Exception Handling

- Error handling in general
  - Run-time errors
- Java's exception handling mechanism
- The catch-or-specify principle
- Checked and unchecked exceptions
- Exceptions impact/usage
  - Overloaded methods
  - Inheritance hierarchies
  - Constructors

Motivation

- Make programs more robust!
  - Less overtime Sunday afternoons
- Make programs shorter!
- Make programs less complicated!

- General ideas applies to most programming languages!

Error Handling

- Not all errors can be caught at compile time!
  - These errors are called run-time errors (the opposite is compile-time errors)
- Help -- run-time error! What next …?

- First ideas:
  - **`System.out.println()`**
  - **`System.err.println()`** (much better than the previous)
- Good guess but some errors call for corrective action, not just warning.
- In general, *printing* is a bad idea!
- Better: tell *someone* (not necessarily the user)!

Error Handling, cont.

- Establish return code convention
  - 0 vs. !0 in C/C++
  - `boolean` in Java

- Set value of a global variable
  - Done in many shells.
  - In Java use a public static field in a class.

- Raise an exception, catch it, and act
  - The idea comes from hardware.
  - Modern language support (Java, Python, Lisp, Ada, C++, C#).

General Errors and Error Handling

- Errors must be handled where they occur
  - One error in a method can be handled very differently in the clients, this is not a good approach. Repeating handling of the same error.
  - Can be extremely hard to debug.

- To handle an error detailed information on the error must be provided.
  - Where did the error occur (class, method, line number)
  - What type of error
  - A good error message
  - Dump of runtime stack? (too much information?)

- In object-oriented languages errors are represented by objects.

How to Handle Errors

- *Ignore*: False alarm just continue.
- *Report*: Write a message to the screen or to a log.
- *Terminate*: Stop the program execution.
- *Repair*: Make changes and try to recover the error.

- To be able to repair seems to be the best.
- The best is often the combination of report and terminate.

Java's Exception Handling

- *Exception*: An event that occurs during the execution of a program the disrupts the normal execution flow.
  - A run-time phenomenon.

- Exception handling is part of the language.
- Exceptions are objects.
- Exceptions are structured in a class hierarchy.
- It is not possible to ignore an exceptions (nice feature?).
  - A method specifies, which exceptions may occur, the client must anticipate these exceptions, otherwise compile-time error.
- It is sometimes possible to recover to a known good state after an exception was raised.

Java's Exception Handling, cont.

- Java's object-oriented way to handle errors
  - more powerful, more flexible than using return values
  - keywords **`try`**, **`catch`**, **`throw`**, **`throws`**, **`finally`**.
- An *exception* is an object that describes an erroneous or unusual situation.
- Exceptions are *thrown* by a program, and may be *caught* and *handled* by another part of the program.
- A program can therefore be separated into a normal execution flow and an *exception execution flow*.

- An *error* is also represented as an object in Java, but usually represents a unrecoverable situation and should not be caught.

Motivation for Exception Handling

```
errorCodeType readFile {
    initialize errorCode = 0;
    open the file;
    if (theFileIsOpen) {
        determine the length of the file;
        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 = errorCode and -4;
        }
    } else {
        errorCode = -5;
    }
    return errorCode;
}
```

```
readFile {
    try {
        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;
    }
}
```

[source: java.sun.com]

Simple Example

```
public class SimpleException extends Exception{}

public class SimpleExample{
  public double calcPrice(int netPrice) throws SimpleException{
        if (netPrice > 100){
            throw new SimpleException(); // too expensive
        }
        return netPrice * 1.25; // add sales tax
    }
  public static void main (String[] args){
        SimpleExample se = new SimpleExample();
        try{
            se.calcPrice(10);
            se.calcPrice(23);
            se.calcPrice(1000);
            se.calcPrice(88);    // never called
        }
        catch(SimpleException e){
            System.err.println("Caught SimpleException");
        }
    }
}
```

Exception Handling Model

- Code where you anticipate a problem:
  - Detect error, probably with an if create a new exception and **`throw`** it
  - Alternatively let JVM detect error, create, and throw an exception

```
public static void main (String[] args) throws
        exception1, exception2, exception3 {
    . . .
}
```

- Code in client (somewhere in message invocation stack)
  - **`try`**, hoping for the best
  - prepare to **`catch`** an exception

```
try{
    // statements that can throws exceptions
} catch (exception1) {
    // do stuff
} catch (exception2) {
    // do stuff
}
```

Java's Catch or Specify Requirement

- Catch
  - A method can catch exception by providing and exception handler.
- Specify
  - If a method chooses not to catch, then specify which exceptions can be thrown.
  - Exceptions are part of a method's public interface.

