OOP 2005
Lecture 8
Exception handling

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Today's schedule

Goal:
- to enable you to write your own exceptions.
- to throw exceptions from your own code.

Contents:
- The programmers roles in exceptions handling
- Design principles for exception handling
  - Checked or unchecked exceptions
  - Fitting level of abstraction
  - Recovery strategies
  - How to get context information from the place the exception was thrown
- The try catch finally statement
- Exceptions and inheritance
- Where can exceptions be thrown, and what is the consequences of that?
- Efficiency of exception handling
- Call stack inspection

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Motivation I

```
readFile {
   open the file;
   determine its size;
   allocate that much memory;
   read the file into memory;
   close the file;
}
```

- What happens if the file can't be opened?
- What happens if the length of the file can't be determined?
- What happens if enough memory can't be allocated?
- What happens if the read fails?
- What happens if the file can't be closed?

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Example taken from
http://java.sun.com/docs/books/tutorial/essential/exceptions/advantages.html

Motivation I

```
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;
}
```

Nice thought:
Let's separate code and error handling code
(note: no clean up code is presented)

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Example taken from
http://java.sun.com/docs/books/tutorial/essential/exceptions/advantages.html

Motivation II –
The two programmers in Exeption handling

The programmer of the class	The user of the class (You?)
• Knows the implementation, and when an error situation occurs	• Knows that something might go wrong, but not where.
• Do not know what to do with the error.	• Knows how to handle the error
• Implements the class independent of any specific usage	• Uses the class in a specific context

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This is the essence of exceptions. Exceptions can be seen as a communication link between the implementer of a class and the user of a class.

When something goes wrong, it is the implementers responsibility to make sure that the user of the class get sufficient information regarding the cause of the error. The user of the class has no other means than the exception object to find out what went wrong.

Therefore, the exception object should contain information that is useful to the user of the program.

Bad design example from Java: If you index an array outside its bounds, you will receive an ArrayIndexOutOfBounds exception. But you cannot see what the offending index was, nor what array you indexed wrongly.

Example

public static Class forName(String className)
throws ClassNotFoundException

Parameters:

className - the fully qualified name of the desired class.

Returns:

the Class object for the class with the specified name.

Throws:

LinkageError - if the linkage fails

ExceptionInInitializerError - if the initialization provoked by this method fails

ClassNotFoundException - if the class cannot be located

The programmer of Class

- Finds out that a class does not exist, but does not know how you want to handle that.
- Finds out that the class depends on a class which cannot be loaded, but does not know how you want to handle that.
- Finds the class, but it cannot be initialized. How do you want to handle that?

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User of the exception might then decide to abort the program, or try with a different spelling (all lowercase for instance).

Also the user is likely to choose different recovery strategies depending on which of the three different exceptions are thrown. ClassNotFound might be because of a spelling error, while the other two indicates that the class file might be wrong.

usage example

```
class Stack {
    LinkedList elements = new LinkedList();
    public void push(Object o) {
        elements.add(o);
    }
    public Object pop() throws EmptyException {
        if(elements.size() ==0)
            throw new EmptyException();
        return elements.removeLast();
    }
    public class EmptyException
                        extends Exception {
    }
}
```

class programmer

```
Stack s = new Stack();
try {
    System.out.println( s.pop() );
}
catch(Stack.EmptyException ee) {
    …
}
```

class user

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Often the code using a stack will actually not know what to do with such an error. But, as we shall see, the user should catch the empty stack error, and then throw another error which is appropriate for the purpose of the user code.

Checked exceptions

- **Checked by the compiler**

A method foo might declare that it throws one or more Exceptions.

If your code call foo, the compiler will check that:

- Either you enclose the call in a try-catch block, which catches the Exceptions mentioned in foo.
- Or your own code declares that it does too throws the samen exceptions.

All exceptions are checked, except from subclasses of RuntimeException.

```
void myMethod() {
    …
    try {
        …
        Class cl = Class.forName("…");
        …
    }
    catch(ClassNotFoundException e) {
        …
    }
}
---------- or ----------
void myMethod() throws ClassNotFoundException {
    …
    Class cl = Class.forName("…");
        …
}
```

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Notice, when you call a method which has checked exceptions, and you do not handle the exception, the compiler will complain. It does so by saying:

" …unreported exception *SomeException*; must be caught or declared to be thrown"

This is one of the better error messages from the compiler. It says which exception the compiler can see is not handled.

- And it says that it " must be caught", that is, you should make a try-catch solution like the topmost solution.
- Or the exception should be " declared to be thrown", which is the second solution, where the exception is declared to be trown.

Unchecked exceptions

- **Not checked by the compiler**

A method foo might throw an unchecked exeption without you knowing it.

If your code call foo, the compiler will not tell you that foo might throw an exception.

You are therefore likely not to handle that situation.

Rationale:

- Every methodcall o.foo() can throw a NullPointerException if o is null.
- It is not practical that correct code (that cannot fail) is poluted with error checks

```
try {
   try {
        Foo f = new Foo();
   } catch(ClassNotFoundExceptien cnfe) {...}
   f.bar();
} catch(NullPointerException e) {...}
```

- Similarly with arithmetic errors, array stores, class casts, and other.
- The rule of thumb is that if the pre-conditions for some method is broken, the method may throw an unchecked exception.

Checked or unchecked Exceptions?

Errors – use checked Exceptions

The provider (class programmer) is not in a position to ensure that the operation can be completed

- that the network is working
- a server is running
- the connection to the phone is not working

If the provider (class programmer) knows that this can happen, the client *must* deal with that potential problem.

