Exception Handling

Program Errors

- Syntax (compiler) errors
  - Errors in code construction (grammar, types)
  - Detected during compilation
- Run-time errors
  - Operations illegal / impossible to execute
  - Detected during program execution
  - Treated as exceptions in Java
- Logic errors
  - Operations leading to incorrect program state
  - May (or may not) lead to run-time errors
  - Detect by debugging code

Exception-Handling Fundamentals

- An *exception* is an abnormal condition that arises in a code sequence at run time
- A Java exception is an object that describes an exceptional condition that has occurred in a piece of code
- When an exceptional condition arises, an object representing that exception is created and *thrown* in the method that caused the error
- An exception can be caught to handle it or pass it on
- Exceptions can be generated by the Java run-time system, or they can be manually generated by your code

What are Exceptions?

Many "exceptional" things can happen during the running of a program, e.g.:

- User mis-types input

checked

- Web page not available
- File not found

- Array index out of bounds

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d

- Method called on a null object
- Divide by zero

- Out of memory

sys errors

- Bug in the actual language implementation

Exceptions are unexpected conditions in programs.

We can distinguish 3 categories:

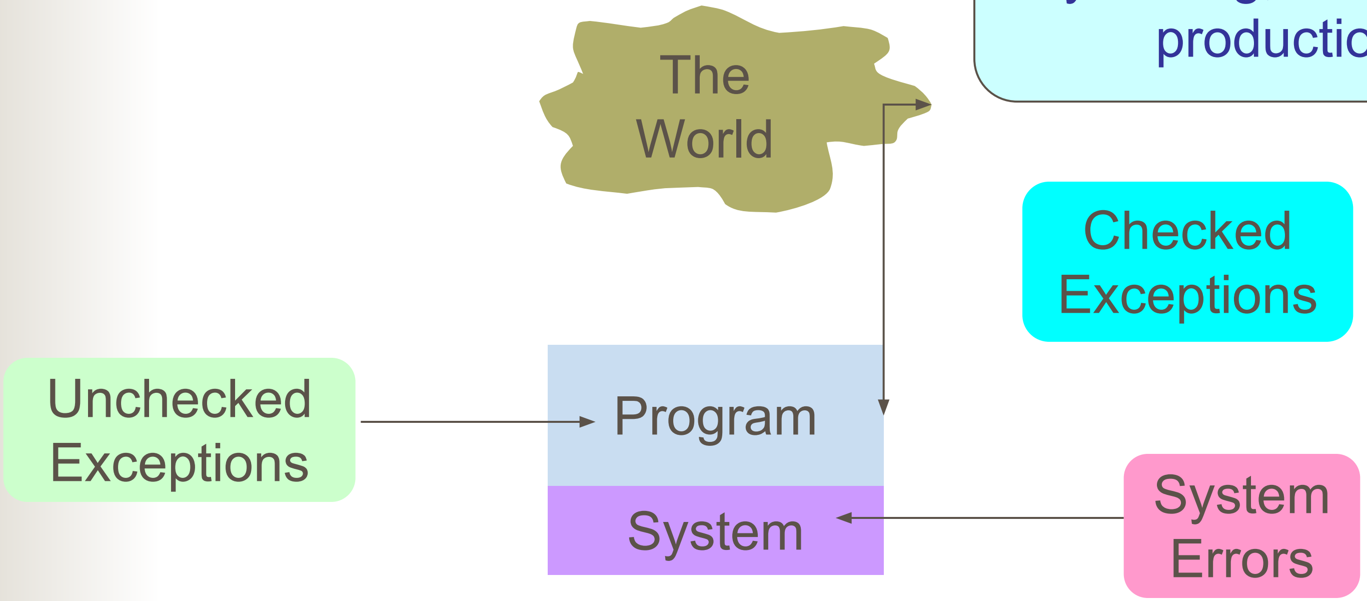
- *checked* exceptions — Problems to do with the program's interaction with “the world”.

- *unchecked* exceptions — P ... e proc ... If (i.e. violations of the contra

- *system errors* — Problems These are outside our control.

The world is unpredictable, so we would expect these things to happen in production code, and so nee

These should be removed by testing, and not occur in production code.

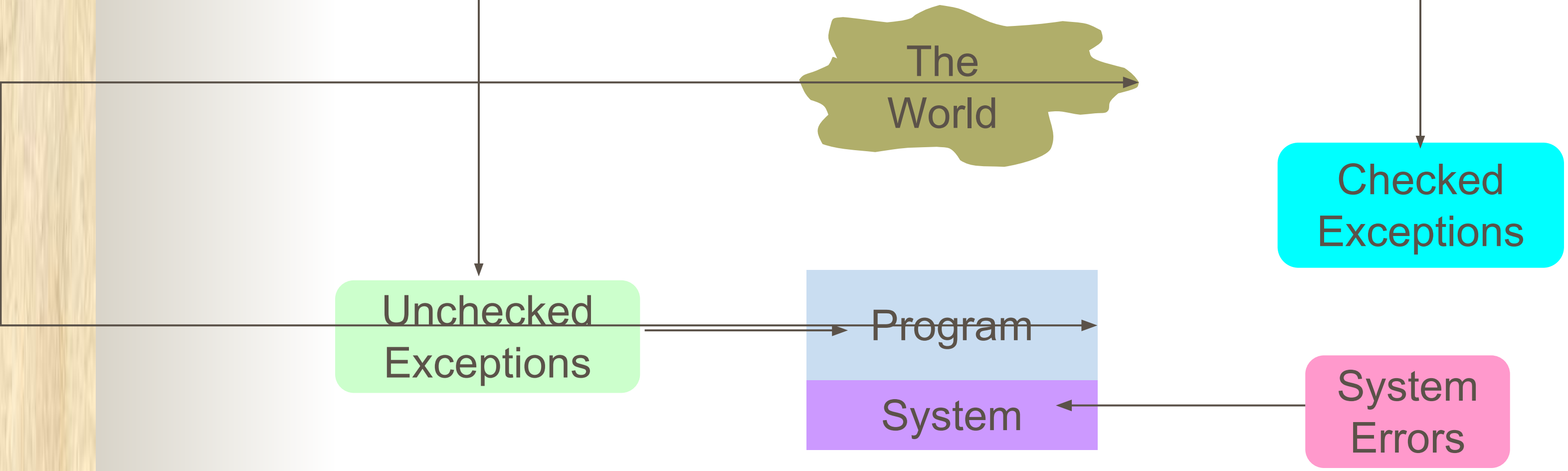


Checked vs Unchecked Exceptions

an important distinction, which the Java **on** class hierarchy does make, but in a rather confusing way

it's normal to let these just crash the program so we can debug it.

we would normally check for these, and deal with them when they occur.



Exception handling is the business of handling these things appropriately.

Exception Handling

- Performing action in response to exception
- Examples
  - Exit program (abort)
  - Ignore exception
  - Deal with exception and continue
    - Print error message
    - Request new data
    - Retry action

Exception Handling – Exit Program

- Approach
  - Exit program with error message / error code
- Example

```
if (error) {
    System.err.println(“Error found”);    // message
    System.exit(1);                       // error code
}
```

- Problem
  - Drastic solution
  - Event must be handled by user invoking program
  - Program may be able to deal with some exceptions

Exception Handling – Error Code

- Approach
  - Exit function with return value ⇒ error code
- Example

```
A( ) { if (error) return (-1); }
B( ) { if ((retval = A( )) == -1) return (-1); }
```

- Problems
  - Calling function must check & process error code
    - May forget to handle error code
    - May need to return error code to caller
  - Agreement needed on meaning of error code
  - Error handling code mixed with normal code

Exception Handling – Throw Exception

- Approach
  - Throw exception
- Example

```
A( ) {
    if (error) throw new ExceptionType();
}
B( ) {
    try {
        A( );
    }
    catch (ExceptionType e) { ...action... }
}
```

Java exception backtracks to caller(s) until matching catch block found

Exception Handling – Throw Exception

- Advantages
  - Compiler ensures exceptions are caught eventually
  - No need to explicitly propagate exception to caller
    - Backtrack to caller(s) automatically
  - Class hierarchy defines meaning of exceptions
    - No need for separate definition of error codes
  - Exception handling code separate & clearly marked

Exception-Handling Fundamentals

- Java exception handling is managed by via five keywords: **try**, **catch**, **throw**, **throws**, and **finally**
- Program statements to monitor are contained within a **try** block
- If an exception occurs within the **try** block, it is thrown
- Code within **catch** block catch the exception and handle it
- System generated exceptions are automatically thrown by the Java run-time system
- To manually throw an exception, use the keyword **throw**
- Any exception that is thrown out of a method must be specified as such by a **throws** clause

