CSE 331
Software Design & Implementation

Dan Grossman
Spring 2015
Exceptions and Assertions
(Based on slides by Mike Ernst, Dan Grossman, David Notkin, Hal Perkins)
Outline

• General concepts about dealing with errors and failures

• Assertions: what, why, how
  – For things you believe will/should never happen

• Exceptions: what, how in Java
  – How to throw, catch, and declare exceptions
  – Subtyping of exceptions
  – Checked vs. unchecked exceptions

• Exceptions: why in general
  – For things you believe are bad and should rarely happen
  – And many other style issues

• Alternative with trade-offs: Returning special values

• Summary and review
Partial failure is inevitable
   – Goal: prevent complete failure
   – Structure your code to be reliable and understandable

Some failure causes:

1. Misuse of your code
   – Precondition violation

2. Errors in your code
   – Bugs, representation exposure, …

3. Unpredictable external problems
   – Out of memory, missing file, …
What to do when something goes wrong

Fail early, fail friendly

Goal 1: *Give information about the problem*
- To the programmer – a good error message is key!
- To the client code: via exception or return-value or …

Goal 2: *Prevent harm*
Abort: inform a human
- Perform cleanup actions, log the error, etc.

Re-try:
- Problem might be transient

Skip a subcomputation:
- Permit rest of program to continue

Fix the problem?
- *Usually* infeasible to repair from an unexpected state
Avoiding errors

A precondition prohibits misuse of your code
  – Adding a precondition weakens the spec

This ducks the problem of errors-will-happen
  – Mistakes in your own code
  – Misuse of your code by others

Removing a precondition requires specifying more behavior
  – Often a good thing, but there are tradeoffs
  – Strengthens the spec
  – Example: specify that an exception is thrown
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Defensive programming

Check:

- Precondition
- Postcondition
- Representation invariant
- Other properties that you know to be true

Check *statically* via reasoning and tools

Check *dynamically* via *assertions*

```java
assert index >= 0;
assert items != null : "null item list argument"
assert size % 2 == 0 : "Bad size for " + toString();
```

- Write assertions as you write code
- Include descriptive messages
Enabling assertions

In Java, assertions can be enabled or disabled at runtime without recompiling

Command line:
  - `java -ea` runs code with assertions enabled
  - `java` runs code with assertions disabled (default)

Eclipse:
  - Select Run>Run Configurations… then add `-ea` to VM arguments under (x)=arguments tab

(These tool details were covered in section already)
When *not* to use assertions

Don’t clutter the code with useless, distracting repetition

```java
int x = y + 1;
assert x == y + 1;
```

Don’t perform side effects

```java
assert list.remove(x); // won’t happen if disabled
```

// Better:
```java
boolean found = list.remove(x);
assert found;
```

Turn them off in rare circumstances (production code?)

- Most assertions better left enabled
assert and checkRep()

CSE 331’s checkRep() is another dynamic check

Strategy: use assert in checkRep() to test and fail with meaningful traceback/message if trouble found
  – Be sure to enable asserts when you do this!

Asserts should be enabled always for CSE 331 projects
  – We will enable them for grading
Expensive `checkRep()` tests

Detailed checks can be too slow in production

But complex tests can be very helpful, particularly during testing/debugging (let the computer find problems for you!)

No perfect answers; suggested strategy for `checkRep`:
- Create a static, global “debug” or “debugLevel” variable
- Run expensive tests when this is enabled
- Turn it off in graded / production code if tests are too expensive

Often helpful: put expensive / complex tests in separate methods and call as needed
// requires: x ≥ 0
// returns: approximation to square root of x
public double sqrt(double x) {
    ...
}

Square root with assertion

// requires: x ≥ 0
// returns: approximation to square root of x
public double sqrt(double x) {
    assert (x >= 0.0);
    double result;
    ... compute result ...
    assert (Math.abs(result*result - x) < .0001);
    return result;
}

- These two assertions serve very different purposes
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Square root, specified for all inputs

