CSE201: Monsoon 2020
Advanced Programming

Lecture 10: Exception Handling

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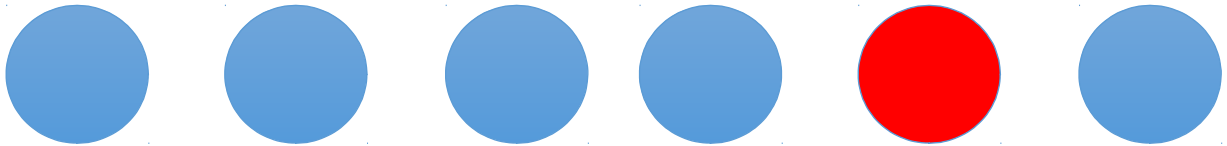
Last Lecture

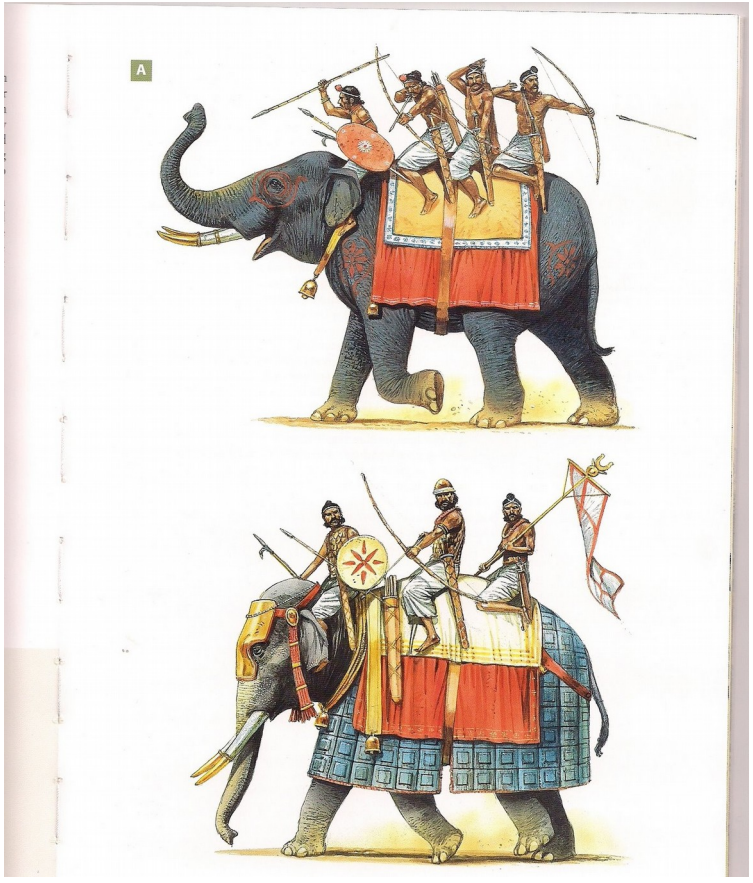
- Generic programming in Java
  - Using generic programming we don't have to implement different classes for different object types
    - Programmer friendly code!
  - Generics are implemented using type erasures
    - Compiler erases all parameter type information
  - Restrictions
    - Type parameters cannot be instantiated with primate types
    - Instantiating type variables is not allowed
    - Generic array creation is not allowed
    - Type variables are not valid as static field of a generic class
    - Generic does not supports sub typing

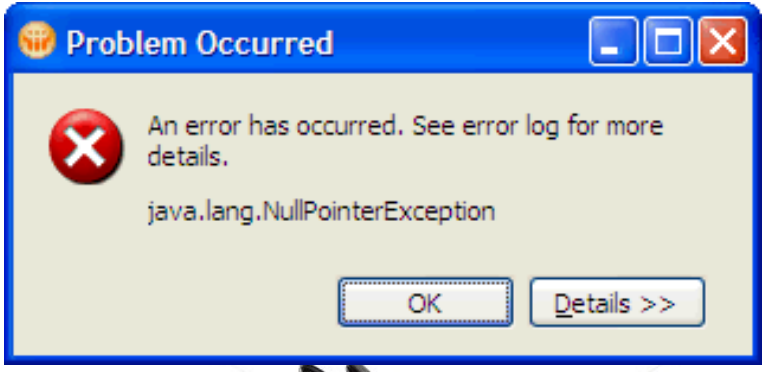

```
public class Pair <T1, T2> {
    private T1 key;
    private T2 value;
    public Pair(T1 _k, T2 _v) {
       key = _k; value = _v;
    }
    public T1 getKey() {  return key; }
    public T2 getValue() { return value; }
}
public class Main {
    public static void main(Sting args[]) {
        MyGenericList<Pair<String, Integer>> db =
              new MyGenericList<Pair<String, Integer>>();
        db.add(new Pair<String, Integer>("John", 2343));
        db.add(new Pair<String, Integer>("Susane", 8908));
        ...
    }
}
```

Today’s Lecture: Exceptions



Being Defensive is Important





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Defensive Programming

- Murphy's law
  - "Anything that can possibly go wrong, does."
- Finagle's law
  - "Anything that can go wrong, will – at the worst possible moment."
- Sod's law
  - "If something can go wrong, it will"

Defensive programming: Hope for the best, expect the worst!