Using try and catch

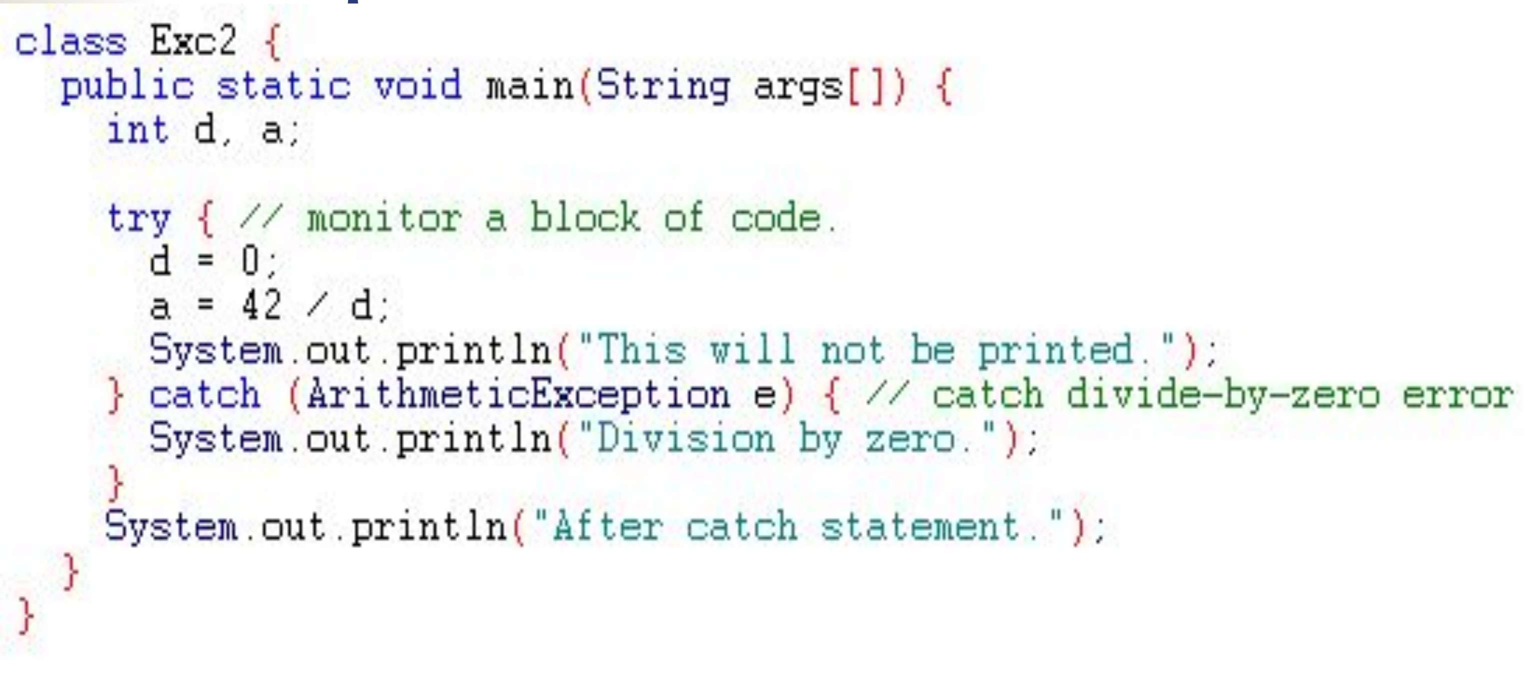
- Handling an exception has two benefits,
  - It allows you to fix the error
  - It prevents the program from automatically terminating
- The **catch** clause should follow immediately the **try** block
- Once an exception is thrown, program control transfer out of the **try** block into the catch block
- Once the **catch** statement has executed, program control continues with the next line in the program following the entire **try/catch** mechanism

Exception-Handling Fundamentals

- Any code that absolutely must be executed before a method returns is put in a **finally** block
- General form of an exception-handling block

```
try{
        // block of code to monitor for errors
}
catch (ExceptionType1 exOb){
        // exception handler for ExceptionType1
}
catch (ExceptionType2 exOb){
        // exception handler for ExceptionType2
}
//…
finally{
        // block of code to be executed before try block ends
}
```

Example



```
class Exc2 {
  public static void main(String args[]) {
    int d, a;

    try { // monitor a block of code.
      d = 0;
      a = 42 / d;
      System.out.println("This will not be printed.");
    } catch (ArithmeticException e) { // catch divide-by-zero error
      System.out.println("Division by zero.");
    }
    System.out.println("After catch statement.");
  }
}
```

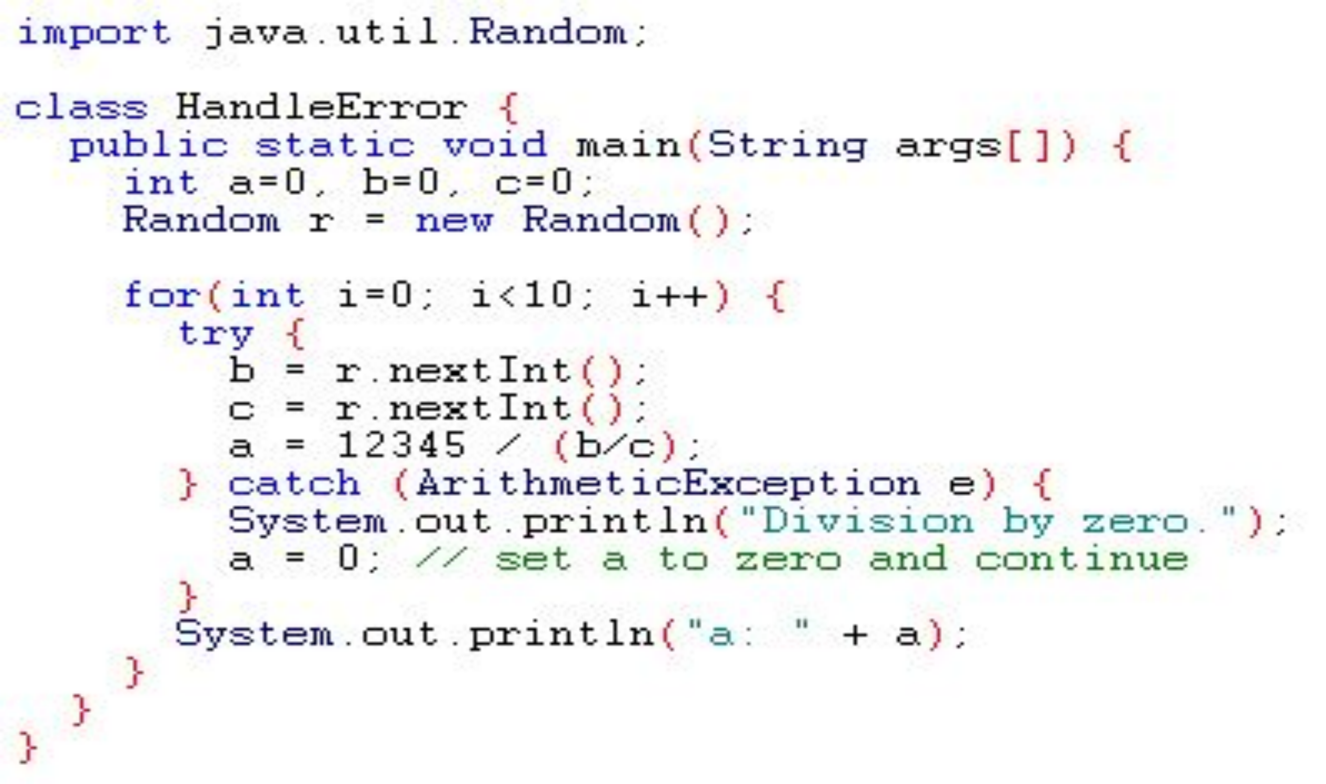
Output:

Division by zero.

After catch statement.

Using try and catch

- A **try** and **catch** statement form a unit. The scope of the **catch** clause is restricted to those statements specified by the immediately preceding **try** statement



```java
import java.util.Random;

class HandleError {
  public static void main(String args[]) {
    int a=0, b=0, c=0;
    Random r = new Random();

    for(int i=0; i<10; i++) {
      try {
        b = r.nextInt();
        c = r.nextInt();
        a = 12345 / (b/c);
      } catch (ArithmeticException e) {
        System.out.println("Division by zero.");
        a = 0; // set a to zero and continue
      }
      System.out.println("a: " + a);
    }
  }
}
```

Uncaught Exceptions

- If an exception is not caught by user program, then execution of the program stops and it is caught by the default handler provided by the Java run-time system
- Default handler prints a stack trace from the point at which the exception occurred, and terminates the program

Ex:

```
class Exc0 {
  public static void main(String args[]) {
    int d = 0;
    int a = 42 / d;
  }
}
```

Output:

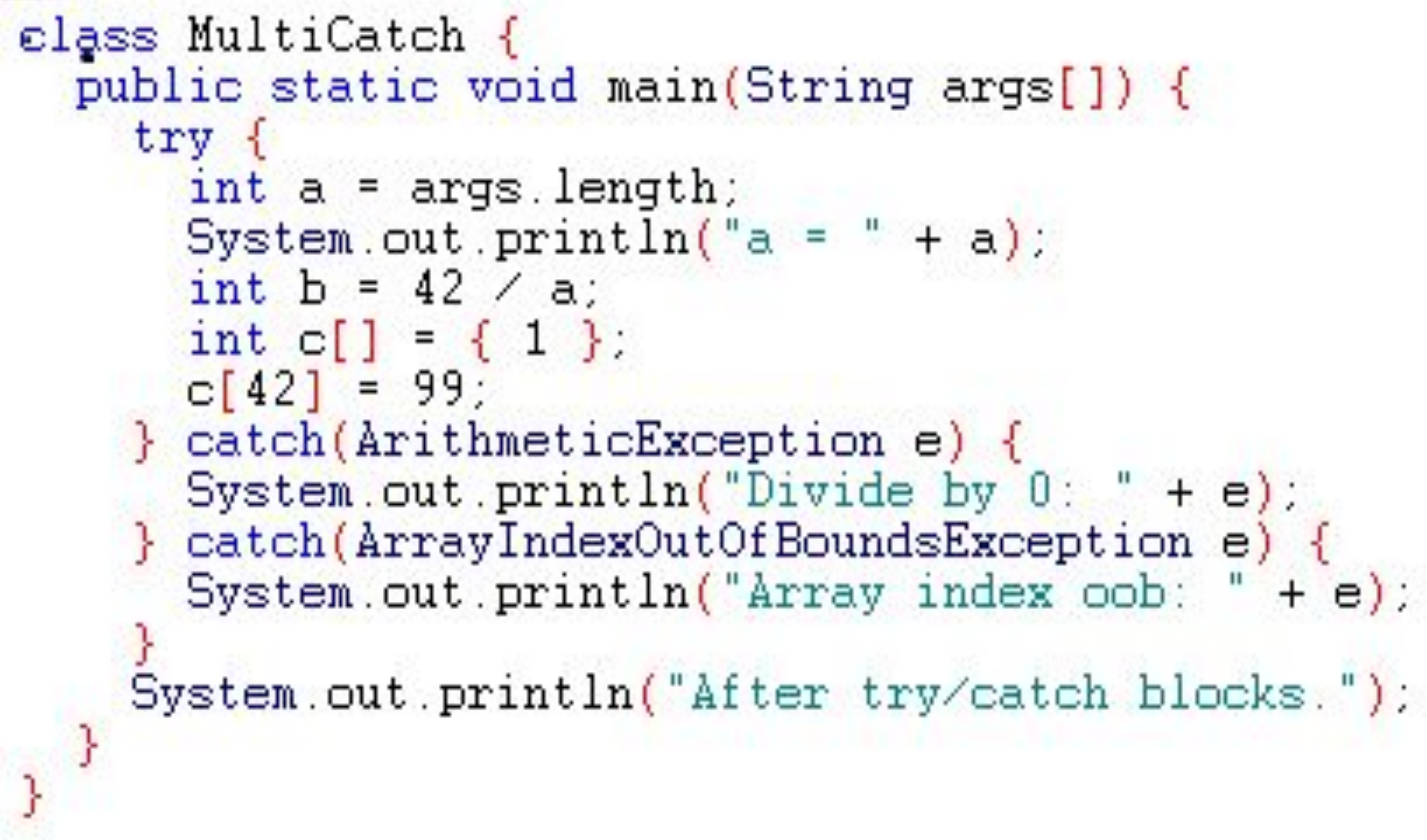
```
java.lang.ArithmeticException: / by zero
        at Exc0.main(Exc0.java:4)

Exception in thread "main"
```

