Object – Oriented Programming

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Exceptions

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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 indx) {
```

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

1.) Return random memory object

```
return m_elements[indx];
```

More choices

2.) Return a special error value

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

But this throws the baby out with the bath!

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

More choices ...

3.) Just die!

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

4.) Die *gracefully (with autopsy!)*

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

When to use exceptions

- Many times, you don't know what should be done
- If you do *anything* you’ll be wrong

- Solution: turf the problem

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

How to raise an exception

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

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 indx) {
   if (indx < 0 || indx >= m_size) {
      // VectorIndexError e(indx);
      // throw e;
      throw VectorIndexError(indx);
   }
   return m_elements[indx];
}
```

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

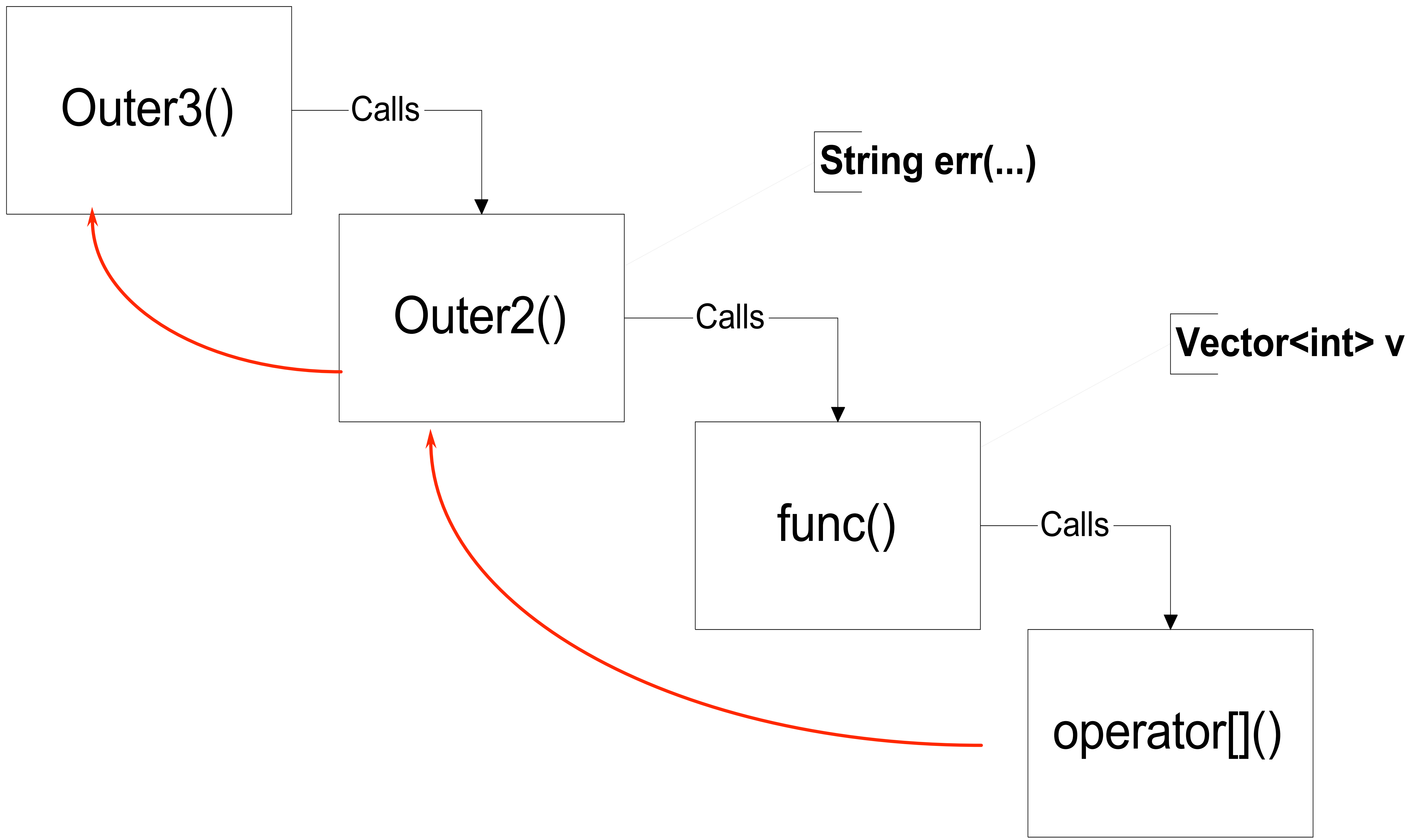
```
void outer2() {
  String err("exception caught");
  try {
      func();
  } catch (VectorIndexError) {
    cout << err;
    throw; // propagate the exception
  }
}
```