Defensive Programming

- Collection of techniques to reduce the risk of failure at run time
  - An analogy is defensive driving by being never sure how other drivers would be driving
- The technique is in making the software behave in a predictable manner despite unexpected inputs or user actions and internal errors
  - After all debugging takes a lot of time!

Types of Programming Errors

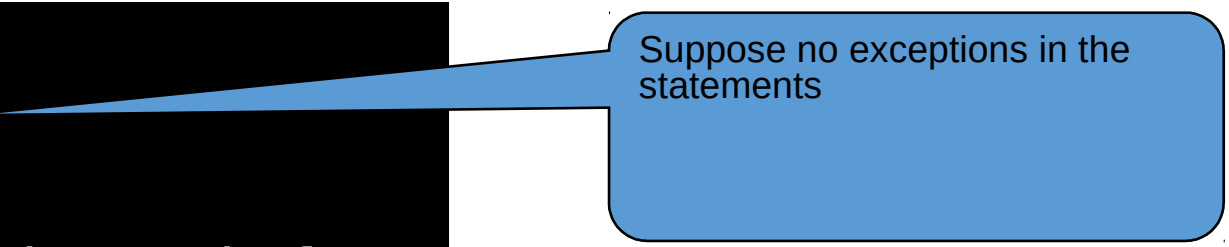
- Syntax errors
  - Compile time errors
  - Easiest to fix
- Logical errors
  - Program runs without crashing but gives incorrect result
  - Most difficult to fix
- Runtime errors
  - Occur while the program is running if the environment detects an operation that is impossible to carry out
  - Could be fixed easily with defensive programming
    - **Exception handling!**

Exception Handling Syntax

- Process for handling exceptions
  - `try` some code, catch exception thrown by tried code, finally, “clean up” if necessary
  - `try`, `catch`, and `finally` are reserved words
- `try` denotes code that may throw an exception
  - place questionable code within a `try` block
  - a `try` block must be immediately followed by a `catch` block unlike an if w/o else
  - thus, `try-catch` blocks always occurs as pairs
- `catch` exception thrown in `try` block and write special code to handle it
  - catch blocks distinguished by type of exception
  - can have several ***catch blocks***, each specifying a particular type of exception
  - Once an exception is handled, execution continues after the catch block
- `finally` (optional)
  - special block of code that is executed whether or not an exception is thrown
  - follows *catch block*

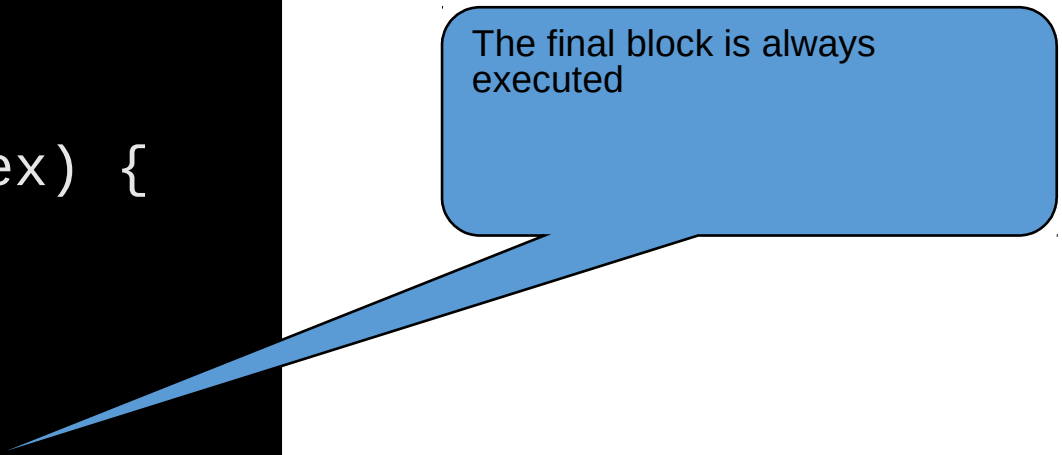
Trace a `try/catch` Program Execution (1/3)

```
try {
  statements;
}
catch(TheException ex) {
  handling ex;
}
finally {
  finalStatements;
}

Next statement;
```



