Chapter 1

Exception Handling

Lecture slides for:

Java Actually: A Comprehensive Primer in Programming

Khalid Azim Mughal, Torill Hamre, Rolf W. Rasmussen

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Overview

- Program Execution
- *Throw-and-catch* principle
- Exception Propagation
- Typical scenarios when using the `try-catch` statement
- Using the `throws` clause with checked exceptions
- Unchecked exceptions

What is an exception?

- An *exception* in Java signals an error situation that can during program execution.
- Some examples of error situations:

1. Programming errors -- occur because of logical errors.
   - Illegal array index
   - Integer division by 0
   - Method call with illegal parameters
   - Using a reference with the `null` value to access members of an object
2. Runtime error -- programmer has little control over.
   - Opening a file that doesn't exist.
   - Read or write errors when using a file.
   - A network connection that goes down.

Program execution

- A *program stack* is used to manage the execution of methods.
- An *element* (called the *stack frame*) on the program stack corresponds to a method call.
  - Each method call results in the creation of a new stack frame.
  - Stack frame contains various information, including storage for local variables.
  - When the method is complete, its frame is removed from the program stack.
  - The method that has the stack frame on the top of the program stack is executed.
- When returning from a method call, program execution continues with the method in the corresponding stack frame that now has been revealed on top of the program stack.
- During execution, all stack frames on the program stack at any given time, specify which methods are *active*, i.e., have not finished executing.

Method Execution and Exception Propagation

- We shall use the following problem to illustrate the method of execution and exception propagation.

  Calculate the speed when the distance and time are given.

  The program uses three methods:

1. `main()`
2. `printSpeed()`
3. `calculateSpeed()`

- Note integer division in the calculation of expression (`distance / time`).
  - Integer division by 0 is an *illegal* operation in Java.

Method Execution (Program 10.1)

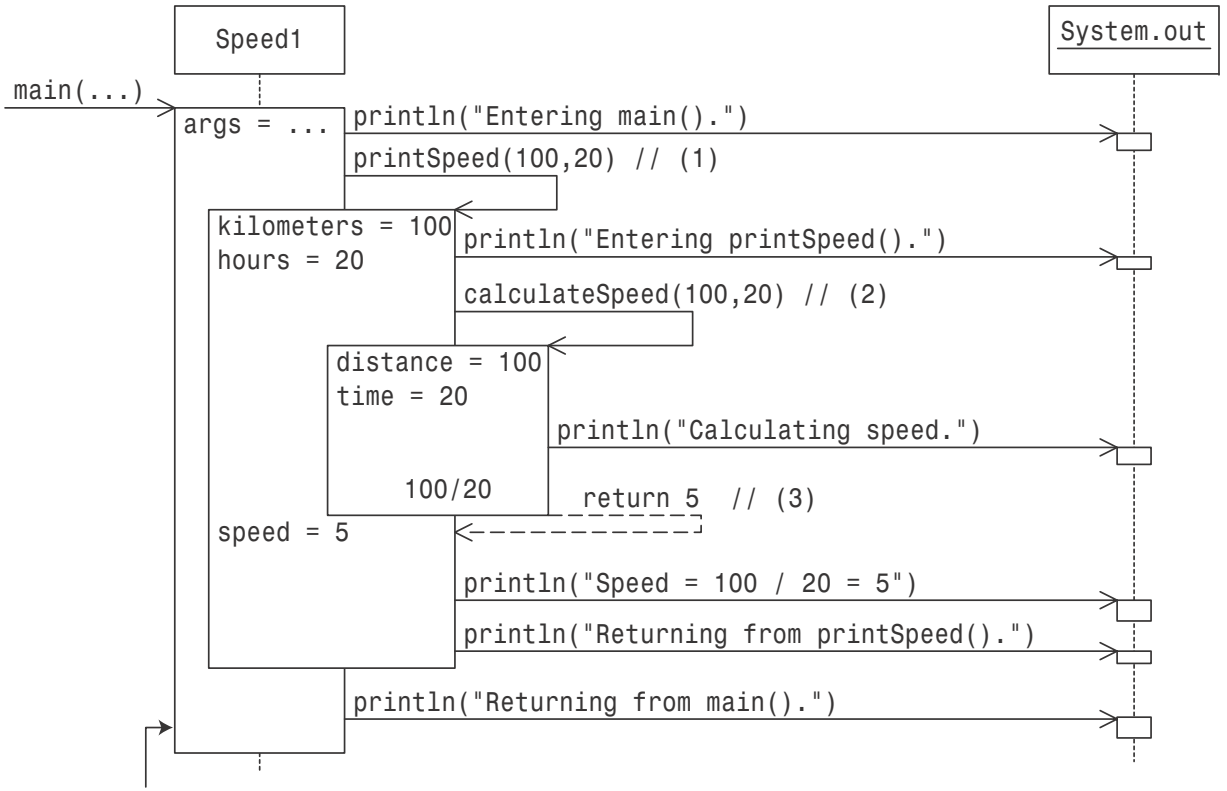
```
public class Speed1 {

  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)
  }
}
```