Multiple catch Clauses

- If more than one can occur, then we use multiple catch clauses
- When an exception is thrown, each **catch** statement is inspected in order, and the first one whose type matches that of the exception is executed
- After one **catch** statement executes, the others are bypassed

Example



```
class MultiCatch {
  public static void main(String args[]) {
    try {
      int a = args.length;
      System.out.println("a = " + a);
      int b = 42 / a;
      int c[] = { 1 };
      c[42] = 99;
    } catch(ArithmeticException e) {
      System.out.println("Divide by 0: " + e);
    } catch(ArrayIndexOutOfBoundsException e) {
      System.out.println("Array index oob: " + e);
    }
    System.out.println("After try/catch blocks.");
  }
}
```

Example (Cont.)

- If no command line argument is provided, then you will see the following output:

```
a = 0
Divide by 0: java.lang.ArithmeticException: / by zero
After try/catch blocks
```

- If any command line argument is provided, then you will see the following output:

```
a = 1
Array index oob: java.lang.ArrayIndexOutOfBoundsException
After try/catch blocks.
```

Example

```
public class Etest {
public static void main(String args[]){
// What we expect to happen
try {
   int x = Integer.parseInt(args[0]);
   int y = Integer.parseInt(args[1]);
   System.out.println( x + "/" + y + " = " + x/y ); }
// Things which can go wrong
catch (IndexOutOfBoundsException e) {
   System.out.println( "Usage: Etest <int> <int>" ); }
catch (NumberFormatException e) {
   System.out.println( e.getMessage() + " is not a
   number" );                                     }
 // Do this regardless
 finally {
    System.out.println( "That's all, folks" );  }
 } // main
 } // Etest
```

```
public class Etest {
public static void main(String args[]){
// What we expect to happen
try {
   int x = Integer.parseInt(args[0]);
   int y = Integer.parseInt(args[1]);
   System.out.println( x + "/" + y + " = " + x/y ); }
// Things which can go wrong
catch (IndexOutOfBoundsException e) {
   System.out.println( "Usage: Etest <int> <int>" ); }
catch (NumberFormatException e) {
   System.out.println( e.getMessage() + " is not a
   number" );                                      }
 // Do this regardless
 finally {
    System.out.println( "That's all, folks" );  }
 } // main
 } // Etest
```

```
> java Etest 99 42
99/42 = 2
That's all, folks
```

```
public class Etest {
public static void main(String args[]){
// What we expect to happen
try {
   int x = Integer.parseInt(args[0]);
   int y = Integer.parseInt(args[1]);
   System.out.println( x + "/" + y + " = " + x/y ); }
// Things which can go wrong
catch (IndexOutOfBoundsException e) {
   System.out.println( "Usage: Etest <int> <int>" ); }
catch (NumberFormatException e) {
   System.out.println( e.getMessage() + " is not a
   number" );                                       }
 // Do this regardless
 finally {
    System.out.println( "That's all, folks" );   }
 } // main
 } // Etest
```

```
> java Etest 99
Usage: Etest <int> <int>
That's all, folks
```

```
public class Etest {
public static void main(String args[]){
// What we expect to happen
try {
   int x = Integer.parseInt(args[0]);
   int y = Integer.parseInt(args[1]);
   System.out.println( x + "/" + y + " = " + x/y ); }
// Things which can go wrong
catch (IndexOutOfBoundsException e) {
   System.out.println( "Usage: Etest <int> <int>" ); }
catch (NumberFormatException e) {
   System.out.println( e.getMessage() + " is not a
   number" );                                        }
 // Do this regardless
 finally {
    System.out.println( "That's all, folks" );   }
 } // main
 } // Etest
```

```
 > java Etest 99 fred
fred is not a number
That's all, folks
```

```
public class Etest {
public static void main(String args[]){
// What we expect to happen
try {
    int x = Integer.parseInt(args[0]);
    int y = Integer.parseInt(args[1]);
    System.out.println( x + "/" + y + " = " + x/y ); }
// Things which can go wrong
catch (IndexOutOfBoundsException e) {
    System.out.println( "Usage: Etest <int> <int>" ); }
catch (NumberFormatException e) {
    System.out.println( e.getMessage() + " is not a
    number" );                                          }
 // Do this regardless
 finally {
    System.out.println( "That's all, folks" );   }
 } // main
 } // Etest
```

```
 > java Etest fred
fred is not a number
That's all, folks
```

```
public class Etest {
public static void main(String args[]){
// What we expect to happen
try {
   int x = Integer.parseInt(args[0]);
   int y = Integer.parseInt(args[1]);
   System.out.println( x + "/" + y + " = " + x/y ); }
// Things which can go wrong
catch (IndexOutOfBoundsException e) {
   System.out.println( "Usage: Etest <int> <int>" ); }
catch (NumberFormatException e) {
   System.out.println( e.getMessage() + " is not a
   number" );                                       }
 // Do this regardless
 finally {
    System.out.println( "That's all, folks" );   }
 } // main
 } // Etest
```

```
> java Etest 99 0
That's all, folks
java.lang.ArithmeticException: / by zero
at Etest.main(Etest.java:8)
```

Using `finally` for Cleanup

Finalizers aren't much good for releasing resources

because we don't know when (or even if) they will be called

To get guaranteed cleanup of network connections etc. use `finally`

```
Socket s;
InputStream in;
try {        s = new Socket(...);       ...
             in = s.getInputStream(); ...
     }

finally {
        try { if (in != null) in.close());
              s.close();
            }
         catch (IOException e){}
        }
```

So we actually need a `try ... catch` block within the `finally` clause

e.g. if the network goes down at the wrong moment

With Exception Handling - Example

```
class WithExceptionCatchThrow{
        public static void main(String[] args){
                int a,b;  float r;  a = 7;   b = 0;
                try{
                        r = a/b;
                        System.out.println(“Result is “ + r);
                }
                catch(ArithmeticException e){
                        System.out.println(“ B is zero);
                        throw e;
                }
                        System.out.println(“Program is complete”);
        }
}
```

Program Does Not
reach here
when exception occurs

With Exception Handling - Example

Program reaches here

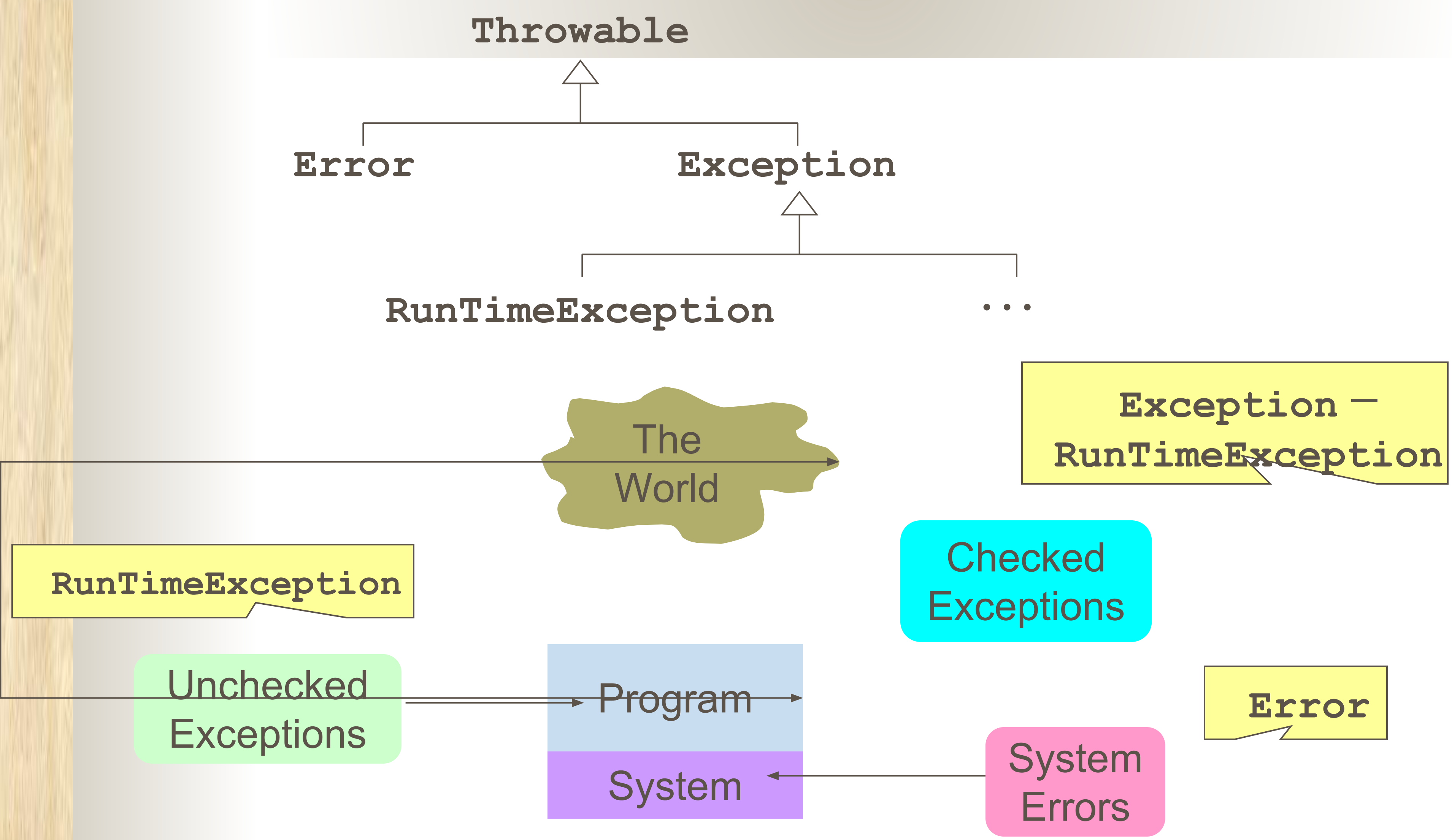
```
class WithExceptionCatchThrowFinally{
        public static void main(String[] args){
                int a,b;  float r;  a = 7;   b = 0;
                try{
                        r = a/b;
                        System.out.println(“Result is “ + r);
                }
                catch(ArithmeticException e){
                         System.out.println(“ B is zero);


                }
                finally{
                                System.out.println(“Program is complete”);
                }
        }
}
```

