BBM 102 – Introduction to Programming II
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Exceptions

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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
  - leads 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.
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

Exceptions

- A Method in Java throws exceptions to tell the calling code:
  
  "Something bad happened. I failed."

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 pass it on

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

```java
import java.util.Scanner;

public class ExceptionDemo {
    public static void main(String[] args) {
        Scanner scanner = new Scanner(System.in);
        System.out.print("Enter an integer: ");
        int number = scanner.nextInt();
        // Display the result
        System.out.println("The number entered is "+ number);
    }
}
```
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 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!*

Handling Exceptions

- Java forces you to deal with *checked* exceptions.
- Two possible ways to deal:

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

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- }

1. An exception is thrown by JVM
2. Execution stops at the exception line and diverges to the following catch block
   - e is a reference to the exception object
   - Exception object is created

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/7/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

```
Object <- Throwable
  |  |
  v  v
Exception
  |  |
  v  v
IOException
  |  |
  v  v
AWTException
  |  |
  v  v
RuntimeException
  |  |
  v  v
ArithmeticException
  |  |
  v  v
IndexOutOfBoundsException

VirtualMachineError

LinkageError

Error
  |  |
  v  v
NoSuchElementException

AWTError

... (Internal errors of JVM. Developers cannot 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

```java
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!");
}
```

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) {
    System.out.println("Exception thrown!");
}
catch (ArithmeticException e) {
    System.out.println("Arithmetic exception thrown!");
}
```

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

```
catch (ArithmeticException e) {
    System.out.println("Arithmetic exception thrown!");
}
catch (Exception e) {
    System.out.println("Exception thrown!");
}
```

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

```java
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)

```java
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.

```java
void method() {
    try {
        ...
        method();
    } catch (Exception e) {
        ...
    }
}
```

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

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

Step1: Exception is thrown

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

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

Step 1: Exception is thrown

Step 2: catch clauses of the try block are inspected for a matching catch statement. First clause catches the exception.

Step 3: statement3 is executed, exception is handled.

Step 4: execution flow will continue bypassing the following catch clauses. statement5 is executed.

Step 5: Assuming no exception is thrown by statement5, program continues with statement7 and statement9.

Scenario: statement2 throws Exception3

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

Step 1: Exception is thrown

Step 2: catch clauses of the try block are inspected for a matching catch statement. None of these catch clauses match Exception3

Step 3: Catch clauses of the outer try statement are inspected for a matching catch. Exception3 is caught and statement8 is executed

Step 4: statement9 is executed

Scenario: statement2 throws Exception1 and statement3 throws Exception2

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

Step 1: Exception is thrown

Step 2: Exception is caught and statement3 is executed.

Step 3: statement3 throws a new exception

Step 4: Catch clauses of the outer try statement are inspected for a matching catch. Exception2 is caught and statement8 is executed

Step 5: statement9 is executed

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 guarantee that a code block will be executed in any condition.
Use the `finally` clause for code that must be executed "no matter what".

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

### Scenario: no exception occurs

1. `try` block is executed
2. `finally` block is executed, `statement4` is executed
3. `statement5` is executed

---

### Scenario: statement1 throws Exception1

1. `statement1` is executed
2. Catch clauses of the `try` block are inspected for a matching catch statement. `Exception1` is caught and `statement2` is executed.
3. `finally` block is executed, `statement4` is executed.
4. `statement5` is executed
Scenario: statement1 throws Exception3

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

Step 1: Exception is thrown
---
Step 2: Catch clauses of the try block are inspected for a matching catch statement. There is no matching catch. Finally is executed before inspecting the outer block. Statement4 is executed.
---
Step 3: Statement5 is not executed, a matching catch will be inspected at outer block(s)

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

```java
public class LessThanZeroException extends Exception {
    public LessThanZeroException() {
        
    }
    public LessThanZeroException(String message) {
        super(message);
    }
}
```

```java
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 in 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:**
  ```java
  catch(ArithmeticException e) {
      System.out.println("Exception is: "+ e);
  }
  **Output:**
  Exception is: java.lang.ArithmeticException: / by zero
  ```

- **Throwable** class also has useful methods. One of these methods is the `getMessage()` method.

  **Example:**
  ```java
  catch(ArithmeticException e) {
      System.out.println("Problem is: "+ e.getMessage());
  }
  **Output:**
  Problem is: / by zero
  ```

- Another method is the `printStackTrace()` method.

  **Example:**
  ```java
  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.

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

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:
```java
public void m1() throws Exception1 {
}
```
```java
public void m2() throws Exception1, Exception2, Exception3 {
}
```
CheckedExceptionExample1

```java
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 superclass of FileNotFoundException. No need to declare both.

CheckedExceptionExample2

```java
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) {
        BufferedReader inputFile = new BufferedReader(new FileReader("a.txt"));
        String line = inputFile.readLine();
        inputFile.close();
        return line;
    }
}
```

FileNotFoundException may be thrown here
IOException may be thrown here
IOException is superclass of FileNotFoundException.

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

- 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