// throws: IllegalArgumentException if x < 0
// returns: approximation to square root of x
public double sqrt(double x) throws IllegalArgumentException {
    if (x < 0)
        throw new IllegalArgumentException();
    ...
}

- **throws** is part of a method signature: “it might happen”
  - Comma-separated list
- **throw** is a statement that actually causes exception-throw
  - Immediate control transfer [like return but different]
Using try-catch to handle exceptions

```java
public double sqrt(double x)
    throws IllegalArgumentException
...
```

Client code:
```java
try {
    y = sqrt(...);
} catch (IllegalArgumentException e) {
    e.printStackTrace(); // and/or take other actions
}
```

Handled by nearest *dynamically* enclosing `try/catch`
- Top-level default handler: stack trace, program terminates
Throwing and catching

• Executing program has a stack of currently executing methods
  – Dynamic: reflects runtime order of method calls
  – No relation to static nesting of classes, packages, etc.

• When an exception is thrown, control transfers to nearest method with a matching catch block
  – If none found, top-level handler prints stack trace and terminates

• Exceptions allow non-local error handling
  – A method many levels up the stack can handle a deep error
Catching with inheritance

```java
try {
    code...
} catch (FileNotFoundException fnfe) {
    code to handle a file not found exception
} catch (IOException ioe) {
    code to handle any other I/O exception
} catch (Exception e) {
    code to handle any other exception
}
```

- A `SocketException` would match the second block
- An `ArithmeticException` would match the third block
- Subsequent catch blocks need not be supertypes like this
Exception Hierarchy
Java’s checked/unchecked distinction

Checked exceptions *(style: for special cases)*
- Callee: *Must* declare in signature (else type error)
- Client: Must either catch or declare (else type error)
  - Even if you can prove it will never happen at run time, the type system does not “believe you”
- There is guaranteed to be a dynamically enclosing catch

Unchecked exceptions *(style: for never-expected)*
- Library: No need to declare
- Client: No *need* to catch
- Subclasses of
  - RuntimeException
  - Error
Checked vs. unchecked

• No perfect answer to “should possible exceptions thrown” be part of a method signature
  – So Java provided both

• Advantages to checked exceptions:
  – Static checking of callee ensures no other checked exceptions get thrown
  – Static checking of caller ensures caller does not forget to check

• Disadvantages:
  – Impedes implementations and overrides
  – Often in your way when prototyping
  – Have to catch or declare even in clients where the exception is not possible
The **finally** block

**finally** block is always executed
- Whether an exception is thrown or not

```java
try {
    code...
} catch (Type name) {
    code... to handle the exception
} finally {
    code... to run after the try or catch finishes
}
```
What **finally** is for

**finally** is used for common “must-always-run” or “clean-up” code
- Avoids duplicated code in catch branch[es] and after
- Avoids having to catch all exceptions

```java
try {
    // ... write to out; might throw exception
} catch (IOException e) {
    System.out.println("Caught IOException: "+ e.getMessage());
} finally {
    out.close();
}
```
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Propagating an exception

// returns: x such that ax^2 + bx + c = 0
// throws: IllegalArgumentException if no real soln exists
double solveQuad(double a, double b, double c)
    throws IllegalArgumentException
{
    // No need to catch exception thrown by sqrt
    return (-b + sqrt(b*b - 4*a*c)) / (2*a);
}

Aside: How can clients know if a set of arguments
to solveQuad is illegal?
Why catch exceptions locally?