Normal execution (Figure 10.1)



Program output:

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

Throw-and-catch principle

- An exception is *thrown* when an error situation arises during program execution, and is *caught* by an exception handler that handles it.
- Replace in Program 10.1:

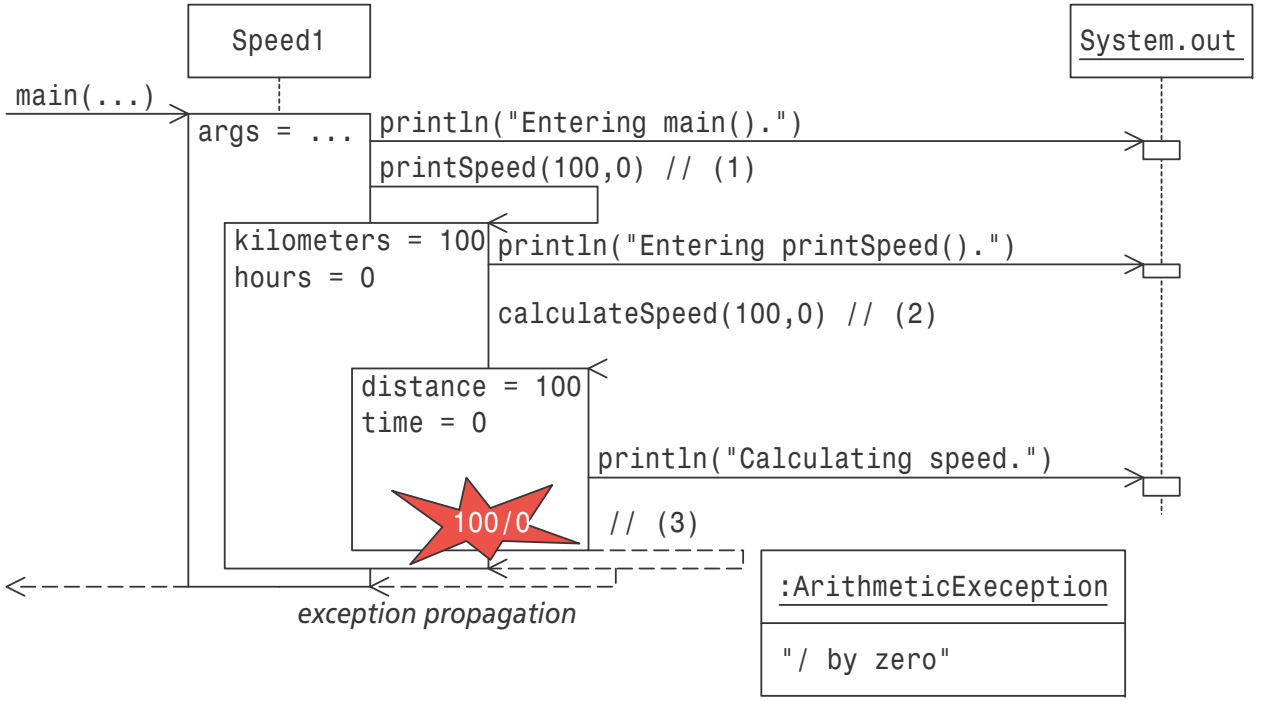
```
printSpeed(100, 20);                    // (1)
```

with

```
printSpeed(100, 0);                     // (1) Second parameter is 0.
```

- Execution of the program is illustrated in the sequence diagram in Figure 10.2.
- In (7) an ArithmeticException is thrown-exception, which is communicated back (*propagated*) through the stack frames of the program stack.

