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Handout #25
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Exceptions

Great Exceptations

Here we'll cover the basic features and uses of exceptions.

Pre-Exceptions

A program has to encode two ideas -- how to do the main computation, and how to identify and handle exceptional (rare) failure conditions that might arise during the computation.

Error Code Checking

The old way to do this is with error codes...

```
int err1 = foo(a, &b);
if (err1 < 0) { ... error handling ... }
int err2 = bar(b, &c);
if (err2 M 0) { ... error handling ...}
```

Error Code Problems

1. The main computation and the error handling are mixed together -- less convenient, less readable.
2. The error must be handled where it occurs, or we must manually pass back error codes of some sort. The error-code-return coding is a bore. Often, the error occurs at a low level, but we want to handle it at a higher level (a few methods up the call chain).
3. The error handling, such as it is, depends on programmer diligence -- the compiler is not enforcing anything. This is especially dangerous for code paths that, as a practical matter, may never execute until the rare error condition actually happens. (e.g. running out of disk space midway through save operation)

Exceptions vs. CPU Rule

Recall the "CPU rule" where code that has never been executed will tend to have bugs in it.

For this reason, it is very common for exception handling code to have bugs in it, simply because it is run so rarely, and interpreting what it is supposed to do is a little unclear as well.

Some testing strategies will put lower level objects, like the memory allocator, in a deliberate 'fail' mode to try to test the error handling cases in the upper level code.

Recall: Client Oriented

Recall from the discussion of client oriented design -- the client will always take the "easy" way to write the code, even if it is somewhat wrong. Therefore, it's bad modular design if there is an easy way for the client code to be written that has hidden problems. For example, if we return an error code, the client will most likely call the function and just not check the error code. Java exceptions are designed with exactly this siutation in mind. A method can declare an exception in such a way that the client **must** write handler code for it.

Exceptions

Exceptions try to formalize and separate the error handling code from the main code, and to do it in a standard, structured way.

Java Exception

At runtime, an "exception" represents an error condition that halts the current computation.

Many common exceptions are detected by the VM -- NullPointerException, ArrayIndexOutOfBoundsException...

```
String s = null;
if (s.length() > 0) { ...  // throws NullPointerException
```

Exception classes

An Exception is a Java object used to represent the error condition.
- Contains a "message" human readable string -- set in the ctor.

The Throwable class is the superclass of all exceptions. It is not generally used directly.

Error subclass
- low-level errors, such as OutOfMemory error. Generally, code does not declare or deal with these. They are fatal.

Exception subclass
- The most commonly used exceptions are subclasses of Exception.
- A method that throws an Exception must declare it with a throws clause (below)
- Also known as a "checked" exception, since the client code must check it

RuntimeException subclass
- Subclass of Exception.
- A method that throws a RuntimeExceptions does not need to declare it
- Also known as an "unchecked" exception, since the client does not need to check for it

Exception vs. RuntimeException
- If it makes sense for the caller to be aware of the exception and have a handling strategy, use Exception.
- If the caller does not have any special handling for the exception, then use RuntimeException.

Exception Subclasses

Code can declare its own FooException subclass off the built-in classes (Exception and RuntimeException) -- appropriate if the client code will want to write a FooException catch clause.

Alternately, if the client will not need to distinguish the Foo exception from other runtime problems (out of memory, ...), then in my opinion it's acceptable to just throw Exception or RuntimeException directly.

A separate named subclass is appropriate if the client cares about the distinction between various exception cases -- FooException which is handled differently from BarException. If the client does not care about the distinction between those two error conditions, then it's ok to lump them togethrer with a single exception type.

e.g. the java IO code declares a separate IOException, since the client code really does care about IOException vs. regular Exceptions -- the error messages shown to the user are quite different for IOExceptions for example.

You may want to store extra info in the exception to help with debugging -- take the extra info in the exception ctor, and then echo it back to the client by overriding getMessage() or providing other getters.

Exceptions: Annoying

With Java exceptions, we force the client to acknowledge that there are two ways the method could return -- normal and exceptional -- and the client can give separate code for the two cases.