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

- 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;`
  - **reraises** 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. Ellipses (...) match all

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
}
```

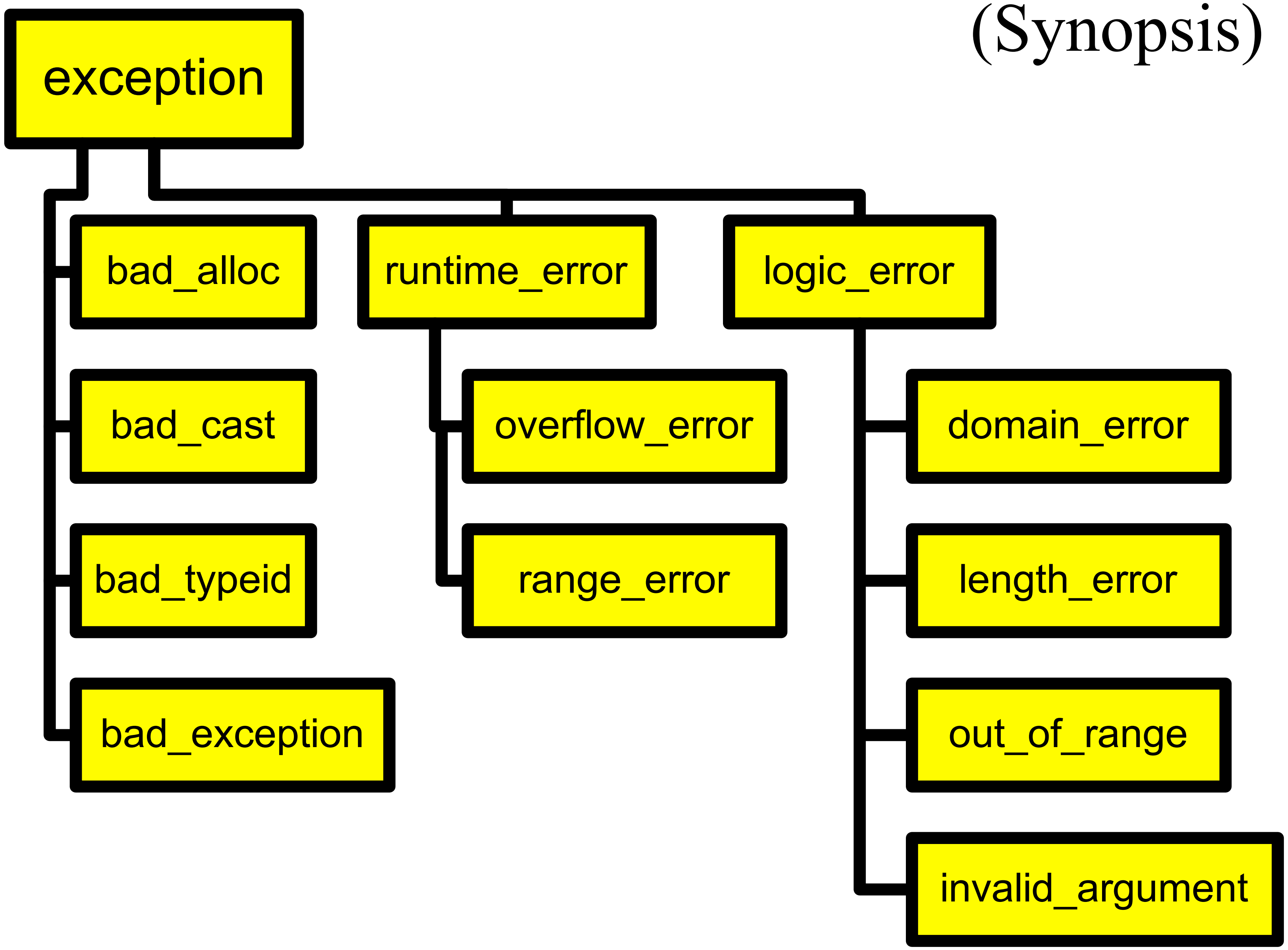
Exceptions and new

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

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

Standard library exceptions

(Synopsis)



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

Examples

```
Printer::print(Document&) :
      throw(PrinterOffLine, BadDocument)
  { ...

