

A large, two-story, light-colored building with a red-tiled roof and a central tower, surrounded by green grass and trees under a clear blue sky.

MAHARISHI UNIVERSITY of MANAGEMENT

Engaging the Managing Intelligence of Nature

Computer Science Department

CS390 Fundamental Programming Practices (FPP)

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Lecture 12:

Exception-Handling in

Java

Wholeness of the Lesson

Java's exception-handling model (which is similar to those in other OO languages) systematizes the task of handling error conditions and integrates it with the OO paradigm supported by the language. This advance in programming practice illustrates the theme that “deeper knowledge has more profound organizing power.”

Outline of Topics

- What Is Exception-Handling All About?
- An Object-Oriented Error-Handling Strategy
- Classification of Error-Condition Classes
 - Objects of type Error
 - Other Unchecked Exceptions
 - Checked Exceptions
- Using/Creating Exception Classes
- Best Practices: When to Handle, When to Throw, When to Log
- Some Syntax Rules For Try/Catch
- The finally Keyword

What Is Exception-Handling All About?

- Problems can arise during execution of an application.
- Examples:
 - Try to open a file but can't
 - Try to access a database, but it's unavailable
 - Try to save data, but disk is full
 - Try to call a method on an uninitialized object
 - Try to access an array index beyond the defined array length
 - Try to divide a number by zero

- Regardless of the problem, any error condition that arises in an application should be handled in one of two ways (depending on the situation):

Either:

- Return to a safe state and enable the user to execute other commands (for example, the user accidentally inputs incorrect data, such as an incomplete phone number – the application should ask the user to try again)
- Allow the user to save all work and terminate the application gracefully (for example, a database may not be accessible, so the user should be allowed to "try again later")

But what is the right way to accomplish this objective?

An Object-Oriented Error-Handling Strategy

Java's solution to the problem is very similar to the solution offered in most OO languages:

- An error of any kind is represented as a special kind of object
- When an error condition arises, an instance of the object is created by the Java runtime and "thrown" (similar to the way an "event" is triggered by a button click or other user action on a GUI)
- Code written by the developer then "catches" the error-related object, analyzes the information in this object as necessary, and performs some action to handle it.

