Intro. & Learning Objectives

Method execution and exception propagation

Exception handling

Checked exceptions

Unchecked exceptions

SFWR ENG/COMP SCI 2S03 Principles of Programming

Dr. Ridha Khedri

Department of Computing and Software, McMaster University
Canada L8S 4L7, Hamilton, Ontario

Acknowledgments: Material based on *Java actually: A Comprehensive Primer in Programming* (Chapter 10)

Topics Covered

1. Introduction and Learning Objectives
2. Method execution and exception prpgtion
    - Method execution
    - Stack trace
    - Exception propagation
3. Exception handling
    - **try-catch** scenario 1: no exception
    - **try-catch** scenario 2: exception
    - **try-catch** scenario 3: exc. propagation
4. Checked exceptions
    - Checked exceptions using **throw**
    - Programming with checked exceptions
5. Unchecked exceptions

What is an exception?

- A program must be able to handle error situations gracefully when they occur at runtime
- This is the role of exception handling provided by Java
- Error situations can be divided into two main categories:
  - Programming errors (e.g., an invalid index to access an array)
    Ideally, they should not occur
  - Runtime environment errors (e.g., opening a file that does not exist)
    Should be properly handled

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Exception Handling
Introduction and Learning Objectives

- A program must be able to handle both kinds of errors
- An exception signals that an error or an unexpected situation has occurred during program execution
- It is based on the "throw and catch" principle
- An exception is thrown when an error situation occurs during program execution
- It is caught by an exception handler that takes an appropriate action to handle the situation

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- This principle is embedded in the try-catch statement
- All exceptions are objects
- Java standard library provides classes that represent different types of exception

Learning Objectives

- Use of exception handling to create programs that are reliable and robust
- Major scenarios of program execution when using the try-catch statement
- Understand how exceptions are thrown, propagated, caught and handled
- Understand the difference between checked and unchecked exceptions

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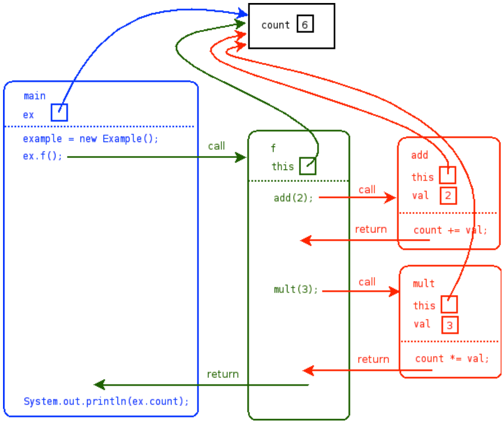
Method Execution (Normal Execution)



Program Stack to control the execution

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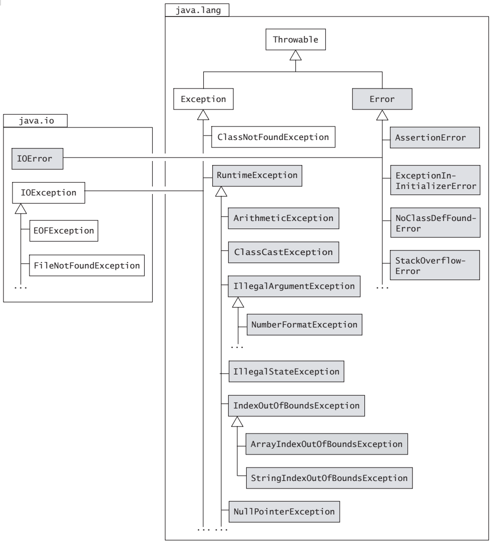
Exception Handling
Method execution and exception prpgtion
Method execution



Classes that are shaded (and their subclasses) represent unchecked exceptions.

