

# CMSC 132: Object-Oriented Programming II

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## Program Correctness, Exceptions

Department of Computer Science  
University of Maryland, College Park

# Overview

- Program correctness is determined by the presence / absence of **program defects** (errors)
- Issues
  - Types of errors
  - Testing
  - Debugging
  - Exceptions

# Program Errors

- **Types of errors**
  - **Compile-time (syntax) errors**
  - **Run-time errors**
  - **Logic errors**

# Program Errors – Compile Time

- **Compile-time (syntax) errors**
  - Errors in code construction
    - Lexical (typographical), grammatical, types
  - Detected during compilation
  - Usually easy to correct quickly
- **Examples**
  - Misspelled keyword
  - Missing or misplaced symbol
  - Incorrect operator for variable type

# Program Errors – Run Time

## ■ Run-time errors

- Operations illegal / impossible to execute
- Detected during program execution
  - But not detectable at compile time
- Treated as **exceptions** in Java

## ■ Example

- Division by zero
- Array index out of bounds
- Using null pointer
- Illegal format conversion

# Program Errors – Logic

## ■ Logic errors

- Operations leading to incorrect program state
- May (or may not) lead to run-time errors
- Problem in design or implementation of algorithm

## ■ Examples

- Computing incorrect arithmetic value
- Ignoring illegal input

## ■ Hardest error to handle

- Detect by **testing**
- Fix by **debugging**

# Testing

- Run program (or part of program) under controlled conditions to verify behavior
  - Detects **run-time error** if exception thrown
  - Detects **logic error** if behavior is incorrect
- Issues
  - Selecting test cases
  - Testing different parts of program
  - Visibility of program code
  - Test coverage
  - ...

# Test Coverage

## ■ Test coverage

- Whether code is executed by **some** test case
- Automatically calculated by submit server
  - For set of tests selected (from link)
    - E.g., student tests, public tests, student+public tests
  - For conditionals, reports X/Y where
    - X = # tests executing True
    - Y = # tests executing False
  - Color
    - Green = executed by some test case
    - Pink = not executed

# Test Coverage Example

## Source Code

Coverage information for public test #all:

| Source file    | statements | conditionals | methods | total |
|----------------|------------|--------------|---------|-------|
| Utilities.java | 4/10       | 1/5          | 1/2     |       |

```
1      package utilities;
2
3      public class Utilities {
4          2      public static String letterGrade(double numericGrade) {
5              1/1          if (numericGrade >= 90.0)
6                  1              return "A";
7              1/0          else if (numericGrade >= 80.0)
8                  1              return "B";
9              0/0          else if (numericGrade >= 70.0)
10                 0              return "C";
11                 0/0          else if (numericGrade >= 60.0)
12                     0              return "D";
13                 else
14                     0              return "F";
15             }
16
17             0      public static boolean passingNumericGrade(double numericGrade) {
18                 0/0          return numericGrade >= 70.0 ? true : false;
19             }
20     }
```

# Debugging

- **Process of finding and fixing software errors**
  - After testing detects error
- **Goal**
  - Determine cause of run-time & logic errors
  - Correct errors (without introducing new errors)
- **Similar to detective work**
  - Carefully inspect information in program
    - Code
    - Values of variables
    - Program behavior

# Debugging – Approaches

## ■ Classic

- Insert debugging statements
- Trace program control flow
- Display value of variables

## ■ Modern

- IDE (integrated development environment)
- Interactive debugger

# Interactive Debugger

## ■ Capabilities

- Provides trace of program execution
- Shows location in code where error encountered
- Interactive program execution
  - **Single step** through code
  - Run to **breakpoints**
- Displays values of variables
  - For current state of program

# Interactive Debugger

## ■ Single step

- Execute single line of code at a time
- When executing method, can
  - Finish entire method
  - Execute first line in method
- Tedious (or impractical) for long-running programs

## ■ Breakpoint

- Specify location(s) in code
- Execute program until breakpoint encountered
- Can skip past uninteresting code

Single Step

# Eclipse Debugger

Data Display

The screenshot shows the Eclipse IDE with the following components:

- Top Bar:** Debug - sampleProject/src/utilities/Utilities.java - Eclipse Platform
- Menu Bar:** File Edit Source Refactor Navigate Search Project Run Window Help
- Toolbar:** Includes icons for file operations, debugging (run, step into, step over, step return), and other IDE functions.
- Left Panel:** Project Explorer showing the package structure: src (1) [JUnit] > org.eclipse.jdt.internal.junit.runner > Thread [main] (Suspended (breakpoint at line 5 in Utilities)) > Utilities.letterGrade(double) line: 5.
- Right Panel:** Variables view showing a table with columns Name and Value.

| Name         | Value |
|--------------|-------|
| numericGrade | 100.0 |
- Main Editor:** Utilities.java source code with a breakpoint at line 5.

```
package utilities;

public class Utilities {
    public static String letterGrade(double numericGrade) {
        if (numericGrade >= 90.0)
            return "A";
        else if (numericGrade >= 80.0)
            return "B";
        else if (numericGrade >= 70.0)
            return "C";
        else if (numericGrade >= 60.0)
            return "D";
        else
            return "F";
    }
}
```
- Bottom Panel:** Console view showing the execution output: src (1) [JUnit] C:\Program Files\Java\jre1.5.0\_12\bin\javaw.exe (Sep 4, 2007 8:23:51 PM)

Red arrows indicate the following features:

- Single Step:** Points to the 'Step Into' button in the toolbar.
- Data Display:** Points to the Variables view showing the value of numericGrade.
- Breakpoint:** Points to the breakpoint icon on the left margin of the source code.

# Exceptions

- Rare event outside normal behavior of code
  - Usually a **run-time error**
- Examples
  - Division by zero
  - Access past end of array
  - Out of memory
  - Number input in wrong format (float vs. integer)
  - Unable to write output to file
  - Missing input file

# Exception Handling

- **Performing action in response to exception**
- **Example actions**
  - Ignore exception
  - Print error message
  - Request new data
  - Retry action
- **Approaches**
  1. Exit program
  2. Exit method returning error code
  3. Throw exception

# Problem

- May not be able to handle error locally
  - Not enough information in method / class
  - Need more information to decide action
- Handle exception in calling function(s) instead
  - Decide at application level (instead of library)
  - Examples
    - Incorrect data format ⇒ ask user to reenter data
    - Unable to open file ⇒ ask user for new filename
    - Insufficient disk space ⇒ ask user to delete files
- Will need to **propagate** exception to caller(s)

# Exception Handling – Exit Program

## ■ Approach

- Exit program with error message / error code

## ■ Example

```
if (error) {  
    System.err.println("Error found");    // message  
    System.exit(1);                      // error code  
}
```

## ■ Problem

- Drastic solution
- Event must be handled by user invoking program
- Program may be able to deal with some exceptions

# Exception Handling – Error Code

## ■ Approach

- Exit function with return value  $\Rightarrow$  error code

## ■ Example

```
A( ) { if (error) return (-1); }
```

```
B( ) { if ((retval = A( )) == -1) return (-1); }
```

## ■ Problems

- Calling function must check & process error code
  - May forget to handle error code
  - May need to return error code to caller
- Agreement needed on meaning of error code
- Error handling code mixed with normal code

# Exception Handling – Throw Exception

## ■ Approach

### ■ Throw exception

## ■ Example

```
A() {  
    if (error) throw new ExceptionType();  
}
```

```
B() {  
    try {  
        A();  
    }
```

```
    catch (ExceptionType e) { ...action... }
```

```
}
```

Java exception backtracks to caller(s) until matching catch block found

# Exception Handling – Throw Exception

## ■ Advantages

- Compiler ensures exceptions are caught eventually
- No need to explicitly **propagate** exception to caller
  - **Backtrack** to caller(s) automatically
- Class hierarchy defines meaning of exceptions
  - No need for separate definition of error codes
- Exception handling code separate & clearly marked