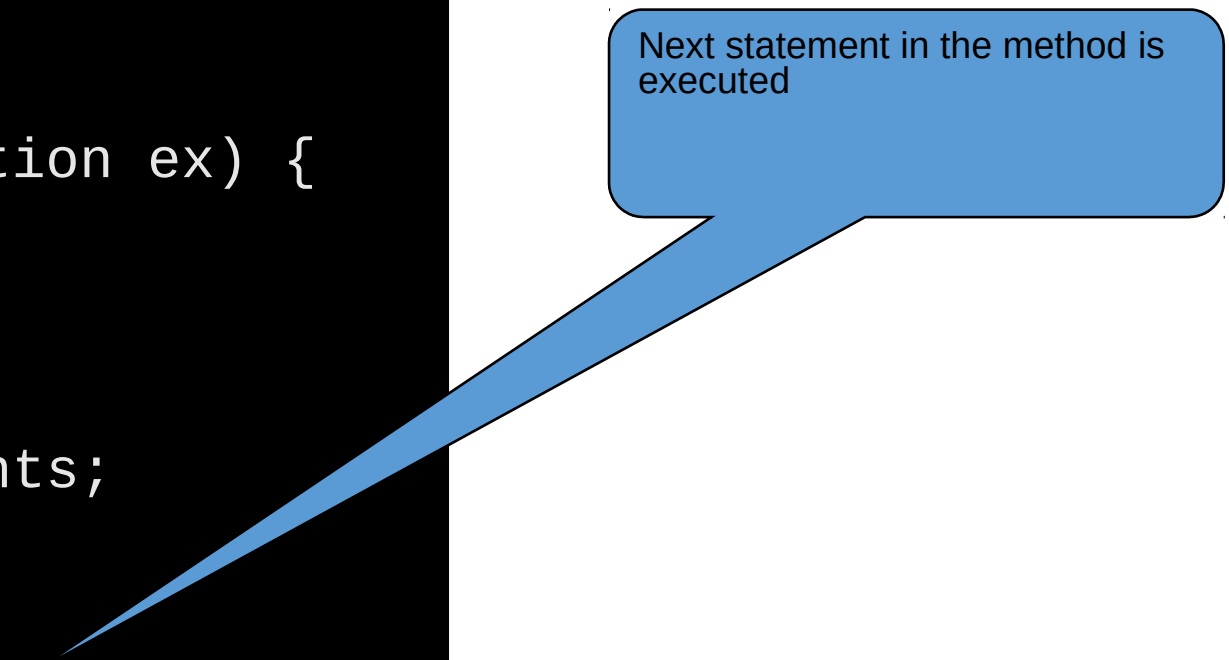
Trace a `try/catch` Program Execution (2/3)

```
try {
  statements;
}
catch(TheException ex) {
  handling ex;
}
finally {
  finalStatements;
}

Next statement;
```



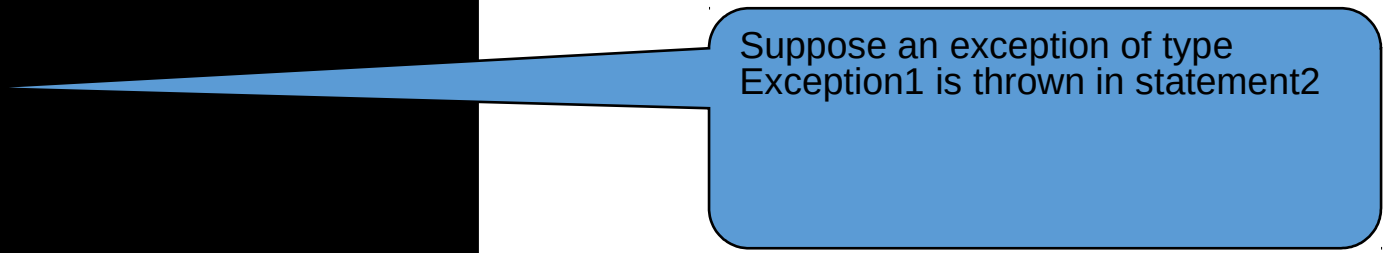
Trace a `try/catch` Program Execution (3/3)

```
try {
  statements;
}
catch(TheException ex) {
  handling ex;
}
finally {
  finalStatements;
}

Next statement;
```



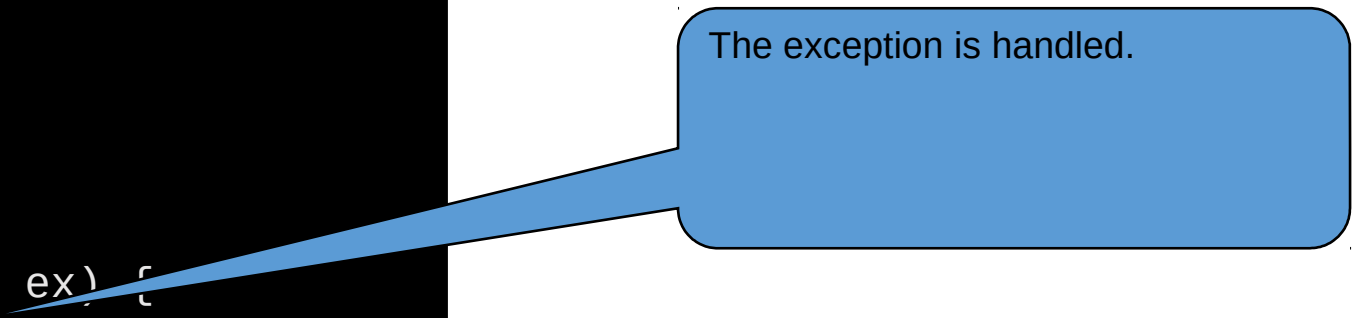
Trace a `try/catch` Program Execution (1/4)

```
try {
  statement1;
  statement2;
  statement3;
}
catch(Exception1 ex) {
  handling ex;
}
finally {
  finalStatements;
}

Next statement;
```



