BBM 102 – Introduction to Programming II

Exceptions

Today

- What is an exception?
- What is exception handling?
- Keywords of exception handling
  - try
  - catch
  - finally
- Throwing exceptions
  - throw
  - custom exception classes
- Getting data from an exception object
- Checked and unchecked exceptions
  - throws

Errors

Syntax errors

- arise because the rules of the language have not been followed.
- detected by the compiler.

Logic errors

- lead to wrong results and detected during testing.
- arise because the logic coded by the programmer was not correct.

Runtime errors

- occur when the program is running and the environment detects an operation that is impossible to carry out.

Errors

Code errors

- Divide by zero
- Array out of bounds
- Integer overflow
- Accessing a null pointer (reference)

Programs *crash* when an exception goes untrapped, i.e., not handled by the program.

Runtime Errors

```
1  import java.util.Scanner;
2
3  public class ExceptionDemo {
4    public static void main(String[] args) {
5      Scanner scanner = new Scanner(System.in);
6      System.out.print("Enter an integer: ");
7      int number = scanner.nextInt();
8
9      // Display the result
10     System.out.println(
11       "The number entered is " + number);
12   }
13 }
```

If an exception occurs on this line, the rest of the lines in the method are skipped and the program is terminated.

Terminated.

What is an exception?

An *exception* is an event, which occurs during the execution of a program, that disrupts the normal flow of the program's instructions.

Exception = Exceptional Event

What is an exception?

An exception is an abnormal condition that arises in a code sequence at **runtime**. For instance:

- Dividing a number by zero
- Accessing an element that is out of bounds of an array
- Attempting to open a file which does not exist

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.

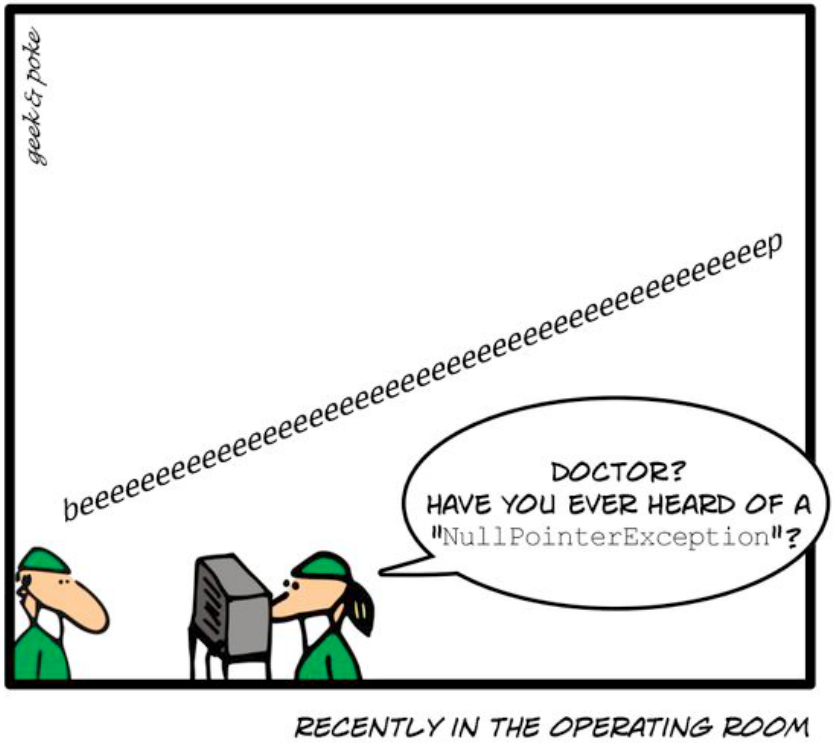
An exception can be caught to handle it or it can be passed on.

Exceptions can be generated by the Java run-time system, or they can be manually generated by your code.

Exceptions

A Method in Java throws exceptions to tell the calling code:

"*Something bad happened. I failed.*"


geek & poke
beeee

What is an exception? (Example)

```
1- public class ExceptionExample {
2-    public static void main(String[] args) {
3-        int dividend = 5;
4-        int divisor = 0;
5-        int division = dividend / divisor;  // !!! Division by zero!
6-        System.out.println(" Result: " + division);
7-    }
8- }
```

Program "*crashes*" on the 5th line and the output is:

Exception in thread "main" java.lang.ArithmeticException: / by zero

at ExceptionExample.main(ExceptionExample.java:5)

Does the program really "crash"?

- Division by zero is an abnormal condition!
- Java run-time system cannot execute this condition normally.
- Java run-time system creates an exception object for this condition and *throws* it.
- This exception can be caught in order to overcome the abnormal condition and to make the program continue.
- There is no exception handling code in the example program, so JVM terminates the program and displays what went wrong and where it was. Remember the output:

*Exception in thread "main" java.lang.ArithmeticException: **/ by zero***

*at ExceptionExample.main(**ExceptionExample.java:5**)*

What is exception handling?

Exception mechanism gives the programmer a chance to do something against an abnormal condition.

Exception handling is performing an action in response to an exception.

This action may be:

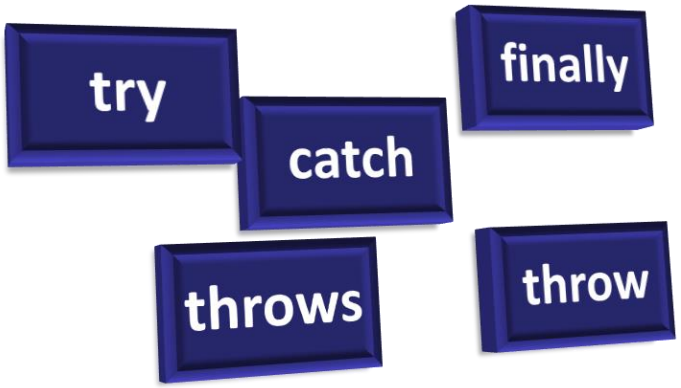
- Exiting the program
- Retrying the action with or without alternative data
- Displaying an error message and warning user to do something
- ...

Keywords of Exception Handling

There are five keywords in Java to deal with exceptions: **try, catch, throw, throws** and **finally.**

try: Creates a block to monitor if any exception occurs.

catch: Follows the try block and catches any exception which is thrown within it.