# Representing Exceptions in Java

## ■ Exceptions represented as

- Objects derived from class Throwable

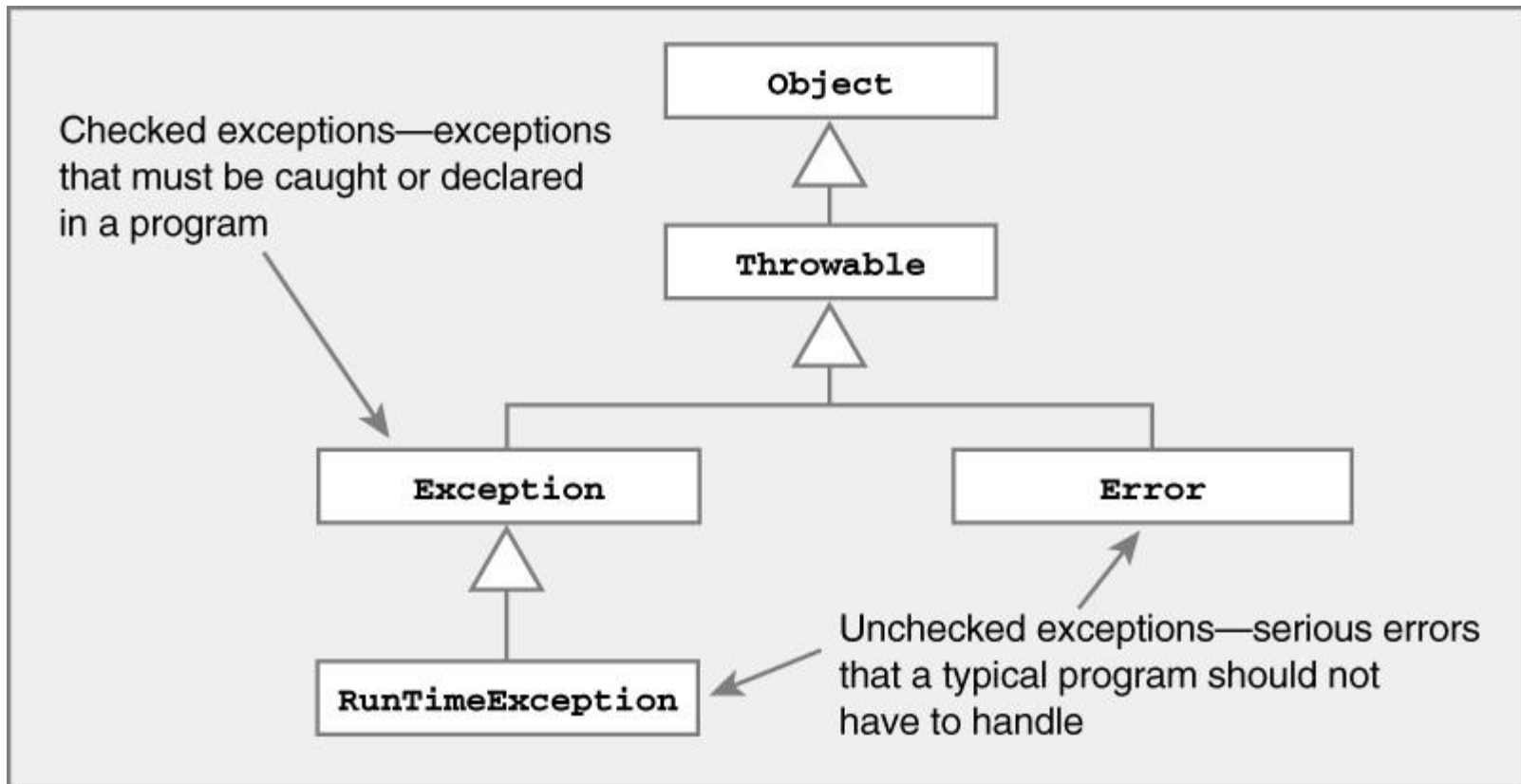
## ■ Code

```
public class Throwable extends Object {  
    Throwable( )                // No error message  
    Throwable( String mesg )    // Error message  
    String getMessage()         // Return error mesg  
    void printStackTrace( ) { ... } // Record methods  
    ...                        // called & location  
}
```

