Engineering Robust Server Software
Exceptions
Exceptions

- Handling problems: exceptions
- C++
  - temp-and-swap
  - RAII
  - Smart Pointers
- Java
  - finally
  - specifications
  - finalizers (and why they are not what you need for this)
Exceptions

• Review: exceptions = way to handle problems
  • Thing goes wrong? throw exception
  • Know how to deal with problem? try/catch exception
    • In python, try/except

• Why exceptions?
  • Return error code? Cluttery, easy to forget/ignore
  • Do nothing? Automatically pass problem to caller
  • Provide details about error
Exceptions: Downsides

- So exceptions: best idea ever?
- Downsides too
  - Unexpected things happen in code
    - Well, that is true anyways
  - Used improperly: corrupted objects, resource leaks, …
- Bottom line:
  - Good if you do all things right
Exception Safety

- Continued review: exception safety
- Remind us of the four levels of exceptions safety?

<table>
<thead>
<tr>
<th>Stronger Guarantees</th>
<th>No Throw</th>
<th>Strong</th>
<th>Basic</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Will not throw any exception. Catches and handles any exceptions thrown by operations it uses</td>
<td>No side-effects if an exception is thrown: objects are unmodified, and no memory is leaked</td>
<td>Objects remain in valid states: no dangling pointers, invariants remain intact. No memory is leaked</td>
<td>Does not provide even a basic exception guarantee. Unacceptable in professional code.</td>
</tr>
</tbody>
</table>
template<typename T>
class LList {
    // other things omitted, but typical

    LList & operator=(const LList & rhs) {
        if (this != &rhs) {
            deleteAll();
            Node * curr = rhs.head;
            while (curr != null) {
                addToBack(curr->data);
                curr = curr->next;
            }
        }
        return *this;
    }
};

Exception Safety

Which guarantee does this make?
template<typename T>
class LList {
    // other things omitted, but typical

    LList & operator=(const LList & rhs) {
        if (this != &rhs) {
            deleteAll();
            Node * curr = rhs.head;
            while (curr != null) {
                addToBack(curr->data);
                curr = curr->next;
            }
        }
        return *this;
    }
};

Which guarantee does this make?
- Need to know what guarantees these make!
Exception Safety

template<typename T>
class LList {
    //other things omitted, but typical

    void deleteAll() {
        while(head != nullptr) {
            Node * temp = head->next;
            delete head;
            head = temp;
        }
        tail = nullptr;
    }
};

Which guarantee does deleteAll() make?

No throw guarantee
(assuming destructors are no-throw)
template<typename T>
class LList {
    //other things omitted, but typical

    void addToBack(const T& d) {
        Node * newNode = new Node(d, nullptr, tail);
        if (tail = nullptr) {
            head = tail = newNode;
        } else {
            tail->next = newNode;
            newNode->prev = tail;
            tail = newNode;
        }
    }
};

Which guarantee does addToBack() make?

Depends on copy constructor for T

<table>
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<tr>
<th>T's Copy Constructor</th>
<th>addToBack()</th>
</tr>
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<tr>
<td>Basic</td>
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<tr>
<td>No Guarantee</td>
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</table>
template<typename T>
class LList {
    // other things omitted, but typical

    LList & operator=(const LList & rhs) {
        if (this != &rhs) {
            // no throw
            deleteAll();  // no throw
            Node * curr = rhs.head;  // no throw
            while (curr != null) {
                // no throw
                addToBack(curr->data);  // strong [let us suppose]
                curr = curr->next;  // no throw
            }
        }
        return *this;  // no throw
    }
};

Which guarantee does this make?

Basic
LList & operator=(const LList & rhs) {
    if (this != &rhs) {
        Node * temp = rhs.head;
        Node * n1 = nullptr;
        Node * n2 = nullptr;
        if (temp != nullptr) {
            n1 = n2 = new Node(temp->data, nullptr, nullptr);
            temp = temp->next;
            while (temp != null) {
                n2->next = new Node(temp->data, n2, nullptr);
                n2 = n2->next;
                temp = temp->next;
            }
        }
        deleteAll();
        head = n1; tail = n2;   No guarantee!  :(  
    }
    return *this;
}
template<typename T>
class LList {
    // other things omitted, but typical

    LList & operator=(const LList & rhs) {
        if (this != &rhs) {
            LList temp(rhs);
            std::swap(temp.head, head);
            std::swap(temp.tail, tail);
        }
        return *this;
    }
};

Which guarantee does this make? Strong!
template<typename T>
class LList {
    // other things omitted, but typical

    LList & operator=(LList rhs) {
        std::swap(temp.head, head);
        std::swap(temp.tail, tail);
        return *this;
    }
};

Same principle, but passed by value instead of reference (going to copy anyways...Will waste work if self assignment)
Temp-and-swap