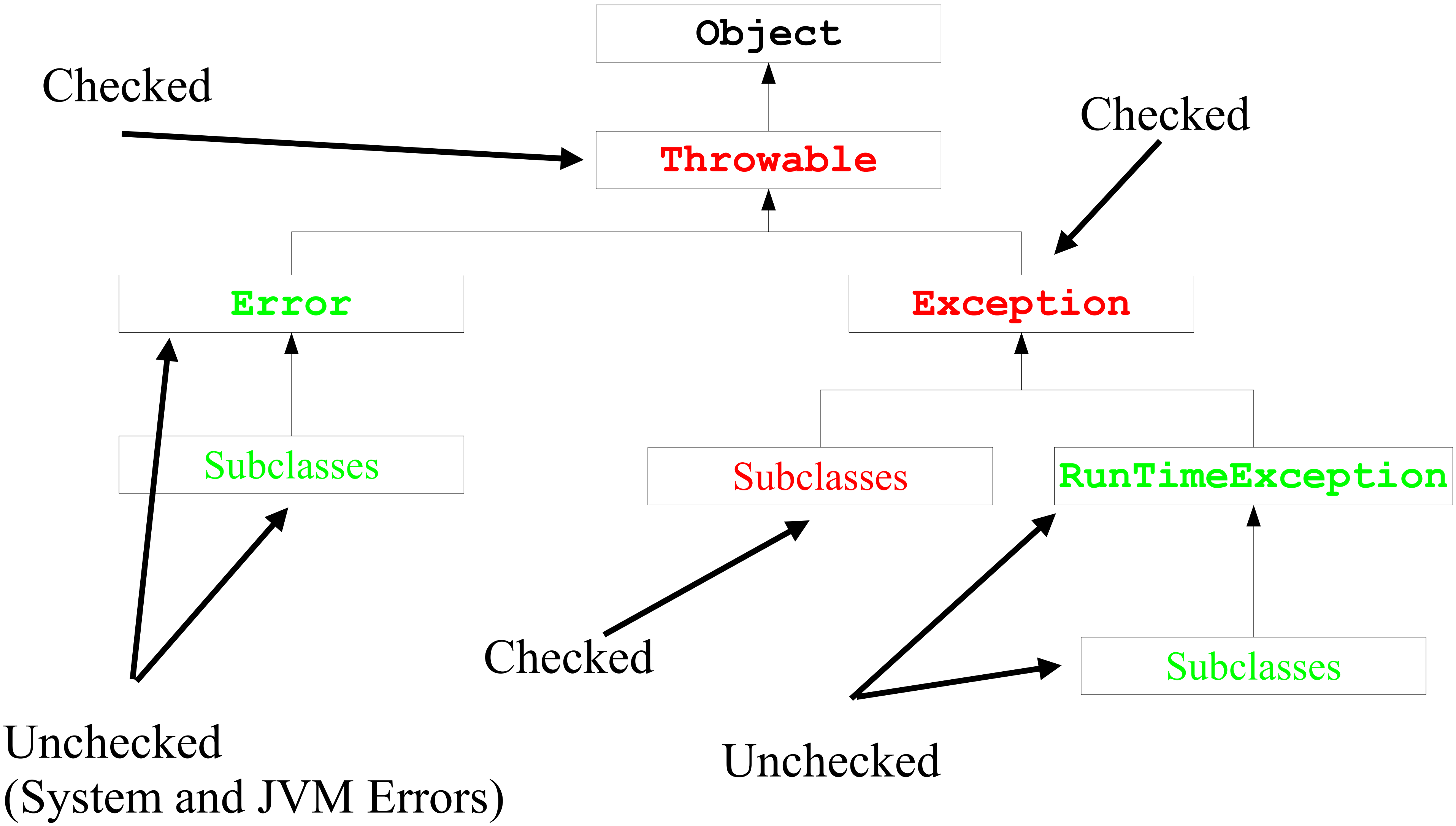
Checked/Unchecked Exceptions

- An exception is either *checked* or *unchecked*
  - Checked = checked by the compiler

- A *checked exception* can only be thrown within a try block or within a method that is designated to throw that exception.
  - The compiler will complain if a checked exception is not handled appropriately.