Exception Types

- All exception types are subclasses of the built-in class **Throwable**
- Throwable has two subclasses, they are
    - Exception (to handle exceptional conditions that user programs should catch)
        - An important subclass of Exception is **RuntimeException**, that includes division by zero and invalid array indexing
    - Error (to handle exceptional conditions that are not expected to be caught under normal circumstances). i.e. stack overflow

Exception Hierarchy in Java



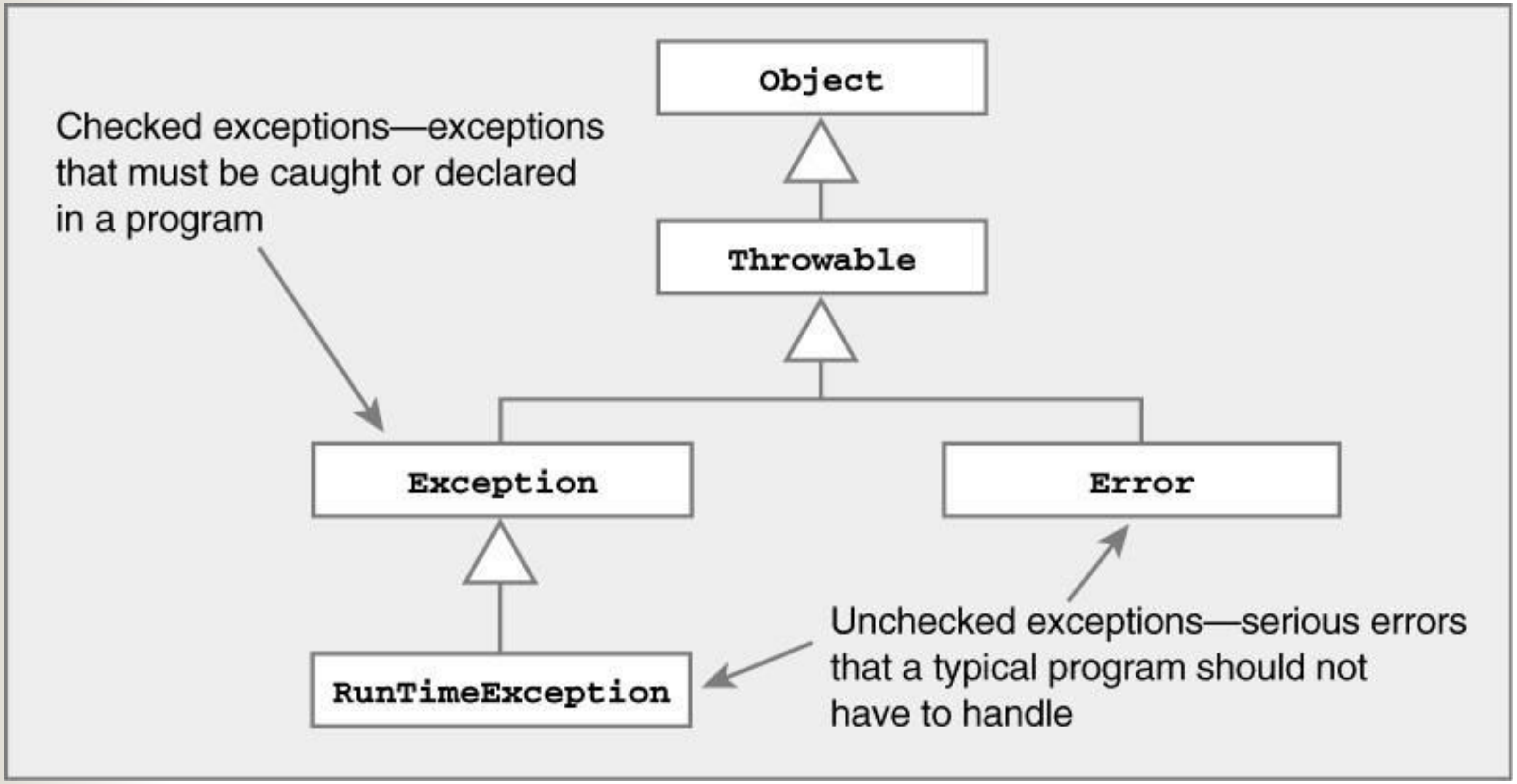
Representing Exceptions

- Exceptions represented as
  - Objects derived from class Throwable
- Code

```
public class Throwable( ) extends Object {
    Throwable( )                    // No error message
    Throwable( String mesg )        // Error message
    String getMessage()             // Return error mesg
    void printStackTrace( ) { … }   // Record methods
    …                               // called & location
}
```

Representing Exceptions

- Java Exception class hierarchy
  - Two types of exceptions ⇒ checked & unchecked

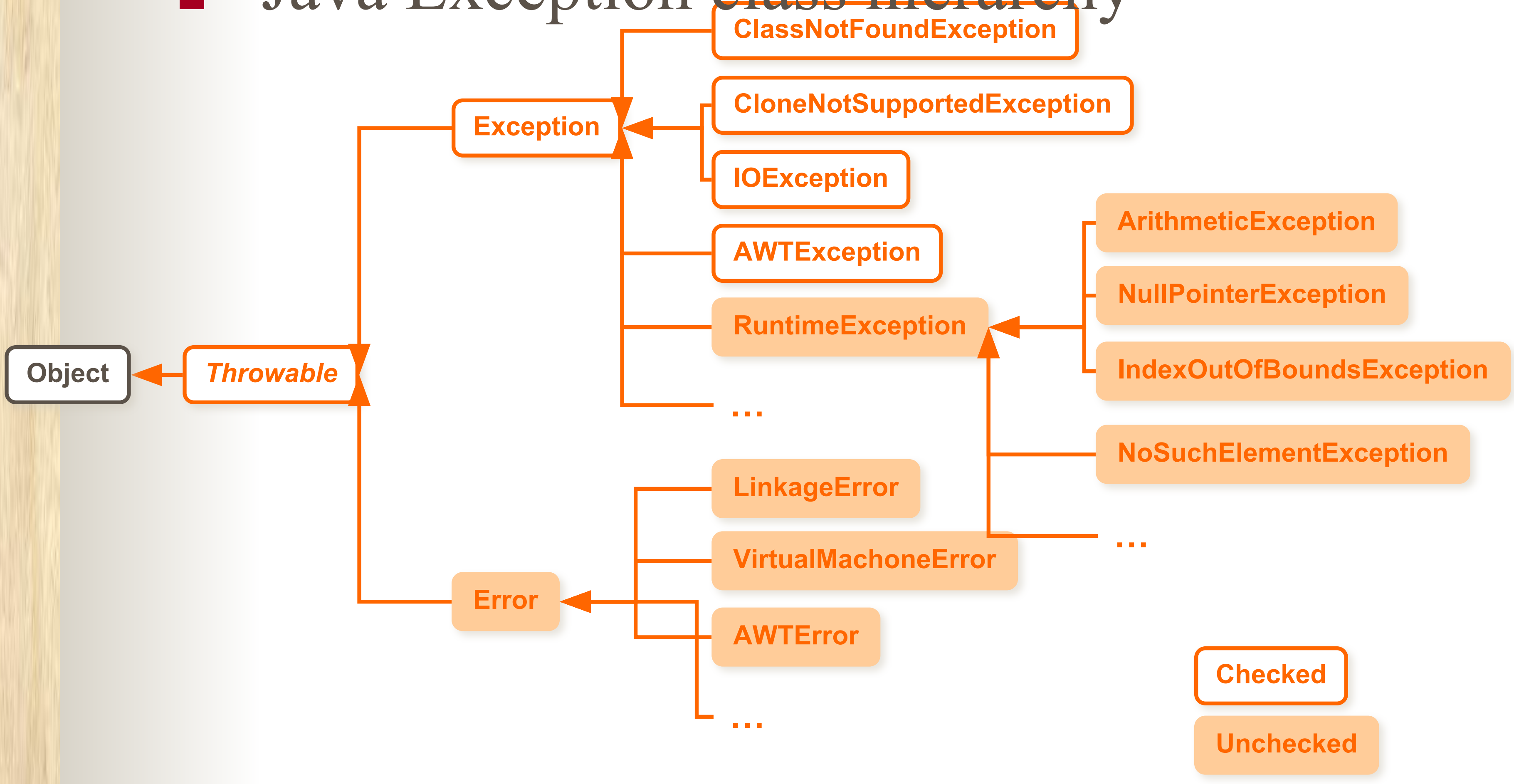


Checked exceptions—exceptions that must be caught or declared in a program

Unchecked exceptions—serious errors that a typical program should not have to handle

Representing Exceptions

- Java Exception class hierarchy



EXCEPTION VS. ERROR

- An **Error** indicates a serious problem that a reasonable application should not try to catch.

