CMSC 132:
Object-Oriented Programming II

Program Correctness, Exceptions

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Overview

- **Program correctness is determined by the presence / absence of program defects (errors)**

- **Issues**
  - **Types of errors**
  - **Testing**
  - **Debugging**
  - **Exceptions**

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

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

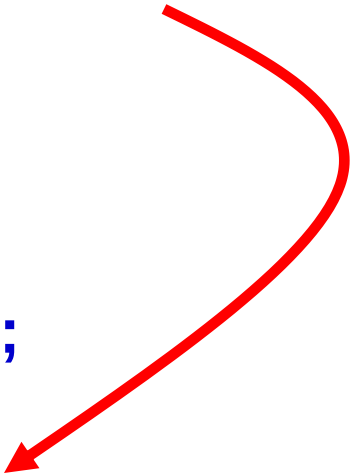
Problem

- 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 – 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**

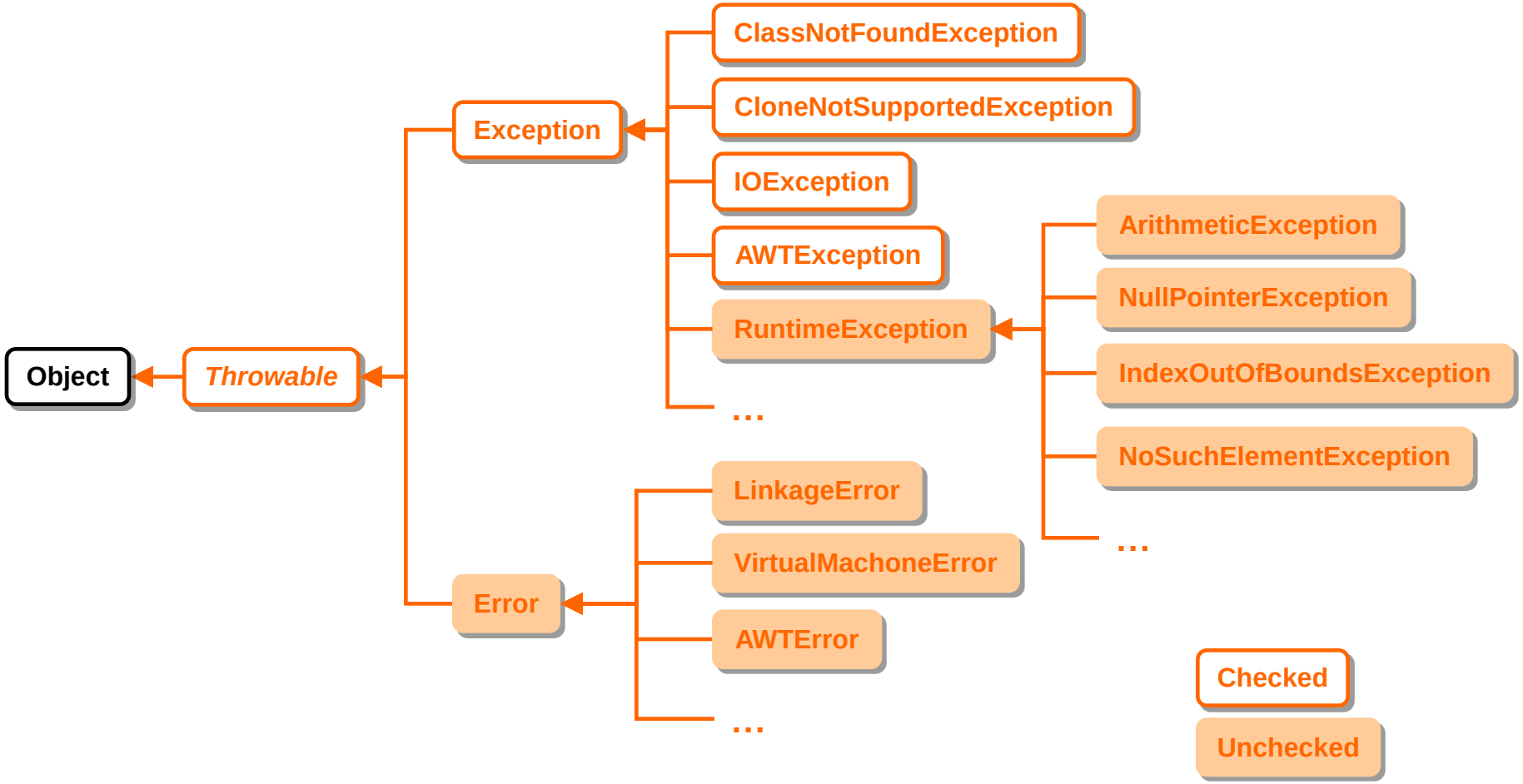
Representing Exceptions in Java

- **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**



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: READ_FROM_FILE

Designing & Using Exceptions

- Use exceptions only for rare events
  - Not for common cases ⇒ 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)
  - Attend 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**