PrintManager::print(Document&) :
     throw (BadDocument) { ...
     // raises or doesn't handle BadDocument

void goodguy() : throw ()  {
   // handles all exceptions

void average() { } // no spec, no checking,
```

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()
      }
   }
```

- 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 you constructor can’t complete, throw an exception.

- Dtors for objects whose ctor didn’t complete *won’t be called*.
- Clean up allocated resources before throwing.

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 addition initialization work in Init()

Exceptions and destructors

Destructors are called when:

- Normal call: object exits from scope
- During exceptions: stack unwinding invokes dtors on objects as scope is exited.

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.

Programming with exceptions

Prefer catching exceptions by reference

- 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:

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

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

Exception Hierarchies

Use inheritance hierarchies for exceptions

Problem:

```
try {
  … throw SomethingElse();
}
catch(This& t) { /* … */ }
catch(That& t) { /* … */ }
catch(Other& t) { /* … */ }
```

Exception Hierarchies

```
class B {};
class D1 : public B {};
class D2 : public B {};
...
try {
  … throw D1();
}
catch(D2& t) { /* catch specific class here */ }
catch(B& t) { /* anything else here. */ }
```

Unexpected exceptions

- *Exception specification* defines the exceptions a function will throw:

```
void f() throw(X, Y) {/* may throw X and Y */}
void g() throw() {/* throws no exceptions  */}
void h() {/* may throw any exception*/}
```

What if f() *throws something else?*

What if g() *throws an exception?*

Unexpected exceptions...

- Exceptions not in the exception specification are *unexpected.*
- Unexpected exceptions become a call to std::unexpected().
- Offers a guarantee (and firewall) to callers.
- unexpected() behavior can be intercepted.

```
#include <exception>
void my_handler() {
  std::cout << "unexpected exception!\n";
  exit(1);
}
void f() throw(X, Y) {
  throw Z(); // whoops! Throwing Z
}
void main() {
  std::set_unexpected(my_handler);
  try {
    f();
  }
  catch (…) {
    std::cout << “caught it!” << endl;
  }
}
```

Uncaught exceptions

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

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

Exceptions wrapup

- 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 will suffice
- Not every function can handle every error.

Exceptions wrapup...

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

Uncaught exceptions

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

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

Comparison w/ Java

- Can throw anything
- No final
- No throws
- … for catching all
- No stack trace print out after termination

Putting it All Together

Templates

Inheritance

Reference Counting

Smart Pointers

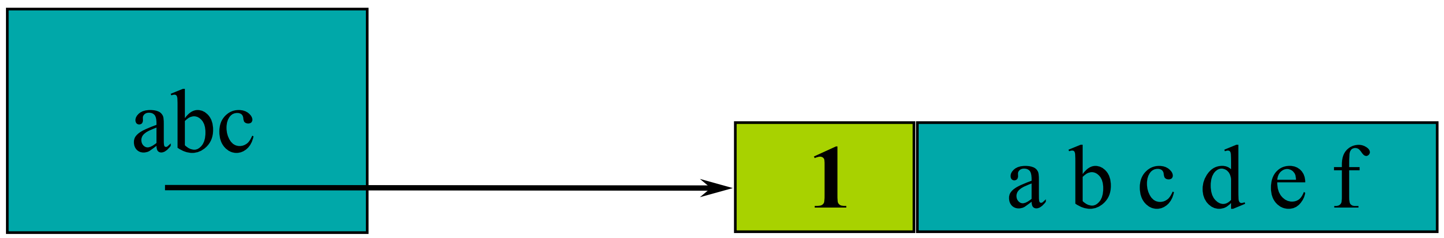
Reference: *C++ Strategies and Tactics*, Robert Murray, 1993

Goals

- Introduce the code for maintaining reference counts
  - A reference count is a count of the number of times an object is shared
  - Pointer manipulations have to maintain the count
- Class <u>UCObject</u> holds the count
  - "Use-counted object"
- <u>UCPointer</u> is a *smart pointer* to a UCObject
  - A smart pointer is an object defined by a class
  - Implemented using a template
  - Overloads operator-> and unary operator*