# Representing Exceptions

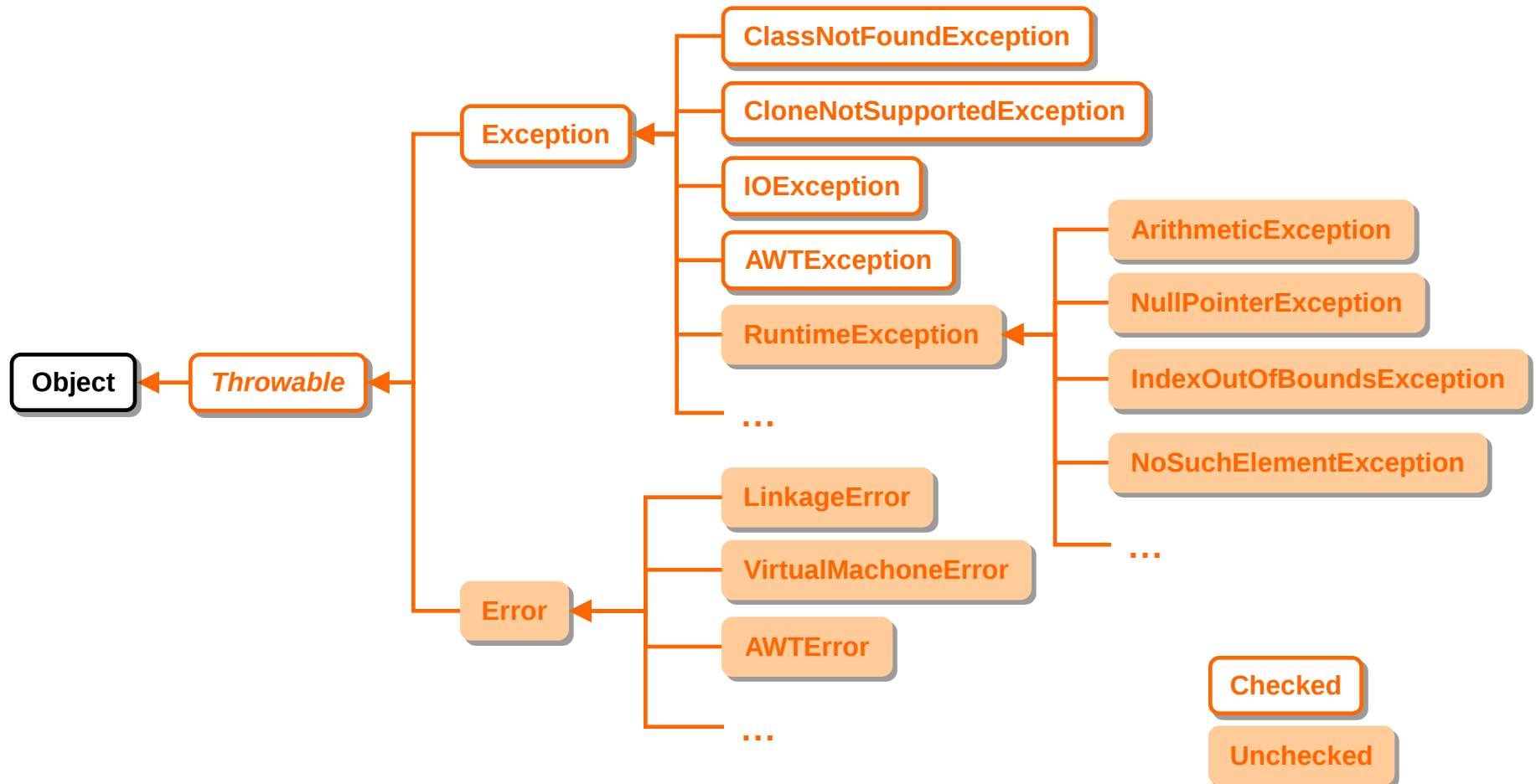
## ■ Java Exception class hierarchy

■ Two types of exceptions ⇒ checked & unchecked



# Representing Exceptions

## ■ Java Exception class hierarchy



# Unchecked Exceptions

- Class **Error** & **RuntimeException**
- Serious errors not handled by typical program
- Usually indicate logic errors
- Example
  - **NullPointerException, IndexOutOfBoundsException**
- Catching unchecked exceptions is **optional**
- Handled by Java Virtual Machine if not caught

# Checked Exceptions

- Class **Exception** (except RuntimeException)
- Errors typical program should handle
- Used for operations prone to error
- Example
  - IOException, ClassNotFoundException
- Compiler requires “**catch or declare**”
  - Catch and handle exception in method, OR
  - Declare method can throw exception, force calling function to catch or declare exception in turn
  - Example
    - void A( ) throws ExceptionType { ... }

# Generating & Handling Exceptions

## ■ Java primitives

- try
- throw
- catch
- finally

## ■ Procedure for using exceptions

1. Enclose code generating exceptions in **try** block
2. Use **throw** to actually generate exception
3. Use **catch** to specify exception handlers
4. Use **finally** to specify actions after exception