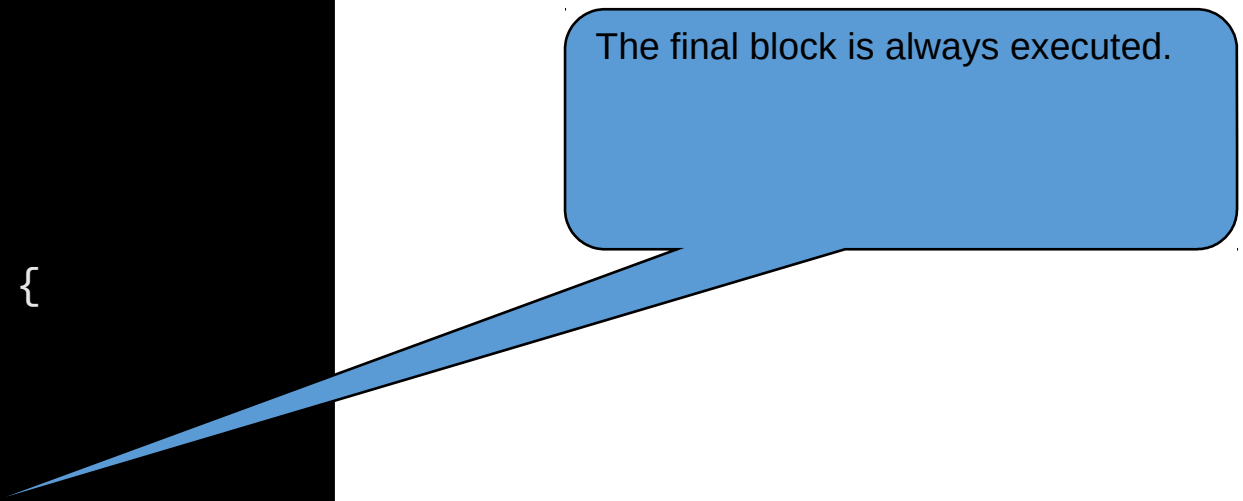
Trace a `try/catch` Program Execution (2/4)

```
try {
  statement1;
  statement2;
  statement3;
}
catch(Exception1 ex) {
  handling ex;
}
finally {
  finalStatements;
}

Next statement;
```



Trace a `try/catch` Program Execution (3/4)

```
try {
  statement1;
  statement2;
  statement3;
}
catch(Exception1 ex) {
  handling ex;
}
finally {
  finalStatements;
}

Next statement;
```



Trace a `try/catch` Program Execution (4/4)

```
try {
  statement1;
  statement2;
  statement3;
}
catch(Exception1 ex) {
  handling ex;
}
finally {
  finalStatements;
}

Next statement;
```

The next statement in the method is now executed.

Is this Defensive Programming ?

```
import java.util.*;
public class Main {

    public static void main(String[] args) {



            System.out.println("Enter Integer
Input");

          Scanner sc = new Scanner(System.in);
          int num = sc.nextInt();









        }
    }
}
```

- Is program correct?
  - Yes
    - But, only if the user is paying attention
      - Invalid input ?
      - String as input?

Exception Handling using `try/catch`

```
import java.util.*;
public class Main {

    public static void main(String[] args) {
        boolean done = false;
        while(!done) {
            System.out.println("Enter Integer
Input");
      try {
          Scanner sc = new Scanner(System.in);
          int num = sc.nextInt(); //exception
point          done = true;
      }
      catch(InputMismatchException inp) {
          System.out.println("Wrong input:");
          System.out.println("Try again");
      }
      finally {
          System.out.println("Always execute");
            }
        }
    }
}
```

- This is a foolproof program now!
- Exception handling using `try/catch` block of statements
  - Defensive programming
- `InputMismatchException` is a type of exception provided by the `Scanner` class in Java

Multiple `catch` Blocks

```
import java.util.*;
public class Main {
    public static void main(String[] args) {
        String[] s = {“a”, “23”, null, “4”, “P”};
        int sum = 0;
        for(int i=0; i<10; i++) {

                sum += (s[i].length() > 0) ?
                           Integer.parseInt(s[i])
: 0;
```

```
        }
```

Multiple `catch` Blocks

```
import java.util.*;
public class Main {
    public static void main(String[] args) {
        String[] s = {“a”, “23”, null, “4”, “P”};
        int sum = 0;
        for(int i=0; i<10; i++) {
      try {
                sum += (s[i].length() > 0) ?
                          Integer.parseInt(s[i])
: 0;
      }
      catch(NumberFormatException e) {
          System.out.println(“Not an Integer”);
      }
            catch(NullPointerException e) {
          System.out.println(“NULL value found”);
      }
            catch(ArrayIndexOutOfBoundsException
e) {
          System.out.println(“Index not in
range”);
      }
        }
```

- There could be multiple `catch` for a single `try` block
- They are designed to catch different types of exceptions that could be raised from a single `try` block
- **How the exceptions are generated here?**
  - i=0 will raise NumberFormatException
  - i=2 will raise NullPointerException
  - i=4 will raise NumberFormatException
  - i>4 will raise ArrayIndexOutOfBounds exception

Question

```
public class Main {
    public static void main(String[] args) {
        String s = null;
        try {
            int length = s.length();
        }

        System.out.println(“Just before catch
block”);

        catch(NullPointerException e) {
            System.out.println(“String was
null”);
        }
    }
}
```

- What is the output of the following program?
- Answer
  - Compilation error!
  - **No statement is allowed between a pair of try and catch**
  - `error: 'catch' without 'try'`