Let's *try* and *catch*

```
1-  public class ExceptionExample {
2-    public static void main(String[] args) {
3-      try {
4-          int dividend = 5;
5-          int divisor = 0;
6-          int division = dividend / divisor;  // !!! Division by zero!
7-          System.out.println(" Result: " + division);
8-      } catch (Exception e) {
9-          System.out.println ("Exception occurred and handled!" );
10-     }
11-   }
12- }
```

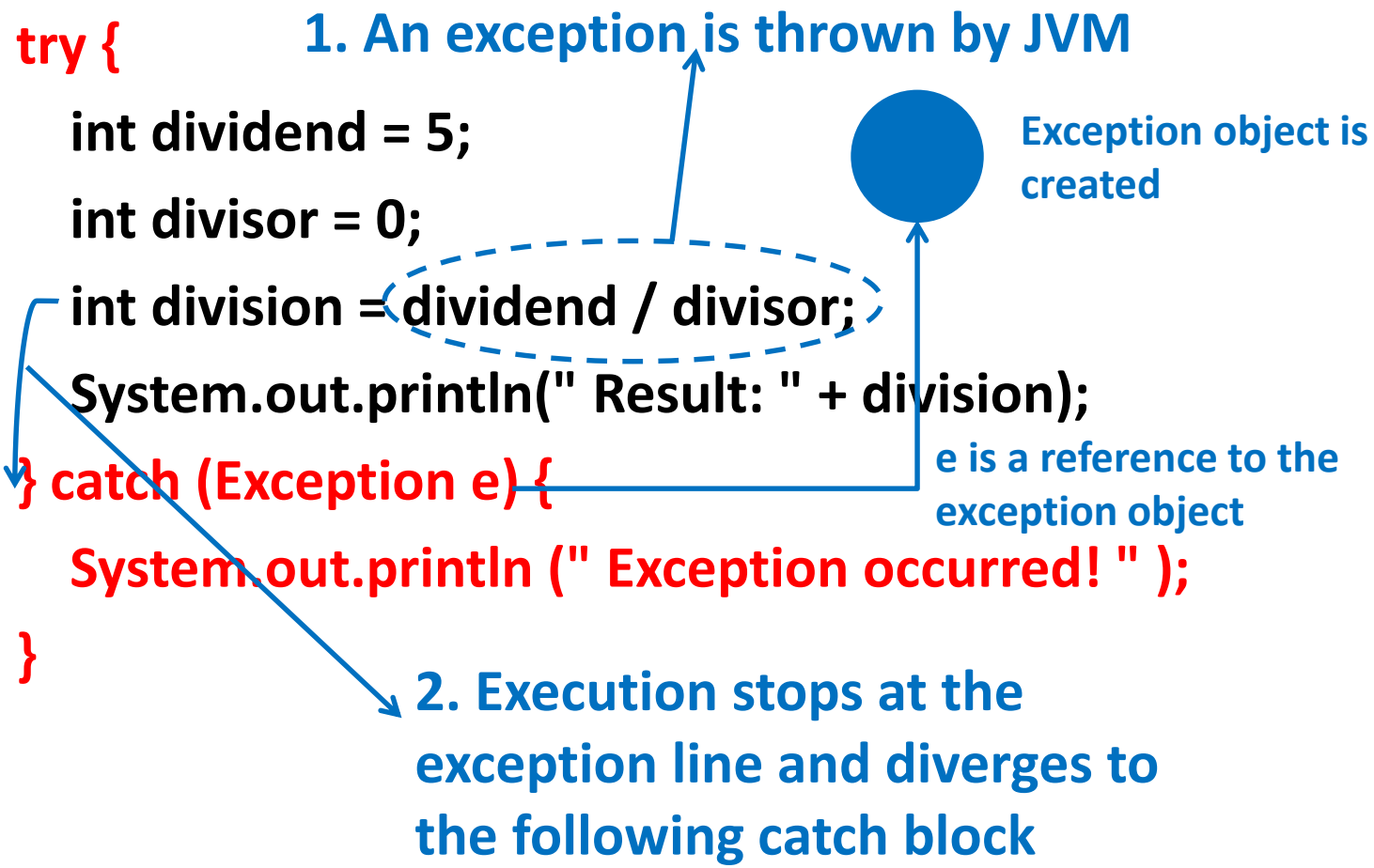
What happens when we *try* and *catch*?

- **int division = dividend / divisor;** statement causes an exception.
- Java run-time system throws an exception object that includes data about the exception.
- Execution stops at the 6th line, and a catch block is searched to handle the exception.
- Exception is caught by the 8th line and execution continues by the 9th line.
- Output of the program is:

Exception occurred and handled!

Let's visualize it!

```
1-  public class ExceptionExample {
2-    public static void main(String[] args) {
3-      try {
4-        int dividend = 5;
5-        int divisor = 0;
6-        int division = dividend / divisor;
7-        System.out.println(" Result: " + division);
8-      } catch (Exception e) {
9-        System.out.println (" Exception occurred! " );
10-     }
11-   }
12- }
```



try and catch statement

- The scope of a **catch** clause is restricted to those statements specified by the immediately preceding **try** statement.
- A **catch** statement cannot catch an exception thrown by another **try** statement.
- The statements that are protected by the **try** must be surrounded by curly braces.

Are there many exceptions in Java?

Yes! Check the Java API Documentation at
http://docs.oracle.com/javase/8/docs/api/
https://docs.oracle.com/en/java/javase/17/docs/api/

