Exception Handling and Recursion

CS102A Lecture 15

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Objectives

- What exceptions are
- How exception handling works
- Exception class hierarchy
- Checked/unchecked exceptions
- Stack traces and chained exceptions
- Recursion

Exception

- An *exception* is an indication of a problem that occurs during a program's execution. It would disrupt the normal flow of instructions.

```
1  public static void main(String[] args) {
2    Scanner scanner = new Scanner(System.in);
3    System.out.print("Enter an integer numerator: ");
4    int numerator = scanner.nextInt();
5    System.out.print("Enter an integer denominator: ");
6    int denominator = scanner.nextInt();
7    int result = quotient(numerator, denominator);
8    System.out.printf("Result: %d / %d = %d\n", numerator, denominator,
         result);
9    scanner.close();
10 }
11 public static int quotient(int numerator, int denominator) {
12   return numerator / denominator;
13 }
```

Three executions of the program

```
Enter an integer numerator: 3
Enter an integer denominator: 2
Result: 3 / 2 = 1
```

```
Enter an integer numerator: 3
Enter an integer denominator: 0
Exception in thread "main" java.lang.ArithmeticException: / by zero
    at ExceptionExample.quotient(ExceptionExample.java:14)
    at ExceptionExample.main(ExceptionExample.java:10)
```

- An execution where the “/ by zero” exception is thrown and the program terminates.

Three executions of the program

```
Enter an integer numerator: 3
Enter an integer denominator: a
Exception in thread "main" java.util.InputMismatchException
    at java.util.Scanner.throwFor(Unknown Source)
    at java.util.Scanner.next(Unknown Source)
    at java.util.Scanner.nextInt(Unknown Source)
    at java.util.Scanner.nextInt(Unknown Source)
    at ExceptionExample.main(ExceptionExample.java:9)
```

- An execution where the “InputMismatch” exception is thrown and the program terminates.

Exception

```
Exception in thread "main" java.lang.ArithmeticException: / by zero
    at ExceptionExample.quotient(ExceptionExample.java:14)
    at ExceptionExample.main(ExceptionExample.java:10)
```

- `java.lang.ArithmeticException`: The name of the exception.
- Followed by stack trace: the method call stack when the exception occurs.
  - Stack trace contains the path of execution that led to the exception.

Exception

```
Exception in thread "main" java.lang.ArithmeticException: / by zero
    at ExceptionExample.quotient(ExceptionExample.java:14)
    at ExceptionExample.main(ExceptionExample.java:10)
```

```java
public static void main(String[] args) {
  Scanner scanner = new Scanner(System.in);
  System.out.print("Enter an integer numerator: ");
  int numerator = scanner.nextInt();
  System.out.print("Enter an integer denominator: ");
  int denominator = scanner.nextInt();
  int result = quotient(numerator, denominator);
  ...
}
public static int quotient(int numerator, int denominator) {
  return numerator / denominator;
}
```

Exception handling

- An exception would disrupt program execution flows (for example, causing crashes).
- *Exception handling* is a nice feature of the Java language that can help you write **robust and fault-tolerant programs**.
- With exception handling, a program can **continue executing (rather than terminating)** after dealing with a problem. It is very useful in mission-critical or business-critical computing.

`try-catch` statement syntax

```
try {
  // code that might throw an exception
} catch( ExceptionType1 e1 ) {
  // code that handles type1 exception
} catch( ExceptionType2 e2 ) {
  // code that handles type2 exception
} catch( ExceptionType3 e3 ) {
  // code that handles type3 exception
} ...
```

- Exception parameter `e1` is a local variable in the catch block.
- At least one `catch` block or a `finally` block must immediately follow the `try` block ("immediately" means no content in between).