Contract violations (pre conditions) – use unchecked Exceptions

The client did not ensure the pre-condition.

- used null argument
- tried to pop empty stack
- tried to read past end of array

If the provider finds out that the pre-condition is not satisfied, the provider method should throw an unchecked exception.

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An error is something which must be handled in order to have robust code. An error is an situation is not caused by bad programming, but by situations in the environment of the program.

A contract violation is a consequence of sloppy programming. One should simply avoid writing programs which will throw run-time exceptions.

Consider again the ArrayIndexOutOfBounds exception. The following program will never encounter such an error:

```
for(int i=0;i<array.length;i++){ … do stuff with array[i]…}
```

So even though array lookup can throw an exception, you can program in such a way that it will not happen. Exceptions which in their nature is that a provider discovers that the client did not ensure the precondition can be avoided if the client *do ensure* that the preconditions are true.

The try catch finally statements

```
try {
   Statement0;
}
catch(ExceptionType1 ex1) {
   Statement1;
}
catch(ExceptionType2 ex2) {
   Statement2;
}
finally {
   Statement3
}
```

- If Statement0 terminates normally, catch statements are ignored.
- If Statement0 terminates abnormally by throwing an exception e of type E, the first catch which matches E is located (if any).
- If a corresponding type is found, e is bound to the corresponding ex*i*, and Statement*i* is executed.
- If no corresponding type is found the entire statement terminates with exception e of type E.
- ***No matter*** what happens in Statement0 or any of the catch statements, Statement3 is executed as the last statement.
- If statement0 throws exception ExceptionType1 and statement1 throws ExceptionType2 what happens?

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If no corresponding exception type is found, the try statement does not catch the exception, and the search for an other try block continues. If no try statement is found which can handle the error, the virtual machine will issue an error and terminate.

If statement0 throws exception ExceptionType1 and statement2 throws ExceptionType2 what happens? Statement2 is not executed, but statement3 is and the exception propagates down the call stack.

How final is finally?

```
String pip() {
    try {
        foo();
        return "Hans";
    }
    catch(FooException e) { System.out.println("123"); }
    finally { return "Grete"; }
}
```

- A Finally block will always be the last code to be executed in a method.
  - Thus, pip() will return ”Grete”.
  - “Grete” is returned if an exception is raised in the foo() call no matter which exception it is
- If the result of the try-catch part is to throw the exception e, the finally can throw an other exception instead.
  - Most certainly do not do this…. But Java let’s you.
- Both cases is needed in rare circumstances.
- All finally blocks from the top of the stack to a matching catch block are executed before the matching catch is executed.

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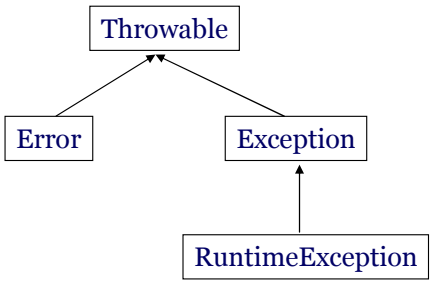
Note there is no relationship between “final” and “finally”

Java exception types hierarchy



An Error is a subclass of Throwable that indicates serious problems that a reasonable application should not try to catch. *Most such errors are abnormal conditions.*

A method is not required to declare in its throws clause any subclasses of Error that might be thrown during the execution of the method but not caught, since these errors are abnormal conditions that should never occur.

Direct Known Subclasses of Error:

AnnotationFormatError, AssertionError, AWTError, CoderMalfunctionError, FactoryConfigurationError, LinkageError, ThreadDeath, TransformerFactoryConfigurationError, VirtualMachineError

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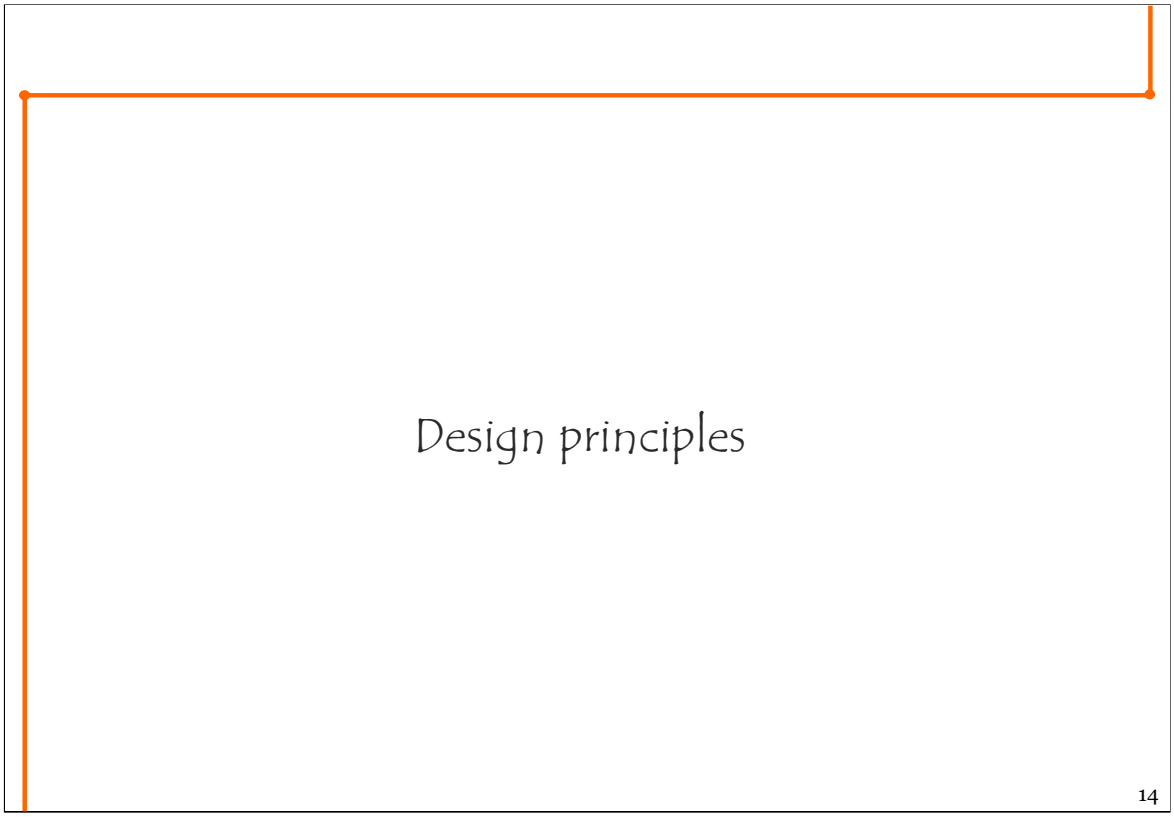
So far we have only been talking about the right branch of the hierarchy.. even when we talked about errors! But Java actually has a concept of an “error”... However, this concept is rather internal and generally you should refrain from it. You should only focus on Exception and RuntimeException as super classes for your exceptions.