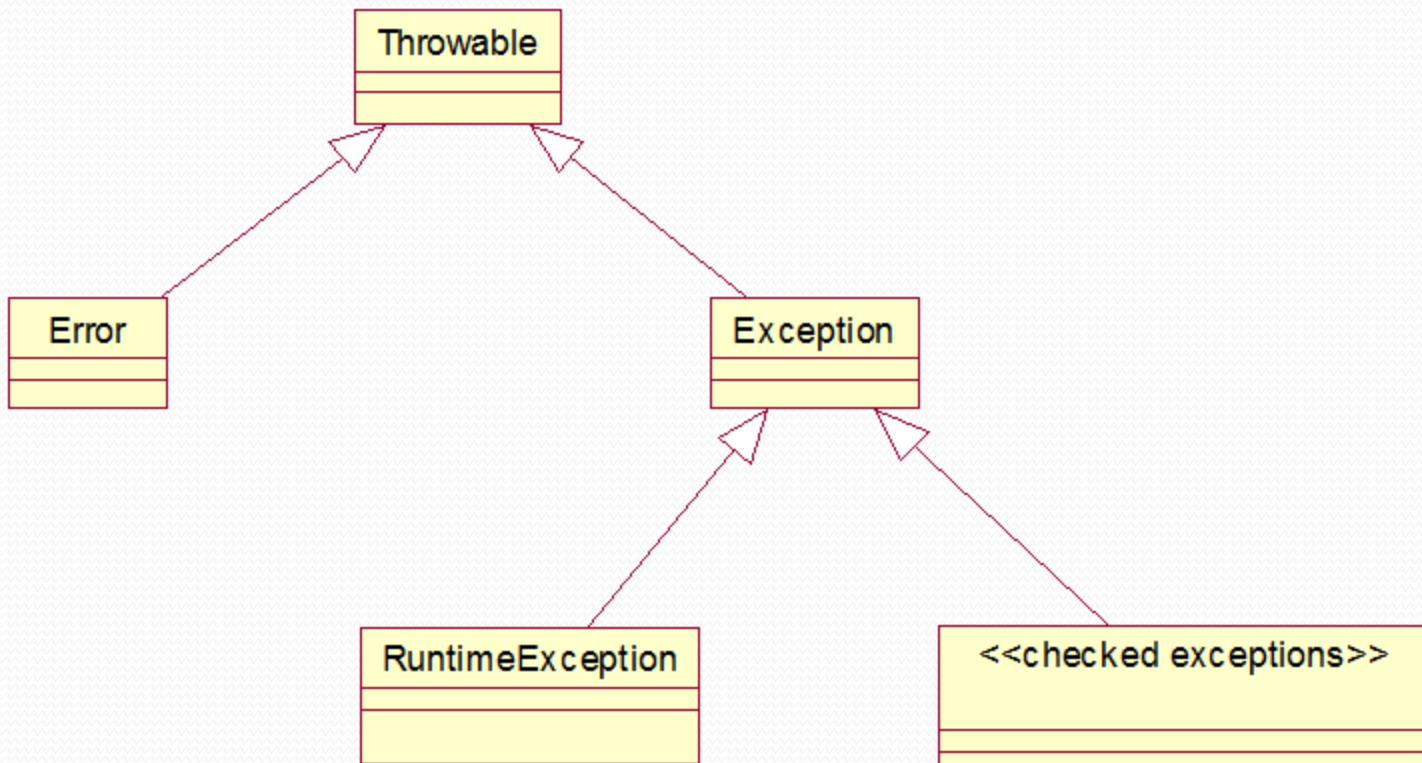
Common Scenarios of Java Exceptions

- **A scenario where `ArithmeticException` occurs**
`int a=50/0;//ArithmeticException`
- **A scenario where `NullPointerException` occurs**
`String s=null;`
`System.out.println(s.length());//NullPointerException`
- **A scenario where `NumberFormatException` occurs**
`String s="abc";`
`int i=Integer.parseInt(s);//NumberFormatException`
- **A scenario where `ArrayIndexOutOfBoundsException` occurs**
`int a[]=new int[5];`
`a[10]=50; //ArrayIndexOutOfBoundsException`

Main Point

Java's exception-handling model supports best practices in handling exceptions that arise during program execution. Likewise, establishing awareness in the home of all the laws of nature results in a life spontaneously lived in accord with natural law.

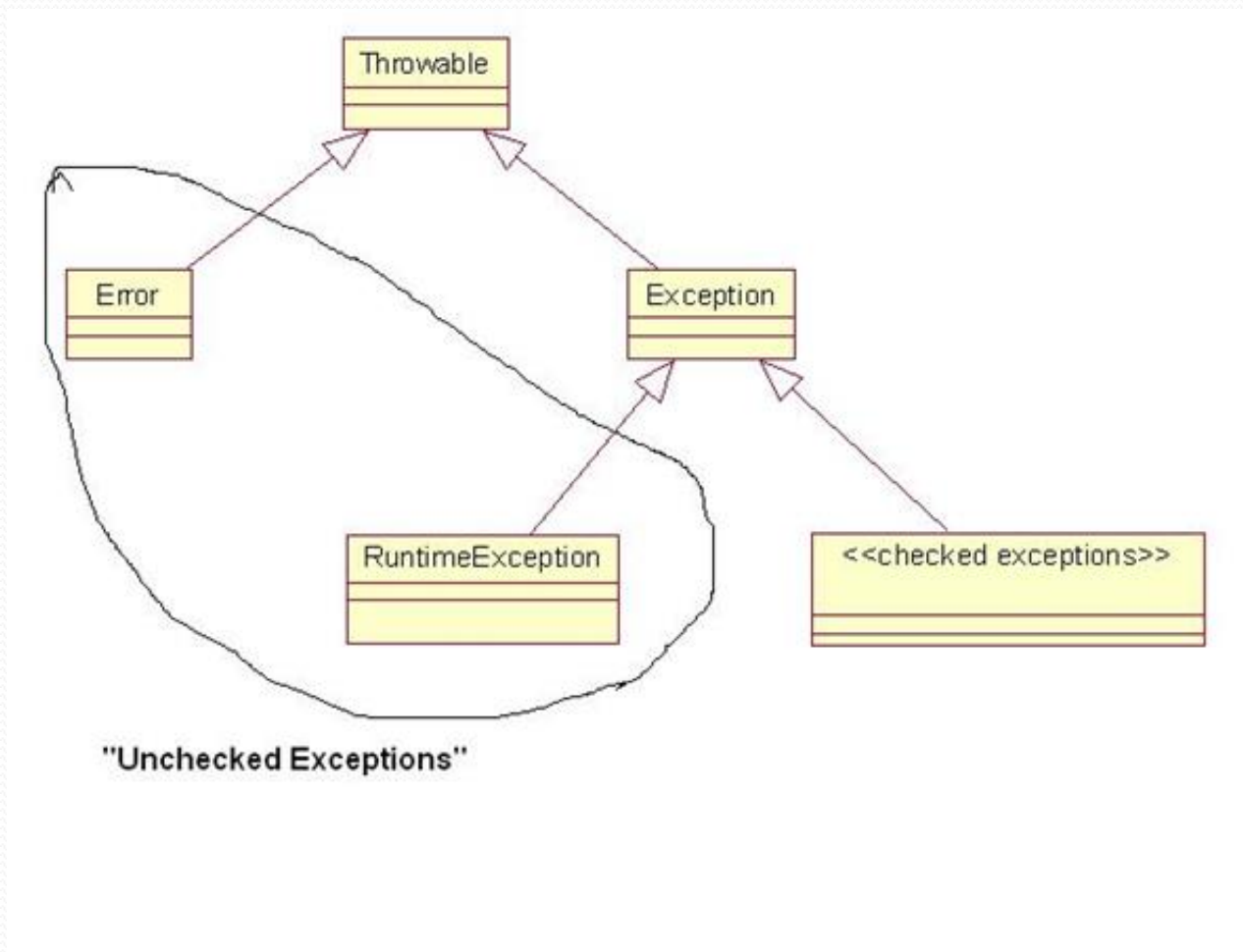
The Hierarchy of Java Classes That Represent Error Conditions



