CSE 331

Software Design & Implementation

Topic: Exceptions and Assertions

Discussion: How many lemons could you fit into a bus?

Reminders

- Wasn't able to give the last lecture – please ask questions!
- Office hours before lecture

Upcoming Deadlines

- Prep. Quiz: HW5 due Monday (7/17)
- HW5 due Thursday (7/20)

Last Time…

- Equality
- Overriding vs. Overloading
- Hashcodes

Today's Agenda

- Some more Equality
- Bugs vs. Errors
- Assertions and **`checkRep`**
- Exceptions

`equals` specification

`public boolean equals(Object obj)` should be:

- *reflexive*: for any reference value `x`, `x.equals(x) == true`
- *symmetric*: for any reference values `x` and `y`, `x.equals(y) == y.equals(x)`
- *transitive*: for any reference values `x`, `y`, and `z`, if `x.equals(y)` and `y.equals(z)` are `true`, then `x.equals(z)` is `true`
- *consistent*: for any reference values `x` and `y`, multiple invocations of `x.equals(y)` consistently return `true` or consistently return `false` (provided neither is mutated)
- For any *non-null* reference value `x`, `x.equals(null)` should return `false`

An example

A class where we may want **`equals`** to mean equal contents

```
public class Duration {
    // RI: min >= 0 && 0 <= sec < 60
    private final int min, sec;

    public Duration(int min, int sec) {
        assert min >= 0 && sec >= 0 && sec < 60;
        this.min = min;
        this.sec = sec;
    }
}
```

Satisfies the contract

```
public class Duration {
    @Override
    public boolean equals(Object o) {
        if (!(o instanceof Duration))
            return false;
        Duration d = (Duration) o;
        return this.min == d.min && this.sec == d.sec;
    }
}
```

Since we satisfy the contract, we are done! Right?

Equality with Inheritance

A class where we may want **`equals`** to mean equal contents

```
public class NanoDuration extends Duration {
    private final int min, sec, nanos;

    public NanoDuration(int min, int sec, int nanos) { ... }

    @Override
    public boolean equals(Object o) {
        if (!(o instanceof NanoDuration))
            return false;
        NanoDuration nd = (NanoDuration) o;
        return super.equals(nd) && this.nanos == nd.nanos;
    }
}
```

We can break the contract

Consider the following code snippet:

```
Duration d1 = new NanoDuration(1, 1, 500);
Duration d2 = new Duration(1, 1);

d1.equals(d2);  // false  [NanoDuration.equals]
d2.equals(d1);  // true   [Duration.equals]
```

What property in the contract do we accidentally break? **Symmetricness**

Outline

- Terminology: 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

Not all “errors” should be failures

Some “error” cases:

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

2. Implementer has an error in 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 above (… 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

With lots of clients, will eventually happen. We need to practice *defensive programming.*

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

```
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)

IntelliJ:

- 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