Reference counts in action

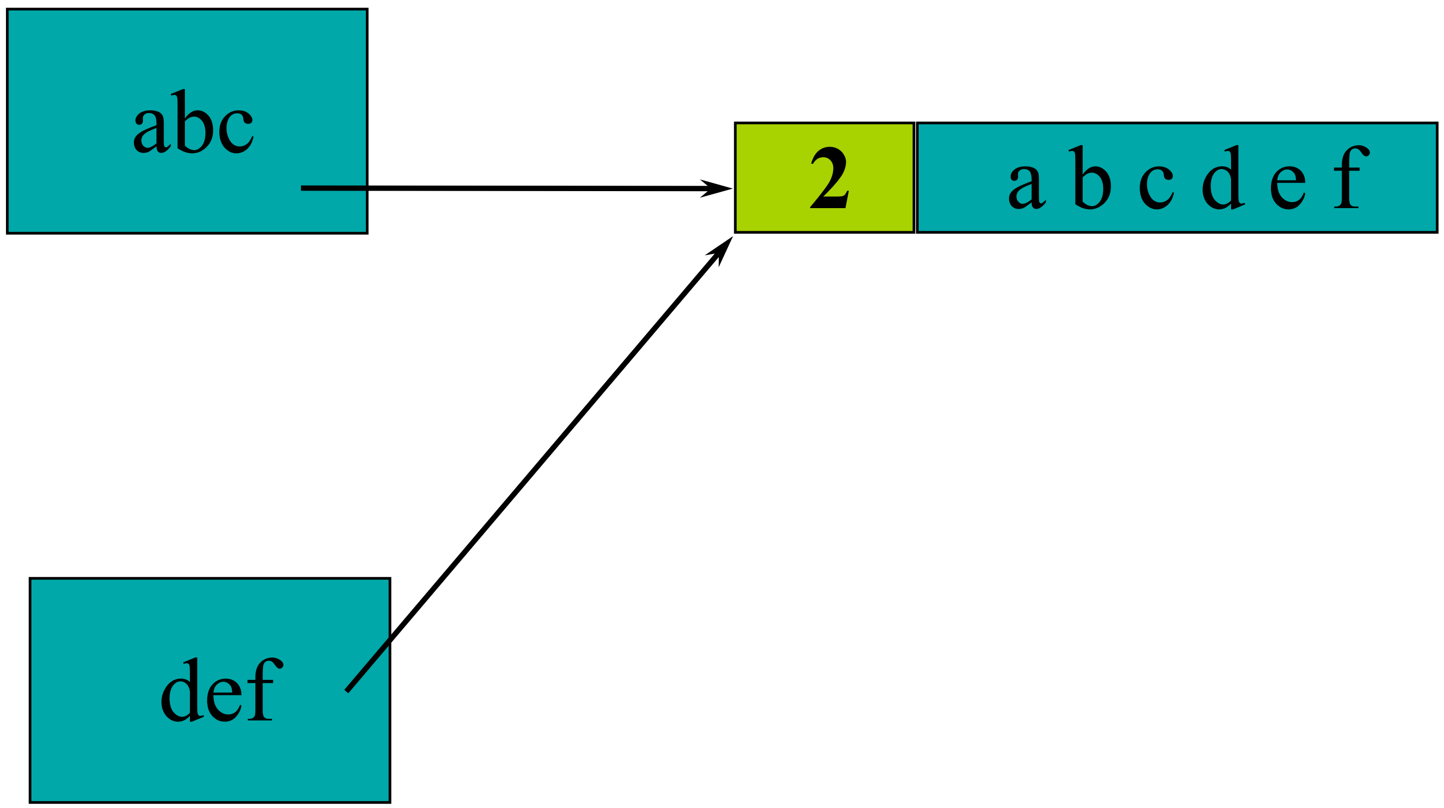
```
String abc("abcdef");
```



Shared memory maintains a count of how many times it is shared

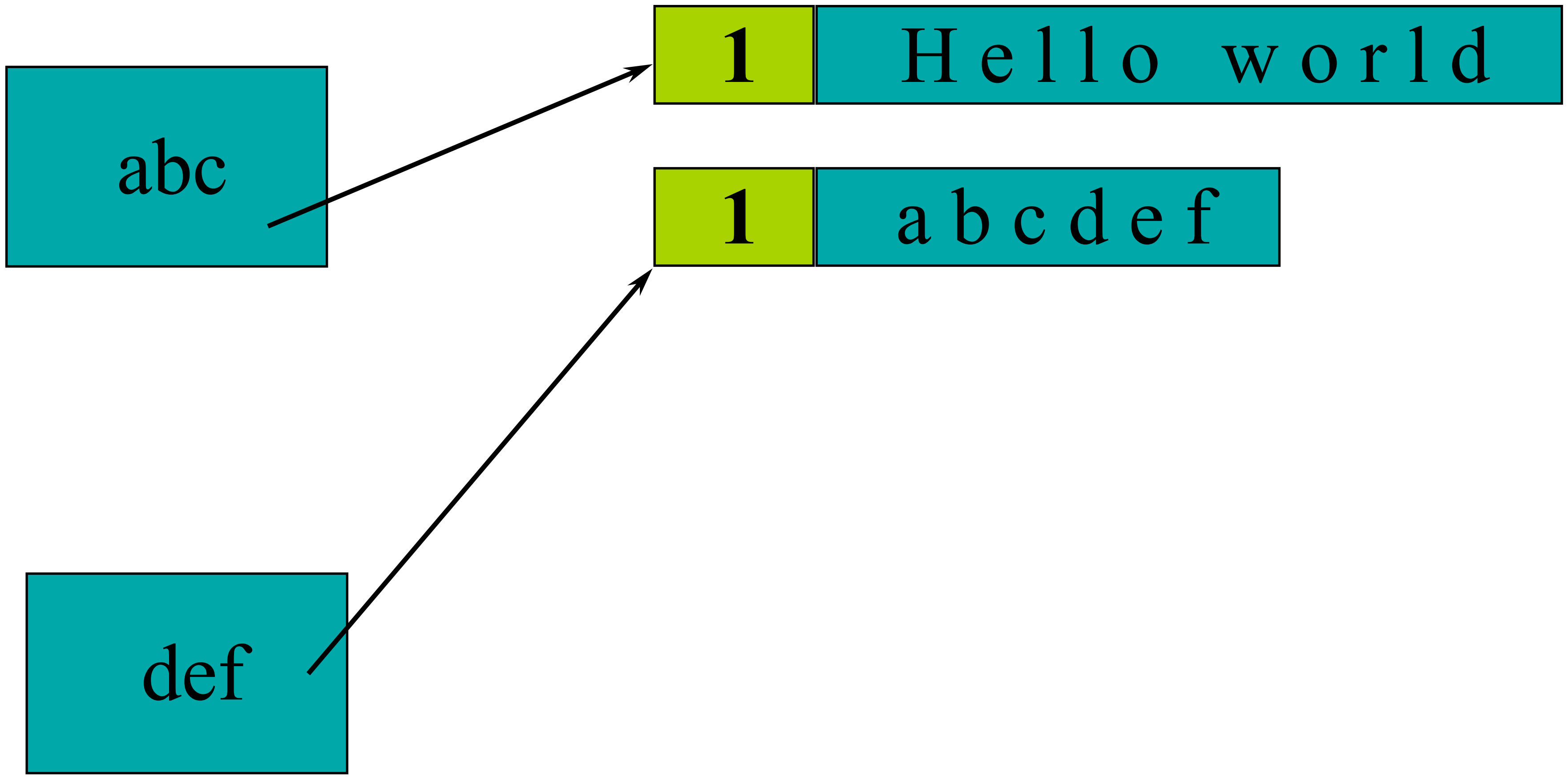
Reference counts in action

```
String abc("abcdef");
String def = abc; // shallow copy of abc
```



Reference counts in action

```
String abc("abcdef");
String def = abc;          // shallow copy of abc
abc = "Hello world";       // copy on write
```