Handling the two exceptions

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```
1  public static void main(String[] args) {
2    Scanner scanner = new Scanner(System.in);
3    boolean continueLoop = true;
4    do {
5      try {
6        System.out.print("Enter an integer numerator: ");
7        int numerator = scanner.nextInt();
8        System.out.print("Enter an integer denominator: ");
9        int denominator = scanner.nextInt();
10       int result = quotient(numerator, denominator);
11       System.out.printf("Result: %d / %d = %d\n", numerator,
             denominator, result);
12       scanner.close();
```

- Enclose the code that might throw an exception in a `try` block.

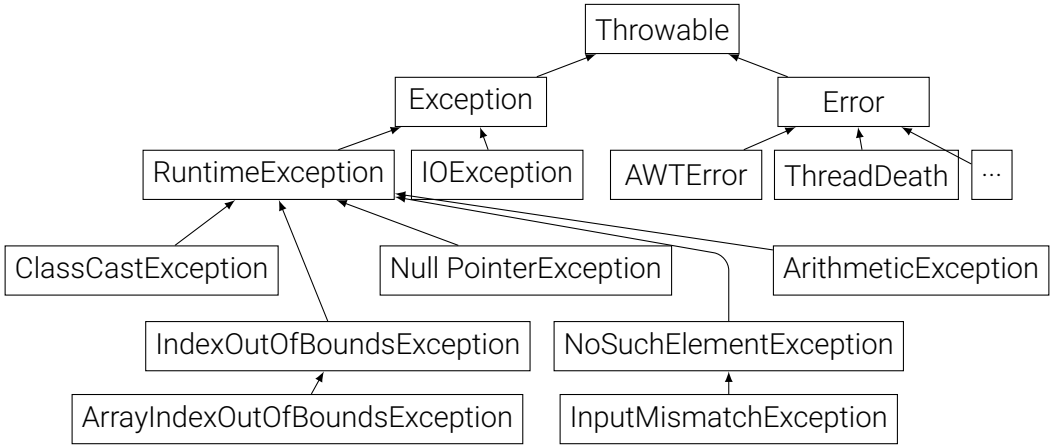
Handling the two exceptions

```
13          continueLoop = false;
14      } catch(InputMismatchException inputMismatchException) {
15          System.err.printf("Exception: %s\n", inputMismatchException);
16          scanner.nextLine(); // discard input so user can try again
17      } catch(ArithmeticException arithmeticException) {
18          System.err.printf("Exception: %s\n", arithmeticException);
19        }
20      } while(continueLoop);
21  }
```

- Each `catch` block (exception handler) handles a certain type of exception.
- The type is specified in the exception parameter.

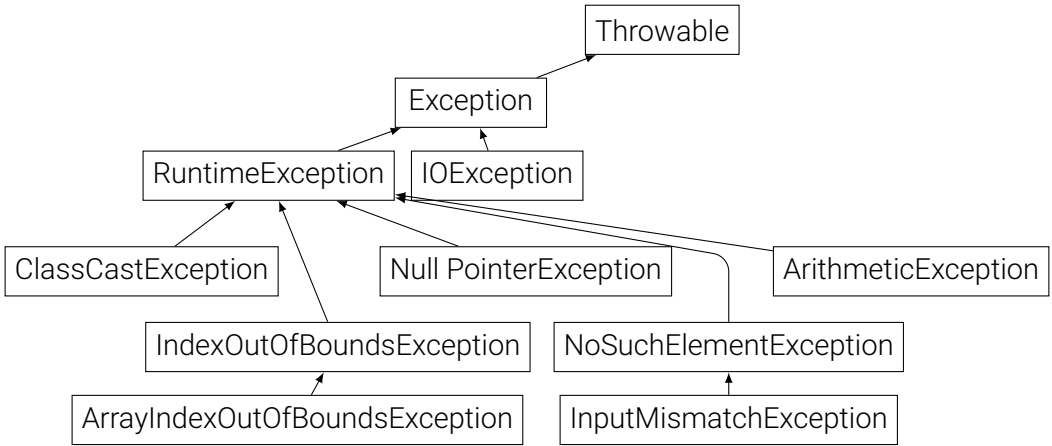
Java exception hierarchy

- In Java, only `Throwable` objects can be used with the exception-handling mechanism.



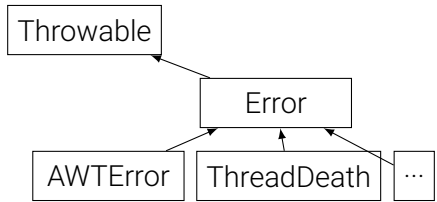
Java exception hierarchy

- `Exception` (in `java.lang`) and its subclasses represent exceptional situations that can occur in a Java program and should be caught by applications.



Java exception hierarchy

- `Error` and its subclasses represent abnormal situations that happen in the JVM (e.g., JVM out of memory) and should not be caught by applications. It's usually impossible for applications to recover from `Error`s.



Checked vs. unchecked exceptions

- Java distinguishes between *checked exception*s and *unchecked exception*s.
- All exception types that are direct or indirect subclasses of the class `RuntimeException` are unchecked exceptions.
- Unchecked exceptions are typically caused by defects in your program's code. Examples include `ArithmeticException`, `InputMismatchException`, `NullPointerException`.

Checked vs. unchecked exceptions

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- All exception types that inherit from the class `Exception` but not `RuntimeException` are checked exceptions.
- Checked exceptions are typically **caused by conditions that are not under the control of the program**. For example, in file processing, the program can't open a file because the file does not exist.
- Unlike unchecked exceptions, checked exceptions cannot be ignored at the time of compilation (must be taken care of by programmers). Java compiler **enforces a catch-or-declare requirement** for checked exceptions.

Example: Unchecked exceptions

