CS/ENGRD 2110
Object-Oriented Programming and Data Structures

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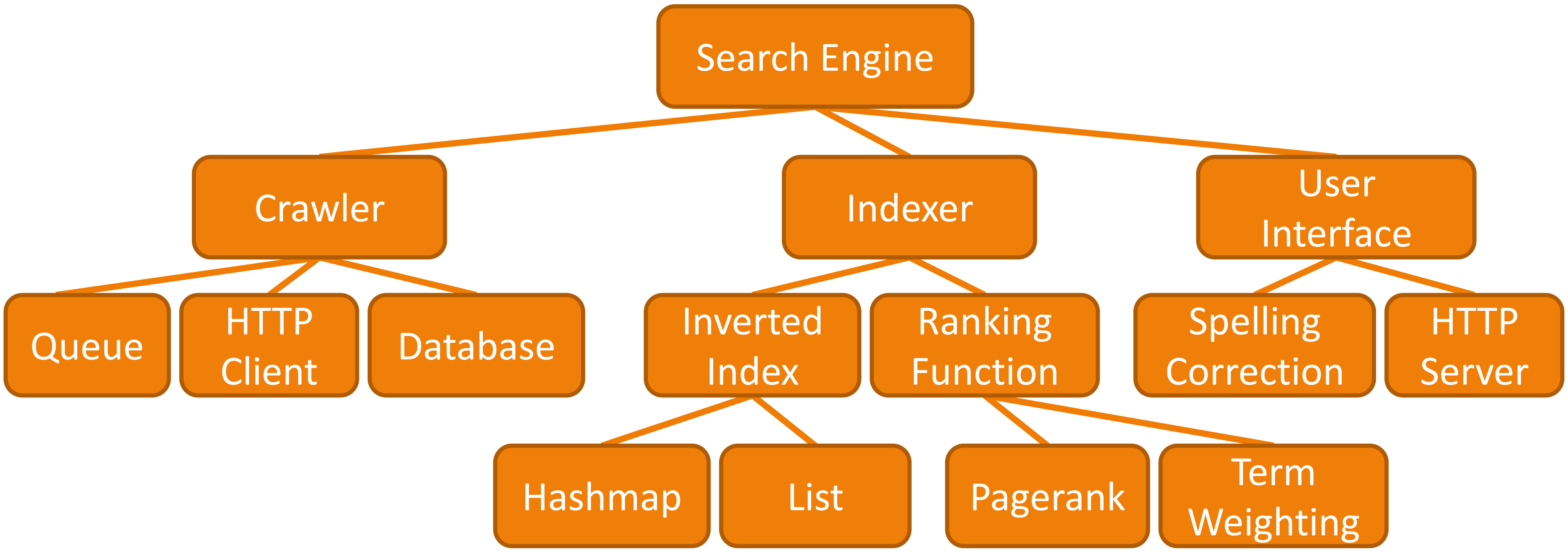
Lecture 7: Software Design

Software Engineering

- The art by which we start with a problem statement and gradually evolve a solution.
- There are whole books on this topic and most companies try to use a fairly uniform approach that all employees are expected to follow.
- The IDE can help by standardizing the steps.

