:
"Never test for a system error you don't know how to handle."

# What is a C++ Exception?

- An object
  - passed from the area where the problem occurs
  - passed to the area where the problem is handled
- The type of object determines which exception handler will be used

# Syntax

```
try {
// a block of code which might generate an exception
}
catch(xNoDisk) {
  // the exception handler(tell the user to
  // insert a disk)
}
catch(xNoMemory) {
  // another exception handler for this “try block”
}
```

# The Exception Class

- Define like any other class:

```
class Set {
private:
    int *pData;
public:
    ...
    class  xBadIndex {}; // just like any other class
};
```

# Throwing An Exception

- In your code where you reach an error node:

```
if(memberIndex < 0)

        throw xBadIndex();
```

- Exception processing now looks for a catch block which can handle your thrown object
- If there is no corresponding catch block in the immediate context, the call stack is examined

# The Call Stack

- As your program executes, and functions are called, the return address for each function is stored on a push down stack
- At runtime, the program uses the stack to return to the calling function
- Exception handling uses it to find a catch block

# Passing The Exception

- The exception is passed up the call stack until an appropriate catch block is found
- As the exception is passed up, the destructors for objects on the data stack are called
- There is no going back once the exception is raised

# Handling The Exception

- Once an appropriate catch block is found, the code in the catch block is executed
- Control is then given to the statement after the group of catch blocks
- Only the active handler most recently encountered in the thread of control will be invoked

# Handling The Exception (cont'd)

```
catch (Set::xBadIndex) {
// display an error message
}
catch (Set::xBadData) {
// handle this other exception
}
//control is given back here
```

- If no appropriate catch block is found, and the stack is at main(), the program exits

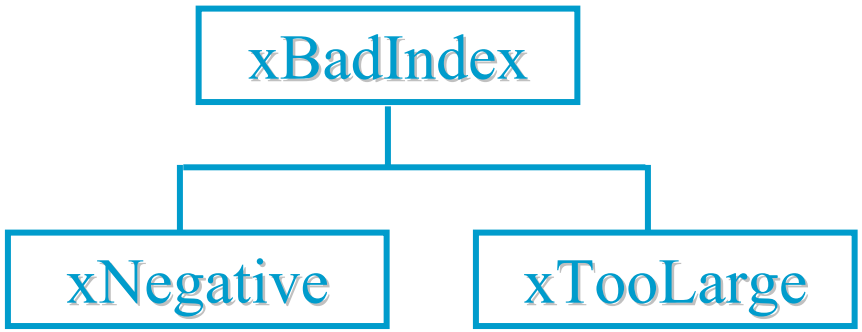
# Default catch Specifications

- Similar to the switch statement

```
catch (Set::xBadIndex)
{ // display an error message }
catch (Set::xBadData)
{ // handle this other exception }
catch (…)
{ // handle any other exception }
```

# Exception Hierarchies

- Exception classes are just like every other class; you can derive classes from them
- So one try/catch block might catch all bad indices, and another might catch only negative bad indices



# Exception Hierarchies (cont'd)

```
class Set {
private:
    int *pData;
public:
    class xBadIndex {};
    class xNegative : public xBadIndex {};
    class xTooLarge: public xBadIndex {};
};
   // throwing xNegative will be
   // caught by xBadIndex, too
```

# Data in Exceptions

- Since Exceptions are just like other classes, they can have data and member functions
- You can pass data along with the exception object
- An example is to pass an error subtype for xBadIndex, you could throw the type of bad index

# Data in Exceptions (Continued)

```
// Add member data,ctor,dtor,accessor method
class xBadIndex {
private:
    int badIndex;
public:
    xBadIndex(int iType):badIndex(iType) {}
    int GetBadIndex () { return badIndex; }
    ~xBadIndex() {}
};
```

# Passing Data In Exceptions

```
// the place in the code where the index is used
if (index <  0)
    throw xBadIndex(index);
if (index > MAX)
    throw xBadIndex(index);
// index is ok
```

