Exceptions in Detail (Especially Inheritance)

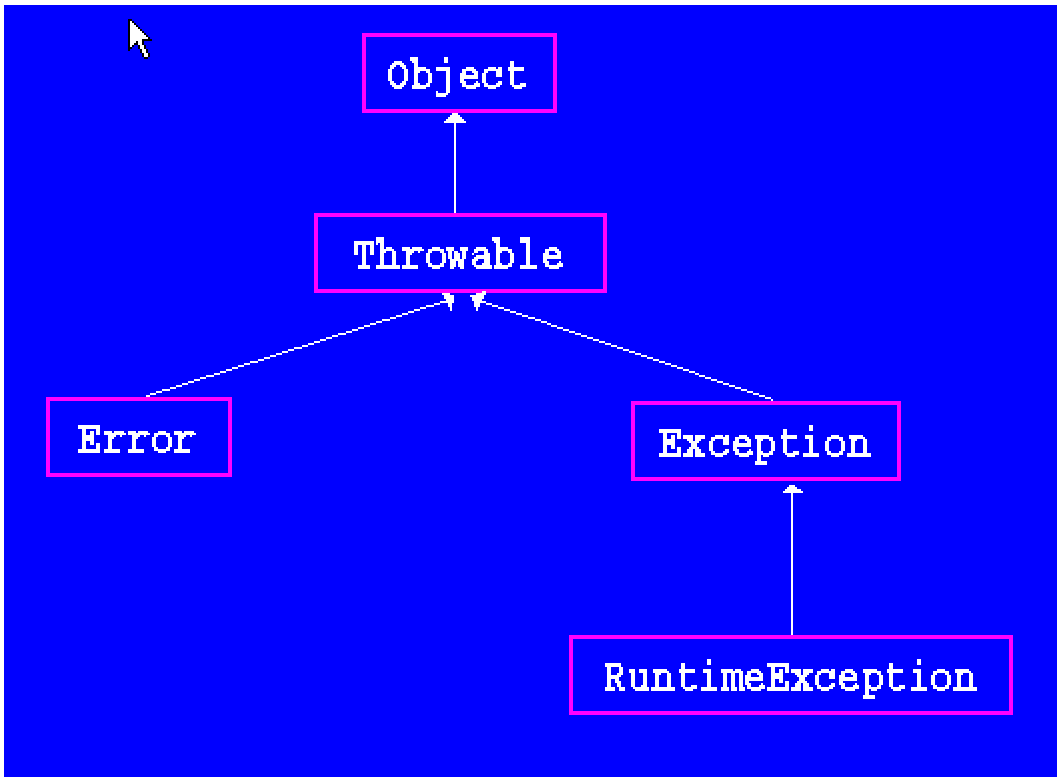
Advanced Programming/Practicum 15-200

Introduction

In this lecture we will continue our discussion of inheritance by examining exceptions more closely: the two are closely linked, and up till now we could not truly understand the meaning/use of exceptions, although we were still able to use them effectively if only naively. Specifically, we will first learn that all the exception classes are arranged in a massive hierarchy; knowledge of this hierarchy is useful in a detailed understanding how **catch** works. We will also examine the difference between how **checked** and **unchecked** exceptions are declared and processed by the Java compiler (there is no runtime difference). Finally we will learn how two write exception classes and re-throw exceptions.

The Throwable Inheritance Hierarchy

Here is a diagram of the most prominent classes in the inheritance hierarchy that Java uses for throwing exceptions.



Below is a much longer -but still not complete- list of the the first four levels in this hierarchy; indentation indicates the subclass relationship: e.g., the **Error** class is a subclass of **Throwable** (and the **Throwable** class itself is a subclass of **Object**). For an objects to be throwable (e.g., **throw new ...**), it must be constructed from some class in the **Throwable** hierarchy (either **Throwable** or one of its subclasses). The **Throwable** class itself declares two constructors (one with a message **String**, one without), and a few interesting methods (**getMessage** and various overloaded versions of **printStackTrace**) that are inherited in sublcasses and often called when exceptions are caught).