- Examples:
  - ClassFormatError,
  - InstantiationError,
  - InternalError,
  - NoSuchMethodError,
  - OutOfMemoryError,
  - StackOverflowError,
  - VirtualMachineError.

RuntimeException

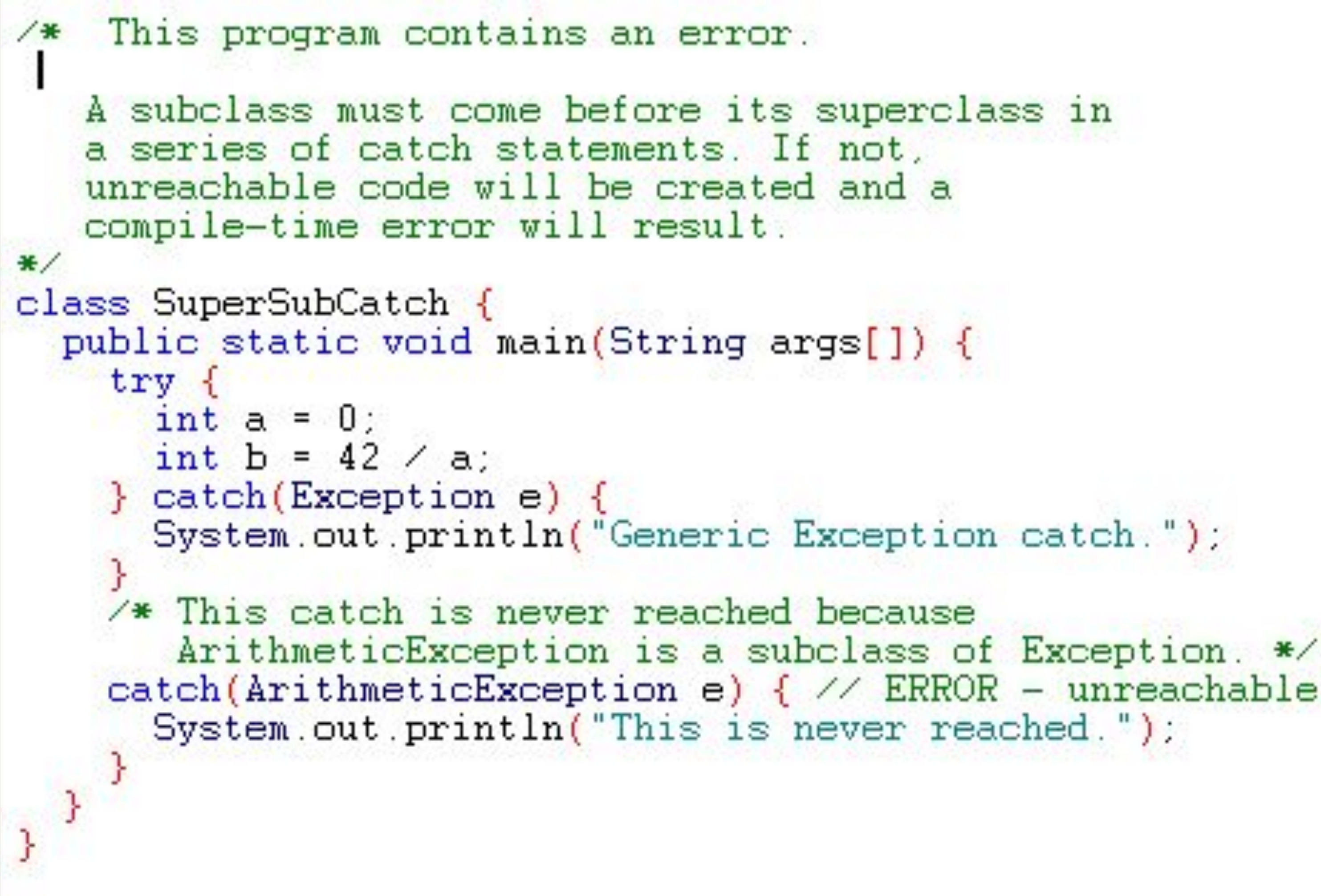
- **RuntimeException** is the superclass of those exceptions that can be thrown during the normal operation of the JVM.

- Examples:
  - NullPointerException,
  - ArrayIndexOutOfBoundsException,
  - NegativeArraySizeException,
  - ClassCastException,
  - NumberFormatException,
  - SecurityException.

Caution

- Remember that, exception subclass must come before any of of their superclasses
- Because, a **catch** statement that uses a superclass will catch exceptions of that type plus any of its subclasses. So, the subclass would never be reached if it come after its superclass
- For example, **ArithmeticException** is a subclass of **Exception**
- Moreover, unreachable code in Java generates error

Example



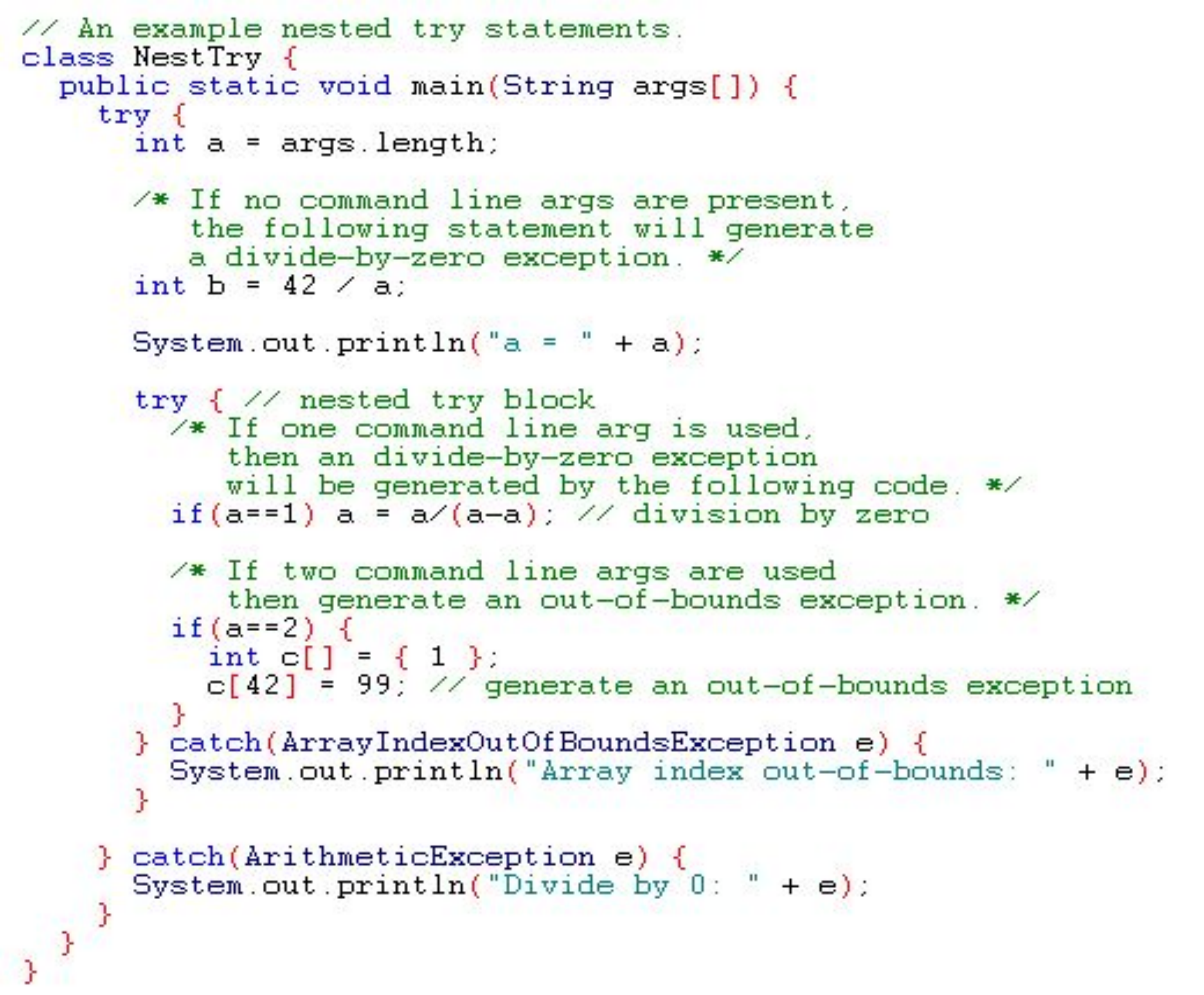
```
/*  This program contains an error.

   A subclass must come before its superclass in
   a series of catch statements. If not,
   unreachable code will be created and a
   compile-time error will result.
*/
class SuperSubCatch {
  public static void main(String args[]) {
    try {
      int a = 0;
      int b = 42 / a;
    } catch(Exception e) {
      System.out.println("Generic Exception catch.");
    }
    /* This catch is never reached because
       ArithmeticException is a subclass of Exception. */
    catch(ArithmeticException e) { // ERROR - unreachable
      System.out.println("This is never reached.");
    }
  }
}
```

Nested try Statements

- A **try** statement can be inside the block of another try
- Each time a **try** statement is entered, the context of that exception is pushed on the stack
- If an inner **try** statement does not have a catch, then the next **try** statement's catch handlers are inspected for a match
- If a method call within a **try** block has **try** block within it, then it is still nested **try**

