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:

<table>
<thead>
<tr>
<th>Source file</th>
<th>statements</th>
<th>conditionals</th>
<th>methods</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilities.java</td>
<td>4/10</td>
<td>1/5</td>
<td>1/2</td>
<td></td>
</tr>
</tbody>
</table>

```java
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";
        }
    }

    public static boolean passingNumericGrade(double numericGrade) {
        return numericGrade >= 70.0 ? true : false;
    }
}
```
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
Eclipse Debugger

Single Step

Data Display

Breakpoint

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";
    }
}
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 $\Rightarrow$ ask user to reenter data
- Unable to open file $\Rightarrow$ ask user for new filename
- Insufficient disk space $\Rightarrow$ 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**
  ```java
  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 ⇒ error code

Example

```c
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**

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

B() {
    try {
        A();
        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

```java
public class Throwable extends Object {
    Throwable() // No error message
    Throwable(String msg) // Error message
    String getMessage() // Return error msg
    void printStackTrace() { … } // Record methods
    …
}
```
Representing Exceptions

Java Exception class hierarchy

- Two types of exceptions ⇒ checked & unchecked

Checked exceptions—exceptions that must be caught or declared in a program

Unchecked exceptions—serious errors that a typical program should not have to handle
Representing Exceptions

Java Exception class hierarchy

- Object
- Throwable
- Exception
  - ClassNotFoundException
  - CloneNotSupportedException
  - IOException
  - LinkageError
  - VirtualMachineError
  - AWTError
  - ArithmeticException
  - NullPointerException
  - IndexOutOfBoundsException
  - NoSuchElementException
  - AWTException
  - RuntimeException
  - ... (Unchecked)
  - LinkageError
  - VirtualMachineError
  - AWTError
  - ArithmeticException
  - NullPointerException
  - IndexOutOfBoundsException
  - NoSuchElementException
  - AWTException
  - RuntimeException
  - ... (Checked)
  - Checked
  - Unchecked
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
  ```java
  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

```java
try {
    throw new eType1();
} // try block encloses throws
catch (eType1 e) { // catch block 1
    ...action...
} // run if type match
catch (eType2 e) { // catch block 2
    ...action...
} // run if type match
finally { // final block
    ...action...
} // always executes
```
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

```java
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 final block (if present)
Java Primitive – Catch

- Placed after try block
- Specifies code to be executed for exception
  - Code in catch block ⇒ 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) { // Catch block 1
  …action… // matches all exceptions
}
catch (eType1 e) { // Catch block 2
  …action… // matches eType1
  // subsumed by block 1
  // will never be executed
Java Primitive – Catch

- Can *rethrow* exception
  - Exception propagated to caller(s)

**Example**

```java
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 ⇒ 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
Avoid simply catching & ignoring exceptions

- Poor software development style

Example

```java
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

```java
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