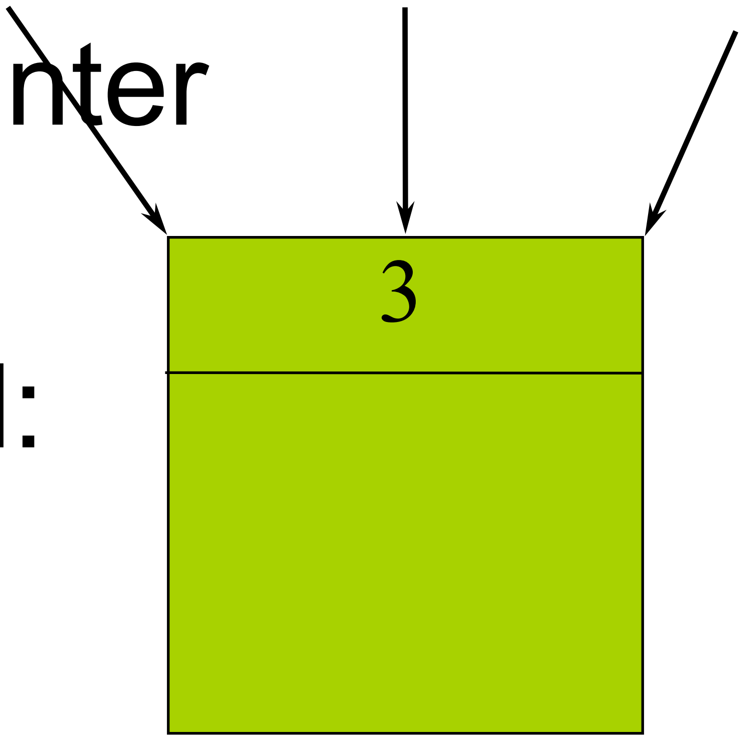
Reference counting

- Each sharable object has a counter
- Initial value is 0
- Whenever a pointer is assigned:

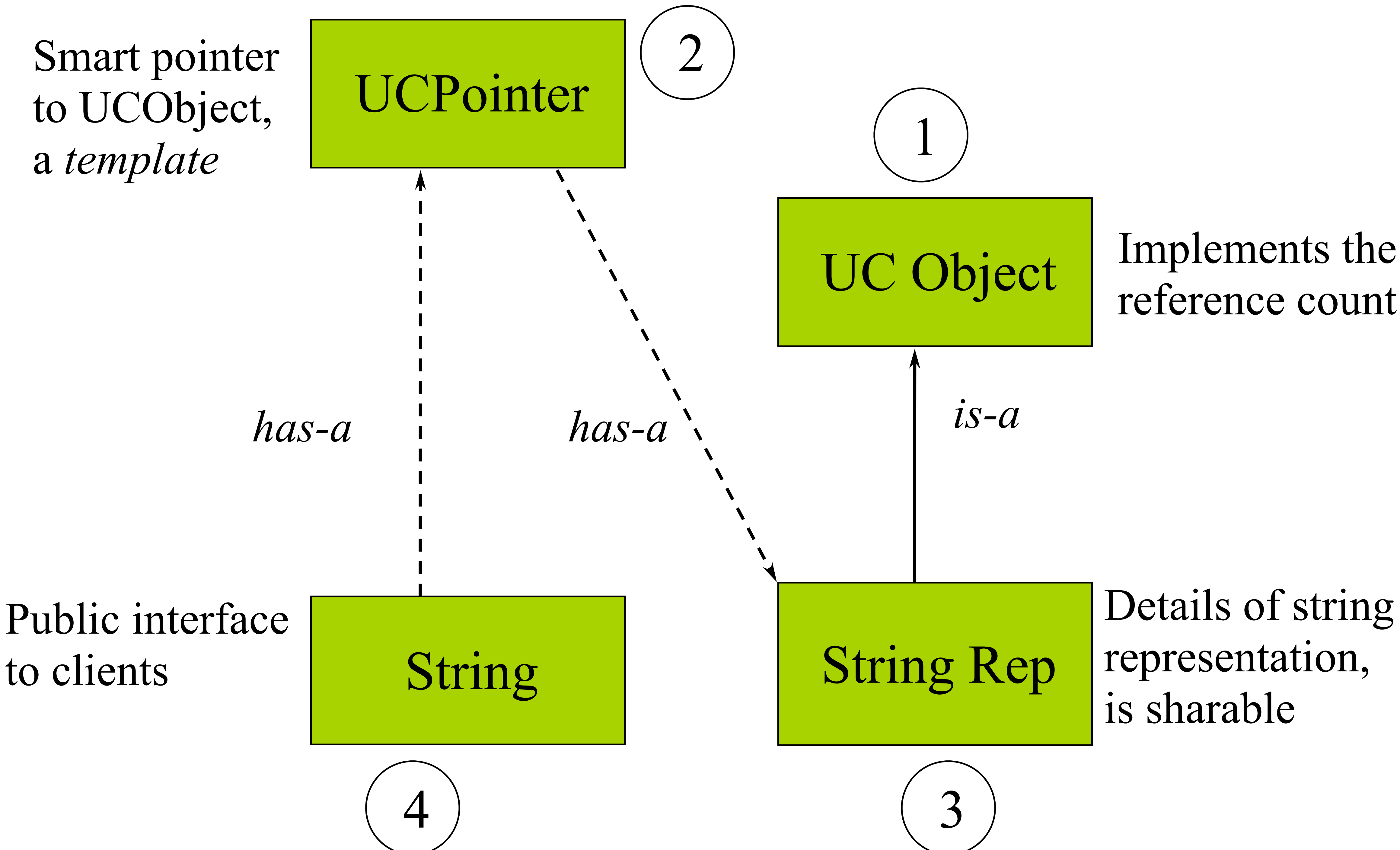
```
p = q;
```

- Have to do the following

```
p->decrement(); // p's count will decrease
p = q;
q->increment(); // q/p's count will increase
```



The four classes involved



Reusing reference counting

```
#include <assert.h>
class UCObject {
public:
   UCObject() : m_refCount(0) { }
   virtual ~UCObject() { assert(m_refCount == 0);};
  UCObject(const UCObject&) : m_refCount(0) { }
   void incr() { m_refCount++; }
   void decr();
   int references() { return m_refCount; }
private:
   int m_refCount;
};
```

UCObject continued

```
inline void UCObject::decr() {
    m_refCount -= 1;
     if (m_refCount == 0) {
       delete this;
    }
}
```

- "Delete this" is legal
  - –But don't use *this* afterwards!

Class UCPointer

```
template <class T>
class UCPointer {
private:
   T* m_pObj;
   void increment() { if (m_pObj) m_pObj->incr(); }
   void decrement() { if (m_pObj) m_pObj->decr
   (); }
public:
   UCPointer(T* r = 0): m_pObj(r) { increment();}
   ~UCPointer() { decrement(); };
   UCPointer(const UCPointer<T> & p);
   UCPointer& operator=(const UCPointer<T> &);
   T* operator->() const;
   T& operator*() const { return *m_pObj; };
};
```

UCPointer copy constructor

```
template <class T>
UCPointer<T>::UCPointer(const UCPointer<T> & p){
   m_pObj = p.m_pObj;
   increment();
}
```

UCPointer assignment

```
template <class T>
UCPointer<T>&
UCPointer<T>::operator=(const UCPointer<T>& p){
   if (m_pObj != p.m_pObj) {
      decrement();
      m_pObj = p.m_pObj;
      increment();
   }
   return *this;
}
```

The -> Operator

- `operator->`() is a unary operator
  - Result must support the -> operation
- C++ allows you to overload
  - [] -- subscripting
  - () -- "function call"
  - ->() -- pointer chasing
  - *() -- unary pointer dereference