`java.lang.Exception` is the base class of the exception hierarchy

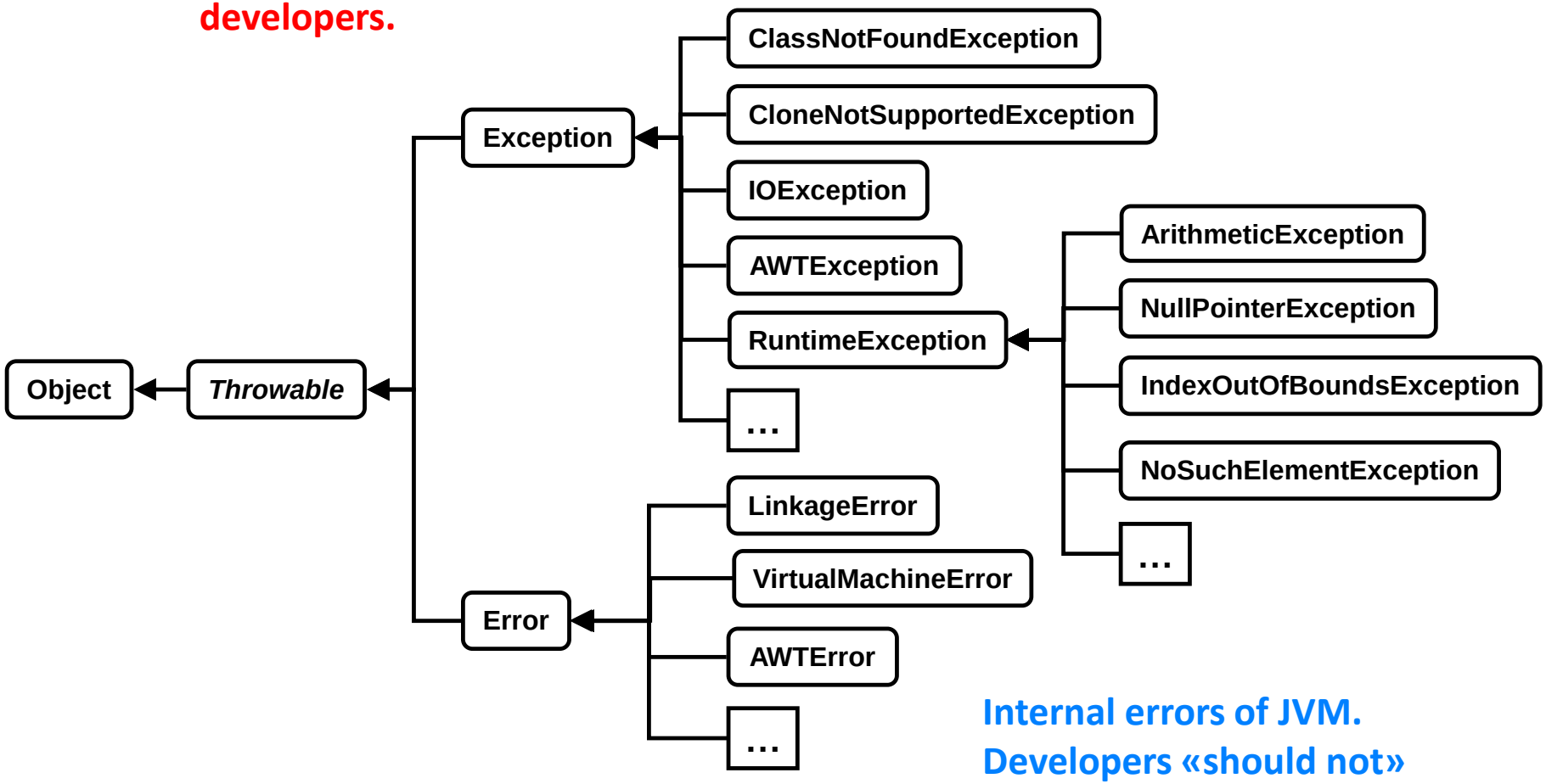
There are many direct and indirect subclasses of java.lang.Exception, for example

- `java.lang.ArithmeticException`
- `java.lang.ArrayIndexOutOfBoundsException`
- `java.lang.NullPointerException`
- `java.io.IOException`
- `java.io.FileNotFoundException`

We can also write custom exception classes.

Hierarchy of Exception Classes in Java

Exceptions handled by developers.



Internal errors of JVM. Developers «should not» handle them

Multiple catch clauses

It is possible that more than one exception can be thrown in a code block.

- We can use multiple **catch** clauses.

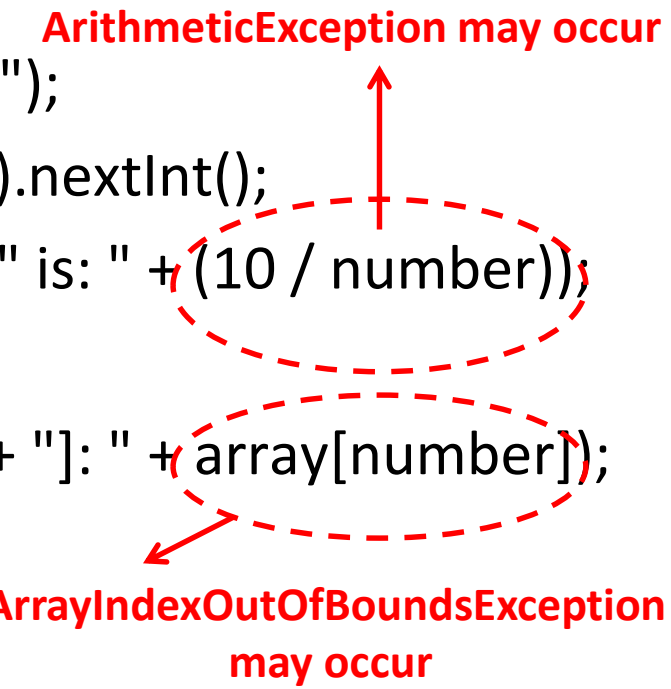
When an exception is thrown, each **catch** statement is inspected in order, and the first one whose type *matches* that of the exception is executed.

- Type matching means that the exception thrown must be an object of the same class or a sub-class of the declared class in the **catch** statement

After one **catch** statement executes, the others are bypassed.

Multiple catch statement example

```
try {
   System.out.print("Give me an integer: ");
   int number = (new Scanner(System.in)).nextInt();
   System.out.println("10 / " + number + " is: " + (10 / number));
   int array[] = new int[]{1, 2, 3, 4, 5};
   System.out.println("array[" + number + "]: " + array[number]);
}
catch (ArithmeticException e) {
   System.out.println("Division by zero is not possible!");
}
catch (ArrayIndexOutOfBoundsException e) {
   System.out.println("Number is out of the array!");
}
```



Multiple catch statement example

1st scenario: Assume that user enters value 2. What is the output of the program?

```
Give me an integer: 2
10 / 2 is: 5
array[2] is: 3
```

2nd scenario: Assume that user enters value 5. What is the output of the program?

```
Give me an integer: 5
10 / 5 is: 2
Number is out of the array!
```

3rd scenario: Assume that user enters value 0. What is the output of the program?

```
Give me an integer: 0
Division by zero is not possible!
```

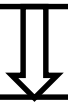
Multiple catch clauses and inheritance

If there is inheritance between the exception classes which are written in catch clauses;

- Exception subclass must come before any of their superclasses.
- 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 comes after its superclass.

```
catch (Exception e) {
}
catch (ArithmeticException e) {
}
```

Compile error! Second clause is unnecessary, because first clause will catch any exception!



```
catch (ArithmeticException e) {
}
catch (Exception e) {
}
```

It is OK now! Any exception other than an ArithmeticException will be caught by the second clause!

More on multiple catch clauses

Multiple catch clauses give programmer the chance to take different actions for each exception

..., but a new catch clause for each possible exception will possibly make the code so complex

A single catch clause with the java.lang.Exception will catch any exception thrown

..., but the programmer will not know which exception was thrown!

Confused about multiple catch clauses?