Top-Down Design

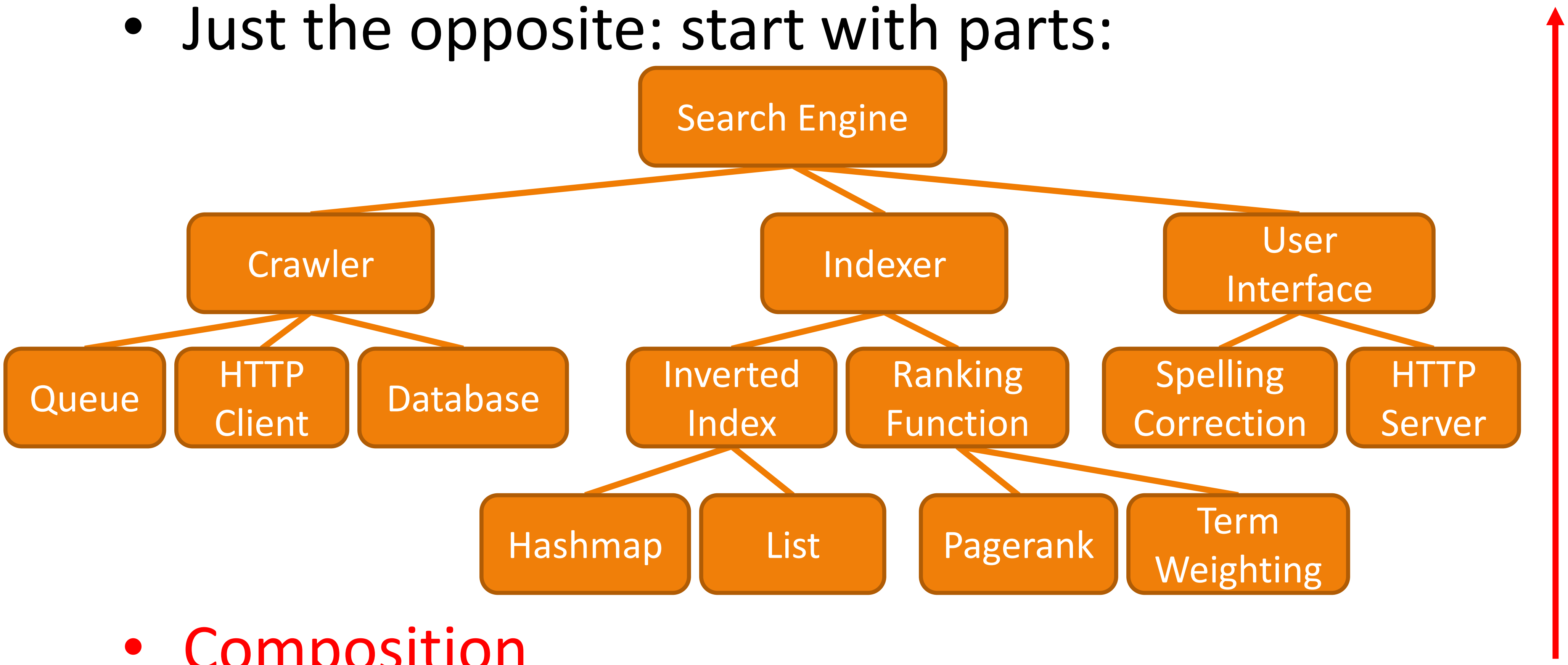
- Building a Search Engine:



- Refine the design at each step
- Decomposition / “Divide and Conquer”

Bottom-Up Design

- Just the opposite: start with parts:



- Composition
- Build-It-Yourself (e.g. IKEA furniture)

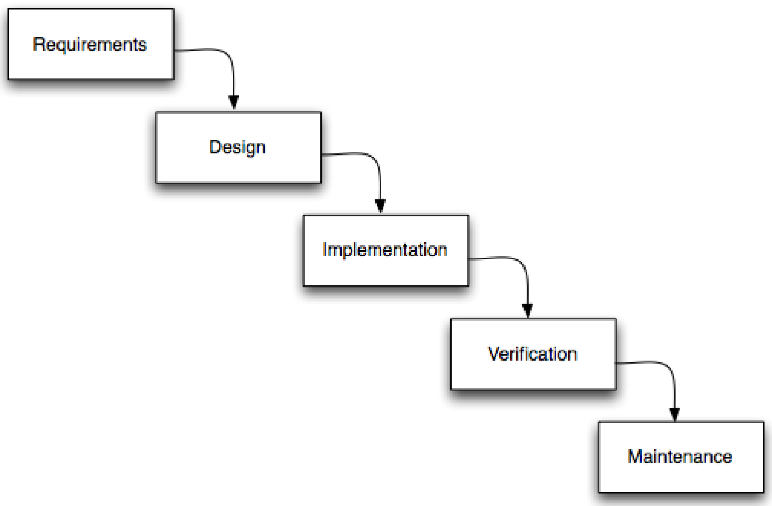
Top-Down vs. Bottom-Up

- Is one of these ways better? Not really!
  - It’s sometimes good to alternate
  - By coming to a problem from multiple angles you might notice something you had previously overlooked
  - Not the only ways to go about it

- With Top-Down it’s harder to test early because parts needed may not have been designed yet
- With Bottom-Up, you may end up needing things different from how you built them