Nested `try/catch` Blocks

```
public class Andy {
    .....

    public void getWater() {
        try {
            _water = _wendy.getADrink();
            int volume = _water.getVolume();
        }
        catch(NullPointerException e) {
            this.fire(_wendy);
            System.out.println("Wendy is
fired!");
            try {
                _water = johny.getADrink();
                int volume = _water.getVolume();
            }
            catch(NullPointerException e) {
                this.fire(johny);
                System.out.println("Johny is
fired!");
            }
        }
    }
```

- `try/catch` block could be nested!
  - If Andy's call to `getADrink` from Wendy returns null, he can ask Johny to `getADrink`

Methods Can `throw` Exception

```
public class Andy {
    .....
    public void drinkWater() {
        try {
            getWater();
        }
        catch(NullPointerException e) {
            System.out.println(e.getMessage());
        }
    }
    public void getWater() {
        _water = _wendy.getADrink();
        if(_water == null) {
            this.fire(_wendy);
            System.out.println("Wendy is fired!");
            throw new NullPointerException("NO
Water");
        }
    }
}
```

- If you wish to throw an exception in your code you use the **`throw`** keyword
- Most common would be for an unmet precondition
- When the program detects an error, the program can create an instance of an appropriate exception type and throw it:

```
throw new TheException("Message");
```

- In the above constructor call for the exception, the message is optional but it's always good to pass some meaningful message

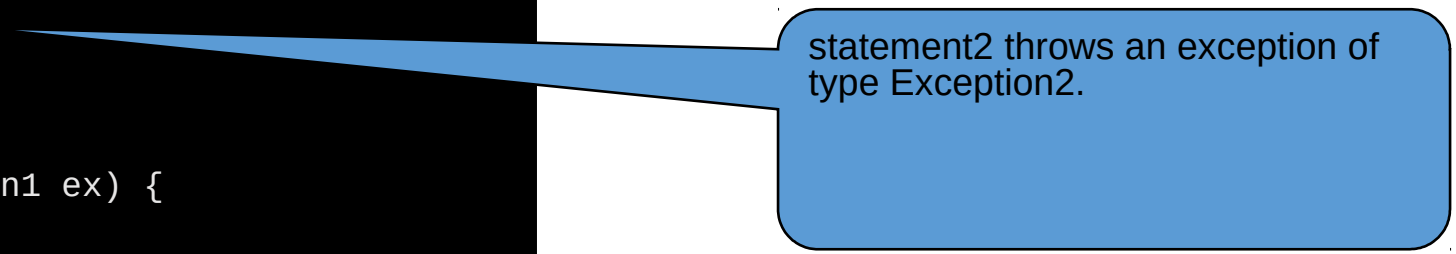
Re-throwing Exception

```
public class Andy {
    .....
    public void drinkWater() {
        try {
            getWater();
        }
        catch(NullPointerException e) {
            System.out.println(e.getMessage());
        }
    }
    public void getWater() {
        try {
            _water = _wendy.getADrink();
            int volume = _water.getVolume();
        }
        catch(NullPointerException e) {
            this.fire(_wendy);
            System.out.println("Wendy is fired!");
            throw new NullPointerException("NO
Water");
        }
    }
}
```

- The caught exceptions can be re-thrown using **`throw`** keyword
- Re-thrown exception must be handled some where in the program, otherwise program will terminate abruptly

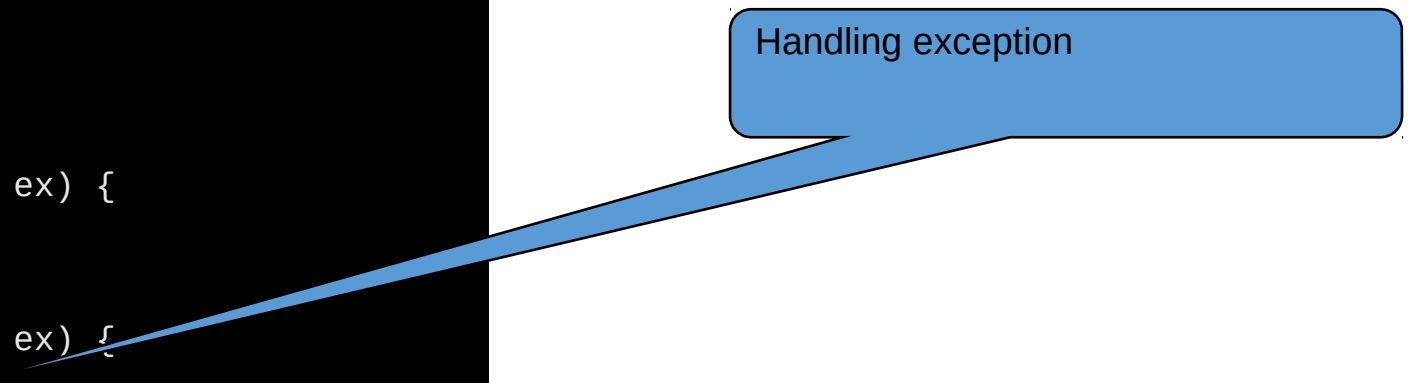
Trace a `try/catch` Program Execution (1/4)

```
try {
  statement1;
  statement2;
  statement3;
}
catch(Exception1 ex) {
  handling ex;
}
catch(Exception2 ex) {
  handling ex;
  throw ex;
}
finally {
  finalStatements;
}

Next statement;
```