Programmer decides on the details of the exception handling strategy

- If it is just enough to know that something went wrong and the same action will be taken for all exceptions (for instance; displaying a message), then **use a single catch clause** with Exception!
- If it is really necessary to know which exception occurs and different actions will be taken for each exception, then **use multiple catch clauses!**

Catching Exceptions

```
try {
        //Statements that may throw exceptions
}

catch (Exception1 exVar1) {
  //code to handle exceptions of type Exception1;
}

catch (Exception2 exVar2) {
  // code to handle exceptions of type Exception2;
}

...
catch (ExceptionN exVarN) {
  // code to handle exceptions of type exceptionN;
}

// statement after try-catch block
```

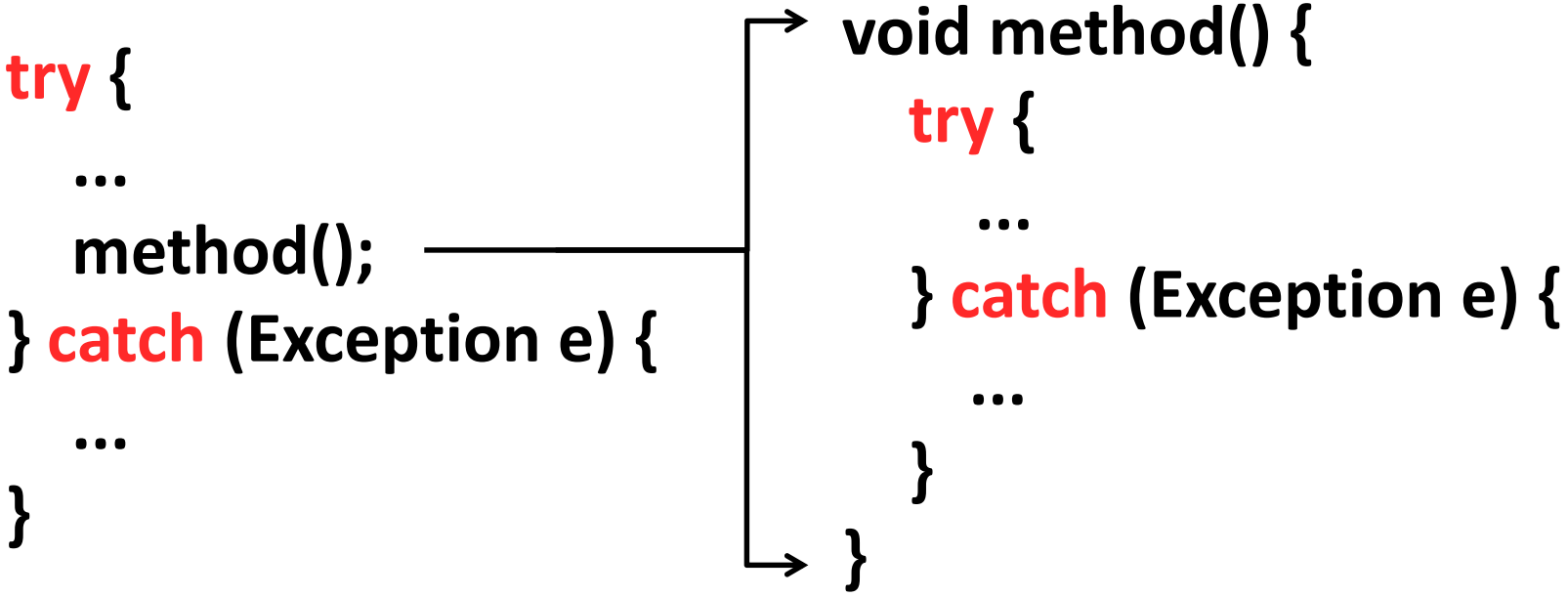
Nested try statements

A **try** block can include other **try** block(s)

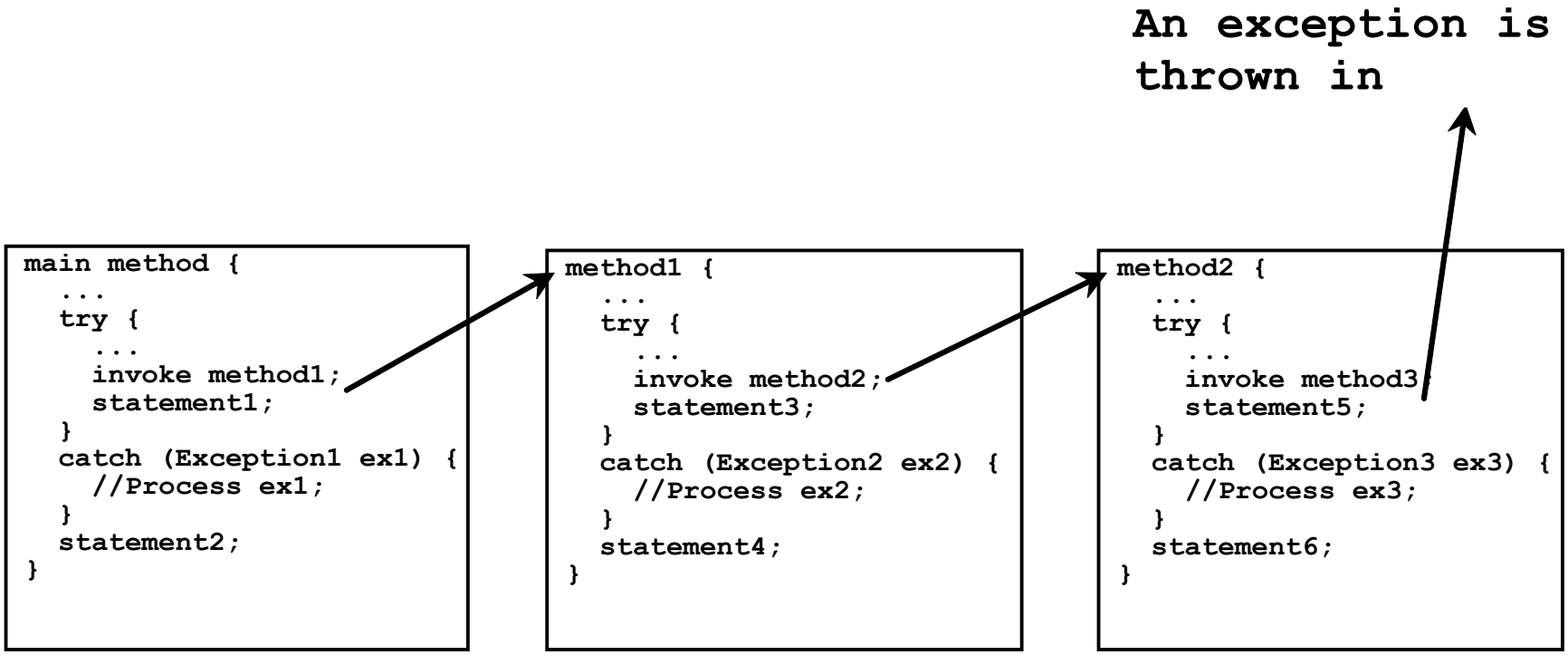
```
try {
    ...
    try {
            ...
    } catch (Exception e) {
            ...
    }
    ...
} catch (Exception e) {
    ...
}
```

Nested try statements

A try block can call a method which has a try block in it.



Nested try statements



Nested try statements

When an exception occurs inside a **try** block;

- If the **try** block does not have a matching catch, then the outer **try** statement's catch clauses are inspected for a match.
- If a matching catch is found, that catch block is executed.
- If no matching catch exists, execution flow continues to find a matching catch by inspecting the outer try statements.
- If a matching catch cannot be found, the exception will be caught by JVM's exception handler.