```
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:

```
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

- Microsoft doesn't use the default asserts 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.)

Not all “errors” should be failures

Some “error” cases:

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Assertions help with the first two

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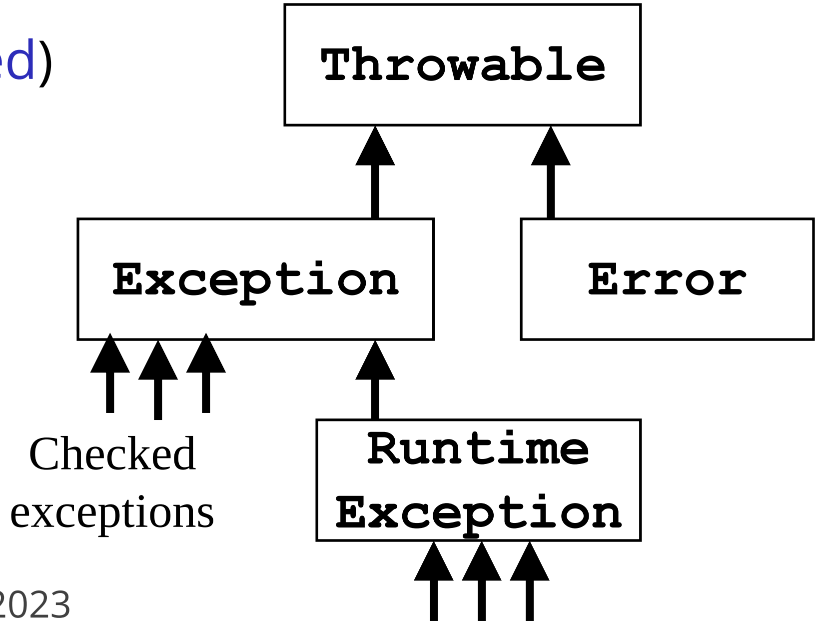
Java's checked/unchecked distinction

Checked exceptions (*style*: for *special cases / abnormal cases*)

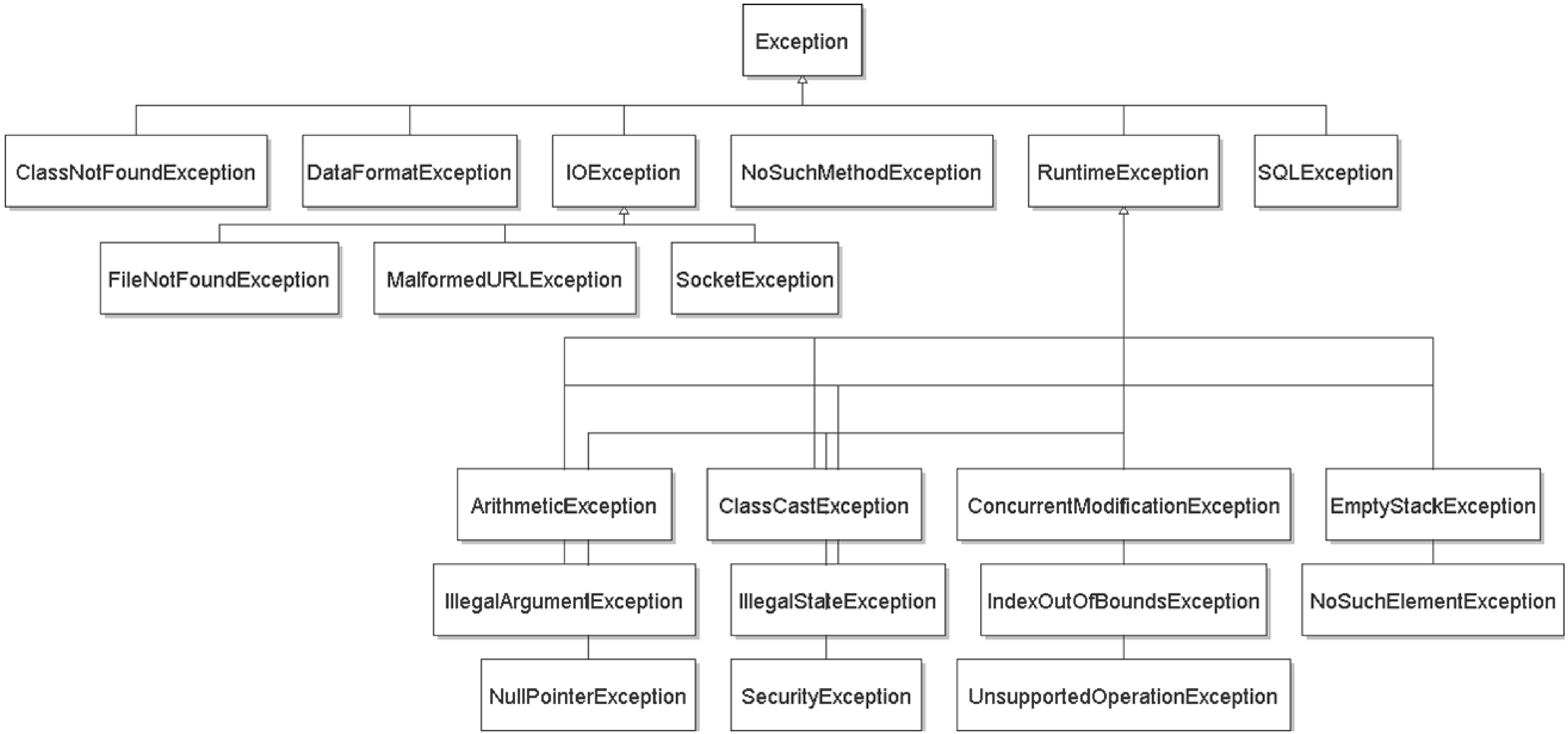
- **callee** must declare in signature (else type error)
- **client** must either catch or declare (else type error)
  - even if you can prove it will never happen at run time, the type system does not "believe you"
- guaranteed to be a matching enclosing catch *at runtime*

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)



(Abridged) Exception Hierarchy



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, possible but not required
- `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 NegativeArgumentException;
```