# Getting Data From Exceptions

```
catch (Set::xBadIndex &theException)
{
   int badIndex = theException.GetBadIndex();
   if (badIndex < 0 )
      cout << “Set Index “ << badIndex << “ less than 0”;
   else
      cout << “Set Index “ << badIndex << “ too large”;
   cout << endl;
}
```

# Passing Data In Exceptions

```
// the place in the code where the index is used
if (index <  0)
    throw xNegative (index);
if (index > MAX)
    throw xTooLarge(index);
// index is ok
```

# Getting Data From Exceptions

```
catch (Set::xNegative &theException)
{
   int badIndex = theException.GetBadIndex();
  cout << "Set Index " << badIndex << " less than 0";
  cout << endl;
}
```

# Getting Data From Exceptions

```
catch (Set::xTooLarge &theException)
{
   int badIndex = theException.GetBadIndex();
  cout << “Set Index “ << badIndex << “ is too large”;
  cout << endl;
}
```

# Caution

- When you write an exception handler, stay aware of the problem that caused it
- Example: if the exception handler is for an out of memory condition, you shouldn't have statements in your exception object constructor which allocate memory

# Exceptions With Templates

- You can create a single exception for all instances of a template
  - declare the exception outside of the template
- You can create an exception for each instance of the template
  - declare the exception inside the template

# Single Template Exception

```
class xSingleException {};

template <class T>
class Set {
private:
    T *pType;
public:
    Set();
    T& operator[] (int index) const;
};
```

# Each Template Exception

```
template <class T>
class Set {
private:
    T *pType;
public:
    class xEachException {};
    T& operator[] (int index) const;
};
// throw xEachException();
```

# Catching Template Exceptions

- Single Exception (declared outside the template class)

```
catch (xSingleException)
```

- Each Exception (declared inside the template class)

```
catch (Set<int>::xEachException)
```

# Exception Specification

- A function that might throw an exception can warn its users by specifying a list of the exceptions that it can throw.

```
class Zerodivide{/*..*/};
int divide (int, int) throw(Zerodivide);
```

- If your function never throws any exceptions

```
bool equals (int, int) throw();
```

- Note that a function that is declared without an exception specification such as bool equals (int, int); guarantees nothing about its exceptions: It might throw any exception, or it might throw no exceptions.

# Exception Specification

- Exception Specifications Are Enforced At Runtime
- When a function attempts to throw an exception that it is not allowed to throw according to its exception specification, the exception handling mechanism detects the violation and invokes the standard function **unexpected()**.
- The default behavior of **unexpected()** is to call **terminate()**, which terminates the program.
- The default behavior can be altered, nonetheless, by using the function **set_unexpected()**.

# Exception Specification

- Because exception specifications are enforced only at runtime, the compiler might deliberately ignore code that seemingly violates exception specifications.
- Consider the following:

```
int f(); //no exception specification
```

- What if f throws an exception

```
void g(int j) throw()
{
        int result = f();
}
```

# Concordance of Exception Specification

C++ requires exception specification concordance in derived classes. This means that an overriding virtual function in a derived class has to have an exception specification that is at least as restrictive as the exception specification of the overridden function in the base class.

```
class BaseEx{};
class DerivedEx: public BaseEx{};
class OtherEx {};
```

```
class A {
public:
    virtual void f() throw (BaseEx);
    virtual void g() throw (BaseEx);
    virtual void h() throw (DerivedEx);
    virtual void i() throw (DerivedEx);
    virtual void j() throw(BaseEx);
};
```

```
class D: public A {
public:
    void f() throw (DerivedEx); //OK
    void g() throw (OtherEx); //error
    void h() throw (DerivedEx); //OK
    void i() throw (BaseEx); //error
    void j() throw (BaseEx,OtherEx); //error
};
```

# Concordance of Exception Specification

An exception could belong to two groups:

```
class Netfile_err : public Network_err, public File_system_err {
        /* ... */
};
```

Netfile_err can be caught by functions dealing with network exceptions:

```
void f(){
    try {
        / / something
    }
    catch (Network_err& e) {
         // ...
    }
}
```

```
void g() {
     try {
          / / something else
     }
     catch(File_system_err& e) {
          / / ...
     }
}
```

# Exception Matching

```
void f() {
     try {
          throw E() ;
     }
     catch(H) {
          // when do we get here?
     }
}
```

The handler is invoked:

[1] If **H** is the same type as **E**.