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Exception Handling

Method execution and exception prpgtion

Method execution

```
public class Speed1 {

  public static void main(String[] args) {
    System.out.println("Entering main().");
    printSpeed(100, 20);                          // (1)
    System.out.println("Returning from main().");
  }

  private static void printSpeed(int kilometers, int hours) {
    System.out.println("Entering printSpeed().");
    int speed = calculateSpeed(kilometers, hours);    // (2)
    System.out.println("Speed = " +
                     kilometers + "/" + hours + " = " + speed);
    System.out.println("Returning from printSpeed().");
  }

  private static int calculateSpeed(int distance, int time) {
    System.out.println("Calculating speed.");
    return distance/time;                         // (3)
  }
}
```

```
Entering main().
Entering printSpeed().
Calculating speed.
Speed = 100/20 = 5
Returning from printSpeed().
Returning from main().
```

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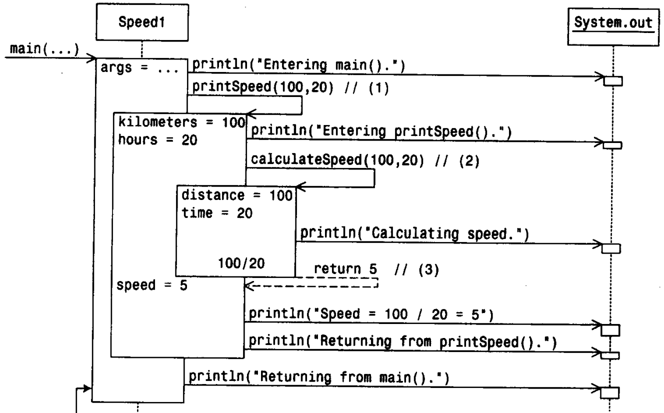
Exception Handling

Method execution and exception prpgtion

Method execution


Speed1
System.out
main(...)
args = ...
println("Entering main().")
printSpeed(100,20) // (1)
kilometers = 100
hours = 20
println("Entering printSpeed().")
calculateSpeed(100,20) // (2)
distance = 100
time = 20
println("Calculating speed.")
100/20
return 5 // (3)
speed = 5
println("Speed = 100 / 20 = 5")
println("Returning from printSpeed().")
println("Returning from main().")

Method execution

Program output:

```
Entering main().
Entering printSpeed().
Calculating speed.
Speed = 100/20 = 5
Returning from printSpeed().
Returning from main().
```

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Exception Handling

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```java
public class Speed1WithException {

  public static void main(String[] args) {
    System.out.println("Entering main().");
    printSpeed(100, 0);                // (1) ***** CHANGED
    System.out.println("Returning from main().");
  }

  private static void printSpeed(int kilometers, int hours) {
    System.out.println("Entering printSpeed().");
    int speed = calculateSpeed(kilometers, hours);     // (2)
    System.out.println("Speed = " +
                       kilometers + "/" + hours + " = " + speed);
    System.out.println("Returning from printSpeed().");
  }

  private static int calculateSpeed(int distance, int time) {
    System.out.println("Calculating speed.");
    return distance/time;                              // (3)
  }
}
```

```
Entering main().
Entering printSpeed().
Calculating speed.
Exception in thread "main" java.lang.ArithmeticException: / by zero
  at Speed1WithException.calculateSpeed(Speed1WithException.java:20)
  at Speed1WithException.printSpeed(Speed1WithException.java:12)
  at Speed1WithException.main(Speed1WithException.java:6)
```

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- Method execution
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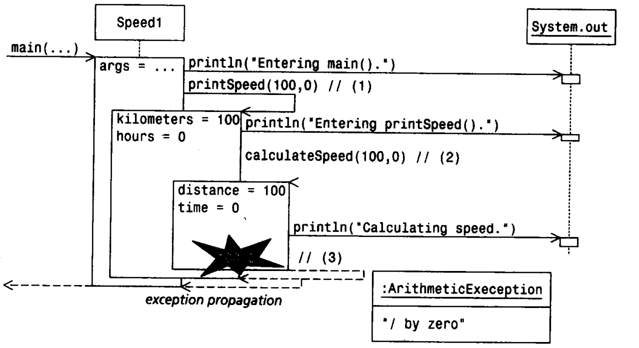
Exception Handling

Method execution and exception prpgtion

Stack trace



Program output: *Printed by the program* *Printed by the default exception handler*