The top three classes in this hierarchy (the **Throwable**, **Error**, and **Exception** classes) are all defined in the **java.lang** package (which is automatically imported into every class file). Many other exceptions are also defined in this package, while others are defined elsewhere (e.g., **IOException** is defined in the **java.io**package; **EmptyStackException** is defined in the **java.util**) package. Many of the exceptions that we have seen are under the hierarchy: **Throwable**, **Exception**, **RuntimeException**.

I compiled the following list by visiting the JavaDoc pages in Sun's API and doing lots of copying and pasting. As you can imagine by the length of this list of built-in classes, exceptions are central to the Java language. Understanding how to throw and catch exceptions is intergral to understanding Java and and how to program in it.

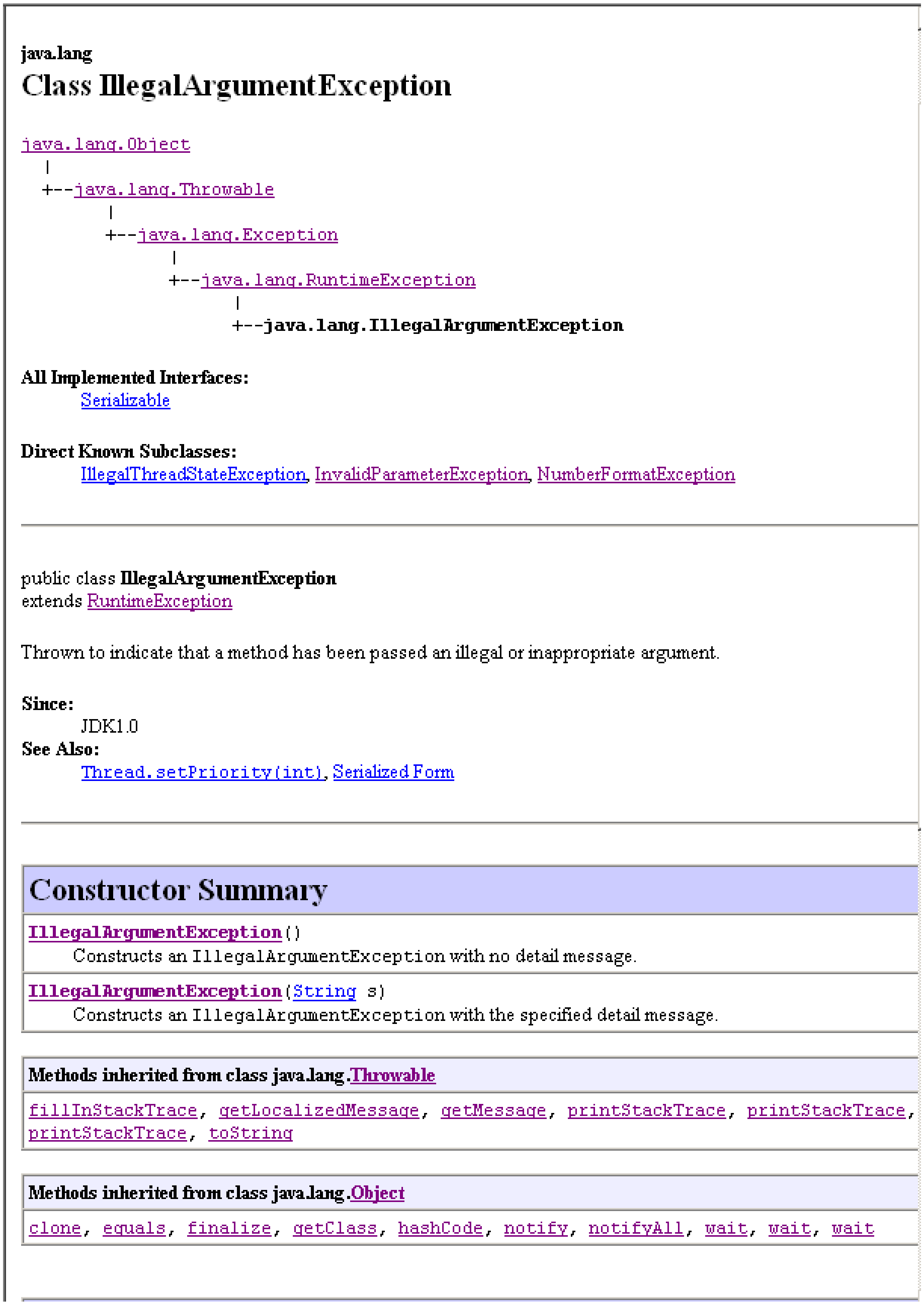
Note that the prime reason that so many different exception classes exist is their different names. The names are used in **try/catch** statements to decide selectively which exceptions to catch, and how to process these exceptions differently. When we define new classes whose methods throw exceptions, we can throw any of the exception classes already written, or we might want to define new exception classes, and by throwing them signal some special failure in the ability of methods to perform their required actions.

```
Throwable
  Error
    AWTError
    LinkageError
     ClassCircularityError
     ClassFormatError
     ExceptionInInitializerError
     IncompatibleClassChangeError
     NoClassDefFoundError
     UnsatisfiedLinkError
     VerifyError
    ThreadDeath
    VirtualMachineError
      InternalError
      OutOfMemoryError
      StackOverflowError
      UnknownError
  Exception
    AclNotFoundException
    ActivationException
      UnknownGroupException
      UnknownObjectException
    AlreadyBoundException
    ApplicationException
    AWTException
    BadLocationException
    ClassNotFoundException
    CloneNotSupportedException
      ServerCloneException
    DataFormatException
    ExpandVetoException
    FontFormatException
    GeneralSecurityException
      CertificateException
      CRLException
      DigestException
      InvalidAlgorithmParameterException
      InvalidKeySpecException
      InvalidParameterSpecException
      KeyException
      KeyStoreException
      NoSuchAlgorithmException
      NoSuchProviderException
      SignatureException
      UnrecoverableKeyException
    IllegalAccessException
    InstantiationException
    IntrospectionException
    InvalidMidiDataException
    InvocationTargetException
    IOException
      ChangedCharSetException
      CharConversionException
      EOFException
      FileNotFoundException
      InterruptedIOException
      MalformedURLException
      ObjectStreamException
      ProtocolException