Client code:

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

Handled by nearest *dynamically* enclosing **`try/catch`**

- top-level default handler: print stack trace & crash

Code Paths with Exceptions

Three potential paths through the code below:

```
try {
  y = foo(…);
  … more code …
} catch (Type name) {
  … code to handle the exception …
}
```

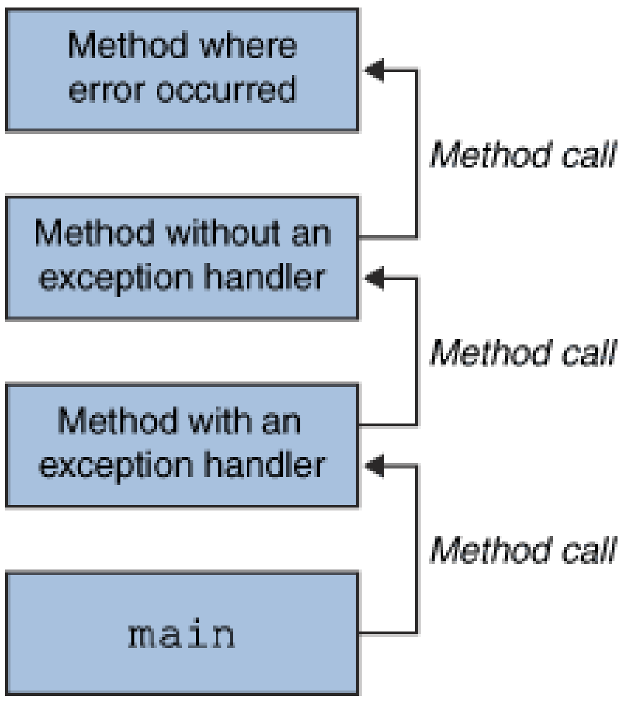
1. sqrt returns normally
2. sqrt throws an exception caught by this catch
3. sqrt throws an exception not caught here

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

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

Need to be careful! In this case, not all blocks will execute…

Catching with inheritance

```
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)

The `finally` block

`finally` block is always executed

- whether an exception is thrown or not

```
try {
  y = foo(…);
  … more 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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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 -> IntSet.insert -> 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 + 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

sometimes okay inside of an exception handler

```
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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- Alternative with trade-offs: Returning special values

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

Exceptions: review

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

Use only a precondition in the specification 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

Before next class…

1. Finish Prep. Quiz: HW5
   - Some helpful concepts for defining and implementing an ADT
   - A bit longer than what we normally give you

2. Start on HW5
   - Unique experience to design an ADT yourself
   - Focuses on testing and specifications