• Common idiom for strong guarantees: temp-and-swap
  • Make \texttt{temp} object
  • Modify \texttt{temp} object to be what you want \texttt{this} to be
  • swap fields of \texttt{temp} and \texttt{this}
  • \texttt{temp} destroyed when you return (Destructor cleans up state)
    • Exception? \texttt{temp} destroyed in stack unwinding
• Downside?
  • Change only some state: may be expensive to copy entire object
What About This Code...

template<typename T>
class LList {
   //other things omitted, but typical

   LList & operator=(const LList & rhs) {

      if (this != &rhs) {
         m.lock();
         rhs.m.lock(); //What if this throws?
         std::swap(temp.head, head);
         std::swap(temp.tail, tail);
         rhs.m.unlock();
         m.unlock();
      }
      return *this;
   }
}
template<typename T>
class LList {
  // other things omitted, but typical

  LList & operator=(const LList & rhs) {
    
    if (this != &rhs) {
      std::lock_guard<std::mutex> lck1(m); // calls m.lock()
      std::lock_guard<std::mutex> lck2(rhs.m); // calls rhs.m.lock()
      std::swap(temp.head, head);
      std::swap(temp.tail, tail);
    }
    return *this;
  };
}
template<typename T>
class LList {
    //other things omitted, but typical

    LList & operator=(const LList & rhs) {

        if (this != &rhs) {
            std::lock_guard<std::mutex> lck1(m); //calls m.lock()
            std::lock_guard<std::mutex> lck2(rhs.m); //calls rhs.m.lock()
            std::swap(temp.head, head);
            std::swap(temp.tail, tail);
        } //destruction calls .unlock()

        return *this;
    }
};
template<typename T>
class LList {
  //other things omitted, but typical

  LList & operator=(const LList & rhs) {

    if (this != &rhs) {
      std::lock_guard<std::mutex> lck1(m);
      std::lock_guard<std::mutex> lck2(rhs.m); //what if exn?
      std::swap(temp.head, head);
      std::swap(temp.tail, tail);
    }
    return *this;
  }
};
RAII

- Resource Acquisition Is Initialization
  - Resource lifetime tied to object lifetime
  - Allocation during initialization
  - Released during destruction

- Example resources:
  - Mutex: lock/unlock
  - Heap Memory: new/delete
  - File: open/close

- Exception safety benefits?
RAII with Heap Objects

- "Smart Pointers"
  - Objects that wrap pointer and provide RAII
  - C++03: std::auto_ptr (deprecated)

- C++11:
  - std::unique_ptr
  - std::shared_ptr
  - std::weak_ptr
std::unique_ptr

{  
    std::unique_ptr<Thing> thing1 (new Thing);  
    // other code here

}  
// thing1 goes out of scope: delete its pointer

- Owns a pointer
  - When destroyed, deletes owned pointer
std::unique_ptr

{
    std::unique_ptr<Thing> thing1 (new Thing);
    //other code here
    Thing * tp = thing1.get();
}

- Owns a pointer
  - When destroyed, deletes owned pointer
- Can use .get() to get raw pointer
std::unique_ptr

```cpp
{
    std::unique_ptr<Thing> thing1 (new Thing);
    //other code here
    Thing * tp = thing1.get();
    thing1->doSomething();
}
```

- Owns a pointer
  - When destroyed, deletes owned pointer
- Can use .get() to get raw pointer
- Can also use * and -> operators
std::unique_ptr

{
    std::unique_ptr<Thing> thing1 (new Thing);
    // ... ... ...
    std::unique_ptr<Thing> thing2 (thing1);

    // thing2 owns pointer, thing1 is empty (holds nullptr)
}

- Assignment operator/copy constructor transfer ownership
Exception Safety

Which guarantee does this make?

```c
Thing * foo(int x, char c) {
    Widget * w = new Widget(x);
    Gadget * g = new Gadget(c);
    Thing * t = new Thing(w,g);
    return t;
}
```
Exception Safety

Thing * foo(int x, char c) {
    std::unique_ptr<Widget> w (new Widget(x));
    std::unique_ptr<Gadget> g (new Gadget(c));
    Thing * t = new Thing(w.get(), g.get());
    return t;
}

Is this code correct?
Exception Safety

Thing * foo(int x, char c) {
    std::unique_ptr<Widget> w (new Widget(x));
    std::unique_ptr<Gadget> g (new Gadget(c));
    Thing * t = new Thing(w.get(),g.get());
    return t;
}

w and g go out of scope here, so... what happens to their pointers?

Is this code correct?  No!
Exception Safety

```cpp
Thing * foo(int x, char c) {
    std::unique_ptr<Widget> w (new Widget(x));
    std::unique_ptr<Gadget> g (new Gadget(c));
    Thing * t = new Thing(w.release(),g.release());
    return t;
}
```

What about this code?

release returns the pointer (like get),
but also gives up ownership (sets the owned pointer to nullptr)
Exception Safety

```cpp
Thing * foo(int x, char c) {
    std::unique_ptr<Widget> w (new Widget(x));
    std::unique_ptr<Gadget> g (new Gadget(c));
    Thing * t = new Thing(w.release(),g.release());
    return t;
}
```

What if `new` fails?