Design principles
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Design principle: Fit level of abstraction

The exceptions thrown by an object should be defined in the same level of abstraction.

Positive examples:

java.util.Stack has a method peek(), which throws EmptyStackException.

java.util.ArrayList has a method get(int index) which throws IndexOutOfBoundsException

java.lang.Class has a method getField(String name) which throws NoSuchFieldException, NullPointerException SecurityException

– The exception should be informative
  - E.g. IndexOutOfBounds should contain a reference to the ArrayList and the index which failed.
– It must be in the vocabulary of the class.

Negative example:

javax.swing.JTextField has a method getText() If the *underlying* document is null, will give a NullPointerException. Should have been NoDocumentException.

It has a method getSelectedText(), which can throw IllegalArgumentException.But there are no arguments!

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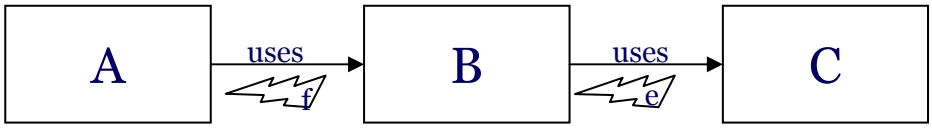

If a class A uses class B, which in turn make use of C, and a method in C causes an exception e to be thrown, it is rarely the case that e should not be captured by B. B captures the exception, but throws a new exception f, which is in the terms of the B abstraction rather than the C abstraction.

There are many ways in which this has been stated

- The exception should be from the same ontology as B
- The exception should originate from the same universe of discourse
- The exception should be in the same vocabulary as B

At any rate, one should not just propagate the e-exception uncritically to A through B.

Exception handling

There are three reasonable ways to deal with exceptions

1. Raise the exception to your level of abstraction (throw a new exception)
2. Try to recover (esp. network app.)
3. Die

1)

```
public Object pop() throws EmptyException {
    try {
        return elements.removeLast();
    } catch(NoSuchElementException  no) {
        throw new EmptyException(this);
    }
}
```

2)

```
public Object popOr(Object default) {
    try {
        return elements.removeLast();
    }
    catch(NoSuchElementException  no) {
        return default;
    }
}
```

3)

```
public Object pop() throws EmptyException {
    try {
        return elements.removeLast();
    }
    catch(NoSuchElementException  no) {
        System.exit(1);
    }
}
```

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Recovery can often be done in the user interface, the input turns out not to be valid, and one can ask the user to correct it.

Also, recovery is a good approach to network errors, simply try the same thing again, maybe 5 times, and then switch strategy (to 1. or 3.).

The example two above is perhaps not the best strategy, as it delegates the error to the caller, and as such it resembles strategy 1).

Diagram of exceptions

- A method call

- try part — catch part — finally part

- Each box represents a call stack entity
  - method call
  - try-catch-finally block

- When an exception of type T is thrown, one looks down through the call stack to find a try block which its black mark in the left side, and with a matching catch. The try block which has a matching catch is then marked in the middle, and the execution continues from there.
- If the try block has its black mark in the middle or in the right, it will be ignored when we look for a matching try block down the call stack.

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Diagram of exceptions

```
class ExTry {
    public static void main(String[] args) {
        new ExTry().m1();
    }
    void m1() {
        try {    m2();    }
        catch(Exception e) {
            System.out.println(e);
        }
        finally {
            System.out.println("hello world");
        }
    }
    void m2() { m3(); System.out.println("foo");}
    void m3() {
        throw new RuntimeException();
    }
}
```

- We try to
  - Use the graphic notation
  - Show the propagation down the call stack upon throwing and catching an exception
    - Skipping some code
    - Ensuring the execution of other code

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We could make a shortcut of not showing the constructor call, but I've chosen here to be a bit more elaborate in the slides than what I expect of the handins.