Classification of Error-Condition Classes

In Java, error-condition classes belong to one of three categories:

- *Error* – Objects in this category belong to the inheritance hierarchy headed by the `Error` class
- *Other Unchecked Exceptions* – Besides `Error` objects, unchecked exceptions include all objects that belong to the inheritance hierarchy headed by the class `RuntimeException`.
- *Checked Exceptions* – Exceptions in this category are subclasses of `Exception` but not subclasses of `RuntimeException`.



Objects of type Error

- `Error` objects describe internal errors, JVM execution errors, or resource exhaustion. They occur rarely, but usually, if they do occur, the application must be terminated.
- From the developer's point of view, there is nothing that must be done to handle this kind of error during execution of the application – no “catch” clause could resolve the problem. It's beyond the control of the developer, like a system or hard disk crash. [Note: A `StackOverflowError` is an example of an `Error` that can typically be handled by rewriting the code, but nothing can be done to solve this problem (or any other `Error`) during program execution.]
- When one of these errors occurs, the JVM *throws* an `Error` object. Typically, since the developer has not written special code to handle the error event, the JVM will handle the `Error` object by displaying a message to the console indicating the type of `Error` and the sequence of method calls that led to the error condition (called a *stack trace*).

Example: (From Lesson 7 – Recursion). If you create an illegal recursion, you will typically cause a `StackOverflowError` to occur because the sequence of self-calls overflows the call stack.