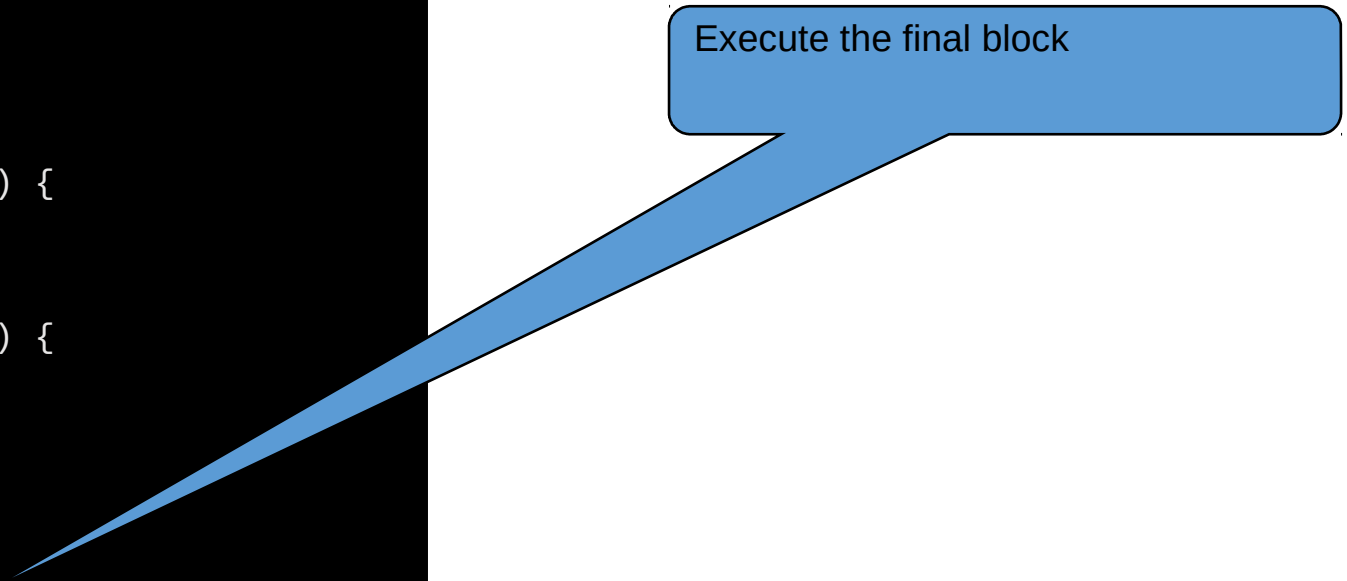
Trace a `try/catch` Program Execution (2/4)

```
try {
  statement1;
  statement2;
  statement3;
}
catch(Exception1 ex) {
  handling ex;
}
catch(Exception2 ex) {
  handling ex;
  throw ex;
}
finally {
  finalStatements;
}

Next statement;
```



Trace a `try/catch` Program Execution (3/4)

```
try {
  statement1;
  statement2;
  statement3;
}
catch(Exception1 ex) {
  handling ex;
}
catch(Exception2 ex) {
  handling ex;
  throw ex;
}
finally {
  finalStatements;
}

Next statement;
```



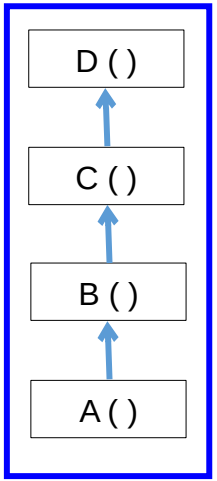
Trace a `try/catch` Program Execution (4/4)

```
try {
  statement1;
  statement2;
  statement3;
}
catch(Exception1 ex) {
  handling ex;
}
catch(Exception2 ex) {
  handling ex;
  throw ex;
}
finally {
  finalStatements;
}

Next statement;
```

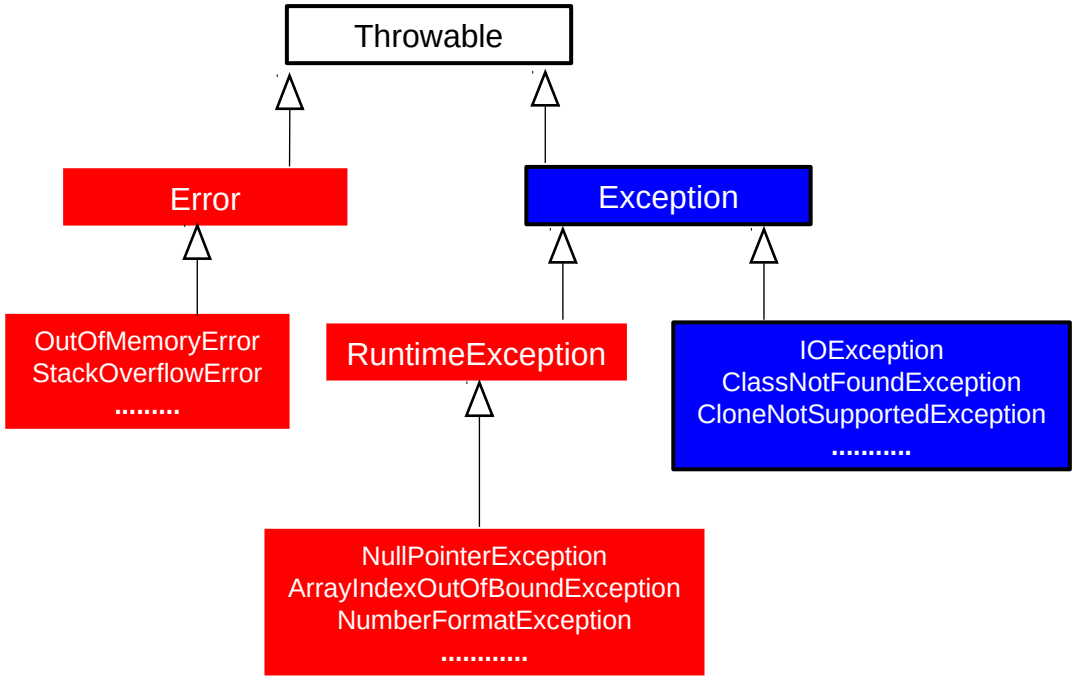
Rethrow the exception and control is transferred to the caller