- An *unchecked exception* does not require explicit handling, though it could be processed that way.

Java's Exception Class Hierarchy



Object

Throwable

Error

Exception

Subclasses

Subclasses

RunTimeException

Subclasses

Checked

Checked

Checked

Unchecked
(System and JVM Errors)

Unchecked

Java's Exception Class Hierarchy, cont.

- **`Throwable`**
  - Superclass for all exceptions
  - Two methods for filling in and printing the stack

- **`Error`**
  - Serious internal errors (should not occur in running programs).
  - Are normally not handled. (report and terminate)
  - Programs should not throw **`Error`**s
  - The catch or specify principle does not apply, because they are so severe.
  - Examples
    - Dynamic linking failure
    - Memory shortage
    - Instantiating abstract class

Java's Exception Class Hierarchy, cont.

- **`Exception`**
  - The base class for most exception used in Java programs
  - The catch or specify principle does apply
  - Examples of subclasses
    - **`IOException`**
    - **`ClassNotFoundException`**
- **`RuntimeException`**
  - Not a good name (all exceptions are at run-time)!
  - Commonly seen run-time errors
    - **`ArrayIndexOutOfBoundsException`**
    - **`ClassCastException`**
  - The catch or specify principle does not apply, because they are so ubiquitous.
  - Examples
    - Divide by zero, Cast error, and Null pointer errors

The `try` Statement

- To process an exception when it occurs, the line that throws the exception is executed within a *try block*.
- A try block is followed by one or more *catch* clauses, which contain code to process an exception.
- Each catch clause has an associated exception type.

```
try {
   // statements
} catch(Exception e){
  // handle error
}
```

```
// what is wrong here?
try {
   // statements
}
```

The **catch** Statement

- The **catch** statement is used for catching exceptions.
- A **try** statement must be accompanied by a **catch** statement.
- **try** and **catch** statements can be nested, i.e., **try** block in **try** block, etc.

```
try {
    // statements that throws exceptions
} catch (ArrayIndexOutOfBoundsException e) {
    System.err.println("Caught first " + e.getMessage());
} catch (IOException e) {
    System.err.println("Caught second " + e.getMessage());
}

// what is ugly here?
try {
    // statements that throw exceptions
} catch (IOException e) {
   System.out.println("Error occured");
}
```

The `catch` Statement, cont.

- When an exception occurs, processing continues at the first catch clause that matches the exception type.
- The catch statements should be should be listed in *most-specialized-exception-first* order.

```
// what is wrong here?
try {
    // statements that throw exceptions
} catch (Exception e) { // very general exception
    System.err.println("Caught first " + e.getMessage());
} catch (ArrayIndexOutOfBoundsException e) {
    // will never be called
    System.err.println("Caught second " + e.getMessage());
}

// what is ugly here?
try {
    // statements that throw exceptions
} catch (Exception e) {
}
```