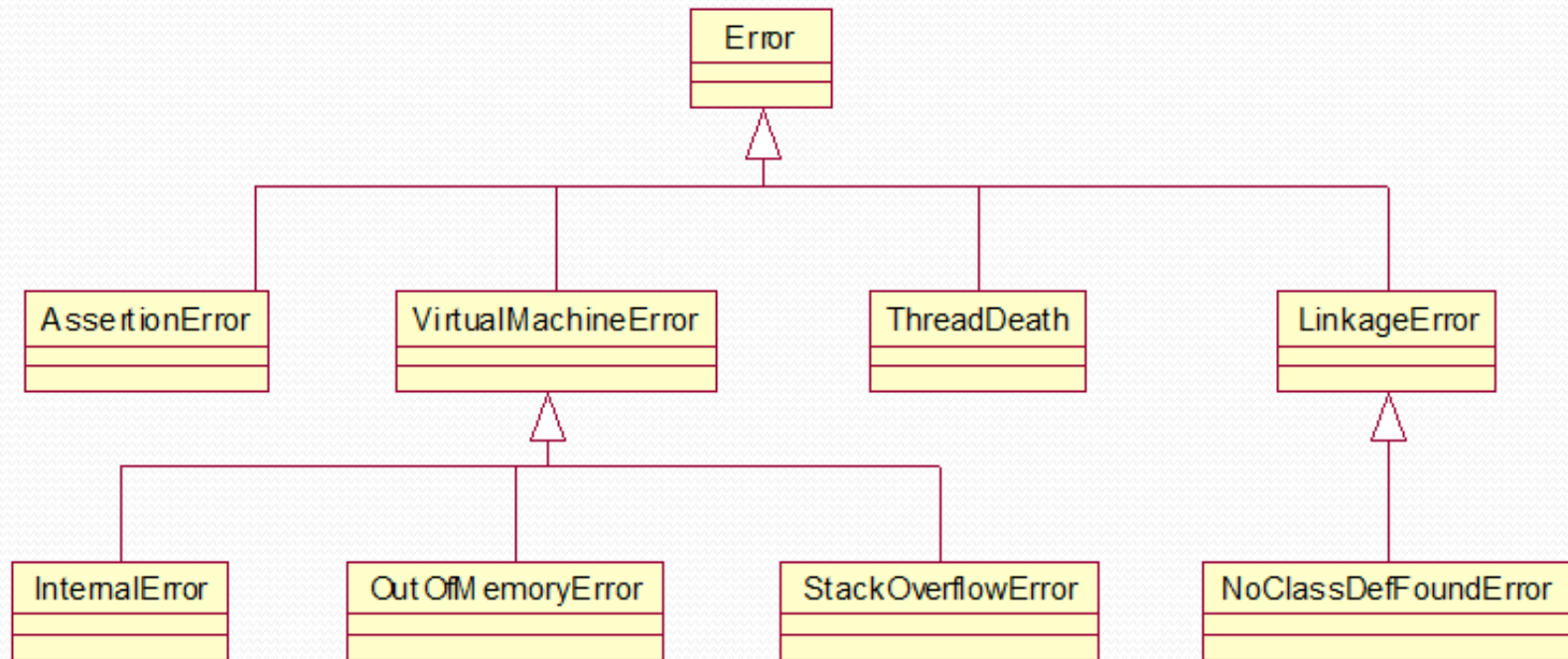
```
class MyClass {
    public static void main(String[] args) {
        new MyClass();
    }
    MyClass() {
        recurse("Hello");
    }
    String recurse(String s) {
        if (s == null)
            return null;
        int r = RandomNumbers.getRandomInt();
        int n = s.length();
        if (r % 2 == 0)
            return recurse(s.substring(0, n / 2));
        else {
            return recurse(s.substring(n / 2, n));
        }
    }
}
```

Running this code leads to the following output: (next slide)


```
Exception in thread "main" java.lang.StackOverflowError
  at java.util.Random.nextInt(Unknown Source)
  at
pencil_4.probl.RandomNumbers.getRandomInt (RandomNumbers.java:20)
  at pencil_4.probl.MyClass.recurse (MyClass.java:15)
  at pencil_4.probl.MyClass.recurse (MyClass.java:20)
  at pencil_4.probl.MyClass.recurse (MyClass.java:20)
  at pencil_4.probl.MyClass.recurse (MyClass.java:18)
  at pencil_4.probl.MyClass.recurse (MyClass.java:20)
  at pencil_4.probl.MyClass.recurse (MyClass.java:20)
  at pencil_4.probl.MyClass.recurse (MyClass.java:20)
  at pencil_4.probl.MyClass.recurse (MyClass.java:18)
  at pencil_4.probl.MyClass.recurse (MyClass.java:20)
```

```
//output abbreviated
```

The Error Hierarchy



Exercise 12.1 – Causing the JVM to Throw an Error

- Using JShell, invent your own piece of code that causes a `StackOverflowError` to be thrown. See if you can do it by writing just a couple of lines of code.
- Then create another piece of code that causes an `OutOfMemoryError` to be thrown. Again, try to make your code as brief as possible.

Exercise 12.1 - Solution

StackOverflowError

```
jshell> int myMethod() {  
    ...> return myMethod() + 1;  
    ...> }  
| created method myMethod()
```

```
jshell> myMethod();  
| java.lang.StackOverflowError thrown  
|     at myMethod (#1:2)  
|     at myMethod (#1:2)  
|     at myMethod (#1:2)  
|     at myMethod (#1:2)  
|     at myMethod (#1:2)
```

OutOfMemoryError

```
jshell> String dbl(String s) {  
    ...> return s + s;  
    ...> }  
| created method dbl(String)
```

```
jshell> String t = "hello";  
t ==> "hello"  
  
jshell> for(int i = 0; i < 50; ++i) {  
    ...> t = dbl(t);  
    ...> }  
| java.lang.OutOfMemoryError thrown: Overflow: String length out of range  
|     at StringConcatHelper.checkOverflow (StringConcatHelper.java:46)  
|     at StringConcatHelper.mixLen (StringConcatHelper.java:118)  
|     at dbl (#1:2)  
|     at (#3:2)
```