```
Entering main().
Entering printSpeed().
Calculating speed.
Exception in thread "main" java.lang.ArithmeticException: / by zero
  at Speed1.calculateSpeed(Speed1.java:20)
  at Speed1.printSpeed(Speed1.java:12)
  at Speed1.main(Speed1.java:6)
```

class name *method name* *file name* *line number in the file where the call to the next method occurred.*

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Propagation of an exception:

- The exception is offered to the method in which the exception occurred
  - No code to deal with this exception, it is terminated
  - Its stack frame is removed
- The exception is next offered to the method at the top of the program stack
  - No code to handle the exception, it is terminated
  - It is also terminated and its stack frame removed
- . . .
- The exception is next offered to the main( ) method $\leadsto$ terminated & its stack frame removed

- After the main terminated, the exception has propagated to the top level
- It is now handled by a default exception handler in the JVM
- The default exception handler prints information about
  - the exception
  - the stack trace at the time when the exception occurred
- The execution of the program is then terminated (For terminal-based applications)
- The program continues (For applications with a GUI)

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- Not advisable to leave exceptions to a default handler
- The consequences:
  - data can be lost
  - lost of control of the system
- The construct **try-catch** can be used for exception handling in Java
- It is formed by a try block followed by a catch block
- A try block contains statements that can result in an exception being thrown during execution
- A catch block constitutes an exception handler

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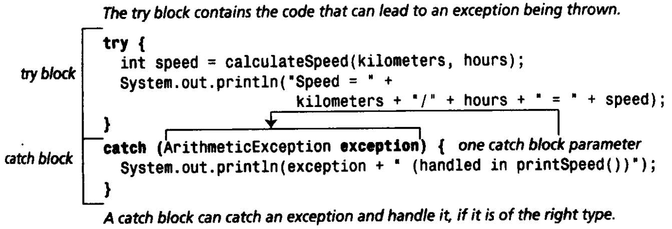
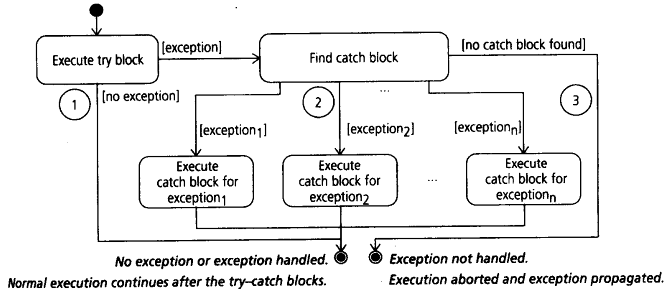
Exception Handling
Exception handling



The try block contains the code that can lead to an exception being thrown.

```
try {
  int speed = calculateSpeed(kilometers, hours);
  System.out.println("Speed = " +
                     kilometers + "/" + hours + " = " + speed);
}
catch (ArithmeticException exception) {
  System.out.println(exception + " (handled in printSpeed())");
}
```

A catch block can catch an exception and handle it, if it is of the right type.


Execute try block
[exception]
Find catch block
[no catch block found]
[no exception]
1
2
3
...
[exception$_1$]
[exception$_2$]
[exception$_n$]
Execute catch block for exception$_1$
Execute catch block for exception$_2$
...
Execute catch block for exception$_n$
No exception or exception handled.
Normal execution continues after the try-catch blocks.
Exception not handled.
Execution aborted and exception propagated.

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Exception handling
try-catch scenario 1: no exception
try-catch scenario 2: exception handling
try-catch scenario 3: exception propagation

Checked exceptions

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Exception Handling

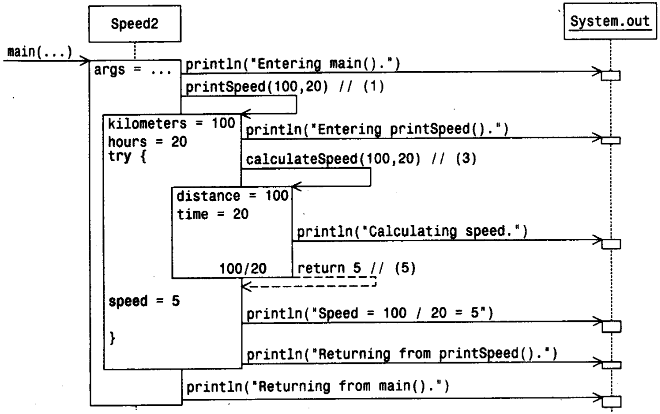
Exception handling

try-catch scenario 1: no exception

