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

1. open the file;
2. determine its size;
3. allocate that much memory;
4. read the file into memory;
5. 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;
}
```

```
try {
    // ------------------------
    // main logic here
    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

```cpp
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);  // How to implement?
};
```

Problem

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

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

Choice

- Return random memory object

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

More choices

- Return a special error value

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

This throws the baby out with the bath water!

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

More choices ...

- Just die!

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

- 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);  // the data object
  }
  return m_elements[idx];
}
```

What about your caller?

- 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?

- 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?

- Mildly interested

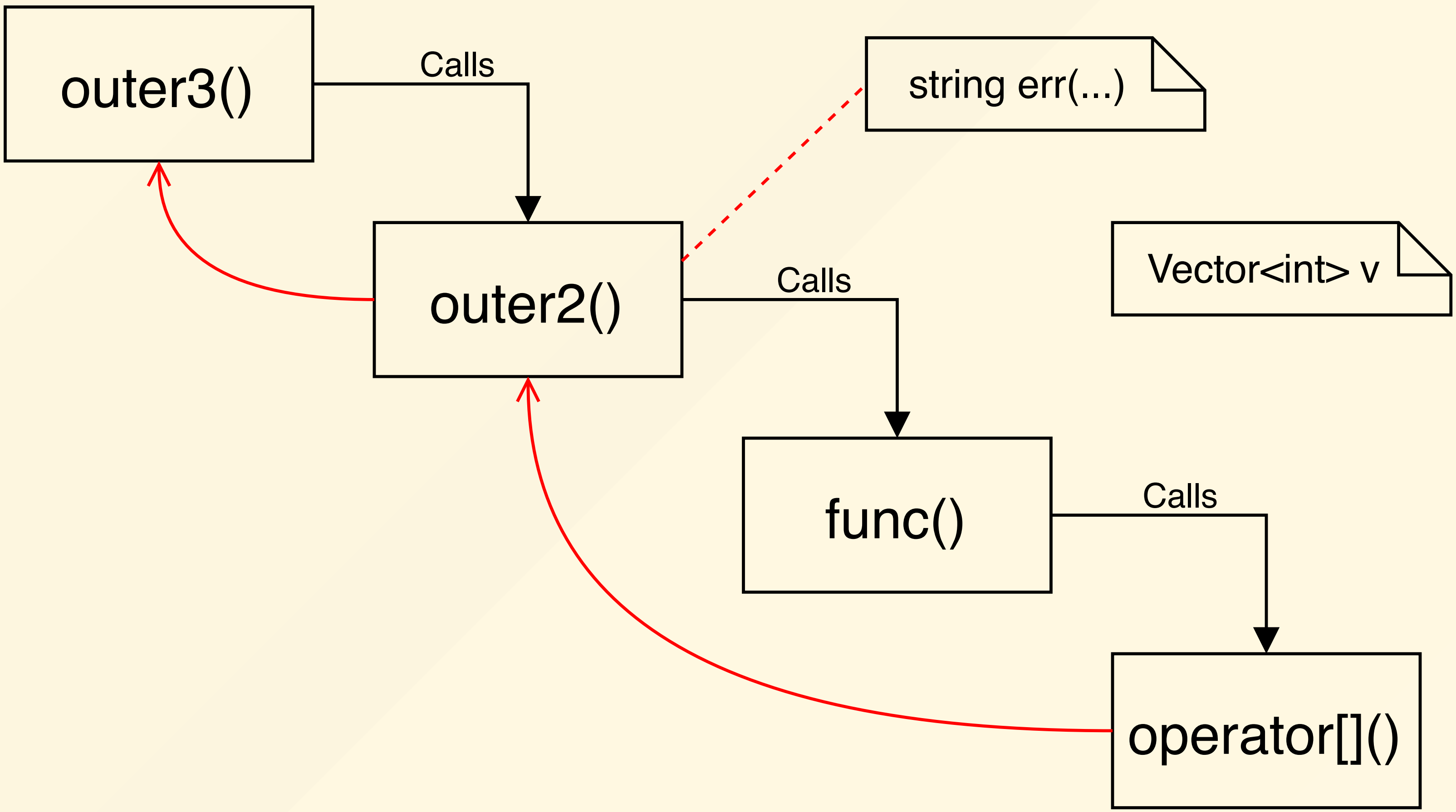
```
void outer2() {
  string err_msg("exception caught");
  try {
    func();
  } catch (VectorIndexError) {
    cout << err_msg;
    throw;  // propagate the exception
  }
}
```

What about your caller?

- Doesn't care about the particulars

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

What happens?



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

Review

- `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, only
3. Catch-all handler (...)