Caution! Execution flow never returns to the line that exception was thrown.

- This means, an exception is caught and catch block is executed, the flow will continue with the lines following this catch block.

Let's clarify it on various scenarios

```
try {
   statement1;
   try {
            statement2;
   } catch (Exception1 e) {
            statement3;
   } catch (Exception2 e) {
            statement4;
   }
   try {
            statement5;
   } catch (Exception3 e) {
            statement6;
   }
   statement7;
} catch (Exception3 e) {
   statement8;
}
statement9;
```

Information: Exception1 and Exception2 are subclasses of Exception3

Question: Which statements are executed if

1- statement1 throws Exception1

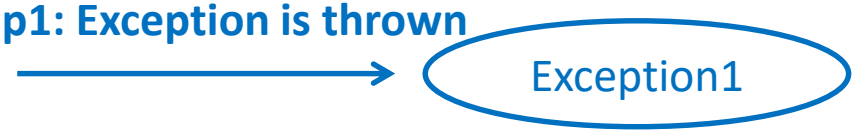
2- statement2 throws Exception1

3- statement2 throws Exception3

4- statement2 throws Exception1 and statement3 throws Exception2

Scenario: statement1 throws Exception1

```
try {
   statement1;
   try {
            statement2;
   } catch (Exception1 e) {
            statement3;
   } catch (Exception2 e) {
            statement4;
   }
   try {
            statement5;
   } catch (Exception3 e) {
            statement6;
   }
   statement7;
} catch (Exception3 e) {
   statement8;
}
statement9;
```



Step2: catch clauses of the try block are inspected for a matching catch statement. Exception3 is super class of Exception1, so it matches.

Step3: statement8 is executed, exception is handled and execution flow will continue bypassing the following catch clauses

Step4: statement9 is executed

Scenario: statement2 throws Exception1

```
try {
   statement1;
   try {
            statement2;
   } catch (Exception1 e) {
            statement3;
   } catch (Exception2 e) {
            statement4;
   }
   try {
            statement5;
   } catch (Exception3 e) {
            statement6;
   }
   statement7;
} catch (Exception3 e) {
   statement8;
}
statement9;
```

Step1: Exception is thrown

Step2: catch clauses of the try block are inspected for a matching catch statement. First clause catches the exception

Step3: statement3 is executed, exception is handled

Step4: execution flow will continue bypassing the following catch clauses. statement5 is executed.

Step5: Assuming no exception is thrown by statement5, program continues with statement7 and statement9.

Scenario: statement2 throws Exception3

```
try {
   statement1;
   try {
         statement2;
   } catch (Exception1 e) {
         statement3;
   } catch (Exception2 e) {
         statement4;
   }
   try {
         statement5;
   } catch (Exception3 e) {
         statement6;
   }
   statement7;
} catch (Exception3 e) {
   statement8;
}
statement9;
```

Step1: Exception is thrown

Exception3

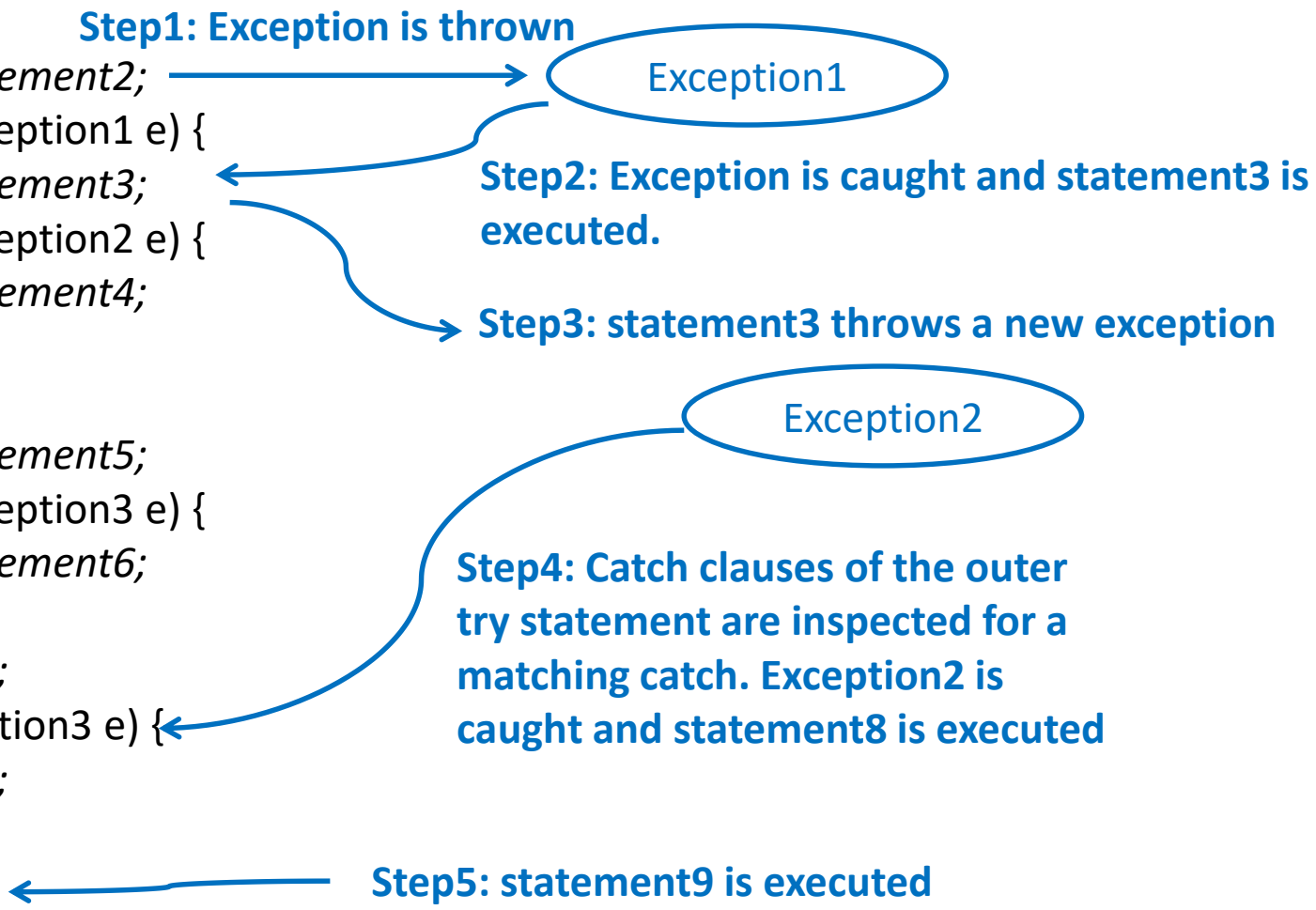
Step2: catch clauses of the try block are inspected for a matching catch statement. None of these catch clauses match Exception3

Step3: Catch clauses of the outer try statement are inspected for a matching catch. Exception3 is caught and statement8 is executed

Step4: statement9 is executed

Scenario: statement2 throws Exception1 and statement3 throws Exception2

```
try {
   statement1;
   try {
         statement2;
   } catch (Exception1 e) {
         statement3;
   } catch (Exception2 e) {
         statement4;
   }
   try {
         statement5;
   } catch (Exception3 e) {
         statement6;
   }
   statement7;
} catch (Exception3 e) {
   statement8;
}
statement9;
```



finally

finally creates a block of code that will be executed after a **try/catch** block has completed and before the following **try/catch** block.

finally block is executed whether or not exception is thrown.

finally block is executed whether or not exception is caught.