The UCPointer -> operator

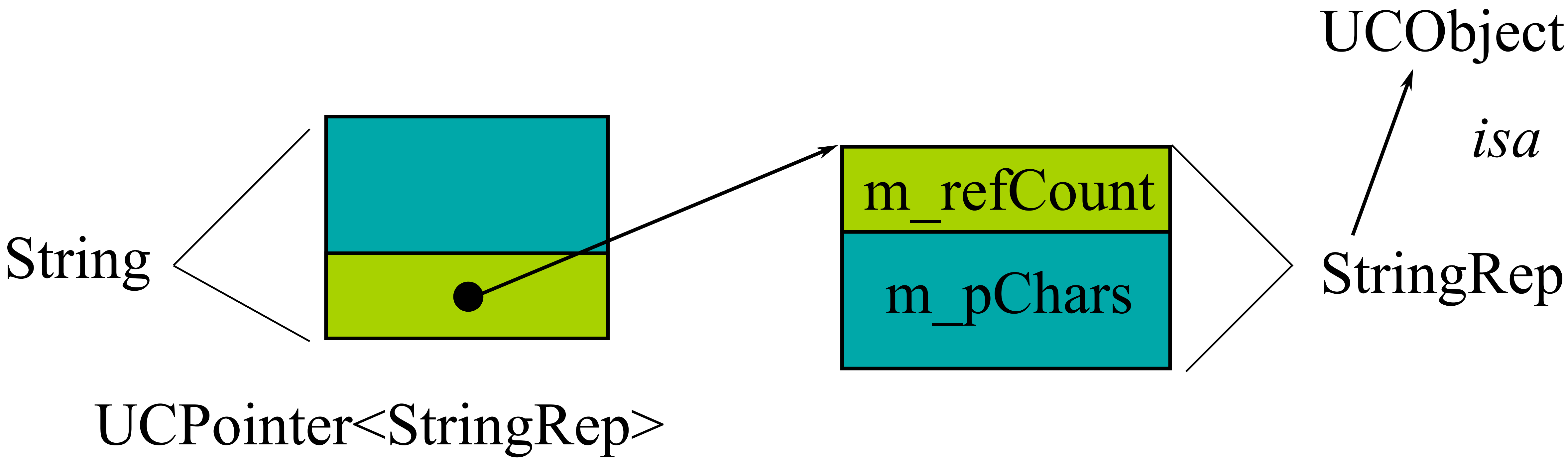
```
template<class T>
T* UCPointer<T>::operator->() const {
   return m_pObj;
}
```

- Example: Shape inherits from UCObject.

```
Ellipse elly(200F, 300F);
UCPointer<Shape*> p(&elly);
p->render(); // calls Ellipse::render() on
elly!
```

Envelope and Letter

- Envelope provides protection
- Letter contains the contents



String Class

```
class String {
public:
    String(const char *);
   ~String();
   String(const String&);
   String& operator=(const String&);
   int operator==(const String&) const;
   String operator+(const String&) const;
   int length() const;
   operator const char*() const;
private:
   UCPointer<StringRep> m_rep;
};
```

Class StringRep

```
class StringRep : public UCObject {
public:
     StringRep(const char *);
    ~StringRep();
    StringRep(const StringRep&);
    int length() const{ return strlen(m_pChars); }
    int equal(const StringRep&) const;
private:
    char *m_pChars;
   // reference semantics -- no assignment op!
   void operator=(const StringRep&) { }
};
```

StringRep implementation

```
StringRep::StringRep(const char *s) {
  if (s) {
       int len = strlen(s) + 1;
    m_pChars = new char[len];
    strcpy(m_pChars , s);
  } else {
       m_pChars = new char[1];
    *m_pChars = '\0';
  }
}
StringRep::~StringRep() {
  delete [] m_pChars ;
}
```

StringRep implementation

```
StringRep::StringRep(const StringRep& sr) {
  int len = sr.length();
  m_pChars = new char[len + 1];
  strcpy(m_pChars , sr.m_pChars );
}

int StringRep::equal(const StringRep& sp)
  const {
  return (strcmp(m_pChars, sp.m_pChars) ==
  0);
}
```

String implementation

```
String::String(const char *s) : m_rep(0) {
  m_rep = new StringRep(s);
}

String::~String() {}

// Again, note constructor for rep in list.
String::String(const String& s) : m_rep(s.m_rep)
   { }

String&
String::operator=(const String& s) {
  m_rep = s.m_rep; // let smart pointer do work!
  return *this;
}
```

String implementation

```
int
String::operator==(const String& s) const {
  // overloaded -> forwards to StringRep
  return m_rep->equal(*s.m_rep); // smart
  ptr *
}

int
String::length() const {
  return m_rep->length();
}
```

Critique

- UCPointer maintains reference counts
- UCObject hides the details of the count String is very clean
- StringRep deals only with string storage and manipulation
- UCObject and UCPointer are reusable
- Objects with cycles of UCPointer will never be deleted

Other smart pointers

- Standard library holder for raw pointers on stack
- Releases resource when destroyed (latest)

```
template <class X> std::auto_ptr {
public:
   explicit auto_ptr(X* = 0) throw();
   auto_ptr(auto_ptr&) throw();
   auto_ptr& operator=(auto_ptr&) throw();
   ~auto_ptr();
   X& operator*() const throw();
   X* operator->() const throw();
   ...
   };
```