Software Process

- For simple programs, a simple process…

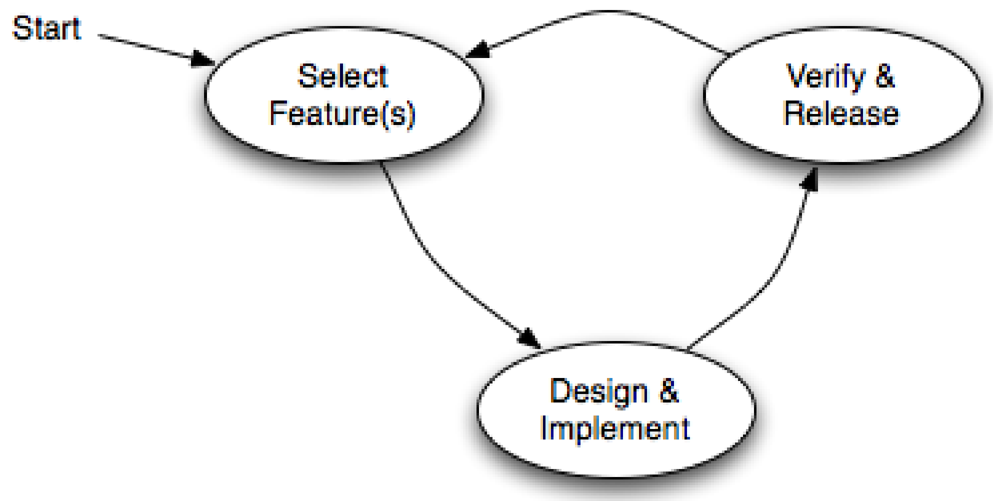


"Waterfall"

- But to use this process, you need to be sure that the requirements are fixed and well understood!
  - Many software problems are not like that
  - Often customer refines the requirements when you try to deliver the initial solution!

Incremental & Iterative

- Deliver versions of the system in several small cycles:



- Recognizes that for some settings, software development is like gardening.
- You plant seeds… see what does well… then replace the plants that did poorly.

TESTING AND TEST-DRIVEN DEVELOPMENT

The Importance of Testing

- Famous last words
  - “Its all done, I just have not tested it yet”.
- Many people
  - Write code without being sure it will work
  - Press run and pray
  - If it fails, they change something random
  - → Never work, and ruins weekend social plans.
- Test-Driven Development!

The Example

- A collection class **`SmallSet`**
  - containing up to N objects (hence “small”)
  - typical operations:

add	adds item
contains	is item in the set?
size	# items

  - we’ll implement **`add(), size()`**

Test Driven Development

- We’ll go about in small iterations
    1. add a test
    2. run all tests and watch the new one fail
    3. make a small change
    4. run all tests and see them all succeed
    5. refactor (as needed)

- We’ll use JUnit

JUnit

- What do JUnit tests look like?

SmallSet.java

```
package edu.cornell.cs.cs2110;

public class SmallSet {
   ...
}
```

SmallSetTest.java

```
package edu.cornell.cs.cs2110;

import org.junit.Test;
import static org.junit.Assert.*;

public class SmallSetTest {
   @Test public void testFoo() {
      SmallSet s = new SmallSet();
      ...
      assertTrue(...);
   }

   @Test public void testBar() {
      ...
   }
}
```

A List of Tests

- We start by thinking about how to test, not how to implement
  - size=0 on empty set
  - size=N after adding N distinct elements
  - adding element already in set doesn't change size
  - throw exception if adding too many
  - ...

- Each test verifies a certain "feature"

A First Test

- We pick a feature and test it:

SmallSet
```
class SmallSet {}
```

SmallSetTest
```
class SmallSetTest {
   @Test public void testEmptySetSize() {
      SmallSet s = new SmallSet();
      assertEquals(0, s.size());
   }
}
```

- This doesn't compile: **`size()`** is undefined
- But that's all right: we've started designing the interface by using it

