Exceptions

Object-Oriented Programming with C++

Run-time error

- The basic philosophy of C++ is that "badly formed code will not be run."
- There's always something happens in run-time.
- It is very important to deal with all possible situation in the future running.

Read a file

- open the file;
- determine its size;
- allocate that much memory;
- read the file into memory;
- close the file;

```
errorCodeType readFile {
    initialize errorCode = 0;
    open the file;
    if ( theFilesOpen ) {
        determine its size;
        if ( gotTheFileLength ) {
            allocate that much memory;
            if ( gotEnoughMemory ) {
                read the file into memory;
                if ( readFailed ) {
                    errorCode = -1;
                }
            } else {
                errorCode = -2;
            }
        } else {
            errorCode = -3;
        }
        close the file;
        if ( theFILEDidntClose && errorCode == 0 ) {
            errorCode = -4;
        }
    } else {
        errorCode = -5;
    }
    return errorCode;
}
```

Working with exception

```
try {
        open the file;
        determine its size;
        allocate that much memory;
        read the file into memory;
        close the file;
} catch ( fileOpenFailed ) {
        doSomething;
} catch ( sizeDeterminationFailed ) {
        doSomething;
} catch ( memoryAllocationFailed ) {
        doSomething;
} catch ( readFailed ) {
        doSomething;
} catch ( fileCloseFailed ) {
        doSomething;
}
```

Exception

- I take exception to that
- At the point where the problem occurs, you might not know what to do with it, but you do know that you can’t just continue on merrily; you must stop, and somebody, somewhere, must figure out what to do.

Why exception?

- The significant benefit of exceptions is that they clean up error handling code.
- It separates the code that describes what you want to do from the code that is executed.

Example: Vector

```
template <class T> class Vector {
private:
    T* m_elements;
    int m_size;
public:
    Vector (int size = 0) : m_size(size)
    { ... }
    ~Vector () { delete [] m_elements; }
    void length(int);
    int length() { return m_size; }
    T& operator[](int);
};
```

Problem

```
template <class T>
T& Vector<T>::operator[](int idx) {
```

What should the [] operator do if the index is not valid?

1) Return random memory object

```
return m_elements[idx];
```

More choices

2) Return a special error value

```
if (idx <  0 || idx >= m_size) {
  T* error_marker =
            new T("some magic value");
  return *error_marker;
}
return m_elements[idx];
```

But this throws the baby out with the bath water!

```
x = v[2] + v[4]; // not safe code!
```

More choices …

3) Just die!

```
if (idx < 0|| idx >= m_size){
  exit(22);
}
return m_elements[idx];
```

4) Die gracefully (with autopsy!)

```
assert(idx >= 0 && idx < m_size);  return
m_elements[idx];
```

When to use exceptions

- Many times, you don't know what should be done
- If you do anything you'll be wrong
- Solution: expose the problem

Make your caller (or its caller ...) responsible

How to raise an exception

```
template <class T>
T& Vector<T>::operator[](int idx) {
    if (idx < 0 || idx >= m_size) {
        // throw is a keyword
        // exception is raised at this point
        throw <<something>>;
    }
    return m_elements[idx];
}
```

What do you throw?

```
// What do you have? Data!
// Define a class to represent the error
class VectorIndexError {
public:
    VectorIndexError(int v) : m_badValue(v) { }
    ~VectorIndexError() { }
    void diagnostic() {
        cerr << "index " << m_ badValue
        << "out of range!"; }
private:
    int m_badValue;
};
```

How to raise an exception

```
template <class T>
T& Vector<T>::operator[](int idx){
  if (idx < 0 || idx >= m_size) {
    throw VectorIndexError(idx);
  }
  return m_elements[idx];
}
```

What about your caller?

Case 1) Doesn't care

–Code never even suspects a problem

```
int func() {
    Vector<int> v(12);
    v[3] = 5;
    int i = v[42]; // out of range
    // control never gets here!
    return i * 5;
}
```

What about your caller?

Case 2) Cares deeply

```
void outer() {
    try {
        func();
        func2();
    } catch (VectorIndexError& e) {
        e.diagnostic();
        // This exception does not propagate
    }
    cout << "Control is here after exception";
}
```

What about your caller?