It is used to gurantee that a code block will be executed in any condition.

finally

Use *finally* clause for code that must be executed "no matter what"

```
try {
        //Statements that may throw exceptions
}

catch (Exception1 exVar1) {
  //code to handle exceptions of type Exception1;
}

catch (Exception2 exVar2) {
  // code to handle exceptions of type Exception2;
}
...
catch (ExceptionN exVar3) {
  // code to handle exceptions of type exceptionN;
}

finally { // optional
   // code executed whether there is an exception or
  not
}
```

Let's clarify it on various scenarios

```
try {
        statement1;
} catch (Exception1 e) {
        statement2;
} catch (Exception2 e) {
        statement3;
} finally {
    statement4;
}
statement5;
```

Question: Which statements are executed if

1- no exception occurs

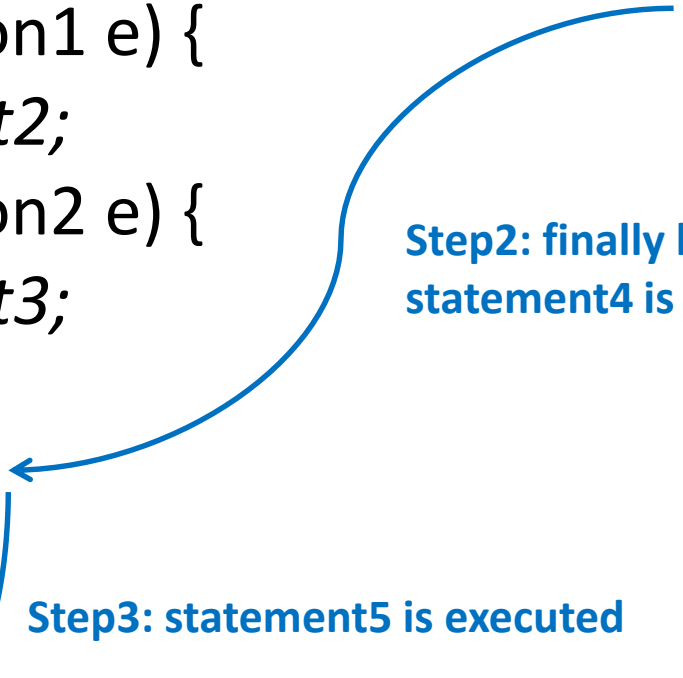
2- statement1 throws Exception1

3- statement1 throws Exception3

Scenario: no exception occurs

```
try {
        statement1;
} catch (Exception1 e) {
        statement2;
} catch (Exception2 e) {
        statement3;
} finally {
    statement4;
}
statement5;
```