```
public class Speed2 {

  public static void main(String[] args) {
    System.out.println("Entering main().");
    printSpeed(100, 20);                                        // (1)
    System.out.println("Returning from main().");
  }

  private static void printSpeed(int kilometers, int hours) {
    System.out.println("Entering printSpeed().");
    try {                                                      // (2)
      int speed = calculateSpeed(kilometers, hours);            // (3)
      System.out.println("Speed = " +
                         kilometers + "/" + hours + " = " + speed);
    }
    catch (ArithmeticException exception) {                    // (4)
      System.out.println(exception + " (handled in printSpeed())");
    }
    System.out.println("Returning from printSpeed().");
  }

  private static int calculateSpeed(int distance, int time) {
    System.out.println("Calculating speed.");
    return distance/time;                                      // (5)
  }
}
```

```
Entering main().
Entering printSpeed().
Calculating speed.
Speed = 100/20 = 5
Returning from printSpeed().
Returning from main().
```

Exception Handling
Exception handling
try-catch scenario 1: no exception


Speed2
System.out
main(...)
args = ...
println("Entering main().")
printSpeed(100,20) // (1)
kilometers = 100
hours = 20
try {
println("Entering printSpeed().")
calculateSpeed(100,20) // (3)
distance = 100
time = 20
println("Calculating speed.")
100/20
return 5 // (5)
speed = 5
println("Speed = 100 / 20 = 5")
}
println("Returning from printSpeed().")
println("Returning from main().")

Program output:
```
Entering main().
Entering printSpeed().
Calculating speed.
Speed = 100/20 = 5
Returning from printSpeed().
Returning from main().
```

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Exception handling
- try-catch scenario 1: no exception
- try-catch scenario 2: exception handling
- try-catch scenario 3: exception propagation

Checked exceptions

Unchecked exceptions

Exception Handling
Exception handling
try-catch scenario 2: exception

```java
public class Speed2WithException {

  public static void main(String[] args) {
    System.out.println("Entering main().");
    printSpeed(100, 0);                     // (1) **** ERROR HERE
    System.out.println("Returning from main().");
  }

  private static void printSpeed(int kilometers, int hours) {
    System.out.println("Entering printSpeed().");
    try {                                                     // (2)
      int speed = calculateSpeed(kilometers, hours);          // (3)
      System.out.println("Speed = " +
                         kilometers + "/" + hours + " = " + speed);
    }
    catch (ArithmeticException exception) {                   // (4)
      System.out.println(exception + " (handled in printSpeed())");
    }
    System.out.println("Returning from printSpeed().");
  }

  private static int calculateSpeed(int distance, int time) {
    System.out.println("Calculating speed.");
    return distance/time;                                     // (5)
  }
}
```

```
Entering main().
Entering printSpeed().
Calculating speed.
java.lang.ArithmeticException: / by zero (handled in printSpeed())
Returning from printSpeed().
Returning from main().
```

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- try-catch scenario 3: exception propagation

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Exception Handling
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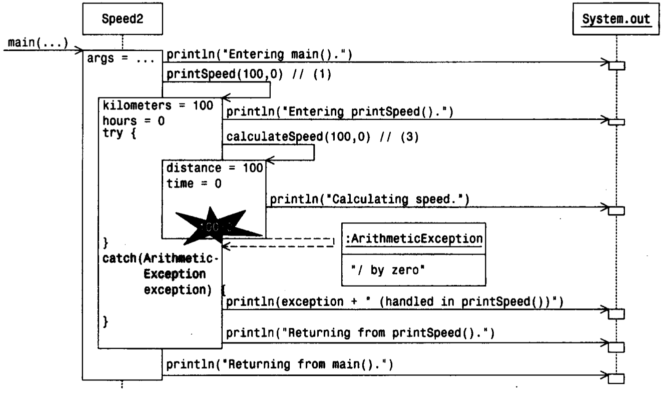
try-catch scenario 2: exception


Speed2
System.out
main(...)
args = ...
println("Entering main().")
printSpeed(100,0) // (1)
kilometers = 100
hours = 0
try {
println("Entering printSpeed().")
calculateSpeed(100,0) // (3)
distance = 100
time = 0
println("Calculating speed.")
100/0
:ArithmeticException
"/ by zero"
}
catch(Arithmetic-Exception exception) {
println(exception + " (handled in printSpeed())")
}
println("Returning from printSpeed().")
println("Returning from main().")

Program output:
```
Entering main().
Entering printSpeed().
Calculating speed.
java.lang.ArithmeticException: / by zero (handled in printSpeed())
Returning from printSpeed().
Returning from main().
```

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- try-catch scenario 1: no exception
- try-catch scenario 2: exception handling
- try-catch scenario 3: exception propagation

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Exception Handling
Exception handling
try-catch scenario 3: exc. propagation

