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: *Give information about the problem*
  – failing quickly helps localize the defect
  – a good error message is important for debugging

Goal 2: *Prevent harm*
  – stop before anything worse happens
  – (do still need to 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**, someone 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 \textit{statically} via reasoning and tools

Check these \textit{dynamically} via \texttt{assertions}
\begin{verbatim}
assert index >= 0;
assert items != null : "null item list argument"
assert size % 2 == 0 : "Bad size for " + toString();
\end{verbatim}
- throws \texttt{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 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) {
    ...
}

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
  – 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 IllegalArgumentException
...

Client code:

```try```
    y = sqrt(...);
    ... other statements ...
```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
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)
(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)
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

```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: 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
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 + 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(Throwabling 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 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
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

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

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

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!