      RemoteException
      SocketException
      SyncFailedException
      UnknownHostException
      UnknownServiceException
      UnsupportedEncodingException
      UTFDataFormatException
      ZipExcept
    LastOwnerException
    LineUnavailableException
    MidiUnavailableException
    MimeTypeParseException
    NamingException
      AttributeInUseException
      AttributeModificationException
      CannotProceedException
      CommunicationException
      ConfigurationException
      ContextNotEmptyException
      InsufficientResourcesException
      InterruptedNamingException
      InvalidAttributeIdentifierException
      InvalidAttributesException
      InvalidAttributeValueException
      InvalidNameException
      InvalidSearchControlsException
      InvalidSearchFilterException
      LimitExceededException
      LinkException
      NameAlreadyBoundException
      NameNotFoundException
      NamingSecurityException
      NoInitialContextException
      NoSuchAttributeException
      NotContextException
      OperationNotSupportedException
      ReferralException
      SchemaViolationException
      ServiceUnavailableException
    NoninvertibleTransformException
    NoSuchFieldException
    NoSuchMethodException
    NotBoundException
    NotOwnerException
    ParseException
```

```
PartialResultException
PrinterException
  PrinterAbortException
  PrinterIOException
PrivilegedActionException
RemarshalException
RuntimeException
  ArithmeticException
  ArrayStoreException
  CannotRedoException
  CannotUndoException
  ClassCastException
  CMMException
  ConcurrentModificationException
  EmptyStackException
  IllegalArgumentException
    IllegalParameterException
    IllegalThreadStateException
    NumberFormatException
  IllegalMonitorStateException
  IllegalPathStateException
  IllegalStateException
  ImagingOpException
  IndexOutOfBoundsException
  MissingResourceException
  NegativeArraySizeException
  NoSuchElementException
  NullPointerException
  ProfileDataException
  ProviderException
  RasterFormatException
  SecurityException
  SystemException
  UndeclaredThrowableException
  UnsupportedOperationException
SQLException
  BatchUpdateException
  SQLWarning
TooManyListenersException
UnsupportedAudioFileException
UnsupportedFlavorException
UnsupportedLookAndFeelException
UserException
  AlreadyBound
  BadKind
  Bounds
  Bounds
  CannotProceed
  InconsistentTypeCode
  Invalid
  InvalidName
  InvalidName
  InvalidSeq
  InvalidValue
  NotEmpty
  NotFound
  PolicyError
  TypeMismatch
  UnknownUserException
  WrongTransaction
```

The class **Error** and its subclasses indicate something wrong with Java itself. It is recommended that programs not throw, or attempt to catch, these errors, but instead let Java itself throw and terminate any program throwing them. Thus, we have and will continue to focus on the class **Exception** and the subclasses its hierarchy.