```
public class Speed3WithException {

  public static void main(String[] args) {
    System.out.println("Entering main().");
    try {                                                        // (1)
      printSpeed(100,0);         // (2) **** ERROR
    }
    catch (ArithmeticException exception) {                      // (3)
      System.out.println(exception + " (handled in main())");
    }
    System.out.println("Returning from main().");
  }

  private static void printSpeed(int kilometers, int hours) {
    System.out.println("Entering printSpeed().");
    try {                                                        // (4)
      int speed = calculateSpeed(kilometers, hours);            //
           (5)
      System.out.println("Speed = " +
                         kilometers + "/" + hours + " = " + speed);
    }
    catch (IllegalArgumentException exception) {                 // (6)
      System.out.println(exception + " (handled in printSpeed())");
    }
    System.out.println("Returning from printSpeed().");
  }

  private static int calculateSpeed(int distance, int time) {
    System.out.println("Calculating speed.");
    return distance/time;                                        // (7)
  }
}
```

```
Entering main().
Entering printSpeed().
Calculating speed.
java.lang.ArithmeticException: / by zero (handled in main())
Returning from main().
```

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- try-catch scenario 3: exception propagation

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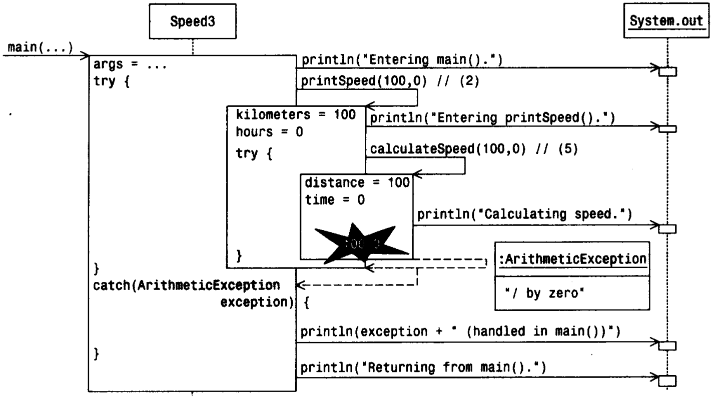
try-catch scenario 3: exc. propagation


Speed3
System.out
main(...)
args = ...
try {
println("Entering main().")
printSpeed(100,0) // (2)
kilometers = 100
hours = 0
try {
println("Entering printSpeed().")
calculateSpeed(100,0) // (5)
distance = 100
time = 0
println("Calculating speed.")
}
}
:ArithmeticException
"/ by zero"
catch(ArithmeticException
exception) {
println(exception + " (handled in main())")
}
println("Returning from main().")

Program output:

```
Entering main().
Entering printSpeed().
Calculating speed.
java.lang.ArithmeticException: / by zero (handled in main())
Returning from main().
```

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try-catch scenario 1: no exception
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Checked exceptions

- Java defines some special exceptions that a program cannot ignore when they are thrown
- Such an exception is called a checked exception
- The compiler will complain if the method in which it can occur does not deal with it explicitly
- Checked exceptions force the programmer to take explicit action to deal with them
- The Java standard library defines classes whose objects represent exceptions

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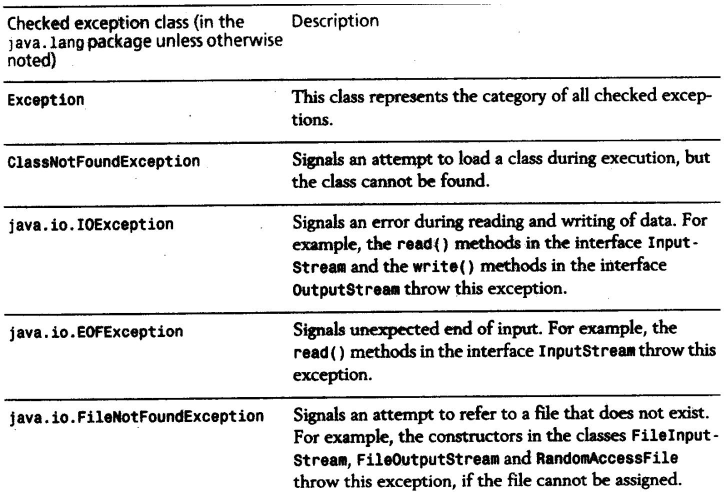
Unchecked exceptions

Exception Handling
Checked exceptions



Checked exception class (in the `java.lang` package unless otherwise noted)	Description
`Exception`	This class represents the category of all checked exceptions.
`ClassNotFoundException`	Signals an attempt to load a class during execution, but the class cannot be found.
`java.io.IOException`	Signals an error during reading and writing of data. For example, the `read()` methods in the interface `InputStream` and the `write()` methods in the interface `OutputStream` throw this exception.
`java.io.EOFException`	Signals unexpected end of input. For example, the `read()` methods in the interface `InputStream` throw this exception.
`java.io.FileNotFoundException`	Signals an attempt to refer to a file that does not exist. For example, the constructors in the classes `FileInputStream`, `FileOutputStream` and `RandomAccessFile` throw this exception, if the file cannot be assigned.

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- A method that can throw a checked exception must satisfy one of the following two conditions
  1. Catch and handle the exception in a try-catch statement
  2. Allow further propagation of the exception with a throws clause specified in its method declaration (to discuss)

- A throws clause is specified in the method header
  . . . method name (. . .) throws exception class$_1$**, . . . , exception class**$_n$ { . . . }

Programming with checked exceptions

- We can use a throw statement to throw an exception explicitly
- We specify the exception object to be thrown in the statement

```
if (distance< 0 || time <= 0)
        throw new Exception("distance and time must be > 0");
```

- We call the constructor of the exception class and pass a suitable message to explain the error situation

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Programming with checked exceptions

```
public class Speed6 {

  public static void main(String[] args) {
    System.out.println("Entering main().");
    try {                                                      //(1)
    printSpeed(100, 20);                                      //(2a)
//       printSpeed(-100,20);                                    //(2b)
    }
    catch (Exception exception) {                              //(3)
      System.out.println(exception + " (handled in main())");
    }
    System.out.println("Returning from main().");
  }

  private static void printSpeed(int kilometers, int hours)
                      throws Exception {                       //(4)
    System.out.println("Entering printSpeed().");
    double speed = calculateSpeed(kilometers, hours);
    System.out.println("Speed = " +
                        kilometers + "/" + hours + " = " + speed);
    System.out.println("Returning from printSpeed().");
  }

  private static int calculateSpeed(int distance, int time)
                     throws Exception {                        //(5)
    System.out.println("Calculating speed.");
    if (distance < 0 || time <= 0)                             //(6)
      throw new Exception("distance and time must be > 0");
    return distance/time;
  }
```

```
Entering main().
Entering printSpeed().
Calculating speed.
Speed = 100/20 = 5.0
Returning from printSpeed().
Returning from main().
```