Diagram of exceptions

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class ExTry {
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    }
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    void m3() {
        throw new RuntimeException();
    }
}
```

:ExTry::ExTry

:ExTry::main

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Diagram of exceptions

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    void m1() {
        try {   m2();    }
        catch(Exception e) {
           System.out.println(e);
        }
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            System.out.println("hello world");
        }
    }
    void m2() { m3(); System.out.println("foo");}
    void m3() {
        throw new RuntimeException();
    }
}
```

:ExTry::m1

:ExTry::main

Diagram of exceptions

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        }
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            System.out.println("hello world");
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    }
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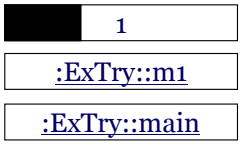

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Diagram of exceptions

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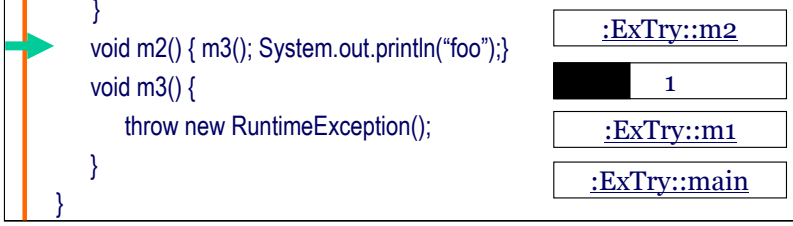

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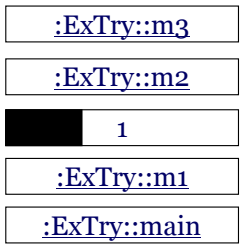

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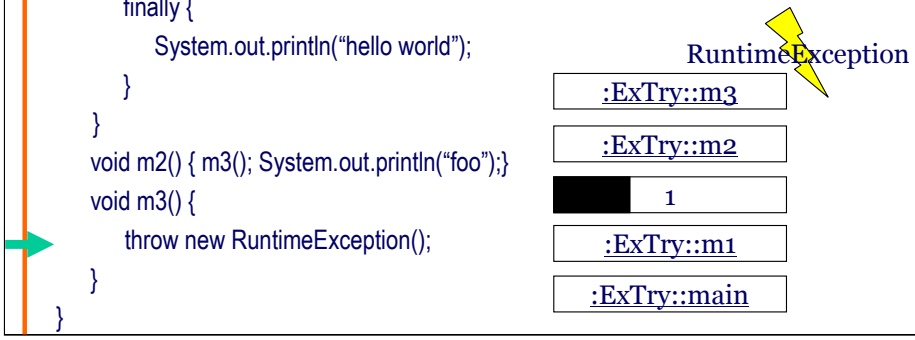

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Diagram of exceptions

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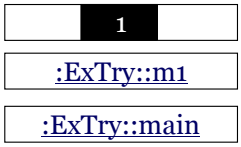

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Diagram of exceptions

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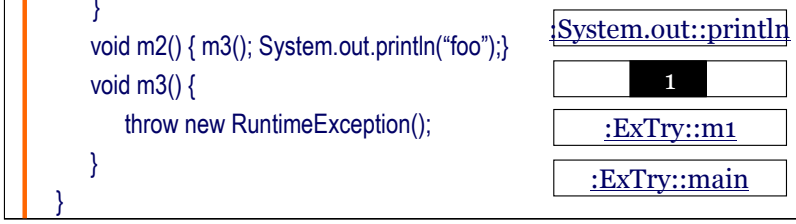

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Diagram of exceptions

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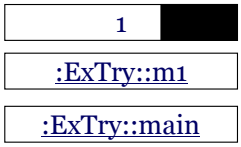

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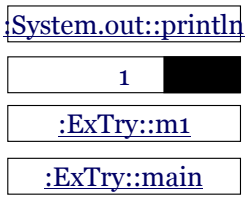

Diagram of exceptions

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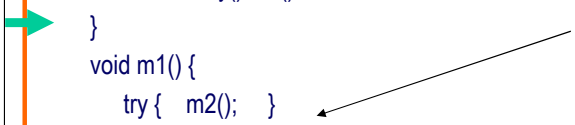
        throw new RuntimeException();
    }
}
```

- Note we never printed "foo" on the screen
- Would "hello world" be printed if our catch was declared to catch "IOException" instead?



:ExTry::main

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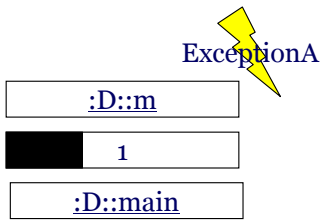
Diagram of exceptions

```
class D {
    void m() { throw new ExceptionA(1); }
    public static void main(String[] args) {
        D d = new D();
        try { d.m();}
        catch(ExceptionA ea) {
            d.m();
}   }   }
```



- We try to
  - Use the graphic notation in a less terse way
  - Show that try-blocks are only candidates for a match of an exception, if they have their black mark on the left.

Diagram of exceptions

```
class D {
    void m() { throw new ExceptionA(1); }
    public static void main(String[] args) {
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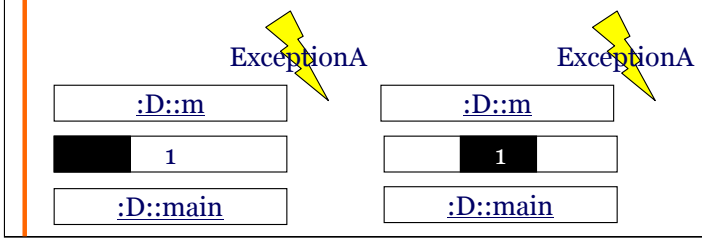