Other Unchecked Exceptions

- Apart from `Error` objects, the other unchecked exceptions are those that belong to the hierarchy `RuntimeException`. As with `Error` objects, when one of these exceptions occurs, the JVM throws an `Exception` object (in this case, of type `RuntimeException` or one of its subclasses) up the call stack.
- Generally, if an exception of this kind is thrown, it indicates that the programmer has made a logic error in the code and needs to fix it.
- Examples:
 - `NullPointerException` //an object needs to be
 //initialized
 - `ClassCastException` //improper cast needs to be fixed
 - `ArrayIndexOutOfBoundsException` //adjust bounds of a loop
 - `NumberFormatException` //could arise from trying to turn
 //a non-numeric String into an Integer
- The techniques for handling exceptional conditions at runtime that need to be used for dealing with *checked exceptions* (discussed below) do *not* typically need to be done for unchecked exceptions.

Examples

```
class Test1 {  
    private Employee emp;  
    public static void main(String[] args) {  
        Test1 test = new Test1();  
        //NullPointerException at runtime  
        String name = test.emp.getName();  
    }  
}  
  
class Test2 {  
    public static void main(String[] args) {  
        List employees = new ArrayList();  
        employees.add(new Employee("Joe"));  
        employees.add(new Employee("Tim"));  
  
        //ClassCastException at runtime  
        Employee first = (Manager) employees.get(0);  
    }  
}
```


Throwing Runtime Exceptions

Because exceptions of type `RuntimeException` are unchecked, they can also be used by developers to indicate a problem that needs to be corrected (useful during development, not for production code). Two examples are `IllegalArgumentException` and `IllegalStateException`.

Example: (From the `Rational` class that was described in an earlier lab)

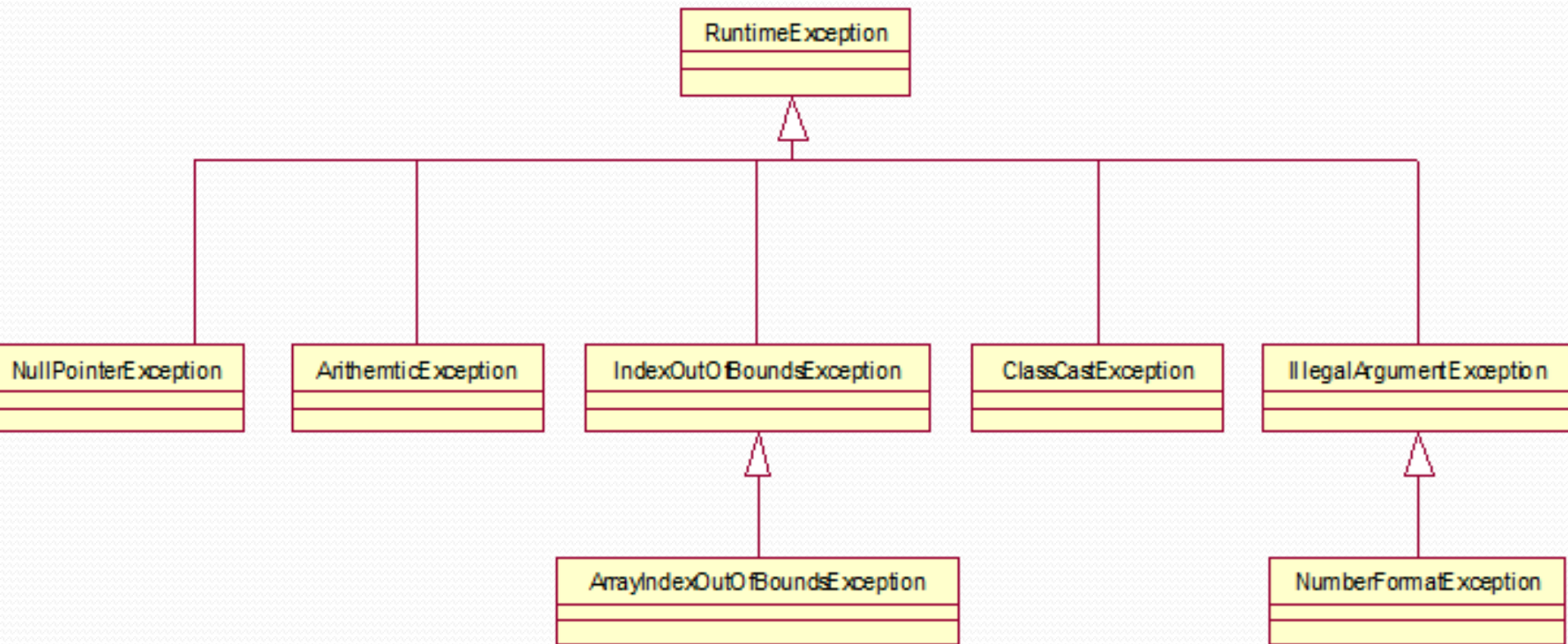
```
public Rational(int num, int denom) {
    if(denom <= 0) {
        throw new IllegalArgumentException("Denominator must be
                                         positive");
    }
    this.num=num;
    this.denom=denom;
}

public static void main(String[] args) {
    //no need to enclose this in a try/catch block
    new Rational(2,5);
}
```