Step1: statement1 is executed

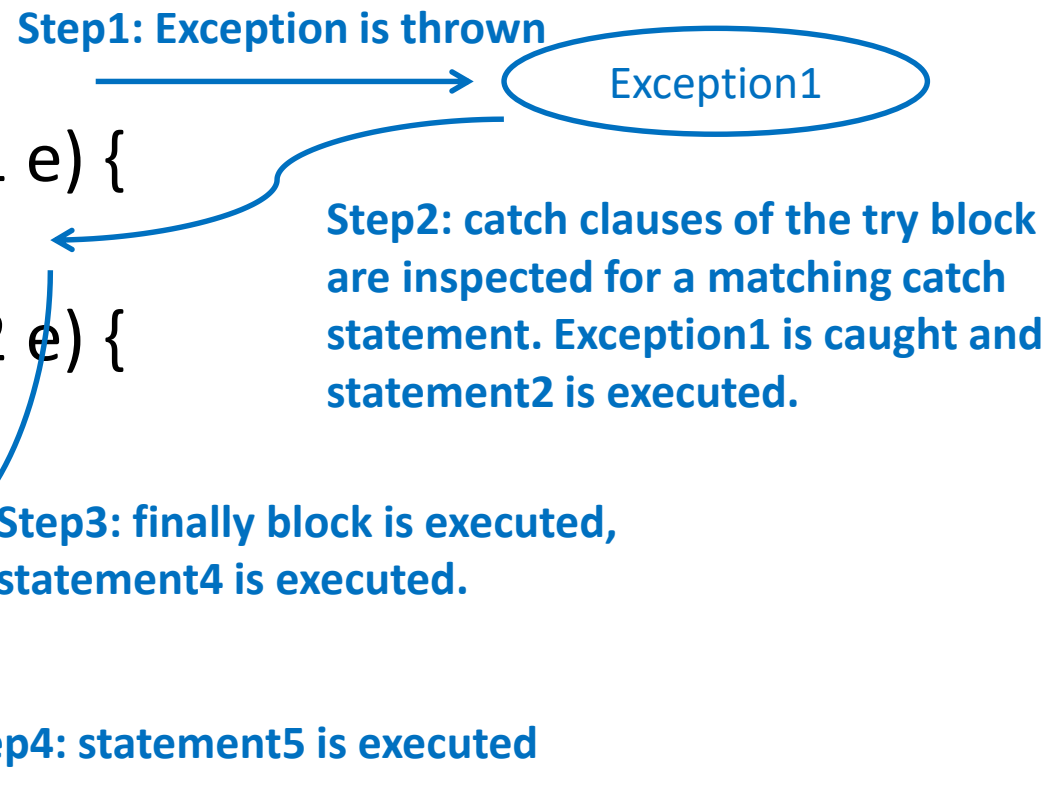


Step2: finally block is executed, statement4 is executed

Step3: statement5 is executed

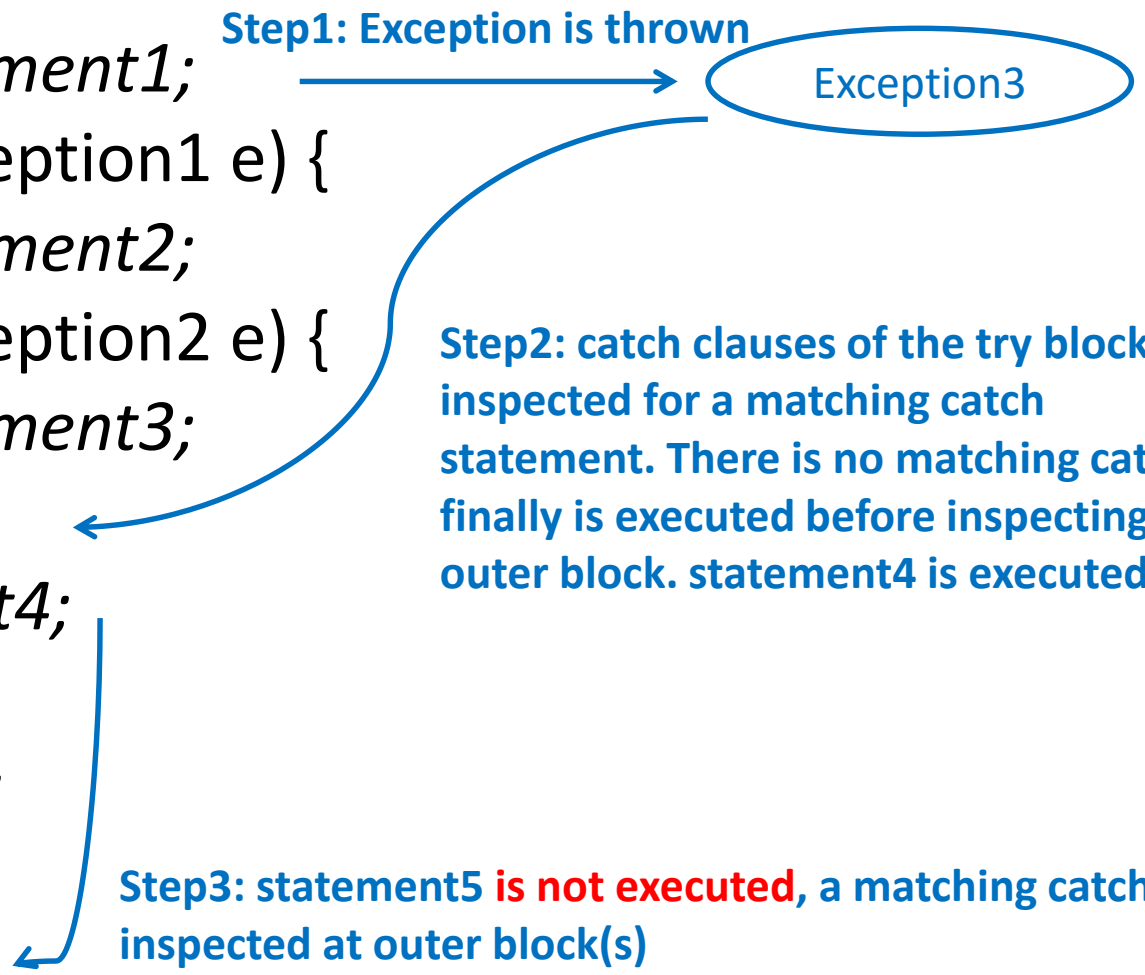
Scenario: statement1 throws Exception1

```
try {
        statement1;
} catch (Exception1 e) {
        statement2;
} catch (Exception2 e) {
        statement3;
} finally {
    statement4;
}
statement5;
```



Scenario: statement1 throws Exception3

```
try {
        statement1;
} catch (Exception1 e) {
        statement2;
} catch (Exception2 e) {
        statement3;
} finally {
    statement4;
}
statement5;
```



throw

Developer can *throw* exceptions. Keyword **throw** is used for this purpose:

throw *ThrowableObject*

ThrowableObject is the object to be thrown. It must directly or indirectly extend the class **java.lang.Throwable.**

Developer can create a new object of an exception class, or rethrow the caught exception.

Throwing and rethrowing example

```
import java.util.Scanner;

public class ThrowingExample {
	public static void main(String[] args) {
		System.out.print("Give me an integer: ");
		int number = new Scanner(System.in).nextInt();
		try {
			if (number < 0)
				throw new RuntimeException();
			System.out.println("Thank you.");
		} catch (Exception e) {
			System.out.println("Number is less than 0!");
			throw e;
		}
	}
}
```

Keyword **throw** is used to throw an exception.

e is already reference of an exception object. It can also be used to throw (rethrow) that exception

Coding custom exception classes

Developer can also code custom exception classes to manage abnormal conditions in his program

If a class extends Throwable, that class can be thrown

We usually prefer to extend class Exception or RuntimeException (difference of these two will be explained).

Extending an exception class and coding necessary constructors is enough to create a custom exception class.

Custom exception example

```
public class LessThanZeroException extends Exception {
        public LessThanZeroException() {
        }
        public LessThanZeroException(String message) {
                super(message);
        }
}
import java.util.Scanner;
public class ThrowingExample {
    public static void main(String[] args) {
        System.out.print("Give me an integer: ");
        int number = new Scanner(System.in).nextInt();
        try {
            if (number < 0)
                throw new LessThanZeroException();
            System.out.println("Thank you.");
        } catch (LessThanZeroException e) {
            System.out.println("Number is less than 0!");
        }
    }
}
```

Getting data from the exception object

Throwable overrides the **toString()** method (defined by class **Object**) so that it returns a string containing a description of the exception

Example:

```
catch(ArithmeticException e) {
        System.out.println("Exception is: " + e);
}
```

Output:

```
Exception is: java.lang.ArithmeticException: / by zero
```

Getting data from the exception object

- **Throwable** class also has useful methods. One of these methods is the **getMessage()** method
- The message that is put in the exception (via the constructor with String parameter) can be taken by **getMessage()** method

Example:

```
catch(ArithmeticException e) {
        System.out.println("Problem is: " + e.getMessage());
}
```

Output:

Problem is: / by zero

Getting data from the exception object

- Another method is the **printStackTrace()** method.
- This method is used to see what happened and where.