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Diagram of exceptions

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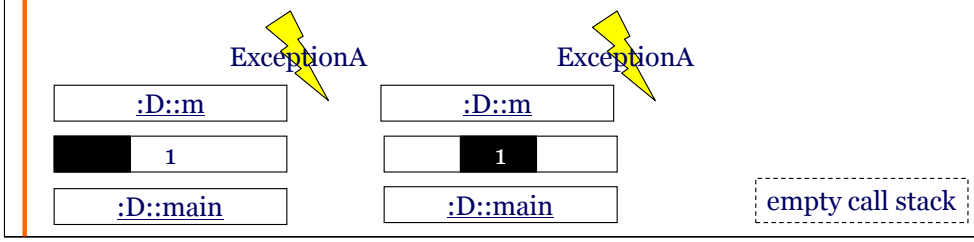
}   }   }
```



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Other exception handling mechanisms

Return an error code:

List and String have a method called indexOf(element) which returns –1 if the element is not in the collection/String.

Error status

The class MediaTracker maintains a list of images and voice objects to be loaded, and one can check an error code to see if anything went wrong.

Differences

-No propagation down the call stack

-No typed information (typically an integer with a certain value is used rather than a type)

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These kinds of exception handling strategies are normally not recommended, but shown here because you will at times encounter them in real programs.

Providing context information

```
class Stack {
    LinkedList elements = new LinkedList();
    public void push(Object o) {
        elements.add(o);
    }
    public Object pop() throws EmptyException {
        if (elements.size() ==0)
            throw new EmptyException(this);
        return elements.removeLast();
    }
    public class EmptyException
                        extends Exception {
        Stack stack;
        EmptyException(Stack stack) {
            this.stack = stack;
} } }
```

```
Stack s1 = new Stack();
Stack s2 = new Stack();
Stack s3 = new Stack();
try {
    ...
    System.out.println( s1.pop() );
    System.out.println( s2.pop() );
    System.out.println( s3.pop() );
}
catch(Stack.EmptyException ee) {
    System.out.println("offending stack was: "
        + ee.stack );
}
```

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Notice that the EmptyException has information about which stack failed.

Often the code using a stack will actually not know what to do with such an error. If this is the case, the user should catch the empty stack error, and then throw another error which is appropriate for the purpose of the user code.


Perspectives on exceptions
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Inheritance and checked exceptions

A method header specify which checked exceptions it throws.

The compiler checks to see that the body of the method does not throw any other exceptions

But what about inheritance, can we add or remove exceptions in the throw list?

```
class A {
   public void foo() throws X {…}
}
class B extends A {
   public void foo() throws X,Y{…} //legal??
}
class C extends A {
   public void foo() {…} // legal??
}
```

```
public void useA(A a) {
    try {
        a.foo();
    }
    catch(X x) {
        … handle x…
    }
}
```

The compiler will accept this code, because all checked exceptions thrown by foo are caught.

But if we call the useA method with an instance of a B, then a Y exception might be thrown, but not caught.

- *We are not allowed to add new exceptions when overriding a method.*
- *We are allowed to remove exceptions*

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These are the rules. The next slide explains why.

Inheritance: require less, promise more

A contract is an agreement between the client C of a method M, and a provider P of that method M.

Can another provider R substitute P?

Slogan: *If R requires less and promises more, C will not be offended.*

E.g. If the post office ask for less postage and/or delivers the letters faster, we are happy.

Contracts

If foo (from class A) has precondition P_A, then foo in B must have a weaker pre-condition P_B. (require less).

If foo in A has post condition Q_A, then foo in B can have a stronger post condition Q_B (promise more).

Exceptions

If foo in A can go wrong in cases X,Y,Z, then foo in B promise to fail only in X and Z (promise more – fewer exceptions to the contract). I will not be offended if the post office delivers also things which are too big.

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The slide is trying to make the point that the specialization slogan is valid for both contracts, and exceptions.

The issue addressed is if a client C is using P, under what situations can it use R instead. In Java, P and R must have the same type (e.g. both implement a common interface, or R being a subclass of P).

The inheritance rule is general for any programming language. As mentioned in the lecture on polymorphism, Java does not allow return type or argument type to change in connection with overriding methods.

For contracts, Java has no build in support, and it is your job as a programmer to adhere to the rule.

For checked exceptions, java checks the throws lists to make sure the rule is followed.

In the contract box, weaker means that the pre condition P_A must imply the pre condition P_B, that is, if P_A is true, P_B is also true. As an example, if P_A is that x is between 1 and 10, and P_B is that x is between 0 and 100, then P_B requires less of x than P_A.

For exceptions, the promise more, is that fewer exceptions can go wrong. We can also see that the rule has to be that way by looking at an example (a is of type A)

```
try{
    a.foo()
}catch(X x){...}
catch(Y y){...}
catch(Z z){...}
```

If a refers to a subtype of A, in which foo could also throw exceptions of type W, then these would not be cought. But the client can see in the definition of type A that only exceptions of type X,Y,Z are thrown.

Therefore Java has a rule that says that one cannot override a method to throw more exceptions, but fewer are OK

Inheritance and catch blocks order

- Catch parts are searched from the top and down.
- When a match is successful, the code for that catch block is executed.
- The rest of the catch blocks are ignored.
- If present the finally block is executed.

```
class ExceptionA extends Exception
class ExceptionB extends Exception
class ExceptionC extends ExceptionA
...
void bar() throws ExceptionA {...}
```

- Can bar() throw exceptions of type ExceptionC ?
- Which of these foo() methods are correct?