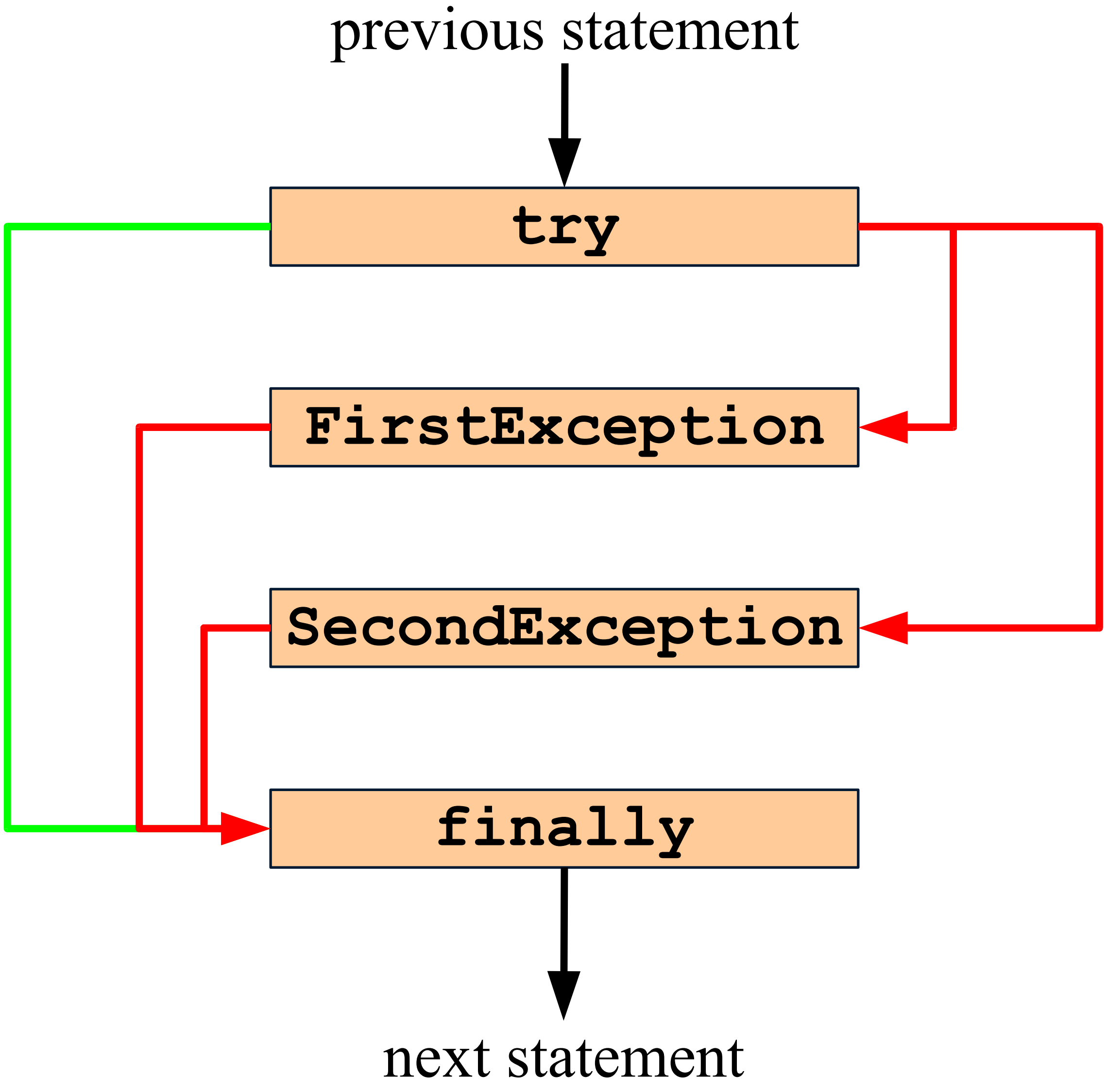
The **finally** Clause

- A try statement can have an optional clause designated by the reserved word **finally**.
- The **finally** clause is always called
  - After the **try** block is ended successfully
  - After each **catch** block is executed

```
try {
        // statements that throw exceptions
} catch(FirstException e) {
        // handle error
} catch(SecondException e) {
        // handle error
} finally {
     // code here always runs
     // clean up file, database etc.


}
```

The `finally` Clause, cont.



The **finally** Clause, Example

```
try {
   // open a file
   out = new PrintWriter(new FileWriter("out.txt"));
   // statements that throws exceptions

    } catch (ArrayIndexOutOfBoundsException e) {
        System.err.println("Caught array error");
    } catch (IOException e) {
        System.err.println("Caught I/O error");
    } finally {
        // always close files that are opened
        if (out != null) {
            System.out.println("Closing file");
            out.close();
        }
    }
}
```

The **throw** Statement

- All methods use the **throw** statement to throw an exception.

```
public class Car {
  // snip
  // prevent cloning
  public Object clone() throws CloneNotSupportedException{
      throw new CloneNotSupportedException("Cannot clone car");
  }
  // check the users input and throw exception if illegal
  // “precondition”
  public void setPrice(double thePrice) {
    if (thePrice < 0)
      throw new IllegalArgumentException(
                     "Price is negative" + thePrice);
        price = thePrice;
    }

  // for testing, do not use in production code
  public static void main(String[] args) throws Exception {
    // snip
  }
}
```

Exception Propagation

- Idea: Solve problems locally!
    - private variables that points to opened resources close these

- If it is not appropriate to handle the exception where it occurs, it can be handled at a higher level.
- Exceptions propagate up through the method calling hierarchy until they are caught and handled or until they reach the outermost level.
- A try block that contains a call to a method in which an exception is thrown can be used to catch that exception.