“ Inheritance can be used to structure exceptions ”

Example: using inheritance

- Hierarchy of exception types

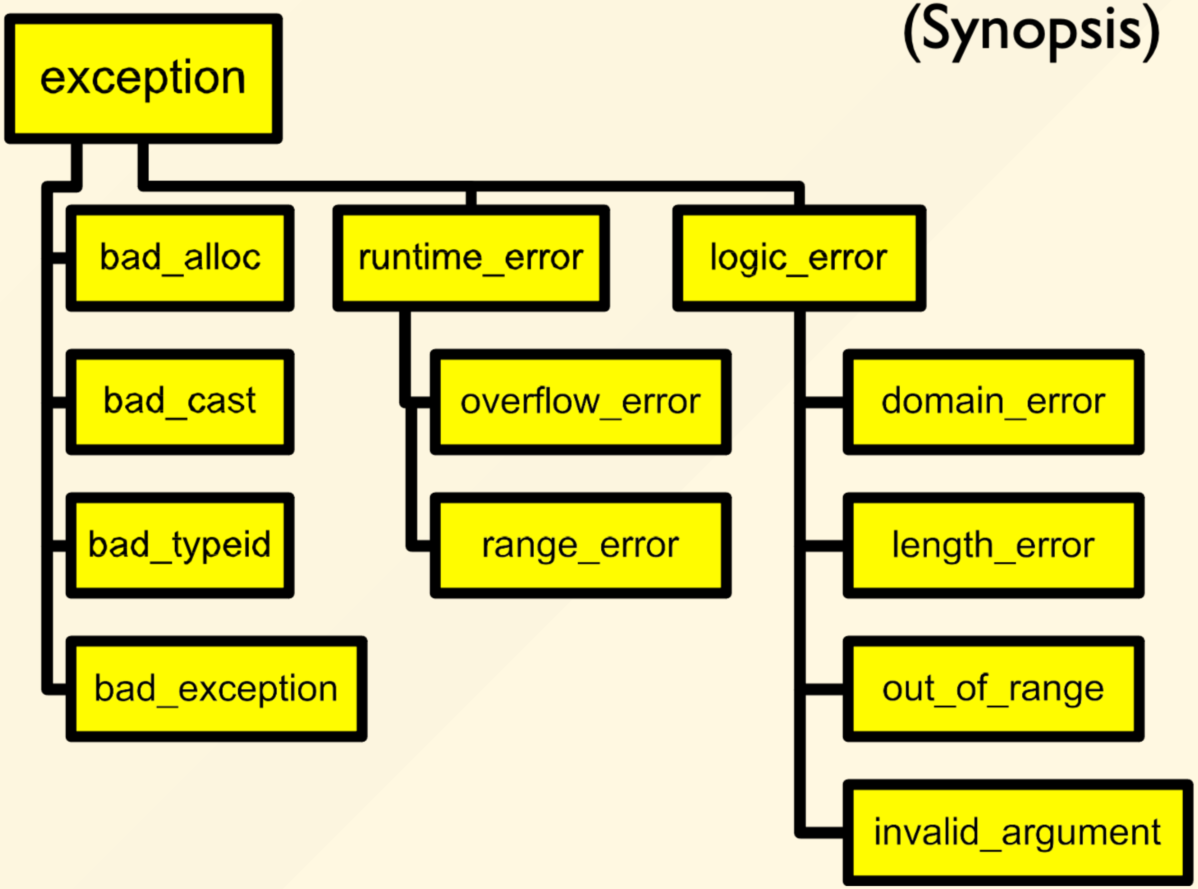
```
class MathErr {
  ...
  virtual void diagnostic();
};

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) {             // 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 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.

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 for
  - Propagating dynamically
  - Destroying objects on stack properly

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 throws 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 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`
- …
- Its destructor will delete the managed native pointer when it dies.

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 regular code and handler code:

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

Programming with exceptions

- Perfer catching exceptions *by reference*:

```
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.

Exceptions wrap-up …

- Use exception-specifications for major interfaces.
- Library code should not decide to terminate a program.
    - Throw exceptions and let the caller decide.

Uncaught exceptions

- If an exception is thrown but not caught, `std::terminate()` will be called.
- The `std::terminate()` can also be intercepted.

```
void my_terminate() {
  /* ... */
}
set_terminate(my_terminate);
```

Write exception-safe code

Write exception-safe code

```
class BankAccount {
  /* ... */

  void withdrawMoney(int amount) {
    reduceBalance(amount);  // Balance already reduced!
    prepareCash();          // Throws an exception!
    releaseCash();
  }

  /* ... */
};
```