That's the good news. However, if the client doesn't want to express a difference about those two cases, the exception is just annoying. There is no one right answer, since some clients will care and some won't. To support the clients who care, we slightly annoy the clients who don't care.

Exception throw

The "throw" primitive can thrown an exception object at runtime....

```
if (!(array.length >= 2))
   throw new IllegalArgumentException("array length must be >= 2");

-or-

   throw (new RuntimeException("oh no!"));
```

When writing code like the above for some line of code that you think should never, ever execute, it's traditional to include the phrase "this never happens!" in the exception text as a little joke on the poor shlub who is debugging your code many years later.

Stack Unwind

The "throw" stops executing the method, exits the method, and its caller, and so on, releasing locks and dealing with catch() and finally() clauses on its way out (below).

If A calls B call C which thows an exception, we exit C, then B, then A

This is sometimes known as a "stack unwind" since it rolls back the runtime stack where parameters and local variables are allocated.

Methods vs. Exceptions

If a method calls something that might throw a checked exception, then...
1. The method must "eat" the exception with a try/catch clause
2. -or- The method may declare the exception with a "throws" clause, in which case its callers will have to deal with the exception.

Does it make sense to force the caller, at compile time, to acknowledge the possibility of the exception, or should it be handled/eaten within the method?

Method throws Example

Here the fileRead() method declares that it throws IOException.
Any code calling fileRead() will need to deal with the exception case -- more inconvenient, but ultimately more robust.

```
public void fileRead(String fname) throws IOException {      // NOTE throws
   // this is the standard way to read a text file...
   FileReader reader = new FileReader(new File(fname));
   BufferedReader in = new BufferedReader(reader);

   String line;
   while ((line = in.readLine()) != null) {
      ...
      // readLine() etc. can fail in various ways with
      // an IOException
   }
}
```

try / catch

A try/catch block attempts to execute a block of statements. If an exception occurs in some method called from within the try block, then the catch() clause can intercept the exception stack unwind.

```
// suppose that foo() etc. can throw IOException

try {
   foo();      // any of these may throw
   bar();
   baz();
   // if they do not throw, control skips the catch clause
}
catch(IOException ex) {
   // control skips to here on IOException
   ex.printStackTrace();
}
```

Having intercepted the exception, the catch clause can handle it in any number of ways (see below).
There can be multiple catch clauses, in which case they are searched from top to bottom, and the first that matches the exception gets it.
If the catch clause matches the exception, it halts the stack unwind and executes the matching catch. Otherwise, the exception keeps going up the call stack. If you want a

catch() clause (below) that catches **everything**, declare it to catch Throwable. More often, you just catch some specific exception that you care about, such as IOException.

try / catch example

Here, the fileRead() method uses a try/catch to catch the IOException internally and print an error message. Note that the IOException is caught inside fileRead(), so IOException is not declared in a "throws" in the method prototype.

```
public void fileRead(String fname) {      // NOTE no throws

   try {
      // this is the standard way to read a text file...
      FileReader reader = new FileReader(new File(fname));
      BufferedReader in = new BufferedReader(reader);

      String line;
      while ((line = in.readLine()) != null) {
         ...
      // readLine() etc. can fail in various ways with
      // an IOException    }

   }

   // Control jumps to the catch clause on an exception
   catch (IOException e) {
      // a simple handling strategy -- see below for better strategies
      e.printStackTrace();
   }
}
```

Exception handling with catch()

What to do in the catch handler...

1. Eat silently -- bad

This is the worst strategy. It would only be appropriate if you are just writing junk code or a lecture example or something where the exception is not meant to be handled. It is polite to name the exception variable "ignored" to emphasize that it is not really being handled. This is rarely appropriate in production code. This strategy can make debugging more difficult, since runtime errors are eaten silently which is unfortunate since seeing the exception is often a big help with debugging.

```
try {
   // file operations
}
catch(IOException ignored) { }   // silently eat the exception
```

2. e.printStackTrace()

Exceptions have a built in printStackTrace() behavior. If you are writing code without a clear exception plan (yet), this is a good default strategy. It does not handle the exception meaningfully, but it does produce debugging output. If the code does find itself actually being used, the unhandled exception will announce itself.