```java
public static void main(String[] args) {
  Scanner scanner = new Scanner(System.in);
  System.out.print("Enter an integer numerator: ");
  int numerator = scanner.nextInt(); // potential runtime exception
  System.out.print("Enter an integer denominator: ");
  int denominator = scanner.nextInt(); // potential runtime exception
  int result = quotient(numerator, denominator);
  System.out.printf("Result: %d / %d = %d\n", numerator, denominator,
      result);
  scanner.close();
}
public static int quotient(int numerator, int denominator) {
  return numerator / denominator; // potential runtime exception
}
```

- It's fine if programmers do not take care of unchecked exceptions in the code.

Example: Checked exceptions

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```java
public static void main(String[] args) {
    File f = new File("test.txt");
    FileReader reader = new FileReader(f);
    reader.close();
}
```

```
Unhandled exception type FileNotFoundException
Unhandled exception type IOException
```

- Fix: `catch` or *declare*.

The `catch` solution

```java
public static void main(String[] args) {
  try {
    File f = new File("test.txt");
    FileReader reader = new FileReader(f);
    reader.close();
  } catch(FileNotFoundException e) {
    // handle file not found exception
  } catch(IOException e) {
    // handle IO exception
  }
}
```

The *declare* solution

```java
public static void main(String[] args)
    throws FileNotFoundException, IOException {
  File f = new File("test.txt");
  FileReader reader = new FileReader(f);
  reader.close();
}
```

- The `throws` clause declares the exceptions that might be thrown when the method is executed and **let the callers handle the exceptions**.

More on unchecked exceptions

```
1 import java.lang.RuntimeException;
2 public static void main(String[] args) { ... }
3 public static int quotient(int numerator, int denominator) throws
      RuntimeException {
4   return numerator / denominator; // potential runtime exception
5 }
```

- Still can compile as `quotient()` throws unchecked exception.

More on unchecked exceptions

```
1 import java.lang.RuntimeException;
2 public static void main(String[] args) { ... }
3 public static int quotient(int numerator, int denominator) throws
      FileNotFoundException {
4   return numerator / denominator; // potential runtime exception
5 }
```

- Fail to compile as `quotient()` throws checked exception. The caller must try and catch it.

Catching subclass-type exceptions

- If a `catch` handler is written to catch superclass-type exceptions, it can also catch subclass-type exceptions. This makes the exception handling code concise (when the handling behavior is the same for all types) and allows for polymorphic processing of exception objects.

```
1 public static void main(String[] args) {
2   try {
3     File f = new File("test.txt");
4     FileReader reader = new FileReader(f);
5     reader.close();
6 } catch(Exception e) {
7     // catch and handle multiple types of exceptions
8   }
9 }
```

`finally` block

```
try {
  // protected code
}
// catch blocks (optional)
finally {
  // always execute
  //when try block exits
}
```

- `finally` is useful for more than just exception handling. It prevents cleanup code from being accidentally bypassed by statements like `return`. Putting cleanup code in a `finally` block is a good practice, even when no exceptions are anticipated.

`finally` block

- In the example below, the `finally` block ensures that the used resource is closed regardless of whether the `try` statement completes normally or abruptly.

```
1  public String readFirstLineFromFile(String path) throws IOException {
2    BufferedReader br;
3    try {
4      br = new BufferedReader(new FileReader(path));
5      return br.readLine();
6    } finally {
7      if (br != null)
8      br.close();
9    }
10 }
```

Common methods of exceptions

- `printStackTrace`: output the stack trace to the standard error stream.
- Standard output stream (`System.out`) and standard error stream (`System.err`) are sequences of bytes. The former displays a program's output in the command prompt and the latter displays errors.
- Using two streams helps separate error messages from other output.