```
public void foo1() {
    try { bar(); }
    catch(ExceptionA) { }
    catch(ExceptionB) { }
    catch(ExceptionC) { }
}
public void foo2() {
    try { bar(); }
    catch(ExceptionA) { }
    catch(ExceptionC) { }
    catch(ExceptionB) { }
}
public void foo3() {
    try { bar(); }
    catch(ExceptionB) { }
    catch(ExceptionC) { }
    catch(ExceptionA) { }
}
```

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foo1() + foo2() are wrong, since they will never be able to catch exceptions of type ExceptionC. ExceptionC can be thrown either in the bar() or in subclasses where bar() is overridden.

The compiler will test for this at compile time for both checked and unchecked exceptions

```
class ExceptionA extends RuntimeException{}
class ExceptionB extends RuntimeException {}
class ExceptionC extends ExceptionA {}
class VarianceTest {
        int i = 0;
        public static void main(String[] args) {
                VarianceTest vt = new VarianceTest();
                try {           vt.bar(); }
                catch(ExceptionA a) {
                                System.out.println("A");
                }
                catch(ExceptionC a) {
                                System.out.println("A");
                }
        }
        void bar() throws ExceptionA    {
                if(i > 0 )
                                throw new ExceptionA();
        }
}
```

Where can exceptions be thrown

- In a method
  - terminates the execution of the method along with all other methods on the call stack from the top till a matching catch is found.
- In a constructor
  - terminates the construction of an object, and terminates all other methods on the call stack from the top till a matching catch is found
- In a static initializer
  - terminates the initialization of the class. However, it is still possible to create instances of that class!! Catching such an exception (outside the initializer) is extremely problematic, as class loading happens asynchronously and is not fully specified.
    - only unchecked exceptions may be thrown, why?
- In a catch or finally block
  - Terminates the rest of the execution of the code in the block and all other methods on the call stack from the top till a matching catch is found.
- Recall that finally blocks are always executed despite the catch block did not match the exception thrown.

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```
class ExceptionFillStackTrace {
        static {
                m(); // throw new Exception(); // statically
determinable exceptions are not allowed
        }

        public static void main(String[] args) {
                System.out.println("hello");
                new ExceptionFillStackTrace().m();
        }

        static void m() {
                try {
                        m1();
                }
                catch(Exception e) {
                        e.printStackTrace();
                }
        }

        static void m1() { m2(); }
        static void m2() { m3(); }
        static void m3() {
                RuntimeException e = new RuntimeException();
                throw e;
        }
}
```

Where to declare the Exception class

If the Exception is bound to a specific class make it a member class (inner class).

If one do not need the 'this' reference in instances of the Exceptions, make the exception class static.

Naming: If the class is name Foo, the exception need not be named Foo as well. E.g. The EmptyException was not called StackEmptyException.
Reason: In use situations, one will write
`catch(Stack.EmptyException ee)`

If the exception can occur in a range of different classes in your package, make it a public class in your package.

Exception handling

```
import java.io.*;
class ReaderWriter {
    public static void main(String[] args) throws IOException {
        Reader r1 = new FileReader("in1.txt");
        Reader r2 = new FileReader("in2.txt");
        Writer w = new FileWriter("out.txt");
        int ch;
        while((ch = r1.read()) != -1) w.write(ch);
        while((ch = r2.read()) != -1) w.write(ch);
        r1.close(); r2.close();
        w.close();
}   }
```

- **Program description**
  Merge two files into one destination file.
  - if the first file i fully read and written but the second file fails, then keep the destination.
  - if the first file fail, remove the destination file and ignore processing the second.
- Our first try is an easy solution. The customer, however, is presented with low level error messages in the form of exceptions. not good!
  - and in case of a failure, we do not check if we should remove the destination file.

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The following set of slides are the result of asking if exceptions really does the job it promises or not! It is my opinion, that when doing thorough error handling and giving correct error information to the user ie. in real life applications, the promises made in the start of the lecture of what exceptions could provide seem to pale.

But they also show that making really robust code is really difficult, as there are so many things one must take into account.

Exception handling

```
import java.io.*;
class ReaderWriter {
    public static void main(String[] args) {
        Reader r1 = null, r2 = null; // must be set to null!
        try {
            r1 = new FileReader("in1.txt");
            r2 = new FileReader("in2.txt");
            Writer w = new FileWriter("out.txt");
            int ch;
            while((ch = r1.read()) != -1) w.write(ch);
            while((ch = r2.read()) != -1) w.write(ch);
            w.close();
        }
        catch(FileNotFoundException e) {+ report to the user
            if(e.getSource()) == r1) {
                r2.close(); new File("out.txt").delete();  }
            else r1.close();
}   }   }
```

- At the place of catching an exception, one cannot get hold of context information from where the exception is thrown.
- Most exceptions in java does not propagate information with them.
- getSource() is **a non-existing method**. We can only get information as strings from the exception.
  - We cannot write this code!
- We can check in the catch block that
  - r1 and r2 == null
  - r1 != null, r2 == null
  - But then we make a high coupling between the order of execution and the error handling (ie. they are not separated at all).
  - Was not possible if we caught the exception elsewhere but within the method!

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We state that we can only get information as strings out of the exceptions. This is the general case for Java's exceptions that are defined in the API. When defining your own exceptions, you are free to incorporate as much information as you wish. Later we shall see how to accomplish this.