[2] If **H** is an unambiguous public base of **E**.

[3] If **H** and **E** are pointer types and [1] or [2] holds for the types to which they refer.

[4] If **H** is a reference and [1] or [2] holds for the type to which **H** refers.

# Resource Management

When a function acquires a resource – that is, it opens a file, allocates some memory from the free store, sets an access control lock, etc., – it is often essential for the future running of the system that the resource be properly released.

```
void use_file(const char* fn)
{
    FILE* f = fopen(fn,"w") ;
    // use f
    fclose(f) ;
}
```

# Resource Management

Fault-tolerant implementation using try-catch:

```
void use_  file(const char* fn)
{
      FILE* f = fopen(fn,"r") ;
      try {
          // use f
      }
      catch (Ex e) {
           fclose(f) ;
           throw e;
      }
      fclose(f) ;
}
```

```
void f(){
  try {
  …
  use_file(“c:\\dat.txt”);
   …
  }
  catch(SomeEx e){
  }
}
```

# Resource Management

The problem with this solution is that it is verbose, tedious, and potentially expensive.

```
class File_ptr {
    FILE* p;
public:
    File_ptr(const char* n, const char* a) { p = fopen(n,a) ; }
    File_ptr(FILE* pp) { p = pp; }
    ~File_  ptr() { fclose(p) ; }
    operator FILE*() { return p; }
};
```

```
void use_file(const char* fn) {
        File_ptr f(fn,"r") ;
        // use f
}
```

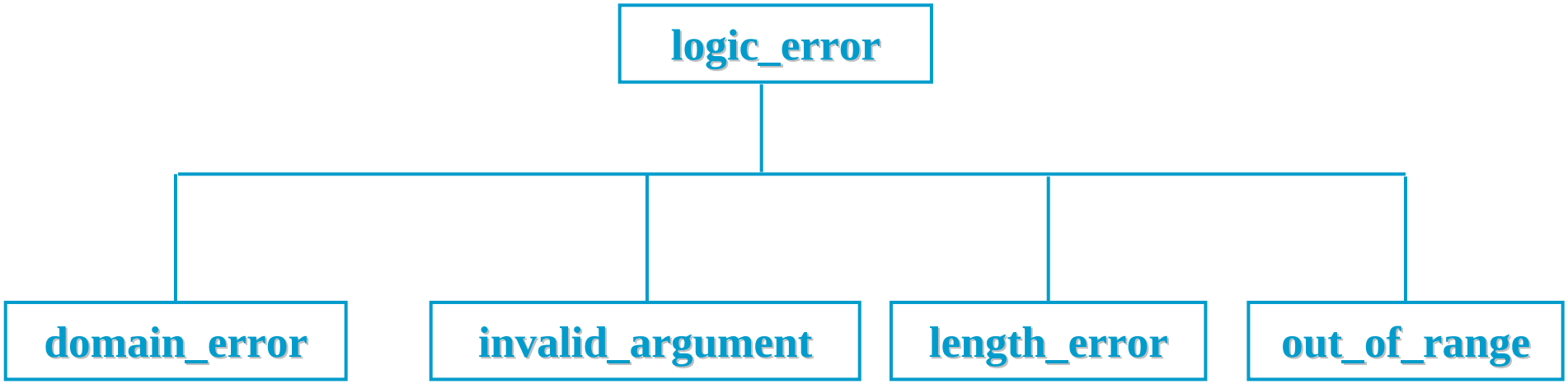
# Standard Exceptions

- The C++ standard includes some predefined exceptions, in <stdexcept>
- The base class is **exception**
  - Subclass **logic_error** is for errors which could have been avoided by writing the program differently
  - Subclass **runtime_error** is for other errors