Common methods of exceptions

```java
public class CheckedExceptionExample {
  public static void main(String[] args) {
    try {
      File f = new File("not-exist.txt");
      FileReader reader = new FileReader(f);
      reader.close();
    } catch (Exception e) { e.printStackTrace(); }
  }
}
```

```
java.io.FileNotFoundException: not-exist.txt
    at java.io.FileInputStream.open0(Native Method)
    at java.io.FileInputStream.open(Unknown Source)
    at java.io.FileInputStream.<init>(Unknown Source)
    at java.io.FileReader.<init>(Unknown Source)
    at CheckedExceptionExample.main(CheckedExceptionExample.java:5)
```

Common methods of exceptions

```java
public class CheckedExceptionExample {
  public static void main(String[] args) {
    try {
      method1();
    } catch (Exception e) {
      StackTraceElement[] traceElements = e.getStackTrace();
      for(StackTraceElement element : traceElements) {
        System.out.printf("%s\t%s\t%s\n", element.getFileName(), element.
            getLineNumber(), element.getMethodName());
      }
    }
  }
  public static void method1() throws Exception {
    throw new Exception("Exception thrown in method1");
  }
}
```

Common methods of exceptions

```java
public class CheckedExceptionExample {
  public static void main(String[] args) {
    try {
      method1();
    } catch (Exception e) {
      System.err.println(e.getMessage());
    }
  }
  public static void method1() throws Exception {
    throw new Exception("Exception thrown in method1");
  }
}
```

```
Exception thrown in method1
```

Chained exceptions

```java
public class CheckedExceptionExample {
  public static void main(String[] args) throws Exception {
    try {
      method1();
    } catch (Exception e) {
      throw new Exception("Exception thrown in main", e);
    }
  }
  public static void method1() throws Exception {
    throw new Exception("Exception thrown in method1");
  }
}
```

```
Exception in thread "main" java.lang.Exception: Exception thrown in main
    at CheckedExceptionExample.main(CheckedExceptionExample.java:6)
Caused by: java.lang.Exception: Exception thrown in method1
    at CheckedExceptionExample.method1(CheckedExceptionExample.java:10)
    at CheckedExceptionExample.main(CheckedExceptionExample.java:4)
```

User-defined exceptions (checked)

```java
public class MyException extends Exception {
  public MyException(String s) {
    super(s);
  }
}
```

```java
public class UserDefinedExceptionDemo {
  public static void main(String args[]) {
    try {
      throw new MyException("User-defined exception");
    } catch (MyException e) {
      System.err.println(e.getMessage());
    }
  }
}
```

User-defined exceptions (unchecked)

```java
public class MyExceptions extends RuntimeException {
  public MyException2(String s) {
    super(s);
  }
}
```

```java
public class UserDefinedExceptionDemo2 {
  public static void main(String args[]) {
    throw new MyException2("User-defined exception");
  }
}
```

```
Exception in thread "main" MyException2: User-defined exception
    at UserDefinedExceptionDemo2.main(UserDefinedExceptionDemo2.java:3)
```

Assertions

- When implementing and debugging a class, it's sometimes useful to state conditions that should be true at a particular point in a method.
- These conditions, called *assertion*s, help ensure a program's correctness by catching potential bugs (such as logic errors) during development.
- Java has two versions of assert statements

```
1 assert expression; // throws an AssertionError if expression is false
2 assert expression1 : expression2; // throws an AssertionError with
      expression2 as the error message if expression1 is false
```

Assertions

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```java
public class AssertionExample {
  public static void main(String[] args) {
    Scanner input = new Scanner(System.in);
    System.out.print("Enter a number between 0 and 10: ");
    int number = input.nextInt();
    assert (number >=0 && number <= 10) : "bad number: " + number;
  }
}
```

- You must explicitly enable assertions: `java -ea AssertionExample`

```
Enter a number between 0 and 10: 12
Exception in thread "main" java.lang.AssertionError: bad number: 12
    at AssertionExample.main(AssertionExample.java:8)
```

Recursion

- Consider the *factorial* of a positive integer n, written $n!$.
  - $n! = n \cdot (n-1) \cdot (n-2) \cdots 1$
- One way of computing $n!$ is using `for` loop:

```
1 factorial = 1;
2 for (int counter = number; counter >= 1; counter--)
3   factorial *= counter;
```

- The following relationship can be observed:
  - $n! = n \cdot (n-1)!$
- We can implement the same problem by *recursion*.

Recursion

```java
public class FactorialCalculator {
  // recursive method factorial (assumes its parameter is >= 0)
  public static long factorial(long number) {
    if (number <= 1) // test for base case
      return 1; // base cases: 0! = 1 and 1! = 1
    else // recursion step
      return number * factorial(number - 1);
  }