Exception handling

... while((ch = r1.read()) != -1) w.write(ch);

- read() can throw an IOException
  - Somehow the file cannot be read
  - access rights
  - EOF is reached
- But handling all cases of IO problems is really difficult – just look at how many direct subclasses there exist for IOException:

  Direct subclasses of IOException: ChangedCharSetException, CharacterCodingException, CharConversionException, ClosedChannelException, EOFException, FileLockInterruptionException, FileNotFoundException, HttpRetryException, IIOException, InterruptedIOException, InvalidPropertiesFormatException, JMXProviderException, JMXServerErrorException, MalformedURLException, ObjectStreamException, ProtocolException, RemoteException, SaslException, SocketException, SSLException, SyncFailedException, UnknownHostException, UnknownServiceException, UnsupportedEncodingException, UTFDataFormatException, ZipException
  - And for each exception one should understand the exception and determine (how is not always clear!) if it applies to the application in the domain it is used, and if we thus need a special error handling and supply specific information to the user.
- Likewise for write() ...
- For both cases, we must remember to close all three streams!

Exception handling

```
import java.io.*;
class ReaderWriter {
    public static void main(String[] args) {
        try {
            Reader r1 = null, r2 = null; Writer w = null;
            try {
                r1 = new FileReader("in1.txt");
                try {
                    r2 = new FileReader("in2.txt");
                    try {
                        w = new FileWriter("out.txt"); int ch;
                        try { while((ch = r1.read()) != -1) w.write(ch); }
                        catch(IOException e) { new File("out.txt").delete(); /* report deleting output */ }
                        try { while((ch = r2.read()) != -1) w.write(ch); }
                        catch(IOException e) { /* report keeping output */ }
                    }
                    catch(IOException e) { }
                    finally { w.close(); }
                }
                catch(FileNotFoundException e) { }
                finally { r2.close(); }
            }
            catch(FileNotFoundException e) { }
            finally { r1.close(); }
        }
        catch(IOException e) { /* if any close() fail... still we do not know which one! */ }
    }   }   }
```

- Reporting to the user may be separated, but low level clean up may be difficult to let external objects take care of.

Exception handling

```
import java.io.*;
class ReaderWriter {
    public static void main(String[] args) {
        try {
            Reader r1 = null, r2 = null; Writer w = null;
            try {
                r1 = new FileReader("in1.txt");
                try {
                    r2 = new FileReader("in2.txt");
                    try {
                        w = new FileWriter("out.txt"); int ch;
                        try { while((ch = r1.read()) != -1) w.write(ch); }
                        catch(IOException e) { new File("out.txt").delete(); /* report deleting output */ }
                        try { while((ch = r2.read()) != -1) w.write(ch); }
                        catch(IOException e) { /* report keeping output */ }
                    }
                    catch(IOException e) { /* report failure */ }
                    finally { w.close(); }
                }
                catch(FileNotFoundException e) { /* report failure */ }
                finally { r2.close(); }
            }
            catch(FileNotFoundException e) {  /* report failure */ }
            finally { r1.close(); }
        }
        catch(IOException e) { /* if any close() fail... still we do not know which one! */ }
    }   }   }
```

- Proper clean up may easily entail almost as bad code as the code from the motivation showing intermixed business code and error handling code!
- Almost more difficult to read code in this style of programming! (but still less redundant than the if-else approach)
- green – business logic
- purple – code which may execute on error
- red – code which execute on error

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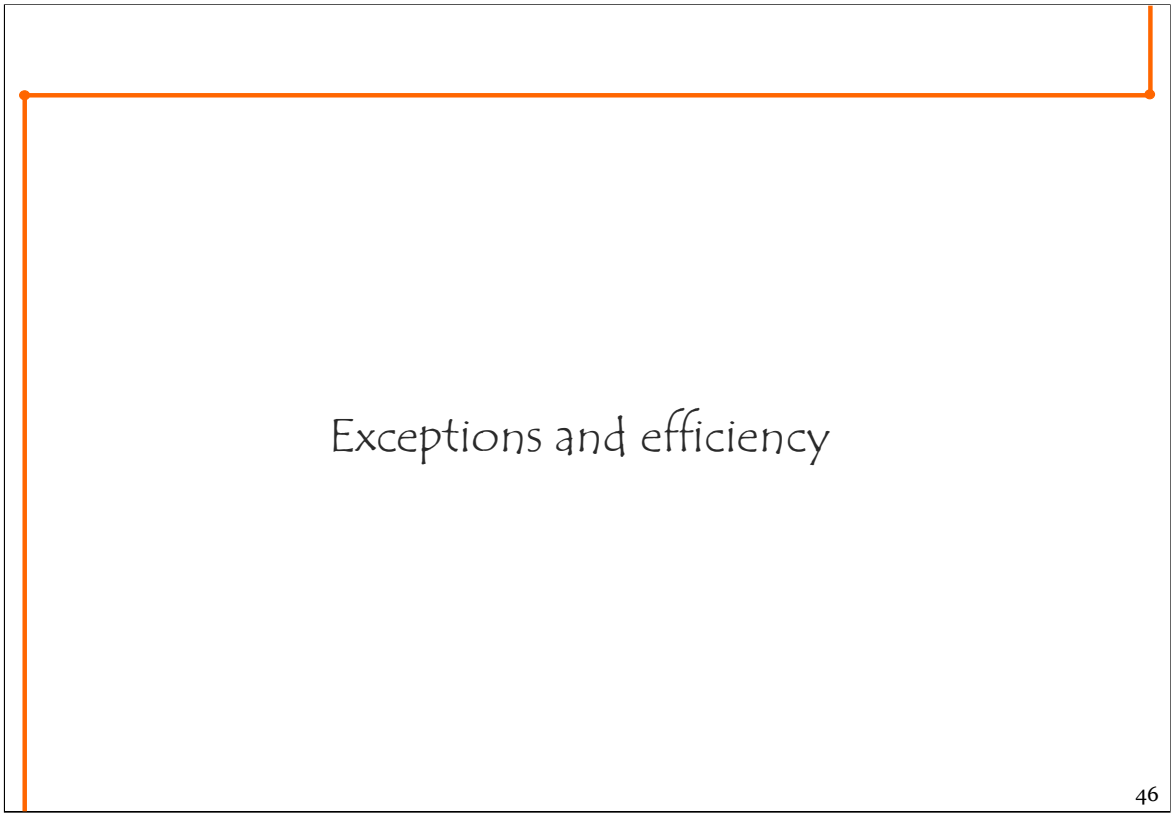
Exceptions and efficiency
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Exceptions and efficiency

In class System there is a method called currentTimeMillis(), which returns number of milliseconds since midnight January 1st 1970.