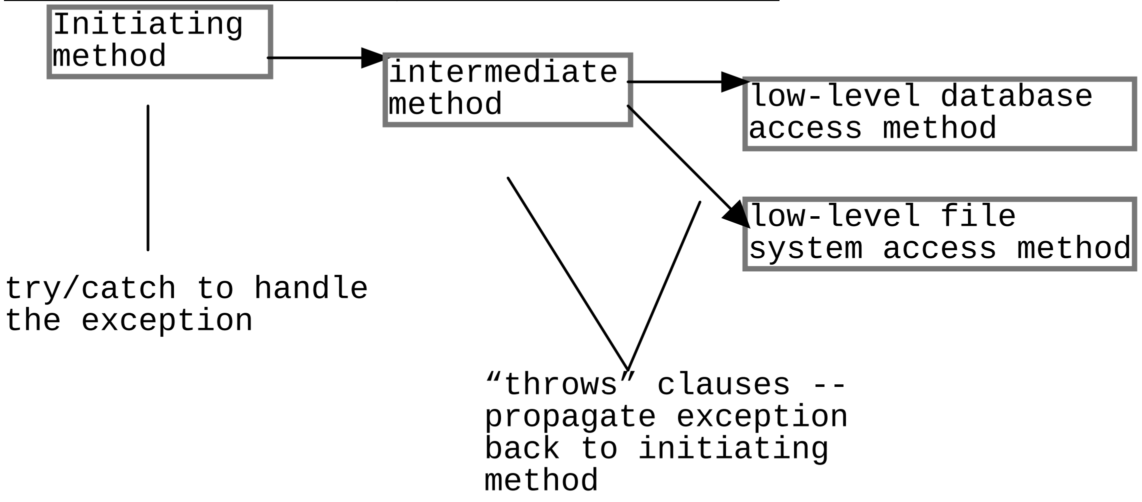
```
try {
   // file operations
}
catch (IOException e) {
   e.printStackTrace();
   // we have not really handled the error, but at least we produce debugging output

   // could allow excution to continue, or could System.exit(1);
}
```

3. Pass it along

Rather than handle the exception internally, we might make a design decision that it is appropriate for the caller to decide how to handle the exception.
In that case, add a "throws" clause to the method prototype (see above)
If the exception is meaningful, hiding it from the client is probably a mistake. The client will need to declare their own try/catch logic to express how they would like to treat the exception condition.

Exception patterns

1. Inner throws, Outer handler


Initiating method
intermediate method
low-level database access method
low-level file system access method
try/catch to handle the exception
“throws” clauses -- propagate exception back to initiating method

Suppose there is some outer GUI or controller code that initiates operations, and it calls lower level methods to do the computation.
1. Suppose the lower level methods can fail with IOExceptions and DatabaseExceptions.
2. The low-level and intermediate methods declare IOException and DatabaseException in their "throws" clauses. The exceptions are, realistically, something the caller needs to know about.
3. The outer, initiating method uses try/catch to bring up an error dialog or write an error log or whatever to deal with the error.

Swing Thread Example

The Swing thread is a simple example of the above inner/outer strategy. The swing thread pulls a task off its queue and executes it with a try/catch similar to the following.

In this way, if your button handler or whatever gets a NullPointerException, the Swing loop prints the exception, but does not let the exception mess up the swing thread itself. After the exception, the swing thread loops around to handle the next task.

Notice that when your Swing program takes, for example, a null pointer exception, the in-progress operation is terminated, but the application itself continues working.

```
loop processing Swing GUI tasks  {
   Runnable task = nextTask();
   try {
      task.run();
   }
   catch (Exception e) {
      e.printStackTrace();
   }
}
```

2. No: try/catch at every level

If every layer in the call chain has its own try/catch -- that's a bad sign.

The low-level methods should just identify the error and pass back the information that it happened.

Ideally, the more complex, try/catch code to do something about the error should be concentrated in one place.