Example



```
// An example nested try statements.
class NestTry {
  public static void main(String args[]) {
    try {
      int a = args.length;

      /* If no command line args are present,
         the following statement will generate
         a divide-by-zero exception. */
      int b = 42 / a;

      System.out.println("a = " + a);

      try { // nested try block
        /* If one command line arg is used,
           then an divide-by-zero exception
           will be generated by the following code. */
        if(a==1) a = a/(a-a); // division by zero

        /* If two command line args are used
           then generate an out-of-bounds exception. */
        if(a==2) {
          int c[] = { 1 };
          c[42] = 99; // generate an out-of-bounds exception
        }
      } catch(ArrayIndexOutOfBoundsException e) {
        System.out.println("Array index out-of-bounds: " + e);
      }

    } catch(ArithmeticException e) {
      System.out.println("Divide by 0: " + e);
    }
  }
}
```

Output

- When no parameter is given:

```
Divide by 0: java.lang.ArithmeticException: / by zero
```

- When one parameter is given

```
a = 1
Divide by 0: java.lang.ArithmeticException: / by zero
```

- When two parameters are given

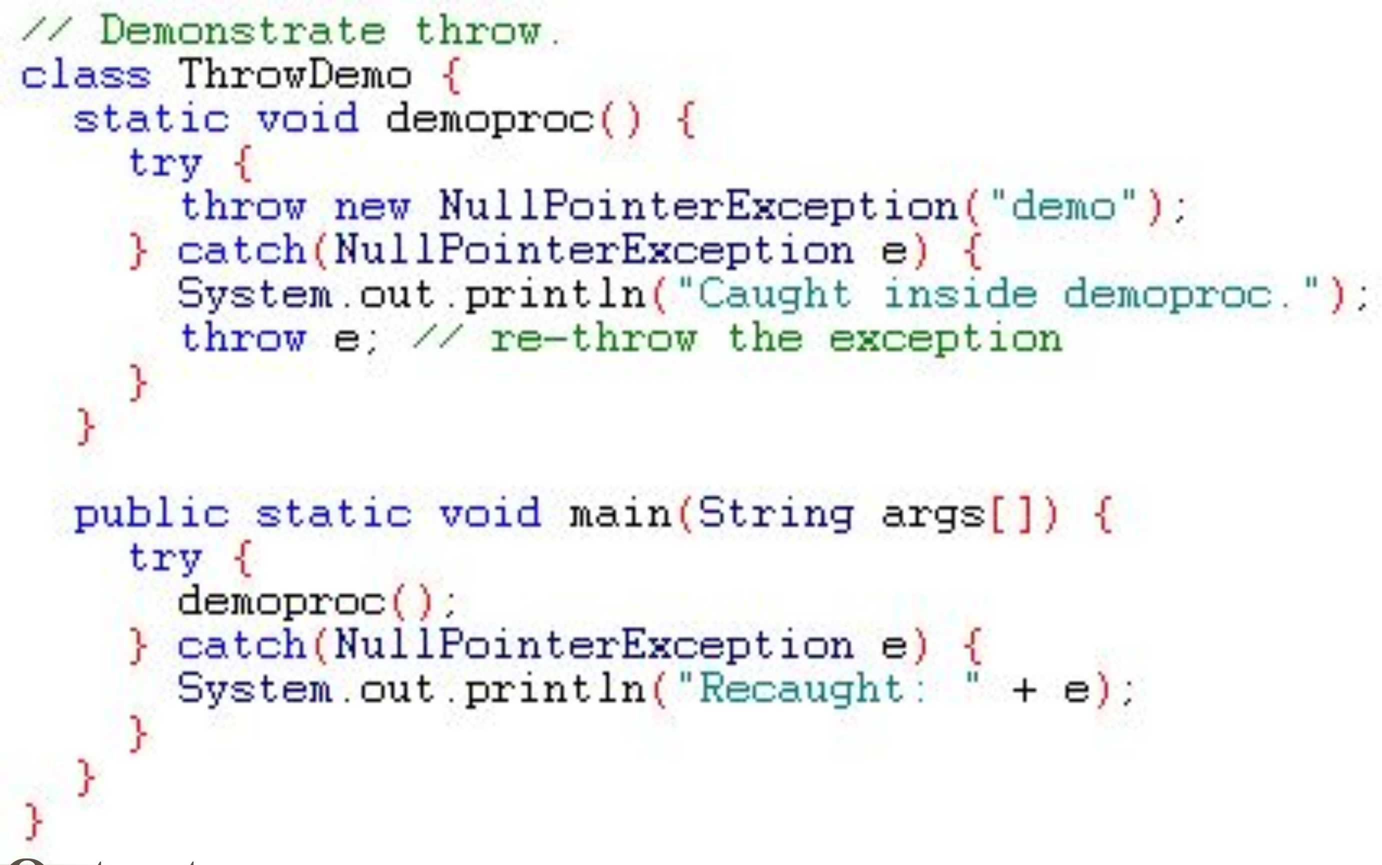
```
a = 2
Array index out-of-bounds: java.lang.ArrayIndexOutOfBoundsException
```

throw

- It is possible for your program to to throw an exception explicitly

  throw *TrrowableInstance*
- Here, *TrrowableInstance* must be an object of type **Throwable** or a subclass **Throwable**
- There are two ways to obtain a **Throwable** objects:
  - Using a parameter into a catch clause
  - Creating one with the **new** operator

Example



```
// Demonstrate throw.
class ThrowDemo {
  static void demoproc() {
    try {
      throw new NullPointerException("demo");
    } catch(NullPointerException e) {
      System.out.println("Caught inside demoproc.");
      throw e; // re-throw the exception
    }
  }

  public static void main(String args[]) {
    try {
      demoproc();
    } catch(NullPointerException e) {
      System.out.println("Recaught: " + e);
    }
  }
}
```

Output:

```
Caught inside demoproc.

Recaught: java.lang.NullPointerException: demo
```

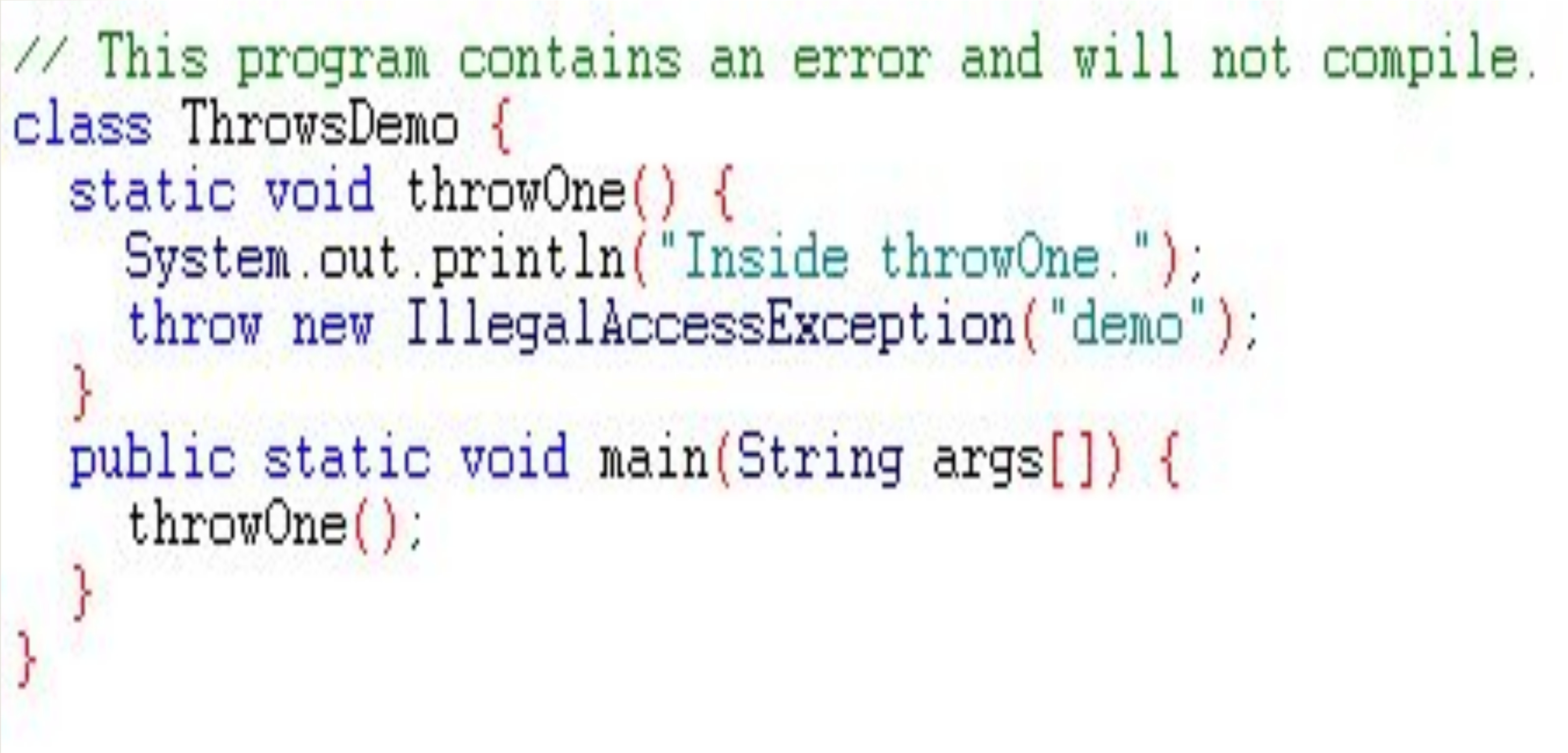
throws

- If a method is capable of causing an exception that it does not handle, it must specify this behavior so that callers of the method can guard themselves against that exception

```
type method-name parameter-list) throws exception-list
{
        // body of method
}
```