Exception Propagation (integer division by 0) (Figure 10.2)



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.*

Exception Propagation

- Program execution does not continue normally during unntakspropageringen, and the exception is not returned by the `return` statement.
- The exception is offered to active methods in turn.
  - If an active method does not catch the exception, the execution of the method is interrupted, i.e. its stack frame is removed from the program stack.
- When the exception propagates to the "top level", it is processed by a standard exception handler in the Java virtual machine.
- *Standard exception handler* generates a stack trace at the terminal.

Exception Handling: try-catch

- A `try` block can contain arbitrary code, but the purpose is to add code that might throw an exception during execution.
- A `catch` block is an *exception handler*.
  - A `catch` block belongs with a `try` block.
  - An exception that can be thrown as a result of executing the code in the `try` block, can be caught and handled in a corresponding `catch` block.

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

try block

```
try {
  int speed = calculateSpeed(kilometers, hours);
  System.out.println("Speed = " +
                     kilometers + "/" + hours + " = " + speed);
}
```

catch block

```
catch (ArithmeticException exception) {
  System.out.println(exception + " (handled in printSpeed())");
}
```

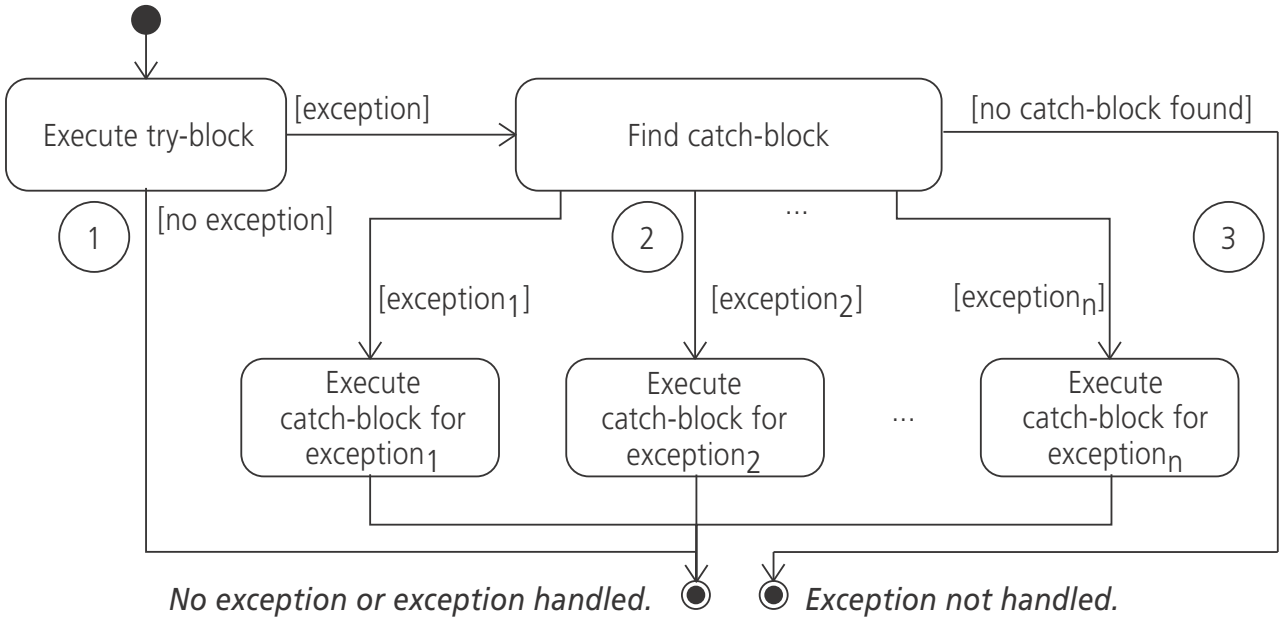
one catch block parameter

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

Typical scenarios when using a try-catch statement

1. The code in the `try` block is executed, and no exception is thrown.
   - Normal execution continues after the `try-catch` blocks.
2. The code in the `try` block is executed, and an exception is thrown. This exception is caught and handled in a corresponding `catch` block.
   - The execution of the `try`-block is cancelled, such that the actions in the rest of the `try` block are not executed.
   - Normal execution continues after the `try-catch` blocks.
3. The code in the `try` block is executed, and an exception is thrown, but no `catch` block is found to handle the exception.
   - The execution of the `try`-block is cancelled, such that the actions in the rest of the `try` block are not executed.
   - The exception is propagated.

try-catch scenarios (Figure 10.4)



No exception or exception handled.
Normal execution continues afer the try-catch-blocks.