Example:

```
catch(ArithmeticException e) {
        e.printStackTrace();
}
```

Output:

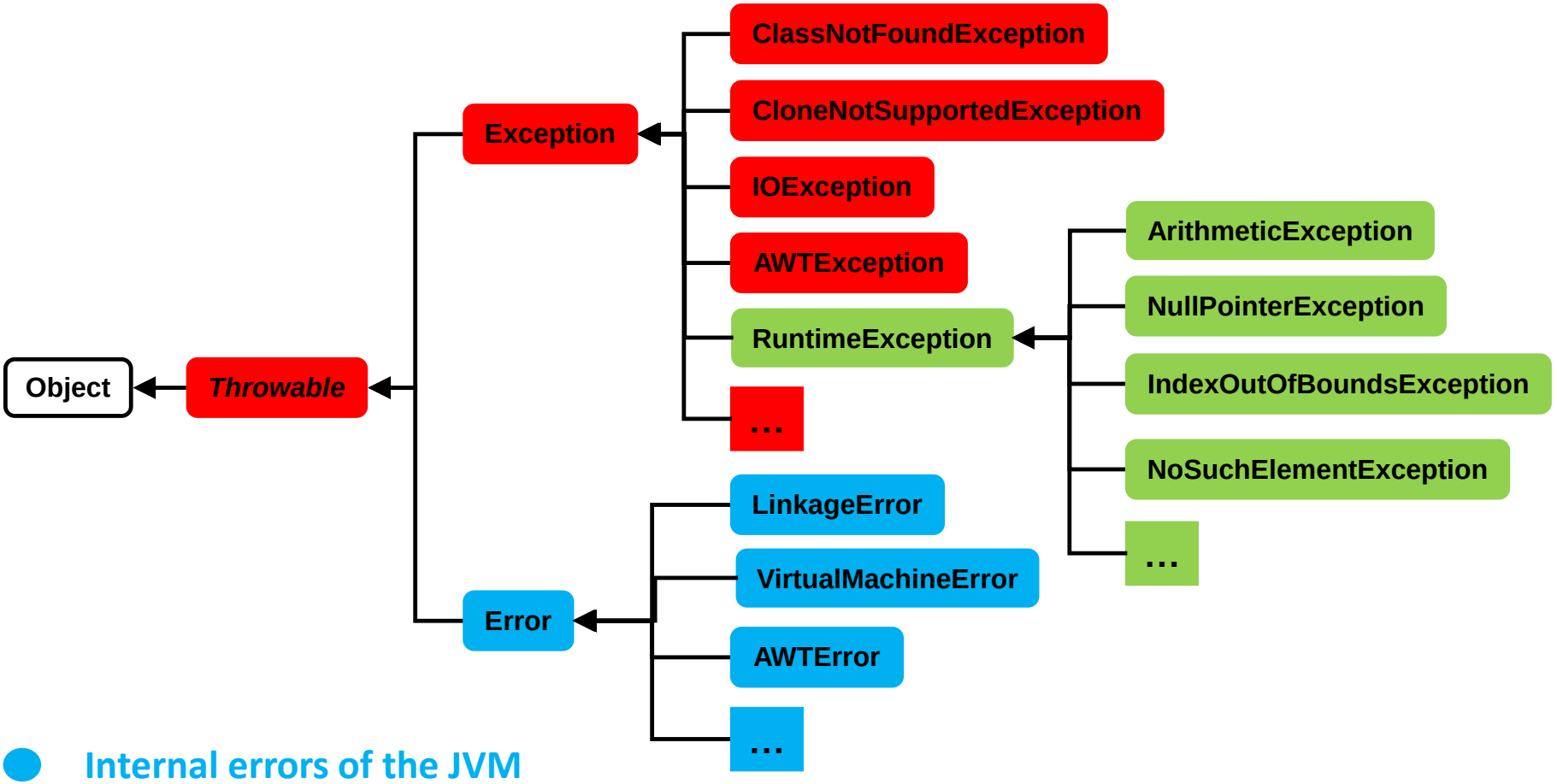
```
java.lang.ArithmeticException: / by zero
        at ExceptionExample.main(ExceptionExample.java:6)
```

This output means:
A java.lang.ArithmeticException occurred at 6th line of the main method of the ExceptionExample class

Did you recognize that... ?

- The output of the **printStackTrace()** method is very similar to the output you have seen before...
- You have seen it when your programs crashed!
- When an exception is not caught by the program, JVM catches it and prints the stack trace to the console.
- This output is very helpful to find the errors in the program.

Checked and Unchecked Exceptions



What does *Checked Exception* mean?

- If a method will possibly throw an exception, compiler *checks* the type of the exception
- if the exception is a checked exception, compiler forces the developer to do one of these:
  - write a matching catch statement for that exception.
  - declare that the method will possibly throw that exception.

Handling Checked Exceptions

Java forces you to deal with checked exceptions.

Two possible ways to deal:

```
void p1() {
  try {
    riskyMethod();
  }
  catch (IOException ex) {
    ...
  }
}
```

(a)

```
void p1() throws IOException {

  riskyMethod();

}
```

(b)

throws

Keyword **throws** is used to declare that a method is capable of throwing exception(s).

Callers of the method can guard themselves against that exception(s).

Examples:

```
public void m1() throws Exception1 {
}

public void m2() throws Exception1, Exception2, Exception3 {
}
```

CheckedExceptionExample1

```
import java.io.BufferedReader;
import java.io.FileReader;
import java.io.IOException;

public class CheckedExceptionExample1 {
	public static void main(String[] args) {
		System.out.println("Line: " + readALine1("input.txt"));
	}

	public static String readALine1(String filename) {
		try {
			BufferedReader inputFile = new BufferedReader(new FileReader("a.txt"));
			String line = inputFile.readLine();
			inputFile.close();
			return line;
		} catch (IOException e) {
			e.printStackTrace();
			return null;
		}
	}
}
```

FileNotFoundException may be thrown here

IOException may be thrown here

IOException is super class of FileNotFoundException

CheckedExceptionExample2

```
import java.io.BufferedReader;
import java.io.FileReader;
import java.io.IOException;

public class CheckedExceptionExample2 {
	public static void main(String[] args) {
		try {
			System.out.println("Line: " + readALine2("input.txt"));
		} catch (IOException e) {
			e.printStackTrace();
		}
	}

	public static String readALine2(String filename) throws IOException {
		BufferedReader inputFile = new BufferedReader(new FileReader("a.txt"));
		String line = inputFile.readLine();
		inputFile.close();
		return line;
	}
}
```

IOException is superclass of FileNotFoundException. No need to declare both.

FileNotFoundException may be thrown here

IOException may be thrown here

What does *Unchecked Exception* mean?

If a code block has the possibility of throwing an unchecked exception, compiler does not force the developer for anything. It is up to the developer to do one of these:

- to handle the exception
- let the program crash

Does a developer let his program crash?

Unchecked exceptions are usually results of the developer's mistakes.

- For example, if a reference may normally be null, then it is developer's responsibility to check if it is null or not. NullPointerException should not occur in this scenario!
- Letting program crash at the development phase will make the developer find such errors and potential bugs.

Summary

- Exceptions are used to take actions against abnormal conditions.
- Exceptions are objects which are *thrown* by JVM or the developer's code.
- There are many exception classes in standard java library, and custom exception classes can be coded.
- Exception handling is *catching* an exception and taking an action against it.
- Keywords **try**, **catch**, and **finally** are used for exception handling.
- Exceptions are classified as unchecked (RuntimeException class and its subclasses), or checked (Throwable class and its subclasses, except Error and RuntimeException).
- If a method has the capability of throwing a checked exception, it must either handle the exception (with try/catch blocks), or declare it with keyword **throws.**

References

Ganesh Wisvanathan, CIS3023: Programming Fundamentals for CIS Majors II, University of Florida