A try/catch may be used at a lower level if the method deals with the error on its own, and the upper layers do not need to know about it.

3. Multiple Catch Clauses

It is possible to have multiple catch clauses to use different strategies for the different types of exceptions...

Here's an example of some SAX XML loading code which can fail with either an IOException or a SAXException...

```
private void loadXML(File file)  {

   try {
      // file opening and XML parsing code
   }
   catch (SAXException e) {
      System.err.println("XML parse err:" + e.getMessage());
   }
   catch (IOException e) {
      System.err.println("IO err:" + e.getMessage());
   }
}
```

4. Clean try/catch

Ideally, the try/catch can be written so that the objects are left in a good state both if the operation succeeds or if the operation is terminated by an exception. (This is the old idea of making a message send work like a "transaction" .)

Wrong -- unclean

Suppose we have an HTTPTester class that makes tests many url connections, and saves the result strings in an array. Suppose there is a URL class that responds to a open() and getData() messages, but they may throw a URLException. (That's not quite how the real URL class works, but it's close enough.)

This code does not work quite right -- if the exception throws out of connect(), resultCount will already have been incremented. If it throws out of open(), it happens to work ok.

```
class HTTPTester {
   private String[] results;
   private int resultCount;

   // Attempts a connection to the given url and adds the result to the array.
   // Suppose that url responds to a connect() message
   public void test(URL url) {

      try {
         url.connect();    // may throw
         resultCount++;
         results[resultCount-1] = url.getData();   // may throw
      }
      catch (ConnectException e) {
         // log the exception
      }
   }

   ...
}
```

Correct -- fail first

This version works correctly -- it tries the unsafe operations first. If one of them fails, the receiver is ok, since we have not yet adjusted any of its state. No cleanup is required. It's a little subtle -- a later code maintainer will need to realize that the order of operations is this way for a reason, so we should put in a comment.

```
class HTTPTester {
   private String[] results;
   private int resultCount;

   // Attempts a connection to the given url and adds the result to the array.
   // Suppose that url responds to a connect() message
   public void test(URL url) {

      try {
         // do all the unsafe operations first, store results on the stack
         // not into ivars
         url.connect();    // may throw
         String result = url.getData();      // may throw

         // if we get here no exceptions happened, so store into the ivars
         resultCount++;
         results[resultCount-1] = result;
      }
      catch (ConnectException e) {
         // log the exception
      }
   }

   ...
}
```

Correct -- clean up

This version also works correctly -- it includes code in the catch clause to detect and undo the partially completed operation. This style makes me a little nervous. The catch() clause has to deal with the object in different possible states of disrepair, and testing all the cases is going to be very difficult. I prefer the above fail-fast strategy where possible.

```
class HTTPTester {
   private String[] results;
   private int resultCount;

   // Attempts a connection to the given url and adds the result to the array.
   public void test(URL url) {
      int oldCount = resultCount;
      try {
         url.connect();    // may throw
         resultCount++;
         results[resultCount-1] = url.getData();      // may throw
      }
      catch (ConnectException e) {
         // log the exception

         // specifically detect and undo the partial operation
         if (resultCount > oldCount) {
            results[resultCount-1] = null;
            resultCount = oldCount;
         }
      }
   }

   ...
}
```

Finally

The "finally" clause defines code that always executes when the block exits -- normally or due to an exception.

In the following example, the finally clause sets processing to false as the method exits -- either normally (exiting, calling return), or because of an exception.

Style: I have some reservations about the finally clause. I think code that executes for both the normal and exception cases is not what most programmers are going to expect, although it's nice to have just one copy of the code (processing = false) that is used for both cases.

```
public void processFile() {
   processing = true;
   try {
      ...
   }
   catch (IOException e) {
      e.printStackTrace();
   }
   finally {
      processing = false;
   }
}
```

The classic use of finally { } clause, is closing an input stream or cleaning up some other resource on exit -- either normally or because of an exception.

A return statement in the try block will execute the finally clause before exiting. This is likely to be quite an unexpected result to the programmer putting in the return, so it makes the whole 'finally' construct a little suspect.