Exception not handled.
Execution aborted and exception propagated.

try-catch scenario 1

- In Program 10.2, the `printSpeed()` method uses a `try-catch` statement, (2).
- The corresponding `catch` block, (4), is declared to catch exceptions of type `ArithmeticException`.
- Execution of Program 10.2 is shown in Figure 10.5.

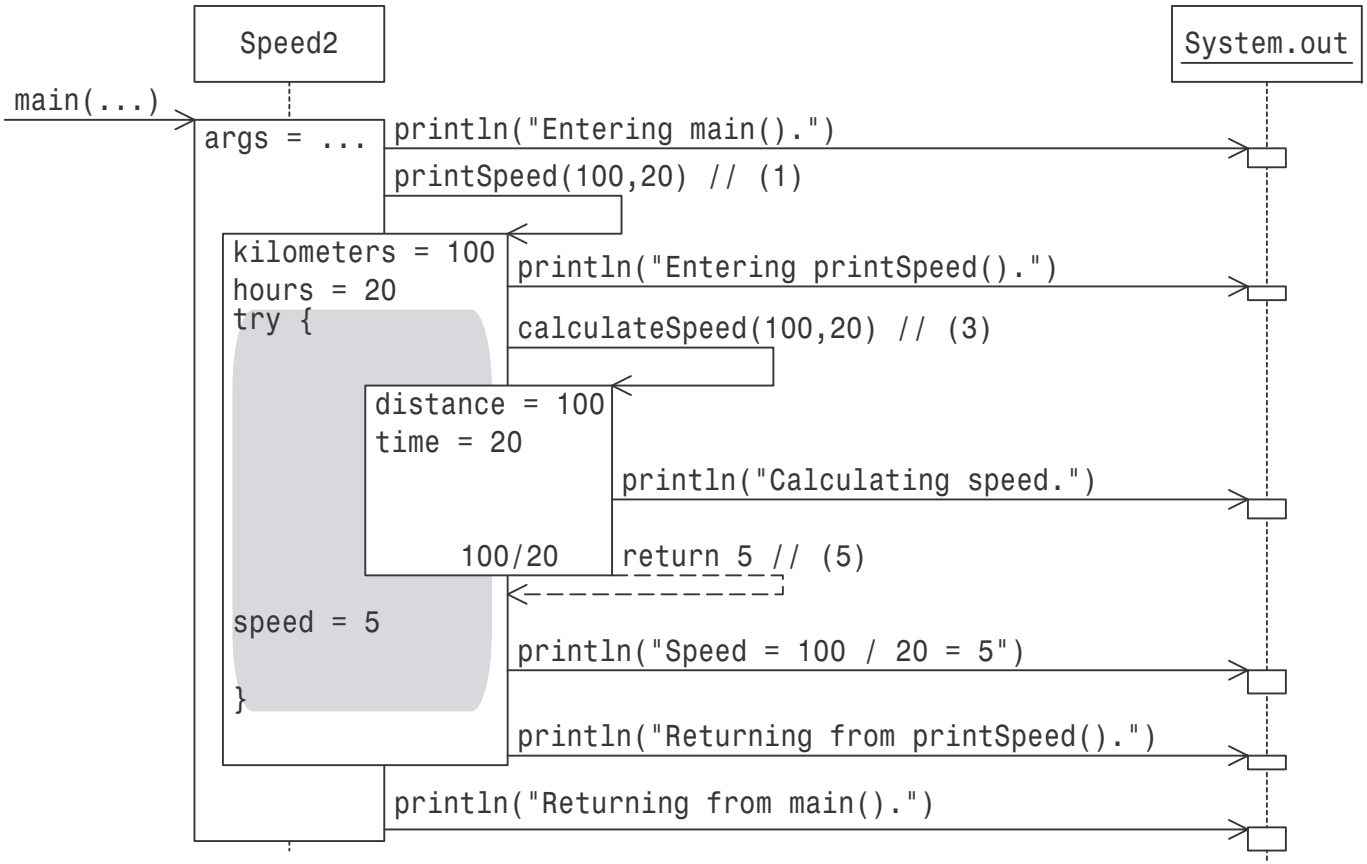
Exception handling (Program 10.2)

```
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)
  }
}
```