How Exceptions are Handled by JVM

- Any method invocation is represented as a "**stack frame**" on the Java "**stack**"
  - **Callee-Caller** relationship
    - If method A calls method B then A is **caller** and B is **callee**
  - Each frame stores local variables, input parameters, return values and intermediate calculations
    - In addition, each frame also stores an "**exception table**"
    - This exception table stores information on each `try/catch/finally` block, i.e. the instruction offset where the `catch/finally` blocks are defined
  - When an exception is thrown, JVM does the following:
    1. Look for exception handler in current stack frame (method)
    2. If not found, then terminate the execution of current method and go to the callee method and repeat step 1 by looking into callee's exception table
    3. If no matching handler is found in any stack frame, then JVM finally terminates by throwing the stack trace (`printStackTrace` method)



Exception Hierarchy



- `Exceptions` are classes that extends `Throwable`
- Come in two types
  - **Checked exceptions**
    - Those that must be handled somehow (we will see soon)
      - E.g., `IOException` – file reading issue
  - **Unchecked exceptions**
    - Those that do not
      - E.g., `RuntimeExceptions` that is caused due to programming errors
      - You should not attempt to handle exceptions from subclass of `Error`
        - Rarely occurring exceptions that even if you try to handle, there is little you can do beyond notifying the user and trying to terminate the program gracefully

Handling Checked Exception (1/3)

```
import java.io.FileReader;

public class Tester {
    public int countChars(String fileName)  {
        FileReader r = new FileReader(fileName);
        int total = 0;
        while( r.ready() ) {
            r.read();
      total++;
        }
        r.close();
        return total;
    }
}
```

- If we have code that tries to build a FileReader we must deal with the possibility of the exception
  - The code contains a syntax error. "`unreported exception java.io.FileNotFoundException`"
    - must be caught or declared to be thrown

Handling Checked Exception (2/3)

```
import java.io.FileReader;

public class Tester {
    public int countChars(String fileName)   {
        FileReader r = new FileReader(fileName);
        int total = 0;
        while( r.ready() ) {
            r.read();
      total++;
        }
        r.close();
        return total;
    }
}
```

- Here, there are 4 statements that can generate checked exceptions:
  - The FileReader constructor
  - the ready method
  - the read method
  - the close method
- To deal with the exceptions we can either state this method **”throws”** an Exception of the proper type or handle the exception within the method itself

Handling Checked Exception (3/3)

```
import java.io.FileReader;

public class Tester {
    public int countChars(String fileName)
throws FileNotFoundException, IOException {
        FileReader r = new FileReader(fileName);
        int total = 0;
        while( r.ready() ) {
            r.read();
      total++;
        }
        r.close();
        return total;
    }
}
```

- It may be that we don't know how to deal with an error within the method that can generate it
- In this case we will pass the buck to the method that called us
- The keyword **`throws`** is used to indicate a method has the possibility of generating an exception of the stated type
- Now any method calling ours, must also throw an exception or handle it

Question

```
public class Main {
    public static void main(String[] args) {
        String s = null;
        try {
            int length = s.length();
        }

        catch (Exception e) {
            System.out.println("Catch block -1");
        }
        catch (NullPointerException e) {
            System.out.println("Catch block -2");
        }
    }
}
```

- What is the output of the following program?
- Answer
  - Compilation error!
  - **Unreachable catch block**
  - `error: exception NullPointerExcepti on has already been caught`

Some Important Methods in Throwable

String **toString**() Returns a short description of the exception

String **getMessage**() Returns the detail description of the exception

void **printStackTrace**() Prints the stacktrace information on the console

```
1. public class Andy {

2.     public void drinkWater() {
3.         getWater();
4.     }
5.     public void getWater() {
6.         try {
7.             _water =
_wendy.getADrink();//null
8.             int volume =
_water.getVolume();
9.         }
10.         catch(NullPointerException e) {
11.             e.printStackTrace();
12.         }
13.     }
14. }
```

- Output:

```
java.lang.NullPointerException
    at Andy.getWater(Andy.java:8)
    at
Andy.drinkWater(Andy.java:3)
    ......
```