# Standard Exceptions

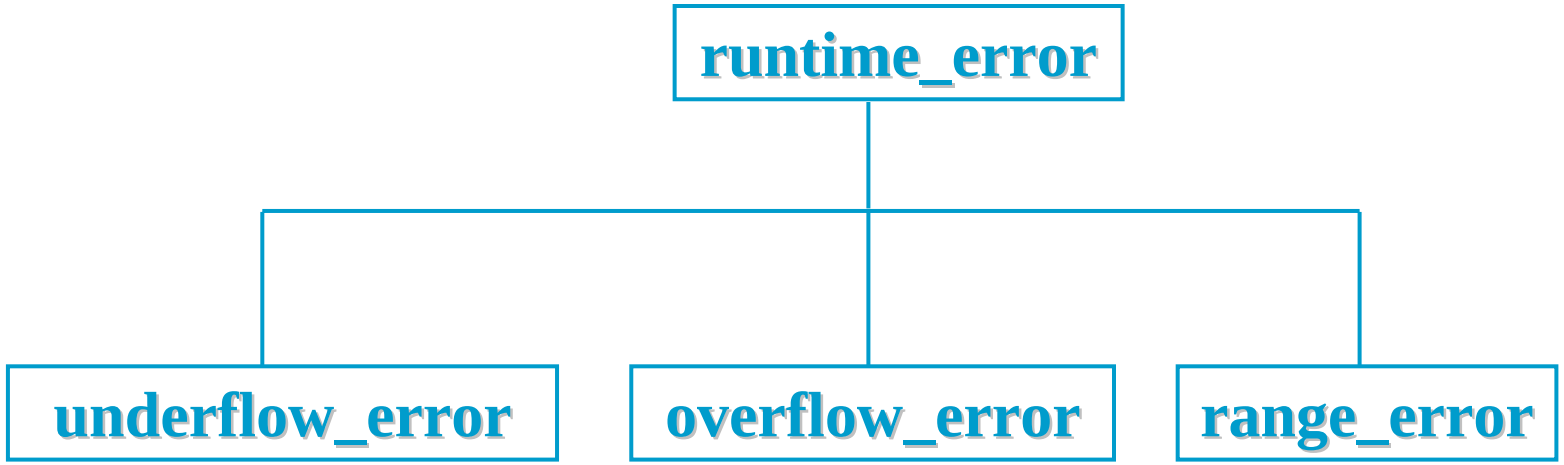
```
class exception {
public:
    exception() throw() ;
    exception(const exception&) throw() ;
    exception& operator=(const exception&) throw() ;
    virtual ~exception() throw() ;
    virtual const char*what() const throw() ;
private:
    / / ...
};
```

# Logic Error Hierarchy



# Runtime Error Hierarchy






The idea is to use one of the specific classes (e.g. range_error) to generate an exception

# Data For Standard Exceptions

```
// standard exceptions allow you to specify
// string information
throw overflow_error(“Doing float division in function div”);

// the exceptions all have the form:
class overflow_error : public runtime_error
{
public:
    overflow_error(const string& what_arg)
        : runtime_error(what_arg) {};
```

# Catching Standard Exceptions

```
catch (overflow_error)
{
    cout << “Overflow error” << endl;
}

catch (exception& e)
{
    cout << typeid(e).name() << “: “ << e.what() << endl;
}
```

# More Standard Exception Data

- catch (exception& e)
  - Catches all classes derived from *exception*
  - If the argument was of type *exception*, it would be converted from the derived class to the exception class
  - The handler gets a *reference to exception* as an argument, so it can look at the object

# RTTI (RunTime Type Information)

- It's one of the more recent additions to C++ and isn't supported by many older implementations. Other implementations may have compiler settings for turning RTTI on and off.
- The intent of RTTI is to provide a standard way for a program to determine the type of object during runtime.
- Many class libraries have already provided ways to do so for their own class objects, but in the absence of built-in support in C++, each vendor's mechanism typically is incompatible with those of other vendors.
- Creating a language standard for RTTI should allow future libraries to be compatible with each other.

# What is RTTI for?

- Suppose you have a hierarchy of classes descended from a common base. You can set a base class pointer to point to an object of any of the classes in this hierarchy. Next, you call a function that, after processing some information, selects one of these classes, creates an object of that type, and returns its address, which gets assigned to a base class pointer.
- How can you tell what kind of object it points to?