Exception handling (Figure 10.5) (scenario 1)



Program output:

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

try-catch scenario 2

- Replace in Program 10.2:

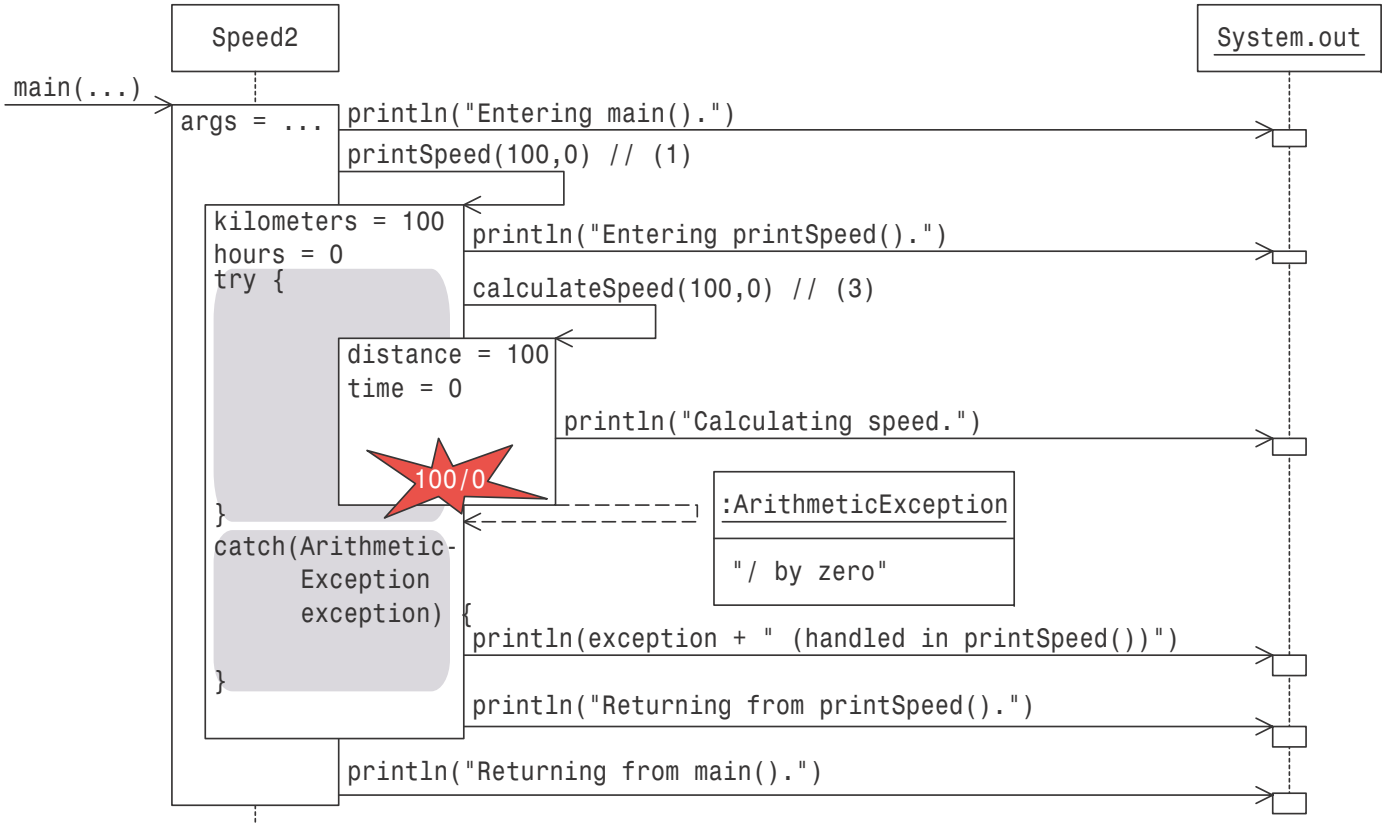
```
printSpeed(100, 20);    // (1)
```

- with

```
printSpeed(100, 0);     // (1) Second parameter is 0.
```

- Integer Division by 0 causes an `ArithmeticException` exception to be thrown at (5) in the method `caculateSpeed()`.
  - Execution of this method is interrupted and the exception is propagated.
  - It is caught by the `catch` block in method `printSpeed()`.
  - After handling the exception, normal execution of the program is restored.
  - Printout shows the normal execution of the `printSpeed()` method from this point.

Exception handling (Figure 10.6) (scenario 2)



Program output:

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

try-catch scenario 3

- Scenario 3 shows what happens when an exception is thrown during the execution of a `try`-block and there is no corresponding `catch` block to handle the exception.
- The program's execution behavior in Figure 10.7 shows that the integer division with 0 again leads to an `ArithmeticException`-exception, thrown at (7) in the method `caculateSpeed()`.