It can be used as a stopwatch to find out how long time it takes to execute a piece of java code:

```
int N = 100000000; // 100.000.000
long start = System.currentTimeMillis();
long time;
for (int i=0; i<N; i++)
   foo(7); // this is what we examine.
time = System.currentTimeMillis()-start;
System.out.println("Calling an empty method"
   + " takes " + (time*1000)/N + " µ seconds");
```

1. Without Exceptions : 0.00401 µ sec
2. With Exceptions : 4.797 µ sec
3. No ex, but finally : 0.0043 µ sec

using java 1.4

1. Without Exceptions : 0.004 µ sec
2. With Exceptions : 2.780 µ sec
3. No ex, but finally : 0.004 µ sec

using java 5

Notice, it is about **700-1000** times slower if the method throws an exception.

The for loop runs 100.000.000 times in the code to the left. That takes a few seconds on my laptop.

Beware: 1000 times a 2 seconds is about half an hour. Run the loop with a small number at first, and then increase by factors of 10.

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There are actually two important pieces of information here. The first is:

- Only use exceptions for handling exceptional cases, they are very costly for normal situations.

The other observation is that normal method calls are quite fast. You can do approximately 200.000.000 empty method calls per second, or one method call takes approx 5 nanosecond (light moves approx 1.5 m in 5 nanoseconds).

The usage of currentTimeMillis as above is standard. In some versions of windows, the timer is only accurate to 10'th of milliseconds.

Note, it changes a bit from one run to an other how long it takes, but normally within 10%

For those of you who are not used to milli, micro, and nano, there are 1000 milliseconds to a second, a 1000 micro seconds to a millisecond, and 1000 nanoseconds to a micro second. That is, there are 1000.000.000 nanoseconds in one second.

If you type very fast, you can type 7 characters a second. How many method calls can you do between to stokes on the keyboard?

Code for the timing experiment

1) No exception thrown

```
void pip1(int N) {
    for (int i = 0; i<N; i++) {
        try {
            noUups();
        }
        catch(Exception e) { }
}
```

2) An exception thrown

```
void pip2(int N) {
    for (int i = 0; i<N; i++) {
        try{
            uups();
        } catch(Exception e) {
    }
}
```

3) No exception thrown, but with a finally

```
void pip3(int N) {
    for (int i = 0; i<N; i++) {
        try {
            noUups();
        }
        catch(Exception e) { }
        finally {}
    }
}
void uups() throws Exception {
    throw new Exception("Oh no");
}

void noUups() throws Exception { }
```


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What takes time with exceptions

The uups method makes a new Exception object, and throws it.

It is making the Exception object which is expensive:

```
void uups() throws Exception {
   throw new Exception("Oh no");
}
void noUups() throws Exception {
   new Exception("Oh no");
}
```

Now the timing results are:

Without Exceptions	: 2.643 micro sec
With Exceptions	: 2.764 micro sec
No ex, but finally	: 2.594 micro sec

That is a difference of ~7%

An alternative is to make the exception object ahead of time:

```
static Exception ohNo = new Exception("Oh no no");
void uups1() throws Exception {
    throw ohNo;
}
void uups2() throw Exception {
    ohNo.fillStackTrace();
    throw onNo;
}
```

Then the timing results become:

With Exceptions1	: 0.1533 micro sec
With Exceptions2	: 0.2424 micro sec

This way exceptions are ”only” 40-60 times slower, not 700 times.

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One can spend quite some time on figuring out what actually goes on by trying to time different primitives in Java.

Here, we have not examined how long time it takes to create a normal object.

Why is it so expensive to make Exception objects?

Exception is a subclass of Throwable.

A throwable object has a stacktrace.

The stack trace tells in which method the Throwable was created, and from which method it was called, and from where it was called...

Establishing the stack trace is done when a new Throwable is created (or any of its subclasses).

Setting the stack trace accounts for the remaining cost of throwing an exception.

The deeper the call stack is when you make the exception object, the more expensive it is to make the exception object.

Runtime reflection: StackTraceElement

The stack trace is an array of StackTraceElement, with the most resent method call being in the zero'th index.

The following method returns true if the method it was called from is named foo, false otherwise.

```
public static boolean amIFoo() {
   Throwable t = new Throwable();
   StackTraceElement[] trace = t.getStackTrace();
   String methodName =trace[1].getMethodName();
   return methodName.equals("foo");
}
public static void main(String[] args) {
   System.out.println("Main:" + amIFoo() );
   foo(); }

public static void foo() {
   System.out.println("Foo: " + amIFoo() );}
```

The API in brief:

```
String getClassName()
String getFileName()
int getLineNumber()
String getMethodName()
```

Notice, the methods does not return the reflection objects, but string names.

Only in recent version of Java is this possible (Java 1.4 and newer)

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Note that the amIFoo is not looking at the stack trace top, but second to top. The reason is that the top is known to be amIFoo when you are inside the method.