What about this code?

"Whether the allocation function is called before evaluating the constructor arguments or after evaluating the constructor arguments but before entering the constructor is unspecified. It is also unspecified whether the arguments to a constructor are evaluated if the allocation function returns the null pointer or exits using an exception."

— C++ standard, 5.3.4 (21)
```cpp
Thing * foo(int x, char c) {
    std::unique_ptr<Widget> w (new Widget(x));
    std::unique_ptr<Gadget> g (new Gadget(c));
    Thing * t = new Thing(w, g);
    return t;
}
```

What about this code?  
(What am I assuming Thing's constructor takes now?)
Shared Pointers + Weak Pointers

- Unique Pointers: exactly one owner
  - Assignment **transfers** ownership
- Shared Pointers: many owners
  - Copying increments count of owners
  - Destruction decrements counts of owners
  - Object freed when owner count reaches 0
- Weak Pointers: non-owners of shared pointer
  - Can reference object, but does not figure into owner count
  - Use .lock() to obtain shared_ptr: has object (if exists) or nullptr (if not)
Java Exceptions: Slightly Different

- RAII: C++, but not Java (why not?)
  - No objects in stack in Java (all in heap…)
- Java's plan: finally
  - **ALWAYS** executed, no matter whether exception or not
public void doAThing(String name) {
    SomeResource sr = null;
    try {
        sr = new SomeResource(name);
        doStuff(sr);
    }
    catch(WhateverException we) {
        dealWithProblem(we);
    }
    finally {
        if(sr != null) {
            sr.close();
        }
    }
}
public void doAThing(String name) throws WhateverException{
    SomeResource sr = null;
    try {
        sr = new SomeResource(name);
        doStuff(sr);
    }
    finally {
        if(sr != null) {
            sr.close();
        }
    }
}
public void doAThing(String name) throws WhateverException{
    try (SomeResource sr = new SomeResource(name)) {
        doStuff(sr);
    }
}

Java also has try-with-resource
- declare/initilize AutoCloseable object in () after try
- o can have multiple declarations, separate with ;
- automatically makes a finally which closes it
- o closes in reverse order of creation
- can have explicit catch or finally if you want
Java Exceptions: Slightly Different

public void doAThing(String name) throws WhateverException{
    SomeResource sr = null;
    try {
        sr = new SomeResource(name);
        doStuff(sr);
    }
    finally {
        if(sr != null) {
            sr.close();
        }
    }
}

Java's exception specification rules different from C++'s
Exception Specifications

- C++ 03
  - No declaration: can throw anything
  - Declaration: restricted to those types \( \text{throw}(x, y, z) \) or \text{throw()}
    - Checked at runtime: when exception is thrown
    - If lied, std::unexpected()
Exception Specifications

```cpp
template<typename T>
class Thing {
    T data;
    public:
        Thing() noexcept(noecept(T())) {}  

     //………
};
```

- C++ 11
  - C++03 specifications valid but deprecated
  - noexcept for "no throw"
    - Can take a **boolean expression** to indicate behavior (true=noexcept)
    - `noexcept(expr)` queries if expr is declared noexcept
  - If noexcept actually throws, calls std::terminate()
Exception Specifications

- **Java**
  - Two types of exceptions: checked and unchecked
  - **Checked**: exception specifications checked at compile time
    - Compiler ensures you don't lie (aka miss one)
  - **Unchecked**: no need to declare in spec
    - Possible in too many places, would clutter code
"Reasonable" applications do not try/catch these
Exception Specifications

Runnable

Error

Exception

IOException

SQLException

RuntimeException

ArrayIndexOutOfBoundsException

NullPointerException

ArithmeticException

......

RuntimeException: too ubiquitous to clutter code with specifications (everything might throw them)
Exception Specifications

Checked exceptions:
- Rare enough to merit specification
- Reasonable enough to try/catch

Transparent exceptions:
- Usually implementation dependent
- Exception class is not generally inheritable

**Diagram:**
- Throwable
  - Error
    - IOException
    - SQLException
    - RuntimeException
  - Exception
    - IOException
    - SQLException
    - RuntimeException
Java: Finalizers

- Java objects have `finalize()`
  - "Called by the garbage collector on an object when garbage collection determines that there are no more references to the object."
- Seems like maybe we could use this to help resource management?
Let's Look at Stack Overflow

When the IO resource `method.

Finalizer: NOT For Resource Management

- Do NOT try to use finalizers for resource management!
  - No guarantee of when they will run (may never gc object!)
- Do NOT use finalizers in general
  - May run on other threads (possibly multiple finalizers at once)
    - Were you thinking about how to synchronize them?
    - What about deadlock?
  - Likely to run when memory is scarce (may cause problems if you allocate)
  - Could accidentally make object re-referenceable?
Exceptions

• Handling problems: exceptions

• C++
  • temp-and-swap
  • RAlI
  • Smart Pointers

• Java
  • finally
  • specifications
  • finalizers (and why they are not what you need for this)