Case 3) Mildly interested

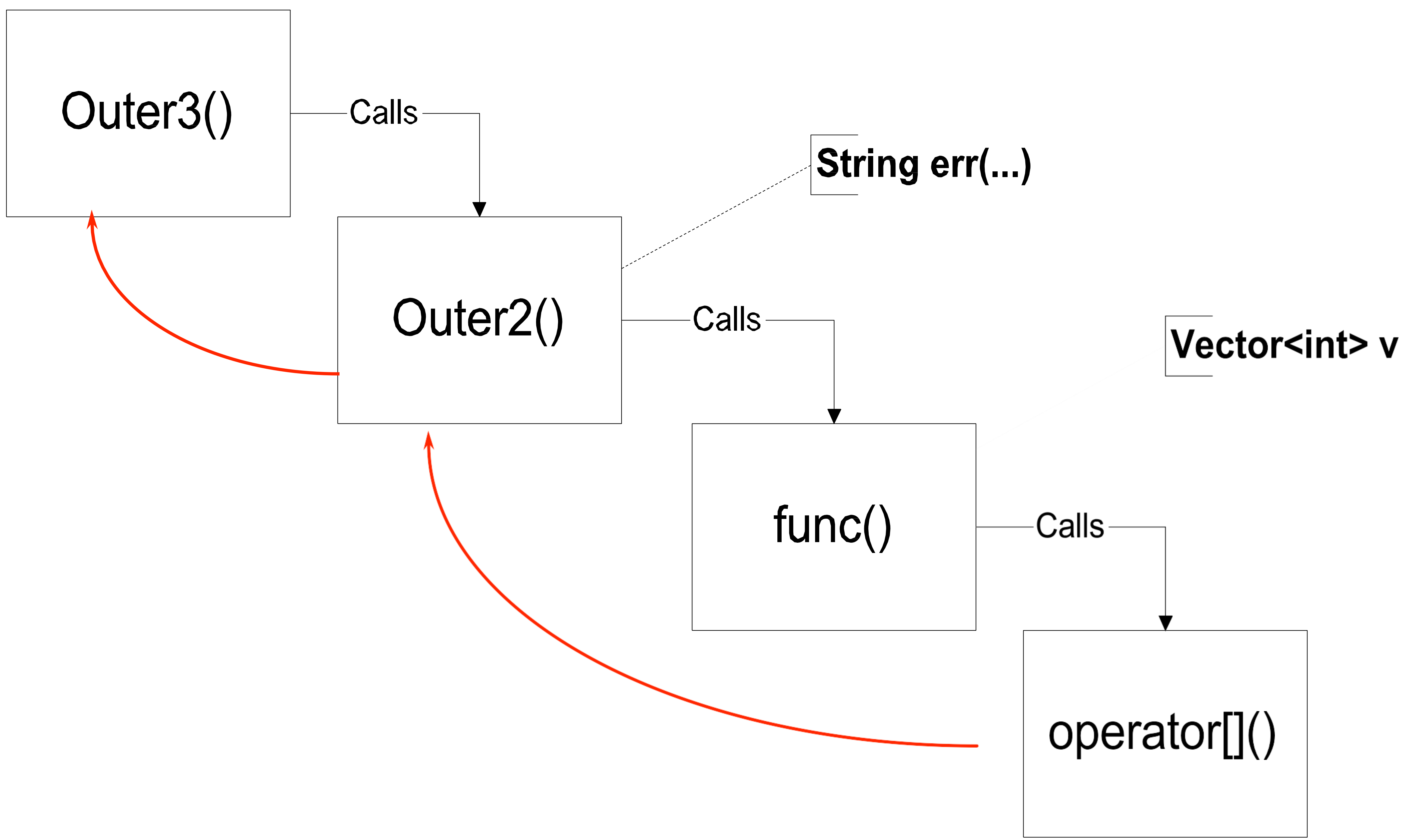
```
void outer2() {
    string err("exception caught");
    try {
        func();
    } catch (VectorIndexError) {
        cout << err;
        throw; // propagate the exception
    }
}
```

What about your caller?

Case 4) Doesn’t care about the particulars

```
void outer3() {
    try {
        outer2();
    }   catch (...) {
        // ... catches ALL exceptions!
        cout << "The exception stops here!";
    }
}
```

What happened?



Review

- Is surrounding a try?
  - NO: leave that scope (trigger stack unwinding)
    - Is it a method body?
      - YES: return to the caller, then go to 1st step
      - NO: terminate program
  - YES: try to match a catch
    - match?
      - YES: do the clause and go to the statement followed by try block
      - NO: continue throw implicitly and go to 1st step

Review

- Throw statement **raises** the exception
  - – Control propagates back to first handler for that exception
  - – Propagation follows the ***call*** chain
  - – Objects on ***stack*** are properly destroyed

- **throw exp;**
  - – throws value for matching

- **throw;**
  - – **re-raises** the exception being handled
  - – valid only within a handler

Try blocks

- Try block

  try { … }
  catch { … }
  catch { … }
- Establishes any number of handlers
- Not needed if you don't use *any* handlers
- Shows where you expect to handle exceptions
- Costs cycles

Exception handlers

- Select exception by type
- Can re-raise exceptions
- Two forms

```
catch (SomeType v) { // handler code
}
catch (...) { // handler code
}
```

- Take a single argument (like a formal parameter)