# How does it work?

C++ has three components supporting RTTI:

- **dynamic_cast** pointer
  generates a pointer to a derived type from a pointer to a base type, if possible. Otherwise, the operator returns 0, the null pointer.
- **typeid** operator
  returns a value identifying the exact type of an object.
- **type_info** structure
  holds information about a particular type.

**RTTI works only for classes with virtual functions**

# dynamic_cast<>

► The dynamic_cast operator is intended to be the most heavily used RTTI component.

► It doesn't answer the question of what type of object a pointer points to.

► Instead, it answers the question of whether you can safely assign the address of the object to a pointer of a particular type.

```
class Grand {  // has virtual methods} ;
class Superb : public Grand {  ... } ;
class Magnificent : public Superb {  ... } ;

Grand * pg = new Grand;
Grand * ps = new Superb;
Grand * pm = new Magnificent;

Magnificent * p1 = (Magnificent *) pm;      // #1
Magnificent * p2 = (Magnificent *) pg;      // #2
Superb * p3 = (Magnificent *) pm;           // #3
```

**Which of the previous type casts are safe?**

```
Superb pm = dynamic_cast<Superb *>(pg);
```

```
class Grand {
     virtual void speak() ;
} ;
class Superb : public Grand {
      void speak() ;
      virtual void say() ;
} ;
class Magnificent : public Superb {
       char ch ;
       void speak() ;
       void say() ;
} ;
```

```
for (int i = 0; i < 5; i++)
{
    pg = getOne();
    pg->speak();
    ...
```

►However, you can't use this exact approach to invoke the **say**() function; it's not defined for the Grand class.

►However, you can use the **dynamic_cast** operator to see if pg can be type cast to a pointer to Superb.

►This will be true if the object is either type Superb or Magnificent. In either case, you can invoke the **say**() function safely:

```
if (ps = dynamic_cast<Superb *>(pg))
    ps->say();
```

# typeid

- typeid is an operator which allows you to access the type of an object at runtime
- This is useful for pointers to derived classes
- typeid overloads ==, !=, and defines a member function name

```
if(typeid(*carType) == typeid(Ford))
    cout << "This is a Ford" << endl;
```

# typeid().name

```
cout << typeid(*carType).name() << endl;
// If we had said:
// carType = new Ford();
// The output would be:
// Ford
```

- So:

  `cout << typeid(e).name()`

  returns the name of the exception

# e.what()

- The class *exception* has a member function ***what***

```
virtual char* what();
```

- This is inherited by the derived classes
- what() returns the character string specified in the throw statement for the exception

throw overflow_error("Doing float division in function div");

cout << typeid(e).name() << ": " << e.what() << endl;

# Deriving New exception Classes

```
class xBadIndex : public runtime_error {
public:
    xBadIndex(const char *what_arg = “Bad Index”)
        :  runtime_error(what_arg) {}
};
// we inherit the virtual function what
// default supplementary information character string
```

```
template <class T>
class Array{
    private:
      T *data ;
      int Size ;
    public:
      Array(void);
      Array(int);
      class eNegativeIndex{};
      class eOutOfBounds{};
      class eEmptyArray{};
      T& operator[](int) ;
};
```

```
template <class T>
Array<T>::Array(void){
   data = NULL ;
   Size = 0    ;
}
template <class T>
Array<T>::Array(int size){
   Size = size ;
   data = new T[Size] ;
}
```

```
template <class T>
T& Array<T>::operator[](int index){
   if( data == NULL ) throw eEmptyArray() ;
   if(index < 0) throw eNegativeIndex() ;
   if(index >= Size) throw eOutOfBounds() ;
   return data[index] ;
}
```

```
Array<int> a(10) ;
try{
  int b = a[200] ;
}
catch(Array<int>::eEmptyArray){
  cout << "Empty Array" ;
}
catch(Array<int>::eNegativeIndex){
  cout << "Negative Array" ;
}
catch(Array<int>::eOutOfBounds){
  cout << "Out of bounds" ;
}
```