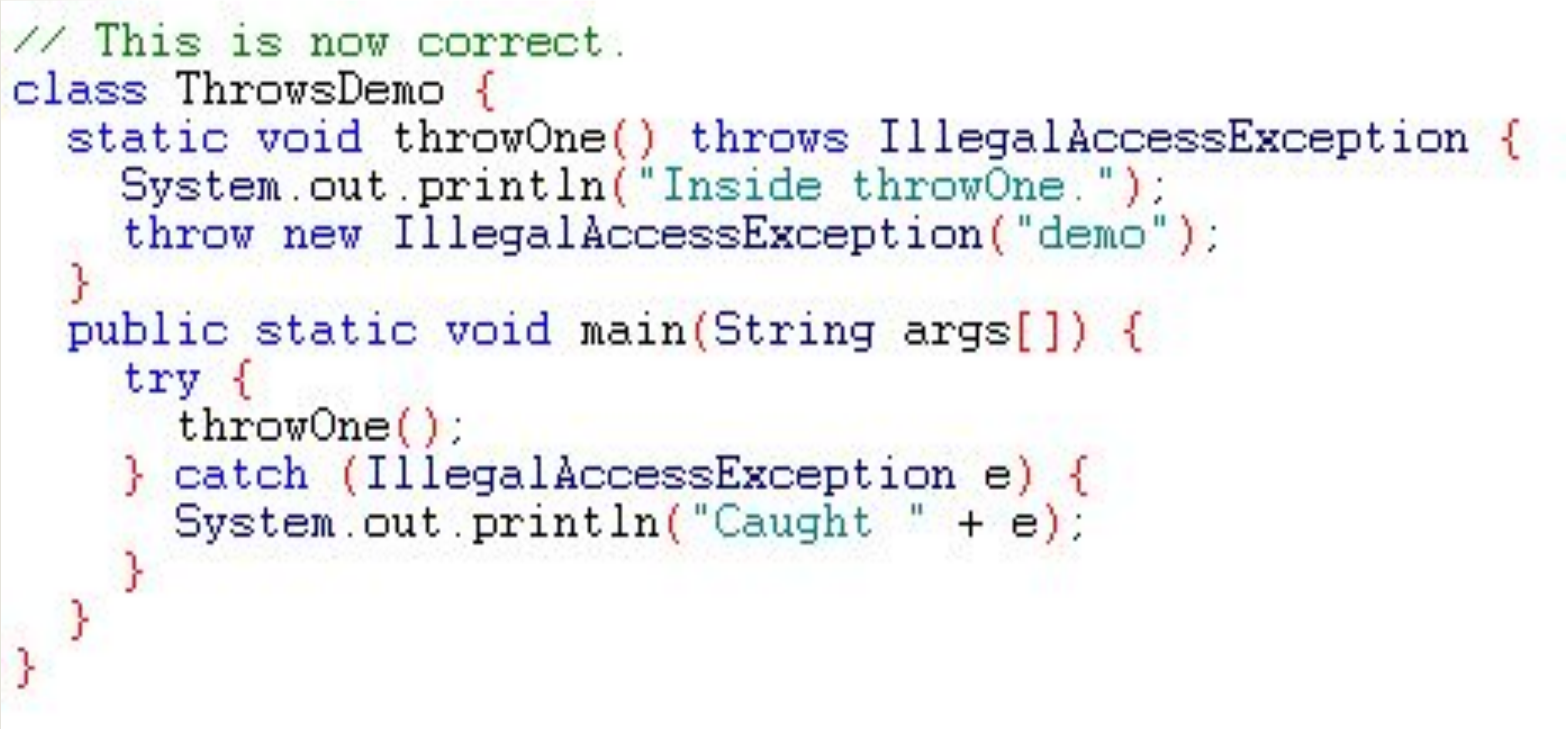
- It is not applicable for **Error** or **RuntimeException,** or any of their subclasses

Example: incorrect program



```
// This program contains an error and will not compile.
class ThrowsDemo {
  static void throwOne() {
    System.out.println("Inside throwOne.");
    throw new IllegalAccessException("demo");
  }
  public static void main(String args[]) {
    throwOne();
  }
}
```

Example: corrected version



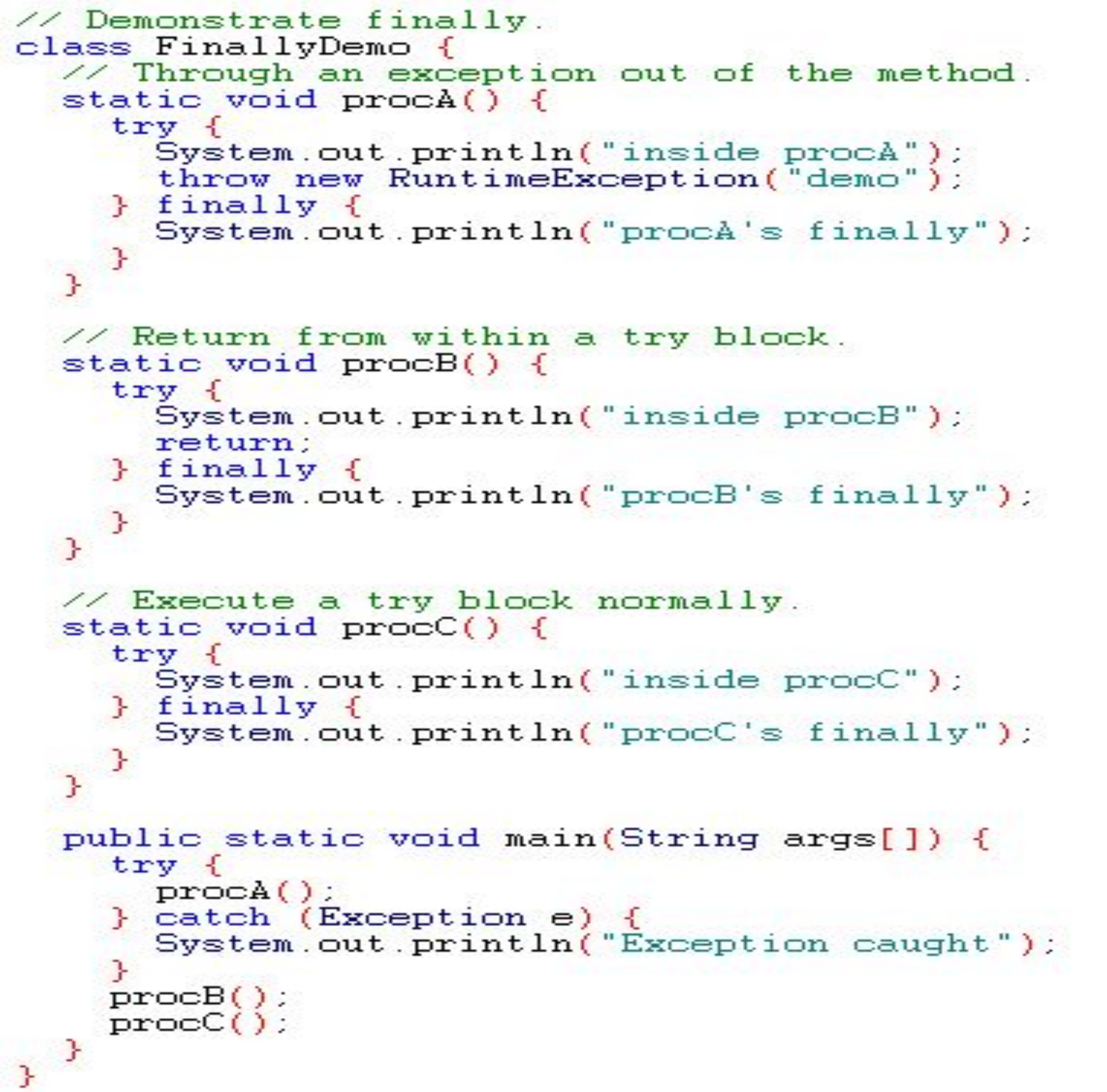
```java
// This is now correct.
class ThrowsDemo {
  static void throwOne() throws IllegalAccessException {
    System.out.println("Inside throwOne.");
    throw new IllegalAccessException("demo");
  }
  public static void main(String args[]) {
    try {
      throwOne();
    } catch (IllegalAccessException e) {
      System.out.println("Caught " + e);
    }
  }
}
```

Output:

```
Inside throwOne.

Caught java.lang.IllegalAccessException: demo
```

Example



```
// Demonstrate finally.
class FinallyDemo {
  // Through an exception out of the method.
  static void procA() {
    try {
      System.out.println("inside procA");
      throw new RuntimeException("demo");
    } finally {
      System.out.println("procA's finally");
    }
  }

  // Return from within a try block.
  static void procB() {
    try {
      System.out.println("inside procB");
      return;
    } finally {
      System.out.println("procB's finally");
    }
  }

  // Execute a try block normally.
  static void procC() {
    try {
      System.out.println("inside procC");
    } finally {
      System.out.println("procC's finally");
    }
  }

  public static void main(String args[]) {
    try {
      procA();
    } catch (Exception e) {
      System.out.println("Exception caught");
    }
    procB();
    procC();
  }
}
```

Output

```
inside procA
procA's finally
Exception caught
inside procB
procB's finally
inside procC
procC's finally
```

User-Defined Exceptions

- Problem Statement :
    - Consider the example of the Circle class
    - Circle class had the following constructor

```
public Circle(double centreX, double centreY,
                          double radius){
     x  = centreX; y = centreY;  r = radius;
}
```

- How would we ensure that the radius is not zero or negative?

