

9

EXCEPTION

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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

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Object Oriented Programming

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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

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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

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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

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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();`

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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

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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

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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

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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."

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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

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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"  
}
```

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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

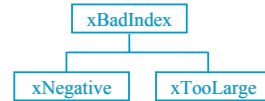
Default catch Specifications

- 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,dctor,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;
}
```

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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
```

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Getting Data From Exceptions

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

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Getting Data From Exceptions

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

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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

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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

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Single Template Exception

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

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Each Template Exception

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

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Catching Template Exceptions

- ▶ Single Exception (declared outside the template class)
catch (xSingleException)
- ▶ Each Exception (declared inside the template class)
catch (Set<int>::xEachException)

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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.

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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()**.

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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();
}

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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.

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```
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);
};
```

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```
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) {
        // ...
    }
}
```

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

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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.

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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);
}
```

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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
}
```

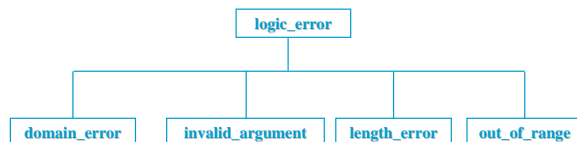
Standard Exceptions

- ▶ 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

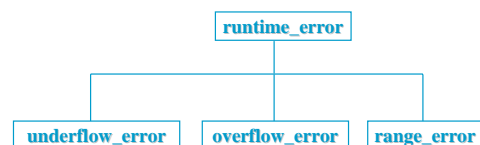
Standard Exceptions

```
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) {};
```

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Catching Standard Exceptions

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

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

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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

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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.

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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?

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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

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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.

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```
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);
```

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```
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();
    ...
}
```

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- ▶ 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();
```

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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;
```

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## 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
```

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## 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" ;
}
```