Here is a Javadoc page for the **IllegalArgumentException** class. Notice its package, its superclasses, and its known (to the standard Java library) subclasses.



java.lang

Class IllegalArgumentException

```
java.lang.Object
  |
  +--java.lang.Throwable
        |
        +--java.lang.Exception
              |
              +--java.lang.RuntimeException
                    |
                    +--java.lang.IllegalArgumentException
```

All Implemented Interfaces:
Serializable

Direct Known Subclasses:
IllegalThreadStateException, InvalidParameterException, NumberFormatException

public class **IllegalArgumentException**
extends RuntimeException

Thrown to indicate that a method has been passed an illegal or inappropriate argument.

Since:
JDK1.0

See Also:
`Thread.setPriority(int)`, Serialized Form

Constructor Summary
`IllegalArgumentException``()`   Constructs an `IllegalArgumentException` with no detail message.
`IllegalArgumentException``(String s)`   Constructs an `IllegalArgumentException` with the specified detail message.

Methods inherited from class java.lang.Throwable
`fillInStackTrace, getLocalizedMessage, getMessage, printStackTrace, printStackTrace, printStackTrace, toString`

Methods inherited from class java.lang.Object
`clone, equals, finalize, getClass, hashCode, notify, notifyAll, wait, wait, wait`

Also notice that this class specifies two constructors (as all exception class should): one parameterless and one with a **String** parameter, which should have **message** as its parameter's name. Notice too that none of the superclasses of this class (except **Throwable**, which defines **getMessage** and various stack tracing methods), define any methods that this class inherits. The **getMessage** method returns **String** parameter (the generic name **s**; it should be **message**) used in the second constructor. So, if they define no new methods, why do all these intervening classes exist? They exist solely to form an inheritance hierarchy, whose use in Java is described below.

Catching Exceptions in a Hierachy

There are three simple, salient, and related facts about **catch** clauses that we can now fully explore because of our knowledge of inheritance. We can explain these features in detail here, although a naive understanding of them is often enough to do simple exception processing in programs (like the standard way that we read files, using the **EOFException** to indicate nothing else to read).

First a **catch** clause catches an exception if the thrown object is an **instanceof** the type that is specified in the **catch** clause. Thus, given the hierarchy above, the clause **catch (RuntimeException re){...}** will catch thrown objects constructed from the **RuntimeException** class, as well as any thrown objects constructed from any subclasses of **RuntimeException** (of which there are a huge number).

Second, the identifier **re** acts like a parameter variable in the block associated with the **catch** clause: Java initializes it to refer to the caught object. Thus, inside the block we can refer to this variable: e.g., call methods on it: **re.getMessage()** (whose method is defined in the **Throwable** class and inherited by all its subclasses). Of course, if the object thrown is an instance of **RuntimeException**, then the assignment of a reference to **re** will work by implicit upcasting. Most often, though, the variable is not used in the associated block; it is enough to know which class of exception is thrown. Typically, I name this variable in all lower-case letters, using the upper-case letters in the class name.

Sometimes we will write a **catch** clause specifying the **IOException** type, which catches **EOFException** objects, as well as others that cause I/O to fail (**EOFException** is a subclass of **IOException**). By specifying a type high up in the inheritance hierarchy, a **catch** clause can catch many different exception classes in the hierarchy.

Third, Java checks the **catch** clauses sequentially. Thus, if I specify

```
  catch (EOFException eofe){...}
  catch (IOException ioe)  {...}
```

Then an **EOFException** will be caught by the first **catch** clause while all other exceptions that have **IOException** as their superclass (or **IOException** itself) are caught by the second **catch** clause.