See `lesson12.improvedrational.Rational`

[We will discuss what it means for exceptions to be “thrown” later in this lesson]

Hierarchy of RuntimeException

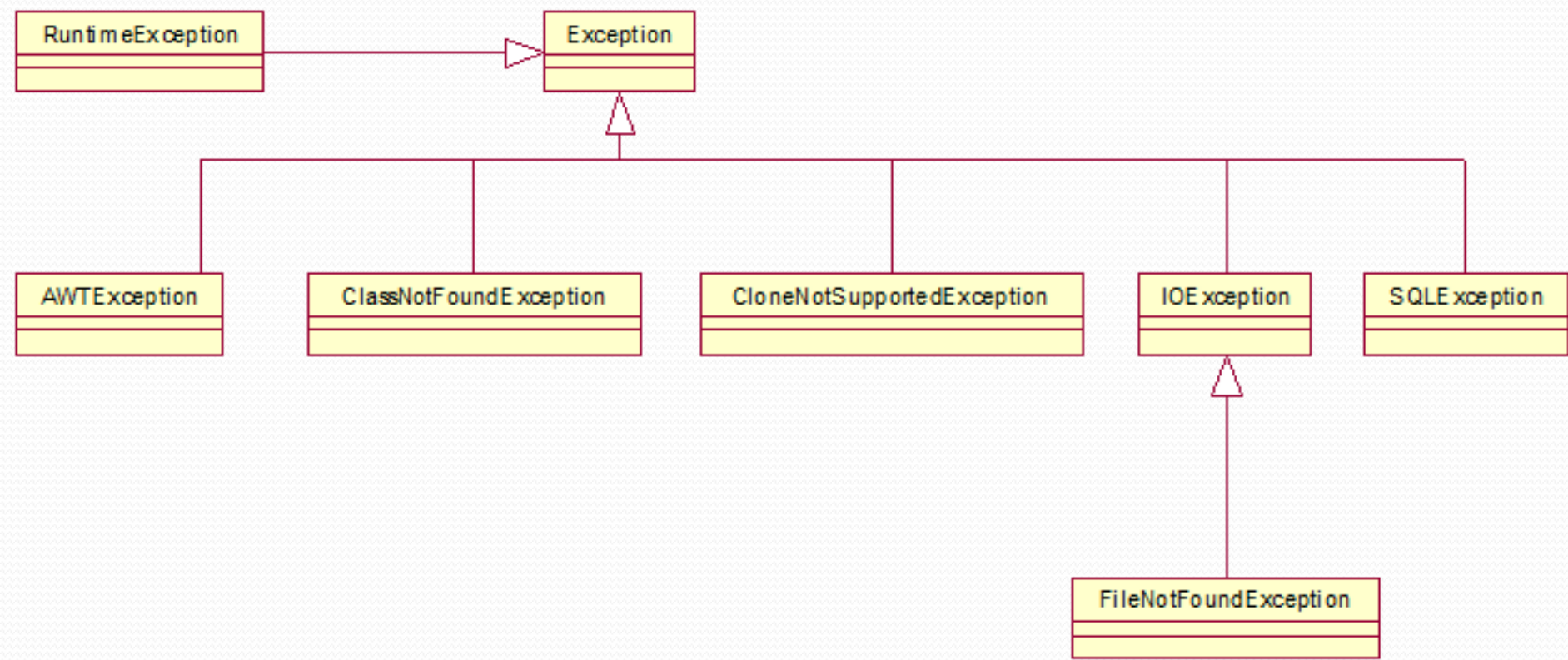


Checked Exceptions

- This kind of exception is considered by the JVM to be the kind of error a developer must be prepared to handle. Examples:
 - `CloneNotSupportedException`
 - `FileNotFoundException`
 - `SQLException`
 - `AWTException`
- Often, these exceptions arise when something goes wrong with the application's environment (can't find a file or class) or with an external system (an SQL query can't be executed).
- The JVM expects you the developer to *handle* any exception of this type that could possibly be thrown, and will *issue a compiler error if you fail to do so*. (This is the reason for the terminology "checked exception".)