  - Execution of this method is interrupted and the exception is propagated.
- `ArithmeticException` is *not* caught by the `catch` block in `printSpeed()` method, since this `catch` block can only handle exceptions of type `IllegalArgumentException`.
- Execution of the `printSpeed()` method is interrupted, and the exception is propagated.
- The exception `ArithmeticException` is now caught by the `catch` block in method `main()` at (3).
  - After handling the exception in the `catch` block in method `main()`, normal execution of the program is restored.
  - Printout shows the normal execution of the method `main()` from this point.

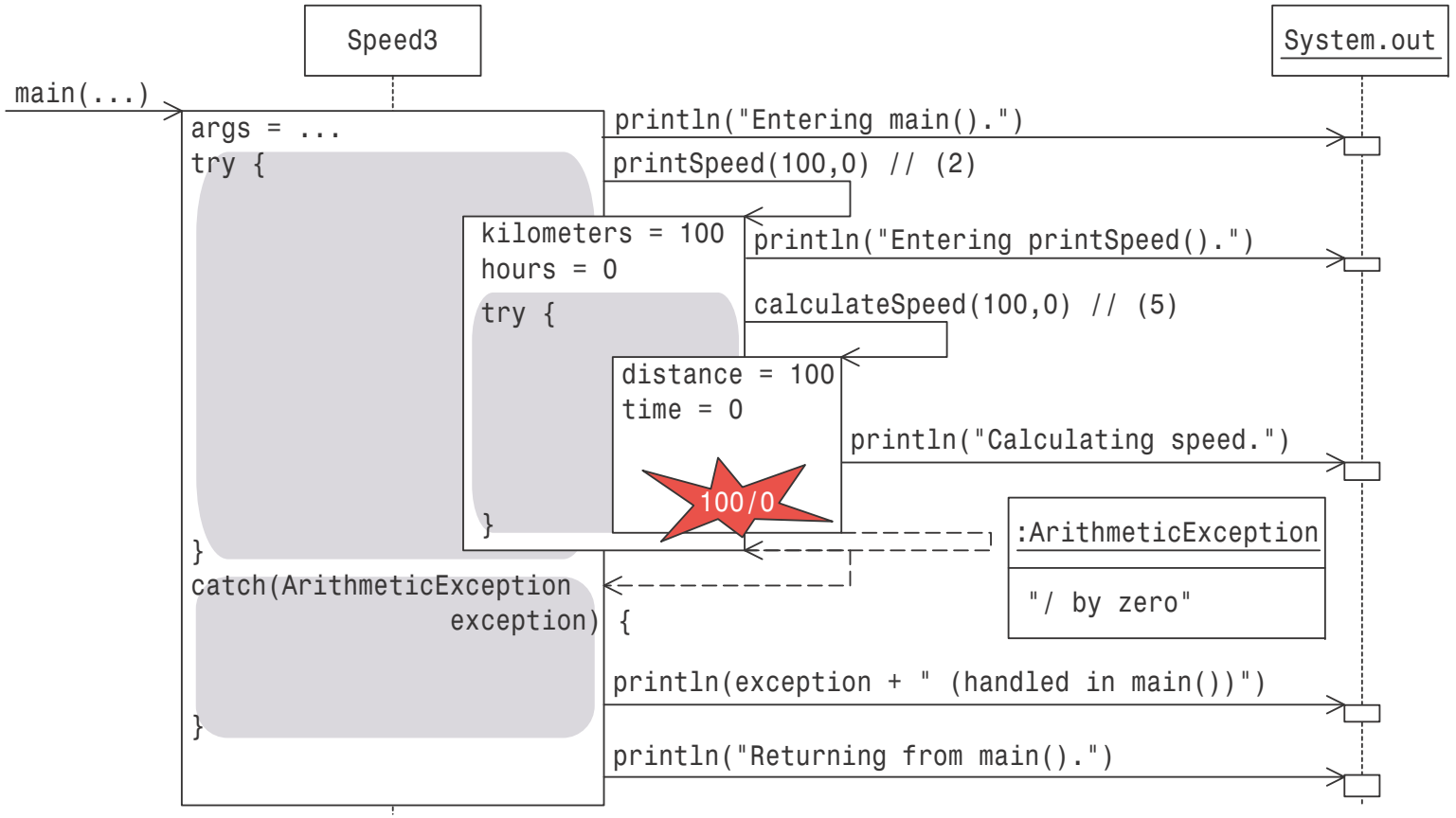
Exception handling (Program 10.3) (scenario 3)

```
public class Speed3 {
  public static void main(String[] args) {
    System.out.println("Entering main().");
    try {                                                          // (1)
      printSpeed(100,20);                                          // (2)
    }
    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)
  }
}
```

