CSE 331
Software Design & Implementation

Kevin Zatloukal
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Exceptions and Assertions
Outline

• General concepts about dealing with errors and failures
• Assertions: what, why, how
  – for things you believe will/should never happen
• Exceptions: what, how
  – how to throw, catch, and declare exceptions in Java
  – 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
Not all “errors” should be failures

Some “error” cases:

1. Misuse of your code
   - e.g., precondition violation
   - **should** be a failure (i.e., made visible to the user)

2. Errors in your code vs reasoning
   - e.g., representation invariant fails to hold
   - **should** be a failure

3. Unexpected resource problems
   - e.g., missing file, server offline, …
   - not an error in the sense of earlier lecture (... these are not bugs)
   - **should not** be a failure (i.e., do try to recover)
What to do when failing

Fail fast and fail friendly

Goal 1: Prevent harm
- stop before anything worse happens
- (do still need to perform cleanup: close open resources etc.)

Goal 2: Give information about the problem
- failing quickly helps localize the defect
- a good error message is important for debugging
Errors that should be failures

A precondition prohibits misuse of your code
   – weakens the spec by throwing out unhandled cases

This ducks the problem of errors-will-happen
   – with enough clients, someone will use your code incorrectly

Practice defensive programming:
   – usually makes sense to check for these errors
   – even though you don’t specify what the behavior will be, it still makes sense to fail fast
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Defensive programming

Assertions about your code:
- precondition, postcondition, representation invariant, etc.

Check these *statically* via reasoning and tools

Check these *dynamically* via assertions

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

- throws AssertionError if condition is false
- includes descriptive messages
Enabling assertions

In Java, assertions can be enabled or disabled at runtime (no recompile is required)

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

Turn them off only in rare circumstances (e.g., production code running on a client machine)
How *not* to use assertions

Don’t *clutter* the code with useless assertions

```c
x = y + 1;
assert x == y + 1;  // the compiler worked!
```

• Too many assertions can make the code hard to read
• Be judicious about where you include them. Good choices:
  – preconditions & postconditions
  – invariants of non-trivial loops
  – representation invariants after mutations
How *not* to use assertions

Don’t perform side effects:

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

// better:
boolean found = list.remove(x);
assert found;
```
assert and checkRep()

CSE 331’s checkRep() is another dynamic check

Strategy: use assert in checkRep() to test and fail with meaningful message if trouble found
  – CSE 331 tests will check that assertions are enabled

Easy to forget to enable them in your own projects
  – Google doesn’t use them for this reason
Expensive `checkRep()` tests

Detailed checks can be too slow in production
   – especially if asymptotically slower than code being checked

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

Suggested strategy for `checkRep`:
   – create a static, global “debug” or “debugLevel” variable
   – run expensive tests when this is enabled
   – turn it on during unit tests
     • can use JUnit’s `@Before` for this
Square root

// 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 different purposes

(Note: the Java library Math.sqrt method returns NaN for x<0. We use different specifications in this lecture as examples.)
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Square root, specified for all inputs

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

• **throws** is part of a method signature: “it might happen”
  – comma-separated list
  – like @modifies, promises are in what is **not listed**
• **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 NegativeArgumentException
...

Client code:

try {
    y = sqrt(...);
    ... other statements ...
} catch (NegativeArgumentException e) {
    e.printStackTrace(); // or other actions
}
```

- Handled by nearest *dynamically* enclosing `try/catch`
  - top-level default handler: print stack trace & crash
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)
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 used
- Exceptions allow *non-local* error handling
  - a method many levels up the stack can handle a deep error
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();
}
```
(Abridged) Exception Hierarchy
Java’s checked/unchecked distinction

Checked exceptions *(style: for special cases / abnormal 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”
  - guaranteed to be a matching enclosing catch *at runtime*

Unchecked exceptions *(style: for never-expected)*
- **library** has no need to declare
- **client** has no need to catch
- these are subclasses of:
  - RuntimeException
  - Error *(rarely caught)*
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Two distinct uses of exceptions

• Errors that should be failures
  – unexpected (ideally, should not happen at all)
  – should be rare with high quality client and library
  – can be the client’s fault or the library’s
  – often unrecoverable

• Special cases (a.k.a. exceptional cases)
  – expected, just not the common case
  – possibly unpredictable or unpreventable by client
Handling exceptions

• Errors that should be failures
  – usually can’t recover
  – unchecked exceptions the better choice (avoids much work)
  – if condition not checked, exception propagates up the stack
    • top-level handler prints the stack trace

• Special cases
  – 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
Checked vs. unchecked

- No perfect answer to the question “should clients be forced to catch (or declare they throw) this exception?”
  - Java provided both options

- Advantages to checked exceptions:
  - Static checking of callee: only declared exceptions are thrown
  - Static checking of caller: exception is caught or declared

- Disadvantages:
  - impedes implementations and overrides (can’t add exceptions)
    - prevents truly giving no promises when @requires is false
  - often in your way when prototyping
  - have to catch or declare even if the exception is not possible
Propagating an exception

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

Aside: does “negative argument” make sense to the caller?
Why catch exceptions locally?

Problems:

1. Failure to catch exceptions often violates modularity
   - call chain: $A \rightarrow \text{IntSet.insert} \rightarrow \text{IntList.insert}$
   - IntList.insert throws some exception
     - implementer of IntSet.insert knows how list is being used
     - implementer of A may not even know that IntList exists

2. Possible that a method on the stack may think that it is handling an exception raised by a different call

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
Exception translation

// 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 + Math.sqrt(b*b - 4*a*c)) / (2*a);
    } catch (NegativeArgumentException e) {
        throw new NotRealException(); // "chaining"
    }
}

class NotRealException extends Exception {
    NotRealException() { super(); }
    NotRealException(String message) { super(message); }
    NotRealException(Throwable cause) { super(cause); }
    NotRealException(String msg, Throwable c) { super(msg, c); }
}
Don’t ignore exceptions

*Effective Java* Tip: Don't ignore exceptions

Empty catch block is poor style

```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 \texttt{Map.get}
- -1 for \texttt{indexOf}
- \texttt{NaN} for \texttt{sqrt} of negative number

Advantages:
- can be less verbose 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
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• **Summary and review**
Exceptions: review

Use an **assertion** for internal consistency checks that should not fail
- when checking at runtime is possible

Use only a **precondition** when
- used in a context in which calls can be checked via reasoning
- but checking at runtime would be prohibitive
  - e.g., requiring that a list be sorted

Use an **exception** when
- used in a dynamic / unpredictable context (client can’t predict)
- for exceptional cases only

Use a **special value** when
- it is a common case (not really exceptional)
- clients are likely (?) to remember to check for it
Exceptions: review, continued

Use *checked* exceptions most of the time
   – static checking is helpful! (*tools*, inspection, & testing)

Avoid checked exceptions if there is probably no way to recover

Handle exceptions sooner rather than later

Good reference: Effective Java chapter
   – a whole chapter: exception-handling design matters!