```
Entering main().
Entering printSpeed().
Calculating speed.
java.lang.Exception: distance and time must be > 0 (handled in main())
Returning from main().
```

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Dealing with checked exceptions using the throws clause

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Unchecked exceptions

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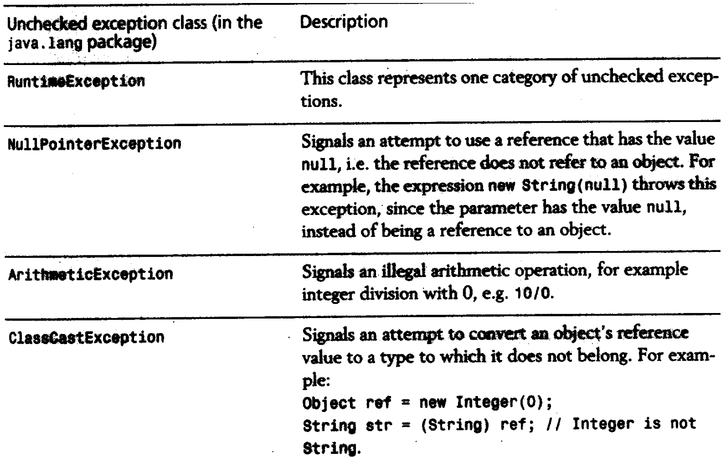
Unchecked exceptions

- Unchecked exceptions are exceptions typically concerning unforeseen errors
- The compiler DOES NOT check whether unchecked exceptions cim be thrown
- A method does not have to deal with unchecked exceptions
- The best solution for handling such situations is to correct the cause of the errors in the program(Use assertions)
- Such exceptions are not specified in the throws clause of a method

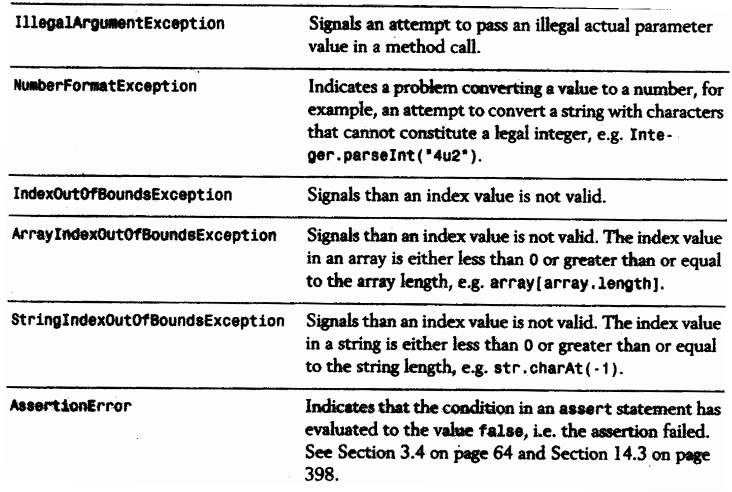
Exception Handling
Unchecked exceptions



Unchecked exception class (in the `java.lang` package)	Description
`RuntimeException`	This class represents one category of unchecked exceptions.
`NullPointerException`	Signals an attempt to use a reference that has the value `null`, i.e. the reference does not refer to an object. For example, the expression `new String(null)` throws this exception, since the parameter has the value `null`, instead of being a reference to an object.
`ArithmeticException`	Signals an illegal arithmetic operation, for example integer division with 0, e.g. `10/0`.

`ClassCastException`	Signals an attempt to convert an object's reference value to a type to which it does not belong. For example:
	`Object ref = new Integer(0);`
	`String str = (String) ref; // Integer is not String.`

Exception Handling
Unchecked exceptions



`IllegalArgumentException`	Signals an attempt to pass an illegal actual parameter value in a method call.
`NumberFormatException`	Indicates a problem converting a value to a number, for example, an attempt to convert a string with characters that cannot constitute a legal integer, e.g. `Integer.parseInt("4u2")`.
`IndexOutOfBoundsException`	Signals than an index value is not valid.
`ArrayIndexOutOfBoundsException`	Signals than an index value is not valid. The index value in an array is either less than `0` or greater than or equal to the array length, e.g. `array[array.length]`.
`StringIndexOutOfBoundsException`	Signals than an index value is not valid. The index value in a string is either less than `0` or greater than or equal to the string length, e.g. `str.charAt(-1)`.
`AssertionError`	Indicates that the condition in an `assert` statement has evaluated to the value `false`, i.e. the assertion failed. See Section 3.4 on page 64 and Section 14.3 on page 398.

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