Selecting a handler

- Can have any number of handlers
- Handlers are checked in order of appearance

1. Check for exact match
2. Apply base class conversions
   Reference and pointer types
3. Catch-all handler (...)

Inheritance can be used to structure exceptions

Example: using inheritance

- Hierarchy of exception types

```
class MathErr {
 ...
 virtual void diagnostic();
};
class OverflowErr : public MathErr { ... }
class UnderflowErr : public MathErr { ... }
class ZeroDivideErr : public MathErr { ... }
```

Using handlers

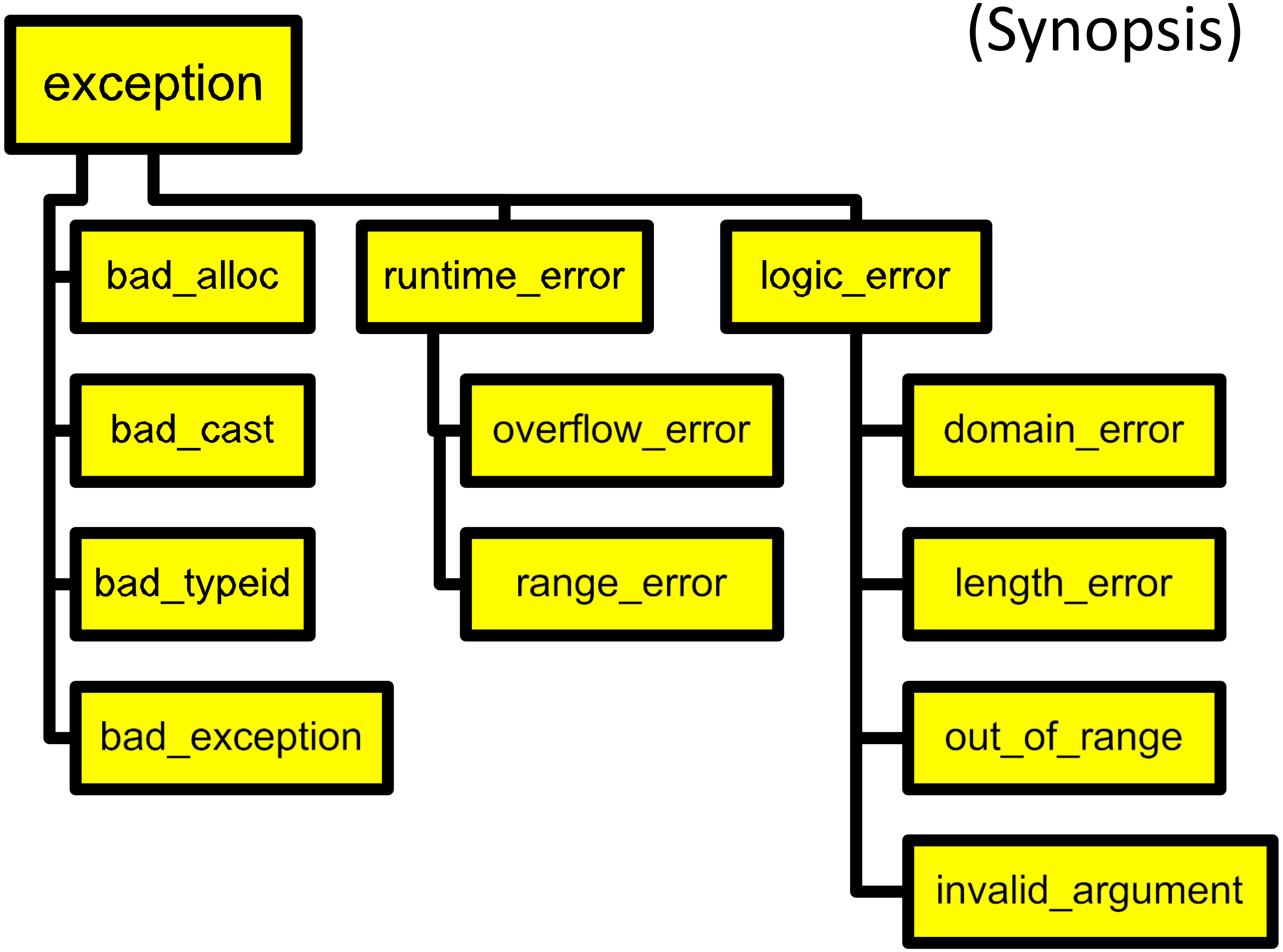
```
try {
    // code to exercise math options
    throw UnderFlowErr();
} catch (ZeroDivideErr& e) {
    // handle zero divide case
} catch (MathErr& e) {
    // handle other math errors
} catch (...) {
    // any other exceptions
}
```