Note that because of this sequentiallity, it would be "silly" to write

```
  catch (IOException ioe)  {...}
  catch (EOFException eofe){...}
```

because a **EOFExeption** would be caught by the first **catch** clause, before ever reaching the second. In fact, the Java compiler knows this too, and would detect and report an error if these clauses appear in this order -with one blocking the use of a later one; this is similar to its "unreachable code" message, which indicates that some use of control structures makes it impossible to execute some line of code: as in **return 0; return 1;**.

These three features give us precise control over how exceptions are caught and processed. Again, this control becomes necessary only in complicated applications that must accurately diagnose and safely recover from all kinds of problems.

Checked and Unchecked Exceptions

Java exception classes (we will ignore errors here, and focus on exceptions) are categorized as either "checked" or "unchecked". These categorization affect compile-time behavior only; they are handled identically at runtime. We (and Java) can easily determine in which category each exception is defined.

- An unchecked exception is any class that IS A SUBCLASS of **RuntimeException** (as well as **RuntimeException** itself).
- A checked exception is any class that is NOT A SUBCLASS of **RuntimeException**.

The Java compiler treats theses classes differently, with the checked exceptions being treated more carefully.

So, how does the compiler treat "checked" exceptions more carefully? In one simple way: if the code in a primary method calls a secondary method that can throw a checked exception, then the primary method must catch the exception or specify that exception in the **throws** part of its header. If it fails to provide either of these options, the Java compiler will detect and report an error. There are no such restrictions on unchecked exceptions.

The purpose of the **throws** part of a method definition is to make clear to anyone calling the method what exceptional circumstances the method might detect but not be able to handle internally. These details are important to any programmer who wants to write code that calls such a method.

So why are unchecked exceptions treated differently? This is subtle question. The best answer that I have read is that these exceptions are mostly caused by programmers writing incorrect code. On the other hand, checked exceptions are caused by external conditions, beyond the control of the programmer.

For example, the **IndexOutOfBoundException** is an unchecked exception. Typically, if this exception is thrown, it is because the programmer has written an incorrect loop that access the array at some illegal index. There is little reason for the program to try to detect such errors and catch them, or to propagate them out of the method in which they occur to be caught by other methods. Best to have Java automatically catch such exceptions and print an error message including a stack trace, so that the programmer can try to fix the bug.

A stack trace, printed in the console window, starts with the exception message and the method name, line number, and file name where the exception was thrown. Next comes the method that called this one (and from which line number in which file). This continues until the **main** method is reached (and the line number it was executing and the file in which it was in). That is the last line in the trace.

In contrast, **EOFException** is a checked exception. When it is thrown, it is not because the programmer wrote incorrect code (we cannot even check "is there another datum in the file"; we have to commit to trying to read one and then learn of the result), it is because external conditions do not allow another value to be read from a file. So, one way to distinguish these exceptions is by the "source" of the error: whether it is internal or external to the program's code.

There are some code examples that blur this distinction. We could use the following code to add up all the values in an array **int[] a**.

```
int sum = 0;
for(int i=0;;i++)
  try {
    sum += a[i]
  }catch (IndexOutOfBoundsException ioobe) {break;}
```

Here we use an exception just as we would use an **EOFException**: to terminate the summing loop. But, the difference is that we can make this code work without exceptions at all, by writing the loop's header as **for(int i=0; i<a.length; i++)**.

Another reason for the distinction is that unchecked exceptions can occur in any statement that accesses a member of an object (**NullPointerExceptions**). Thus, to avoid cluttering up method definitions, such exceptions do not have to be caught or listed after **throws**. Certainly we can list these exceptions after **throws** (and I often do) to indicate that the method might be thrown, but the Java compiler does not require it.

When programmers write a new exception class in Java, it should probably be a subclass of **Exception**, not **RuntimeExeption**. This approach is very strongly advocated in the Java Language Reference Manual. In fact, although we have studied many exceptions that are subclasses of **RuntimeException** (because they are intimately related to the semantics of Java's language elements), most exceptions in the large list above are checked exceptions.

Download a small program that defines new checked and unchecked exceptions, and illustrates how the Java compiler treats them differently. It is stored in Exception Demonstration.

