CSE 331
Software Design & Implementation

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Summer 2017
Exceptions and Assertions
(Based on slides by Mike Ernst, Dan Grossman, David Notkin, Hal Perkins, Zach Tatlock)
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
   - e.g., representation invariant fails to hold
   - **should** be a failure

3. Unexpected resource problems
   - e.g., missing file, server offline, …
   - **should not** be a failure (try to recover / hide from user)
     • (these are not bugs)
What to do when failing

Fail fast and fail friendly

Goal 1: Give information about the problem
  - a good error message is important for debugging
  - failing quickly helps localize the defect

Goal 2: Prevent harm
  - stop before anything worse happens
  - perform cleanup: close open resources etc.
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, some will use your code incorrectly
  – it often 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();
```

- write assertions as you write code
- include 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:
```java
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 off in graded / production code if tests are too expensive
Square root

// requires: x >= 0
// returns: approximation to square root of x
public double sqrt(double x) {
    ...
}

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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: 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

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

Client code:

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

• Handled by nearest dynamically enclosing try/catch
  – top-level default handler: print stack trace & crash
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
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)
(Abridged) Exception Hierarchy

```
Exception
  └── ClassCastException
      ├── ArithmeticException
      │    └── IllegalArgumentException
      │          └── NullPointerException
      └── ClassCastException
          └── ConcurrentModificationException
              └── IndexOutOfBoundsException
                  └── NoSuchElementException
```
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)
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)
  – often in your way when prototyping
  – have to catch or declare even if 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

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: should we call it “illegal” to give a quadratic with no real soln?
Why catch exceptions locally?

Problems:

1. Failure to catch exceptions often violates modularity
   - call chain:  A  ->  IntegerSet.insert  ->  IntegerList.insert
   - IntegerList.insert throws some exception
     - implemener of IntegerSet.insert knows how list is being used
     - implemener of A may not even know that IntegerList 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
// 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(Throwabe 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 (a bit) expensive if thrown/caught
- Reserve exceptions for exceptional conditions
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 results
  - 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 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
Don’t ignore exceptions

*Effective Java* Tip #65: 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

} 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:
- 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
- up for debate if indexOf not-present-value is exceptional
  - Python has two versions, one w/ exception and one w/out
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 indicates 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 dynamic / unpredictable context (client can’t predict)
- checking for the error is feasible

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

Use a special value when
- it is a reasonable common case
- 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! (tools, inspection, & testing)

Avoid checked exceptions if there is probably no way to recover

Handle exceptions sooner rather than later

Not all exceptions are errors (just special cases)
  – example: file not found

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