  // output factorials for values 0-21
  public static void main(String[] args) {
    // calculate the factorials of 0 through 21
    for (int counter = 0; counter <= 21; counter++)
      System.out.printf("%d! = %d%n", counter, factorial(counter));
  }
} // end class FactorialCalculator
```

Recursion

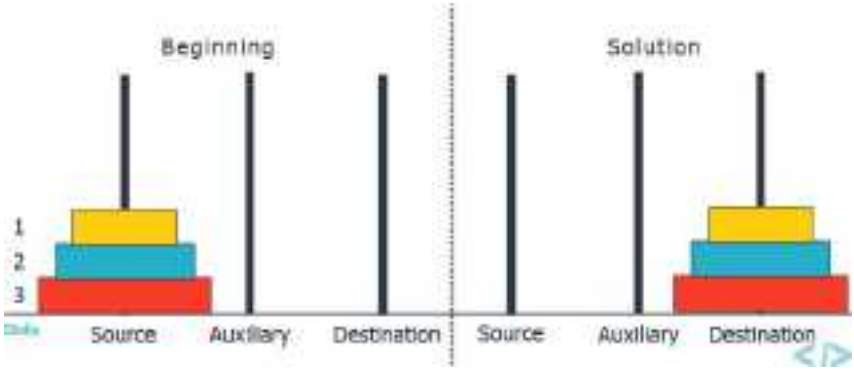
```
...
12! = 479001600
...
20! = 2432902008176640000
21! = -4249290049419214848
```

- $12!$ causes overflow for `int` variables.
- $21!$ causes overflow for `long` variables.

Recursion vs. iteration

- Both iteration and recursion are based on a control statement.
  - Iteration uses a repetition statement (e.g., `for`, `while` or `do-while`).
  - Recursion uses a selection statement (e.g., `if`, `if-else` or `switch`).
- Both iteration and recursion involve repetition.
  - Iteration explicitly uses a repetition statement.
  - Recursion achieves repetition through repeated method calls.
- Iteration and recursion each involve a termination test.
  - Iteration terminates when the loop-continuation condition fails.
  - Recursion terminates when a base case is reached.
- Both iteration and recursion can occur infinitely.
  - An infinite loop occurs with iteration if the loop continuation test never becomes `false`.
  - An infinite recursion occurs if the recursion step does not reduce the problem each time in a manner that converges on the base case, or if the base case is not tested.

Case study: Towers of Hanoi



Case study: Towers of Hanoi

- Moving n disks can be viewed in terms of moving only $n-1$ disks (hence the recursion) as follows:
  1. Move $n-1$ disks from peg 1 to peg 2, using peg 3 as a temporary holding area.
  2. Move the last disk (the largest) from peg 1 to peg 3.
  3. Move $n-1$ disks from peg 2 to peg 3, using peg 1 as a temporary holding area.
- The process ends when the last task involves moving $n=1$ disk (i.e., the base case). This task is accomplished by moving the disk, without using a temporary holding area.

Case study: Towers of Hanoi

```java
public class TowersOfHanoi {
  // recursively move disks between towers
  public static void solveTowers(int disks, int sourcePeg, int
      destinationPeg, int tempPeg) {
    // base case -- only one disk to move
    if (disks == 1) {
      System.out.printf("%n%d --> %d", sourcePeg, destinationPeg);
      return;
    }
    // recursion step -- move (disk - 1) disks from sourcePeg
    // to tempPeg using destinationPeg
    solveTowers(disks - 1, sourcePeg, tempPeg, destinationPeg);
    // move last disk from sourcePeg to destinationPeg
    System.out.printf("%n%d --> %d", sourcePeg, destinationPeg);
    // move (disks - 1) disks from tempPeg to destinationPeg
    solveTowers(disks - 1, tempPeg, destinationPeg, sourcePeg);
  }
```

Case study: Towers of Hanoi

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```
18   public static void main(String[] args) {
19     int startPeg = 1; // value 1 used to indicate startPeg in output
20     int endPeg = 3; // value 3 used to indicate endPeg in output
21     int tempPeg = 2; // value 2 used to indicate tempPeg in output
22     int totalDisks = 3; // number of disks
23     // initial nonrecursive call: move all disks.
24     solveTowers(totalDisks, startPeg, endPeg, tempPeg);
25   }
26 } // end class TowersOfHanoi
```

```
1 --> 3
1 --> 2
3 --> 2
1 --> 3
2 --> 1
2 --> 3
1 --> 3
```