Failure to catch exceptions usually violates modularity

- Call chain: $A \rightarrow \text{IntegerSet.insert} \rightarrow \text{IntegerList.insert}$
- $\text{IntegerList.insert}$ throws some exception
  - Implementer of $\text{IntegerSet.insert}$ knows how list is being used
  - Implementer of $A$ may not even know that $\text{IntegerList}$ exists

Method on the stack may think that it is handling an exception raised by a different call

Better alternative: catch it and throw again

- “chaining” or “translation”
- Do this even if the exception is better handled up a level
- Makes it clear to reader of code that it was not an omission
// returns: x such that ax^2 + bx + c = 0
// throws: NotRealException if no real solution exists

double solveQuad(double a, double b, double c)
    throws NotRealException {
    try {
        return (-b + sqrt(b*b - 4*a*c)) / (2*a);
    } catch (IllegalArgumentException e) {
        throw new NotRealException(); // "chaining"
    }
}

class NotRealException extends Exception {
    NotRealException() { super(); }
    NotRealException(String message) { super(message); }
    NotRealException(Throwlable cause) { super(cause); }
    NotRealException(String msg, Throwable c) { super(msg, c); }
}
Exceptions as non-local control flow

```java
void compile() {
  try {
    parse();
    typecheck();
    optimize();
    generate();
  } catch (RuntimeException e) {
    Logger.log("Failed: " + e.getMessage());
  }
}
```

- Not common – usually bad style, particularly at small scale
- Java/C++, etc. exceptions are expensive if thrown/caught
- Reserve exceptions for exceptional conditions
Two distinct uses of exceptions

- Failures
  - Unexpected
  - Should be rare with well-written client and library
  - Can be the client’s fault or the library’s
  - Usually unrecoverable

- Special results
  - Expected but not the common case
  - Unpredictable or unpreventable by client
Handling exceptions

• Failures
  – Usually can’t recover
  – If condition not checked, exception propagates up the stack
  – The top-level handler prints the stack trace
  – Unchecked exceptions the better choice (else many methods have to declare they could throw it)

• Special results
  – Take special action and continue computing
  – Should always check for this condition
  – Should handle locally by code that knows how to continue
  – Checked exceptions the better choice (encourages local handling)
Don’t ignore exceptions

Effective Java Tip #65: Don't ignore exceptions

Empty catch block is (common) poor style – often done to get code to compile despite checked exceptions
  – Worse reason: to silently hide an error

```java
try {
    readFile(filename);
} catch (IOException e) {} // silent failure
```

At a minimum, print out the exception so you know it happened
  – And exit if that’s appropriate for the application

```java
} catch (IOException e) {
    e.printStackTrace();
    System.exit(1);
}
```
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Informing the client of a problem

Special value:
- `null` for `Map.get`
- `-1` for `indexOf`
- `NaN` for `sqrt` of negative number

Advantages:
- For a normal-ish, common case, it “is” the result
- Less verbose clients than try/catch machinery

Disadvantages:
- Error-prone: Callers forget to check, forget spec, etc.
- Need “extra” result: Doesn’t work if every result could be real
  - Example: if a map could store `null` keys
- Has to be propagated manually one call at a time

General Java style advice: Exceptions for exceptional conditions
- Up for debate if `indexOf` not-present-value is exceptional
Special values in C/C++/others

- For errors and exceptional conditions in Java, use exceptions!
- But C doesn’t have exceptions and some C++ projects avoid them
- Over decades, a common idiom has emerged
  - Error-prone but you can get used to it 😞
  - Affects how you read code
  - Put “results” in “out-parameters”
  - Result is a boolean (int in C) to indicate success or failure

```c
    type result;
    if(!computeSomething(&result)) { ... return 1; } // no "exception", use result
```

- Bad, but less bad than error-code-in-global-variable
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Exceptions: review

Use an exception when
  – Used in a broad or unpredictable context
  – Checking the condition is feasible

Use a precondition when
  – Checking would be prohibitive
    • E.g., requiring that a list be sorted
  – Used in a narrow context in which calls can be checked

Use a special value when
  – It is a reasonable common-ish situation
  – Clients are likely (?) to remember to check for it

Use an assertion for internal consistency checks that should not fail
Exceptions: review, continued

Use *checked* exceptions most of the time
  – Static checking is helpful

But maybe avoid checked exceptions if possible for many callers to *guarantee* exception cannot occur

Handle exceptions sooner rather than later

Not all exceptions are errors
  – Example: File not found

Good reference: Effective Java, Chapter 9
  – A whole chapter? Exception-handling design matters!