Exception Propagation, Example

```
static void method1 throws IOException {
    throw new IOException("Error in method1");
}

static void method2 throws IOException {
    // do stuff, but no catch, just specify
    method1();
}
static void method3 throws IOException {
    // do stuff, but no catch, just specify
    method2();
}

public static void main (String[] args){
   // catch if just specify error to console
   try {
      method3();
   } catch (IOException e){
      // handle the exception from method1
   }
}
```

Rethrowing an Exception

```
static void method1 throws IOException {
    throw new IOException("Error in method1");
}
static void method2 throws IOException {
    try{
        method1();
    } catch (IOException e) {
        System.err.println("Handle partly here");
        throw e; // 1st method
        // throw e.fillInStackTrace;          // 2nd method
        // throw new IOException ("new one"); // 3th method
    }
}
public static void main (String args[]){
   // catch if just specify error to console
   try {
      method2();
   } catch (IOException e){
      System.err.println("Handle rest here");
   }
}
```

Creating New Exceptions

- Requires careful design (part of the public interface).
- Can an existing **`Exception`** be used?
- Choose the correct superclass.
- Choosing the name
  - The most important thing for new exceptions.
  - Tends to be long an descriptive
    - **`ArrayIndexOutOfBoundsException`**
- Code for exception class typically minimal

- Sun exception naming convention
  - All classes that inherits from **`Exception`** has 'Exception' postfixed to their name.
  - All classes that inherits from **`Error`** has 'Error' postfixed to their name.

Creating New Exceptions, Example

```
class SimplestException extends Exception {
    // empty method body okay, just give it a good name
}

class SimpleException extends Exception {
    SimpleException () { super(); } // default constructor
    SimpleException (String str) { super(str); }
}

class ExtendedException extends Exception {
    private static int counter = 0;   // no of exceptions
    private int instanceNo;
    ExtendedException () { super(); counter++; }
    ExtendedException (String str) {
        super(str); counter++;    }
    ExtendedException (String str, int no) {
        super(str);
        instanceNo = no;
        counter++;
    }
}
```

Overloading and Exception

- Methods cannot be overloaded based on exception specification.

```
public class OverloadedMethod{
    /** An overloaded method */
    public int calc(int x) throws SimpleException {
        return x;
    }
    /** NOT allowed */
    public int calc(int y) throws AnotherException {
        return y;
    }
    /** Is allowed */
    public int calc(int x, int y){
        return x + y;
    }
    public static void main(String[] args){
        OverloadedMethod om = new OverloadedMethod();
        System.out.println(om.calc(3));
    }
}
```

Inheritance and Exceptions

- If base-class method throws an exception, derived-class method may throw that exception or one derived from it.

- Derived-class method cannot throw an exception that is not a type/subtype of an exception thrown by the base-class method.
    - Otherwise subclass cannot be upcasted to base-class.

```
class BaseException extends Exception{}
class DerivedException extends BaseException{}
class AnotherException extends Exception{}

class A           { void f() throws BaseException{}}
// allowed
class B extends A { void f() throws DerivedException{}}

// not allowed compile-error
class C extends B { void f() throws AnotherException{} }
```

Inheritance and Constructors

- Constructors can throw exceptions
- Subclass constructor *cannot* catch exception throws by base class constructor.

```
class A{
    int i;
    A(int j) throws SimpleException{
        if (j < 0){ throw new SimpleException(); }
        i = j;
    }
}
class B extends A {
    B(int j) throws SimpleException, AnotherException{
        // cannot have try block here
        super(j);
        if (j > 100){ throw new AnotherException();  }
    }
}
```

Guidelines

- Do not use exceptions for normal control flow!
  - Slows down the program
- Do use exceptions to indicate abnormal conditions!

- Handle the error (fully or partially) if you have enough information in the current context. Otherwise, propagate!
- Handle group of statements
  - Do not encompass every single statement in a try block
- Use exceptions in constructors!
- Do something with the exceptions your code catches!
- Clean up using **`finally`**.

Summary

- The manner in which an exception is processed is an important design consideration.
- Advantages of Exceptions
  - Separates error handling from “regular” code.
  - Propagation of errors up the call stack.
    - Handle error in a context
  - Grouping of error type and differentiation of errors.
    - Overview
    - Reuse of error handling code
- Exception handling similar in most object-oriented languages!
  - Knowledge transfer between languages!

Interfaces and Exception

- Exceptions can naturally be specified for methods in interfaces

```
public interface InterfaceException{
    int calc(int x) throws SimpleException;

    // not allowed
    //int calc(int y) throws AnotherException;

    int calc(int x, int y)
         throws SimpleException, AnotherException;
}
```