Hierarchy of Checked Exceptions

Not a checked
exception



Dealing With Checked Exceptions

- Every method in the Java API (and, as we discuss shortly, any user-created method) that is capable of throwing an `Exception` belonging to the Checked Exception Hierarchy indicates this fact with a `throws` clause in its declaration.
- Example:
 - The constructor of the class `FileWriter` (which is used for writing text to a file) is:

```
public FileWriter(File file) throws FileNotFoundException
```

- When you call a method that has a `throws` clause in its declaration, there are four ways of dealing with it:
(All four cases are illustrated in package `lesson12.checkedexceptions`)
 1. Do not attempt to handle directly; instead, declare that *your* method **throws** this kind of exception too
 2. Surround the calling code in a `try` block, and then do one of the following:
 - a. write exception-handling code in a **catch** block (as in `lesson12.exceptionhandlingdemo`, mentioned earlier)
 - b. partially handle the exception in a **catch** block, and then *re-throw* the exception to allow other methods in the call stack to handle it further
 - c. **throw** a new kind of exception from within the **catch** block

What Happens in Each Case

- Whenever an exception is thrown at runtime, the JVM looks to see if the active method has a `catch` clause whose `Exception` type matches the type of the thrown `Exception`. If not, it moves up the call stack to see if any calling methods provide a `catch` clause with a match.
- If `try/catch` blocks have been provided, and the `catch` block's parameter matches the thrown exception type, then:
 - the program skips the remainder of code in the `try` block
 - the program executes the code in the `catch` block

- The code inside a `catch` block may
 - a) gracefully handle the error condition – in which case the program will continue to run immediately after the `catch` block, or
 - b) cause the application to terminate (using `System.exit(0)`), or
 - c) re-throw the `Exception` that it just caught, or
 - d) throw a new `Exception` of a different type
- Note: Details of this behavior will change slightly if a `finally` block is also included – this point is discussed at the end.

- Java's exception-handling model is based on three operations:
 1. declaring an exception
 2. throwing an exception
 3. catching an exception
- The keyword to declare an exception is **throws**.
- The keyword to throw an exception is **throw**.

1. Declaring an exception

```
public void myMethod() throws IOException
```

2. Throwing an exception

```
throw new IllegalArgumentException("Wrong Argument");
```

3. Catching an exception

Main Point

Methods whose declaration includes a *throws* clause can be called by another method only if the calling method is declared with the same *throws* clause, or if a try/catch block is included to catch any of the declared exceptions that are thrown. This phenomenon is reminiscent of the Principle of Diving: once the initial conditions have been met, a correct dive into the depths occurs automatically. (The *throws* clause is the initial condition; the compiler then automatically requires additional coding in order to handle exceptions that may occur.)

Summary of Exception Types

- *Errors*. When an `Error` is thrown, it indicates an internal JVM error or other problem beyond the control of the developer. No attempt should be made to catch `Errors` and typically, no adjustment to the code needs to be done to prevent them (*except* for `StackOverflowError`, which is usually thrown because of an illegal recursion).
- *Other unchecked exceptions* are thrown as objects of type `RuntimeException`, or one of its subclasses. These exceptions indicate a programming error needs to be fixed (like `NullPointerException`, `ClassCastException`, and `ArrayIndexOutOfBoundsException`). These objects should not be "caught" (i.e. used in conjunction with `try/catch` blocks), though for debugging purposes, this can be done.
- *Checked exceptions* are exceptions that are subclasses of `Exception` but that are not part of the `RuntimeException` hierarchy. They must be dealt with in code by the developer. Failure to write such code results in a compiler error. Each call of a method that declares that it `throws` such an exception must either explicitly handle (in a `try/catch` block) exceptions that may arise from the call, or must pass the exception object up the call stack (using a `throws` declaration).

Best Practices:

When to Handle, When to Throw, When to Log

Which Class Should Handle An Exception?

- Exceptions are thrown at the exact point during execution where a problem arises
- Exceptions should be handled by a class that has among its responsibilities the proper knowledge about what should be done.
- One or more classes in an application should be delegated the responsibility of knowing what to do in case an exception occurs. Often, this responsibility entails nothing more than displaying an appropriate message to the user if an exception occurs.

Mapping Exceptions to Custom Exception Classes

For production-level applications, it is good practice to pre-define a set of application-specific Exception classes as part of an overall error-handling policy. These classes should represent a simple classification of the kinds of errors that might occur, and a mapping of these to a classification of the kinds of information you want to log and/or present to the user.