Defining your own exceptions

```
import java.lang.Exception;
class InvalidRadiusException extends Exception {

        private double r;

        public InvalidRadiusException(double radius){
                r = radius;
        }
        public void printError(){
              System.out.println("Radius [" +  r + "] is not valid");
        }
}
```

Throwing the exception

```
class Circle    {
        double x, y, r;

       public Circle (double centreX, double centreY, double
radius ) throws InvalidRadiusException {
        if (r <= 0 ) {
                throw new InvalidRadiusException(radius);
        }
        else {
                x = centreX ; y = centreY;  r = radius;
        }
      }
}
```

Catching the exception

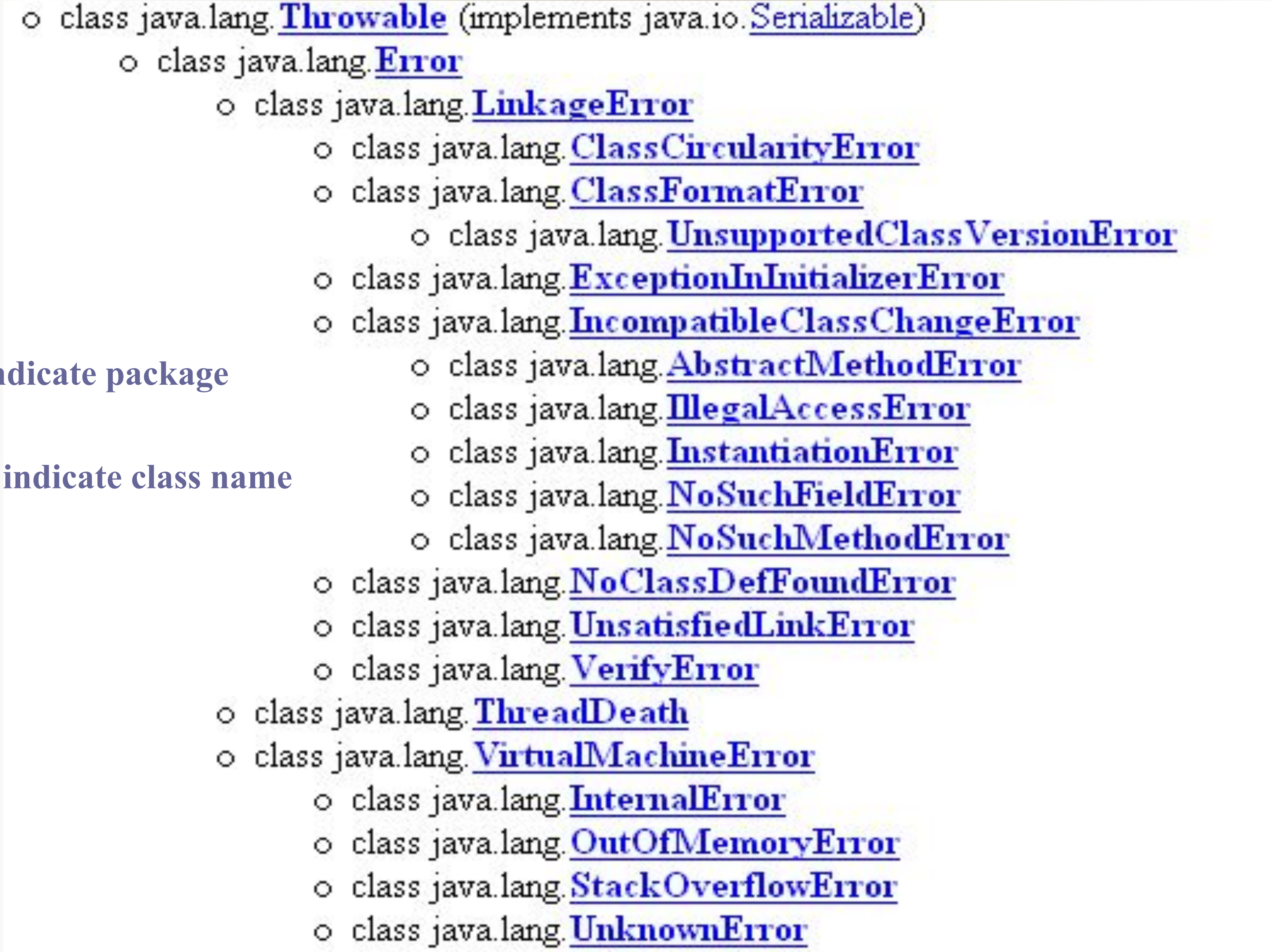
```
  class CircleTest {
      public static void main(String[] args){
       try{
              Circle c1 = new Circle(10, 10, -1);
              System.out.println("Circle created");
       }
       catch(InvalidRadiusException e)
       {
              e.printError();
       }
      }
}
```

User-Defined Exceptions in standard format

```
class MyException extends Exception
{
        MyException(String message)
        {
                super(message); // pass to superclass if parameter is not handled by used defined exception
        }
}
class TestMyException {
…
  try {
        ..
        throw new MyException(“This is error message”);
        }
        catch(MyException e)
        {
                System.out.println(“Message is: “+e.getMessage());
        }
  }
}
```

Get Message is a method defined in a standard Exception class.

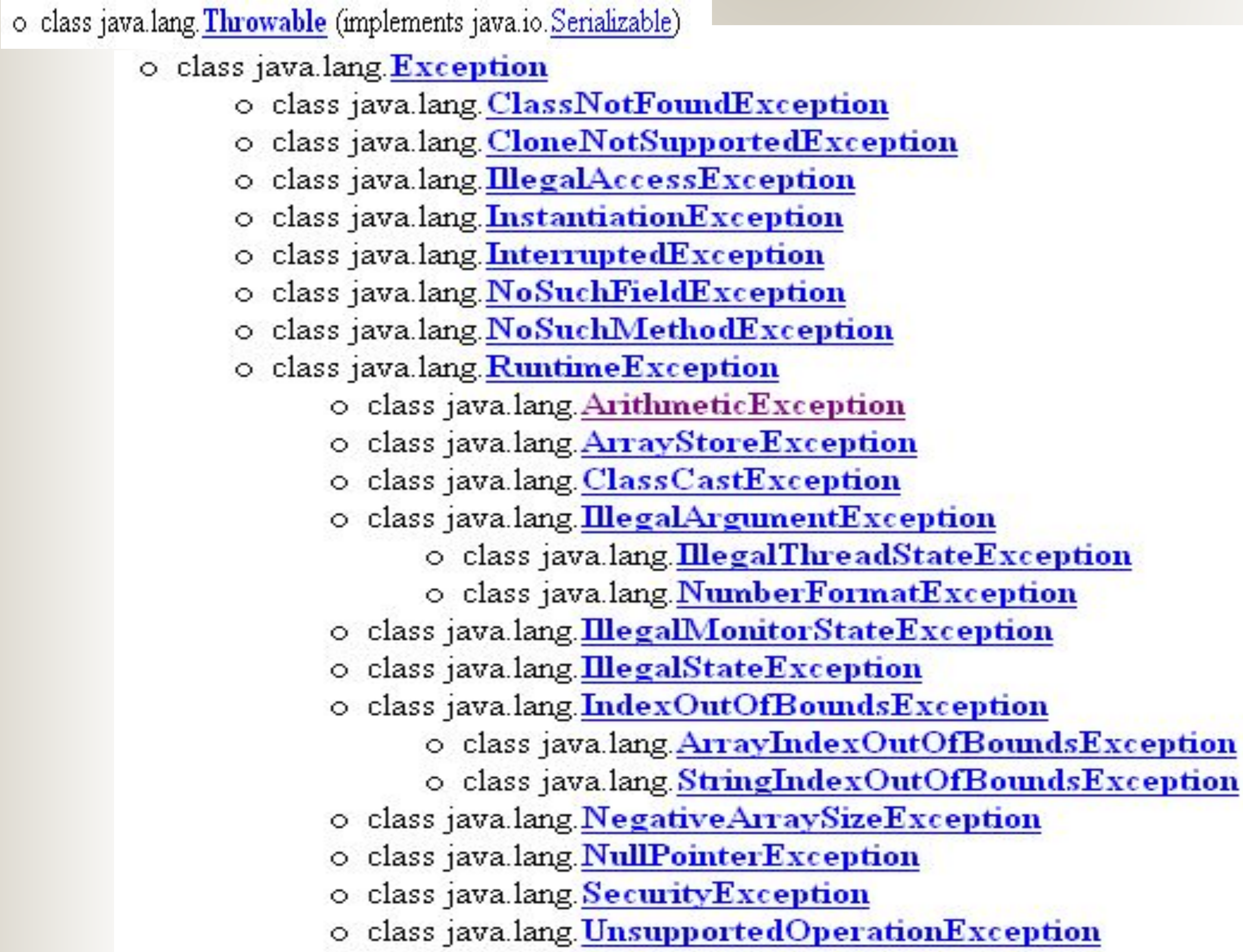
Java’s Built-in Errors



- class java.lang.Throwable (implements java.io.Serializable)
  - class java.lang.Error
    - class java.lang.LinkageError
      - class java.lang.ClassCircularityError
      - class java.lang.ClassFormatError
        - class java.lang.UnsupportedClassVersionError
      - class java.lang.ExceptionInInitializerError
      - class java.lang.IncompatibleClassChangeError
        - class java.lang.AbstractMethodError
        - class java.lang.IllegalAccessError
        - class java.lang.InstantiationError
        - class java.lang.NoSuchFieldError
        - class java.lang.NoSuchMethodError
      - class java.lang.NoClassDefFoundError
      - class java.lang.UnsatisfiedLinkError
      - class java.lang.VerifyError
    - class java.lang.ThreadDeath
    - class java.lang.VirtualMachineError
      - class java.lang.InternalError
      - class java.lang.OutOfMemoryError
      - class java.lang.StackOverflowError
      - class java.lang.UnknownError

- **Small letter indicate package name**
- **Capital letter indicate class name**

Java’s Built-in Exceptions



- class java.lang.Throwable (implements java.io.Serializable)
    - class java.lang.Exception
        - class java.lang.ClassNotFoundException
        - class java.lang.CloneNotSupportedException
        - class java.lang.IllegalAccessException
        - class java.lang.InstantiationException
        - class java.lang.InterruptedException
        - class java.lang.NoSuchFieldException
        - class java.lang.NoSuchMethodException
        - class java.lang.RuntimeException
            - class java.lang.ArithmeticException
            - class java.lang.ArrayStoreException
            - class java.lang.ClassCastException
            - class java.lang.IllegalArgumentException
                - class java.lang.IllegalThreadStateException
                - class java.lang.NumberFormatException
            - class java.lang.IllegalMonitorStateException
            - class java.lang.IllegalStateException
            - class java.lang.IndexOutOfBoundsException
                - class java.lang.ArrayIndexOutOfBoundsException
                - class java.lang.StringIndexOutOfBoundsException
            - class java.lang.NegativeArraySizeException
            - class java.lang.NullPointerException
            - class java.lang.SecurityException
            - class java.lang.UnsupportedOperationException