Overriding Methods Having `throws` (1/3)

```
import java.lang.CloneNotSupportedException;

public class Cloning {

    public void createClone()
            throws CloneNotSupportedException {

        System.out.println(“Clone created”);
    }
}

public class Human extends Cloning {

    @Override
    public void createClone()
    {

        System.out.println(“Cloning not
allowed”);
    }
}
```

- If a method in parent class throws an exception (either checked or unchecked), then overridden implementation of that method in child class is not required to throw that exception
  - Although throwing that **same** exception in overridden method won’t hurt

Overriding Methods Having `throws` (2/3)

```
import java.lang.CloneNotSupportedException;

public class Cloning {

    public void createClone()
    {

        System.out.println("Clone created");
    }
}

public class Human extends Cloning {

    @Override
    public void createClone()
           throws CloneNotSupportedException {

        System.out.println("Cloning not
allowed");
    }
}
```

- However, the reverse may/may not work
- Case-1: Overridden method throws **checked exception** but not the actual method in parent class
  - Compilation error

Overriding Methods Having `throws` (3/3)

```
import java.lang.CloneNotSupportedException;

public class Cloning {

    public void createClone()
    {

        System.out.println(“Clone created”);
    }
}

public class Human extends Cloning {

    @Override
    public void createClone()
           throws RuntimeException {

        System.out.println(“Cloning not
allowed”);
    }
}
```

- However, the reverse may/may not work
- Case-2: Overridden method throws **unchecked exception** but not the actual method in parent class
  - This works fine

Defining Your Own Exception (1/4)

```
public class NoWaterException extends Exception {
    public NoWaterException(String message) {
        super(message);
    }
}
public class Andy {
    public void drinkWater() {
        try {
            getWater();
        }
        catch(NoWaterException e) {
            System.out.println(e.getMessage());
        }
    }
    public void getWater() throws
NoWaterException {
        _water = _wendy.getADrink();
        if(_water == null) {
            this.fire(_wendy);
            throw new NoWaterException("NO
Water");
        }
    }
```

- You can define and throw your own specialized exceptions
  - `throw new NoWaterException(…);`
- Useful for responding to special cases, not covered by pre-defined exceptions
- The class `Exception` has a method `getMessage()`.The String passed to `super` is printed to the output window for debugging when `getMessage()` is called by the user

Defining Your Own Exception (2/4)

```
public class NoWaterException extends Exception {
    public NoWaterException(String message) {
        super(message);
    }
}
public class Andy {
    public void drinkWater() {
        try {
            getWater();
        }
        catch(NoWaterException e) {
            System.out.println(e.getMessage());
        }
    }
    public void getWater() throws
NoWaterException {
        _water = _wendy.getADrink();
        if(_water == null) {
            this.fire(_wendy);
            throw new NoWaterException("NO
Water");
        }
    }
```

- Every method that throws `Exceptions` that are not subclasses of `RuntimeException` must declare what exceptions it throws in method declaration
- `getWater()` is throwing the exception, hence it must declare that using the "`throws`" on method declaration

Defining Your Own Exception (3/4)

```
public class NoWaterException extends Exception {
    public NoWaterException(String message) {
        super(message);
    }
}
public class Andy {
    public void drinkWater() throws
NoWaterException {
        getWater();
    }
    public void getWater() throws NoWaterException
{
        _water = _wendy.getADrink();
        if(_water == null) {
            this.fire(_wendy);
            throw new NoWaterException("NO
Water");
        }
    }
    public static void main(String[] args) {
        Andy obj = new Andy();
        obj.drinkWater();
    }
```

- Any method that directly or indirectly calls `getWater()` must declare that it can generate `NoWaterException` using `throws` keyword
  - Not doing this generate compilation error
  - `error: unreported exception NoWaterException; must be caught or declared to be thrown`

Defining Your Own Exception (4/4)

```
1.public class NoWaterException extends Exception {
2.    public NoWaterException(String message) {
3.        super(message);
4.    }
5.}
6.public class Andy {
7.    public void drinkWater() throws
NoWaterException {
8.        getWater();
9.    }
10.    public void getWater() throws
NoWaterException {
11.        _water = _wendy.getADrink();
12.        if(_water == null) {
13.            this.fire(_wendy);
14.            throw new NoWaterException("NO
Water");
15.        }
16.    }
17.    public static void main(String[] args)
18.                throws NoWaterException {
19.        Andy obj = new Andy();
20.        obj.drinkWater();
```

- This works fine, although we are not catching the `NoWaterException` anywhere that is again not a defensive programming!
  - Running this program with `_water = null`

```
Exception in thread "main"
NoWaterException: NO Water
at Andy.getWater(Andy.java:14)
at Andy.drinkWater(Andy.java:8)
at Andy.main(Andy.java:20)
```

Pros and Cons of Exception

- Pros
  - Cleaner code: rather than returning a boolean up chain of calls to check for exceptional cases, throw an exception!
  - Use return value for meaningful data, not error checking
  - Factor out error-checking code into one class, so it can be reused
- Cons
  - Throwing exceptions requires extra computation
  - Can become messy if not used economically
  - Can accidentally cover up serious exceptions, such as `NullPointerException` by catching them

Next Lecture

- Assertions
- Java collection framework