Writing New Exception Classes

It is simple to define a new exception class. First, we must decide whether it should be a subclass of some other exception: if so we extend that class; if not we need to decide whether it should be a checked or unchecked (see the discussion above), extending **Exception** or **RuntimeException** respectively. The class should have the two standard constructors for exception classes (whose bodies just call **super**), and define no other fields or methods. That's it (unless you want to do something very non-standard). It would look something like this.

```
public MyException extends Exception
  public MyException()
  {super();}

  public MyException(String message)
  {super(message);}
}
```

Catching and Rethrowing Exceptions

Sometimes it is useful in a method to catch an exception that has been thrown, process it a bit in the method itself, and then rethrow the same (or a different) exception. Note that writing

```
catch (RuntimeException re)
  {
    System.out.println("Runtime exception: " + re.getMessage();
    throw re;
  }
```

tells Java to catch any **RuntimeException** (or one of its subclasses), print an error message, and then rethrow the same exception; here the **throw** statement indicates to throw not a new exception, but whatever exception object **re** now refers to.

Suppose that the class **Item** defines the following method

```
public static Item readFromFile(TypedBufferReader tbr)
  throws EOFException, IllegalStateException
```

This method either returns a reference to an **Item**, throws an **EOFException** (if there are no more items to read), or throws an **IllegalStateException** (if the data in the file is not what is expected: that generalizes something like **NumberFormatException**).

Now suppose the class **Database** defines a **load** method that wants to read all the **Item**s from a file into a database (storing them in an array, represented by **db** and **used**). We can write this method as

```
public void load () throws IOException
{
  TypedBufferReader tbr =
    new TypedBufferReader("Enter name of file with items")

  for(used=0;;used++)
    try {
      if (used == db.length)
        doubleLength();
      db[used] = Item.readFromFile(tbr);
    }catch (EOFException eofe)
       {break;}
     catch {IllegalStateException ise )
       {
         System.out.println("Error reading Item in DB: "
                                  + ise.getMessage());
         throw new IOException("load: Error reading file");
       }
}
```

So, in the expected case, this method catches an **EOFException** and terminates the loop and returns (successfully loading the database with items). But, if this method catches an **IllegalStateException** it first prints an error, (including this exception's message). Then this method itself throws an **IOException** (to be handled by whoever calls this method). This code is sophisticated, but it should not be beyond your capability to understand.

Problem Set

To ensure that you understand all the material in this lecture, please solve the the announced problems after you read the lecture.

If you get stumped on any problem, go back and read the relevant part of the lecture. If you still have questions, please get help from the Instructor, a CA, or any other student.

1. In what packages are the following exceptions declared; are they categorized as checked or unchecked: **ClassCastException**, **EOFException**, **IllegalArgumentException**, **IllegalStateException**, **IndexOutOfBounds**, **NumberFormatException**, **NullPointerException**.

2. We declare exception classes with a one parameter constructor (**String**); in what class is this value actually stored as an instance variable.

3. Draw the full inheritance hierarchy exhibited by the following jumbled class definitions (along with any other Java classes that you must include to write the full hierarchy).

```
public class A extends Exception {...}
public class E extends RuntimeException {...}
public class F extends D {...}
public class G {...}
public class C extends E {...}
public class D extends A {...}
public class B extends A {...}
```

   Now, using only the classes in the hierarchy above, list all the classes whose objects can be caught by the following catch parts of a try/catch statement.

```
catch (A a){...}
catch (RuntimeException re){...}
catch (G g){...}
catch (F f){...}
```

4. Do you think the following code fragment is legal (both catch clauses using the same identifier **e**)? Explain your answer.

```
try {
  .....
}catch (EOFException e) {...}
 catch (IOException  e) {...}
```

5. In the lecture we some code like the following.

```
int sum = 0;
for(int i=0;;i++)
  try {
    ...do some complicated array stuff here
    sum += a[i]
  }catch (IndexOutOfBoundsException ioobe) {break;}
```

   Suppose that we wrote the "complicated array stuff" code incorrectly and it accessed an array out of bounds; explain why would the code

```
int sum = 0;
for(int i=0; i<a.length; i++) {
  ...do some complicated array stuff here
  sum += a[i]
}
```

   be better.