Exception handling (Figure 10.7) (scenario 3)



Program output:

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

Handling of controlled exceptions

- The purpose of the exception handling is to deal with error situations during program execution.
  - It is possible for a method that throws an exception, to let the exception propagate further without doing something about it.
  - This results in applications that are not very *robust*.
- Use of controlled exception provides a strategy in which a method, that can throw such an exception, is forced to decide how the exception should be handled:

1. Catch and handle the exception in a `try-catch` statement.
2. Allow further propagation of the exception with a `throws`-clause specified in the method declaration.

- A `throws` clause is specified in the method header, between the parameter list and the method body:

```
... method name (...) throws exception class1, ..., exception classn {...}
```

Handling of controlled exceptions

- Given that the method foo() calls the method bar():

```
void bar () throws { /*...*/ } // K is a checked exception.

void foo () { bar (); }        // Compile-time error.
```

- Solution:

  Either

```
void foo () throws K { bar (); } // Throws the exception further.
```

  or:

```
void foo () {
  try { bar (); }
  catch (K k) { k.printStackTrace (); }  // Catch and handle the exception.
}
```

- The compiler will check that a method that can throw a checked exception meets one of the above requirements.
- This means that any client of a method that can propagate a checked exception in a `throws` clause, must decide how this exception should be handled.
- If a checked exception specified in a `throws` clause propagates all the way to the top level, it will be processed by a standard exception handler in the normal way.

Example: checked exceptions (Program 10.4)

- The method `caculateSpeed()` explicitly throws an `Exception` in an `if` statement, (6), using the `throw` statement.
  - This exception is further propagated in a `throws`-clause (5).
- The method `printSpeed ()`, which calls the method `caculateSpeed()`, also chooses to propagate the exception in a `throws`-clause (4).
- The method `main()` that calls the `printSpeed()` method, chooses to catch and handle this exception in a `try-catch` block, (1) and (3).
  - Normal execution continues after the exception is handled.
- Attempts to exclude the `throws`-clauses will result in compile-time errors.

Handling checked exceptions (Program 10.4)

```
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;
  }
}
```

- Running the program with (2a):

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

- Running the program with (2b):

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

Unchecked Exceptions

- Unchecked exceptions are exceptions that the compiler does not check, i.e. the compiler does not care whether the code deals with them or not.
- Unchecked exceptions are usually the result of programming errors and should be corrected.
- The unchecked `AssertionError` should never be caught as it thrown by the assert statement.
- See Table 10.2.