Using handlers

```
try {
    // code to exercise math options
    throw UnderFlowErr();
} catch (ZeroDivideErr& e) {
    // handle zero divide case
} catch (MathErr& e) {  // Note the order
    // handle other math errors
} catch (UnderFlowErr& e) {// Note the order
    // handle underflow errors
} catch (...) {
    // any other exceptions
}
```

Standard library exceptions

(Synopsis)



Exceptions and new

- **new** does NOT returned 0 on failure
- **new** raises a bad_alloc() exception

```
void func() {
    try {
        while(1) {
            char *p = new char[10000];
        }
    } catch (std::bad_alloc& e) {
        // ...
    }
}
```

Exception specifications

- Specifies whether a function could throw exceptions.
- Part of function type, but not part of signature.

```
void abc(int a) noexcept {
    …
}
```

- May not be checked at compile time, but utilized by the compiler to enable certain optimizations.
- At run time,
  - if an exception is thrown out, the std::terminate is called.

Exception specifications

- Declare which exceptions function *might* raise
- Part of function prototypes

```
void abc(int a) : throw(MathErr) {
    …
}
```

- Not checked at compile time
- At run time,

  –if an exception not in the list propagates out, the unexpected exception is raised
- throw(optional_type_list) specification, was deprecated in C++11 and removed in C++17, except for throw()
  - throw() is an alias for noexcept(true)

Design considerations

- Exceptions should indicate errors
- Here is an inappropriate use:

```
try {
    for (;;) {
        p = list.next()
    // ...
} catch (List::end_of_list) {
    // handle end of list here
}
```

Design considerations…

- Don’t use exceptions in place of good design

```
void func() {
    File f;
    if (f.open("somefile")) {
      try {
        // work with f
      } catch (...) {
      f.close()
      }
    }
}
```

Design considerations…

- This is a good place to use the destructor

```
void func() {
  File f("some file");
  // assume destructor closes f
  // will still be closed if exception
  // is raised!
  if (f.ok()) {
  }
}
```

Summary

- Error recovery is a hard design problem
- All subsystems need help from their clients to handle exceptional cases
- Exceptions provide the mechanism
  - –Propagated dynamically
  - –Objects on stack destroyed properly
  - –Act to terminate the problematic function
- Another big use:
  - –Constructors that can’t complete their work

More exceptions

- Exceptions and constructors
- Exceptions and destructors
- Design and usage with exceptions
- Handlers

Failure in constructors

- No return value is possible
- Use an “uninitialized flag”
- Defer work to an init() function

Better: Throw an exception

Failure in constructors…

If your constructor can’t complete, throw an exception.

- Dtors for the object *won’t be called*.
- Manually clean up allocated resources before throwing, otherwise memory leak happens.

Two stages construction

- Do normal work in ctor
  - –Initialize all member objects
  - –Initialize all primitive members
  - –Initialize all pointers to 0
  - –NEVER request any resource
    - File
    - Network connection
    - Memory

- Do additional initialization work in Init()

Using smart pointers

- std::unique_ptr
- std::shared_ptr
- …

- The destructor will delete the native pointer when it dies.

See ExceptionCtor.cpp

Exceptions and destructors

Destructors are called when:

- Normal call ended: object exits from scope
- Exceptions throwed: “stack unwinding” invokes dtors on objects as they exit from scope.

What happens if an exception is thrown in a destructor?

Exceptions and destructors…

Throwing an exception in a destructor that is itself being called as the result of an exception will invoke std::terminate().

- Allowing exceptions to escape from destructors should be avoided, never throw it!

Programming with exceptions

- throwing/catching by value involves slicing:

```
struct X {};
struct Y : public X {};
try {
    throw Y();
} catch(X x) {
    // was it X or Y?
}
```

Programming with exceptions…

- throwing/catching by pointer introduces coupling between normal and handler code:

```
try {
    throw new Y();
} catch(Y* p) {
    // whoops, forgot to delete..
}
```

Catch exceptions by reference:

- Prefer catching exceptions by reference:

```cpp
struct B {
    virtual void print() { /* … */ }
};
struct D : public B { /* … */ };

try {
    throw D("D error");
}
catch(B& b) {
    b.print(); // print D's error.
}
```

Exceptions wrap-up

- Develop an error-handling strategy early in design.
- Avoid over-use of try/catch blocks. Use objects to acquire/release resources.
- Don’t use exceptions where local control structures would suffice.
- Not every function can handle every error.
- Use exception-specifications for major interfaces.
- Library code should not decide to terminate a program. Throw exceptions and let the caller decide.

Write exception-safe code

Write exception-safe code

```
class BankAccount {
  // …

  void withdrawMoney(int amount) {
    // …

    reduceBalance(amount);
    prepareCash();
    releaseCash();

    // …
  }

  // …
};
```

Balance already reduced…

Throws an exception