# Java Syntax

|                                                            |                                                                                      |                                                                       |
|------------------------------------------------------------|--------------------------------------------------------------------------------------|-----------------------------------------------------------------------|
| <code>try {<br/>    throw new eType1();<br/>}</code>       |    | <code>// try block encloses throws<br/>// throw jumps to catch</code> |
| <code>catch (eType1 e) {<br/>    ...action...<br/>}</code> |    | <code>// catch block 1<br/>// run if type match</code>                |
| <code>catch (eType2 e) {<br/>    ...action...<br/>}</code> |   | <code>// catch block 2<br/>// run if type match</code>                |
| <code>finally {<br/>    ...action...<br/>}</code>          |  | <code>// final block<br/>// always executes</code>                    |

# Java Primitive – Try

- Forms **try block**
- Encloses all statements that may throw exception
- Scope of try block is **dynamic**
- Includes code executed by methods invoked in try block (and their descendents)

# Java Primitive – Try

## ■ Example

```
try {           // try block encloses all exceptions in A & B
    A( );       // exceptions may be caught internally in A & B
    B( );       // or propagated back to caller's try block
}
```

```
void A( ) throws Exception { // declares exception
    B( );
}
```

```
void B( ) throws Exception { // declares exception
    throw new Exception( );  // propagate to caller
}
```

# Java Primitive – Throw

- Indicates exception occurred
- Normally specifies one operand
  - Object of class Exception
- When an exception is thrown
  1. Control exits the try block
  2. Proceeds to closest matching exception handler after the try block
  3. Execute code in exception handler
  4. Execute code in finally block (if present)

# Java Primitive – Catch

- Placed after try block
- Specifies code to be executed for exception
  - Code in catch block  $\Rightarrow$  exception handler
- Catch block specifies matching exception type
- Can use multiple catch blocks for single try
  - To process different types of exceptions
  - First matching catch block executed
  - Superclass may **subsume** catch for subclass
    - If catch block for superclass occurs first

# Java Primitive – Catch

## ■ Example

```
class eType1 extends Exception { ... }
```

```
try {
```

**... throw new eType1() ...**

}

```
catch (Exception e) {
```

## ...action...

}

```
catch (eType1 e) {
```

## ...action...

}

## // Catch block 1

```
// matches all exceptions
```

## // Catch block 2

```
// matches eType1
```

**// subsumed by block 1**

**// will never be executed**

# Java Primitive – Catch

- Can **rethrow** exception

- Exception propagated to caller(s)

- Example

```
catch (ExceptionType e) {  
    ...           // local action for exception  
    throw e;      // rethrow exception  
}                // propagate exception to caller
```

# Java Primitive – Finally

- Placed after try & all catch blocks
- Forms **finally block**
- Cleanup code
  - Executed by all exception handlers
  - Try restore program state to be consistent, legal
- Always executed
  - Regardless of which catch block executed
  - Even if no catch block executed
  - Executed before transferring control to caller
    - If exception is not caught locally

# Designing & Using Exceptions

- **Use exceptions only for rare events**
  - **Not for common cases  $\Rightarrow$  checking end of loop**
  - **High overhead to perform catch**
- **Place statements that jointly accomplish task into single try / catch block**
- **Use existing Java Exceptions if possible**

# Designing & Using Exceptions

- Avoid simply catching & ignoring exceptions
  - Poor software development style

- Example

```
try {  
    throw new ExceptionType1( );  
    throw new ExceptionType2( );  
    throw new ExceptionType3( );  
}  
catch (Exception e) { // catches all exceptions  
    ...                // ignores exception & returns  
}
```

# Exceptions – Examples

- **FileNotFoundException ( java.io )**
  - Request to open file fails
- **IllegalArgumentException ( java.lang )**
  - Method passed illegal / inappropriate argument
- **IOException ( java.io )**
  - Generic I/O error
- **NullPointerException ( java.lang )**
  - Attempt to access object using null reference
- **UnsupportedOperationException ( java.lang )**
  - Object does not provide requested operation

# Exceptions – Examples

## ■ Used in programming project

```
public void MethodRequiredForProject() {  
    throw new UnsupportedOperationException(  
        "You must implement this method.");  
}
```

## ■ Behavior

- If method is invoked during program execution
- Exception is thrown
  - Of type `UnsupportedOperationException`
  - Message string is displayed
- Program execution stops unless exception caught