Example: In a small application, you may need only two kinds of exception: a `UserException` and a `SystemException`.

`UserException`: When the user makes a mistake

`SystemException`: When something goes wrong that is not the user's fault

Once this design decision has been made, then all exceptions that could arise in the application would be caught and either a `UserException` or `SystemException` would then be thrown.

```
public class UserException extends Exception {  
    public UserException() {  
        super();  
    }  
    public UserException(Throwable t) {  
        super(t);  
    }  
    public UserException(String msg) {  
        super(msg);  
    }  
}
```

Exercise 12.2 – Include Exception-Handling in Stack Implementation

In InClassExercise 9.1, you created an implementation `NodeStack` of the Stack ADT. The `peek` and `pop` operations return null when the stack is empty. Modify this implementation so that when `peek` or `pop` is called on an empty stack, a `StackException` is thrown. To do this, first create your own `StackException` class. Then, update the clauses in the `peek` and `pop` code so they throw a `StackException` when `peek` or `pop` is called on an empty array.

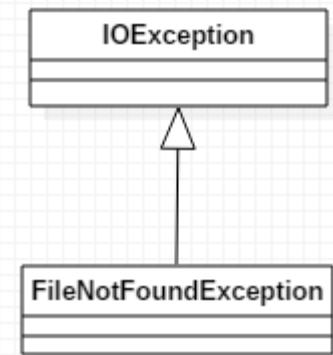
Some Syntax Rules for Try/Catch

1. Every use of try must have at least one corresponding catch (or finally – see below) clause.
2. When an exception object is thrown, it will be caught by the nearest catch clause for which the catch clause parameter matches the class of the exception object, or *is a superclass of this class*

Example: The following produces a compiler error – 2nd catch clause is *unreachable*

```
try {  
    . . .  
}  
catch(IOException ex1) {  
    . . .  
}  
catch(FileNotFoundException ex2) {  
    . . .  
}
```

**unreachable
code**



The following however is legal

```
try {  
    . . .  
}  
catch (FileNotFoundException ex1) {  
    . . .  
}  
catch (IOException ex2) {  
    . . .  
}
```

This also explains why you should never catch an "Exception" object directly – otherwise, you could end up catching all kinds of unchecked exceptions (by accident).

```
//bad programming style  
try {  
    . . .  
}  
catch (Exception e) {  
    . . .  
}
```

3. It is legal to have `try/catch` blocks inside other `try` blocks and inside other `catch` blocks (sometimes this is necessary)

```
try{
    try {
        . . .
    }
    catch (AnExceptionType ex1) {
        . . .
    }
}
catch (AnotherExceptionType ex2) {
    try {
        . . .
    }
    catch (ThirdExceptionType ex3) {
        . . .
    }
}
```

The finally Keyword

- A `finally` clause can be introduced after all `catch` clauses.
- Any `finally` block is guaranteed to run after a `try/catch` block, even if a `return` or `break` occurs; even if another exception is thrown inside those blocks.
- Exception to the rule: If `System.exit(0)` occurs in one of the blocks, the `finally` clause is skipped.
- A `finally` clause is used to cleanup resources (like database connections, open files)

finally Exercise

Demo: `lesson12.finallyexercise`

```
class FinallyTest{
    public static void test() throws Exception {
        try {
            // return;                // 1
            // System.exit(0);        // 2
            // throw new Exception("first");    // 3a
        }
        catch (Exception x){
            System.out.println(x.getMessage());
            // throw new Exception("second");    // 3b
        }
        finally {
            System.out.println("finally!");
        }

        System.out.println("last statement");
    }
    public static void main(String[] args){
        try{
            test();
        }
        catch(Exception x){
            System.out.println(x.getMessage());
        }
    }
}
```

Program Output

0: finally!
 last statement

1: finally!

2: no output

3a: first
 finally!
 last statement

3a & 3b:
 first
 finally!
 second

Connecting the Parts of Knowledge With the Wholeness of Knowledge

Right action in the field of exception-handling

1. If a Java method has a throws clause in its declaration, the compiler requires the developer to (write code to) handle potential exceptions whenever the method is called.
 2. To handle exceptions in the best possible way, logging should occur as soon as an exception is thrown, and the exception should be re-thrown up the call stack until a method belonging to a class with an appropriate set of responsibilities is reached – and within this method, the exception should be caught and handled.
-
3. **Transcendental Consciousness:** TC is the home of all the laws of nature, the home of "right action".
 4. **Wholeness moving within itself:** Action in the state of Unity Consciousness is spontaneously right and uplifting to the creation as a whole.