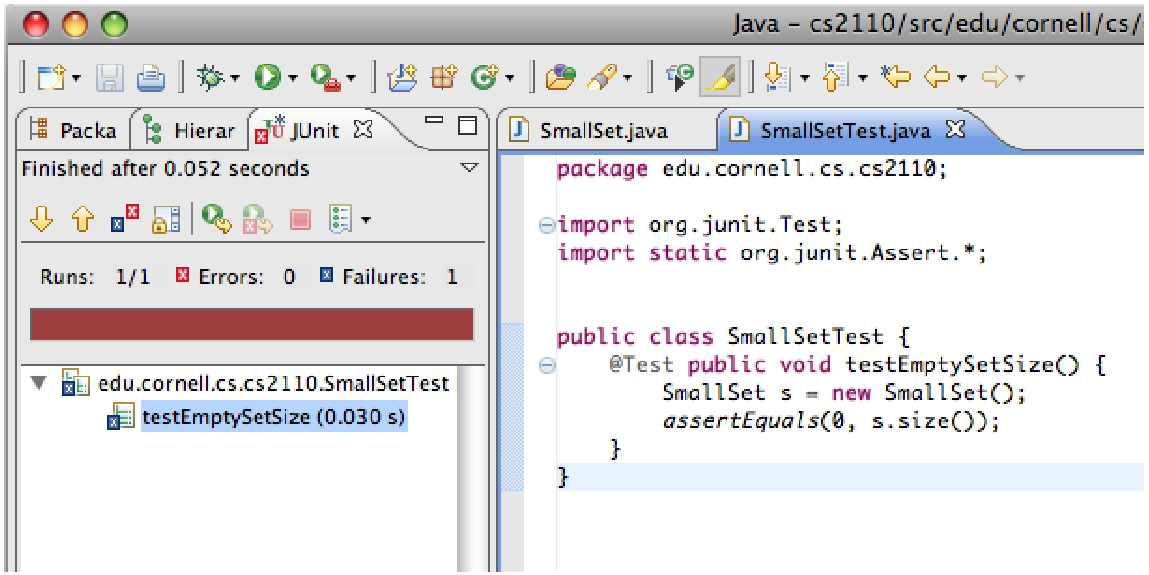
Red Bar

- A test can be defined *before* the code is written

SmallSet

```
class SmallSet {
    public int size() {
        return 42;
    }
}
```

- Running the test yields a red bar indicating failure:



- If we add the size function and re-run the the test, it works!

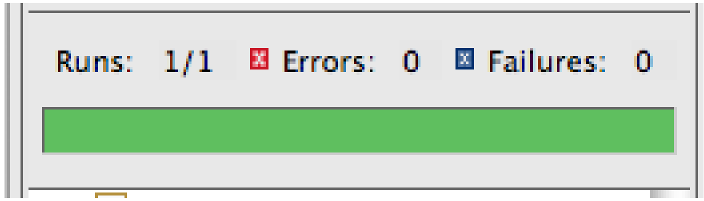
Green Bar

- What's the simplest way to make a test pass?

SmallSet

```
class SmallSet {
    public int size() {
        return 0;
    }
}
```

- "Fake it till you make it"
- Re-running yields the legendary JUnit Green Bar:



- Move on with the next feature

Adding Items

- To implement adding items, we first test for it:

SmallSetTest

```
class SmallSetTest {
   @Test public void testEmptySetSize() ...

   @Test public void testAddOne() {
      SmallSet s = new SmallSet();
      s.add(new Object());
      assertEquals(1, s.size());
   }
}
```

- **`add()`** is undefined, so to run the test we define it:

SmallSet

```
public int size() ...

public void add(Object o) {}
```

Adding Items

- The test now fails as expected: 
- It seems obvious we need to count the number of items:

SmallSet

```
private int _size = 0;

public int size() {
    return 0;
    return _size;
}

public void add(Object o) {
    ++_size;
}
```

- And we get a green bar: 

Adding Something Again

- So what if we added an item already in the set?

SmallSetTest

```
class SmallSetTest {
   @Test public void testEmptySetSize() ...

   @Test public void testAddOne() ...

   @Test public void testAddAlreadyInSet() {
      SmallSet s = new SmallSet();
      Object o = new Object();
      s.add(o);
      s.add(o);
      assertEquals(1, s.size());
   }
}
```

- As expected, the test fails...

Remember that Item?...

- We need to remember which items are in the set...

SmallSet

```
private int _size = 0;
public static final int MAX = 10;
private Object _items[] = new Object[MAX];
...
public void add(Object o) {
   for (int i=0; i < MAX; i++) {
      if (_items[i] == o) {
         return;
      }
   }
   _items[_size] = o;
   ++_size;
}
```

- All tests pass, so we can refactor that loop...

Refactoring

- FOR-loop doesn't "speak to us" as it could...

SmallSet (before)

```
public void add(Object o) {
    for (int i=0; i < MAX; i++) {
        if (_items[i] == o) {
            return;
        }
    }
    _items[_size] = o;
    ++_size;
}
```

SmallSet (after)

```
private boolean inSet(Object o) {
    for (int i=0; i < MAX; i++) {
        if (_items[i] == o) {
            return true;
        }
    }
    return false;
}

public void add(Object o) {
    if (!inSet(o)) {
        _items[_size] = o;
        ++_size;
    }
}
```

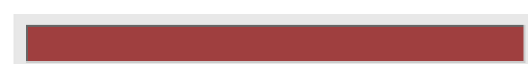
- All tests still pass, so we didn't break it!

Too Many

- What if we try to add more than `SmallSet` can hold?

SmallSetTest

```
...
@Test public void testAddTooMany() {
   SmallSet s = new SmallSet();
   for (int i=0; i < SmallSet.MAX; i++) {
      s.add(new Object());
   }
   s.add(new Object());
}
```

- The test fails with an error: 
  `ArrayIndexOutOfBoundsException`
- We know why this occurred, but it should bother us: “ArrayIndex” isn’t a sensible error for a “set”

Size Matters

- We first have **`add()`** check the size,

SmallSet

```
public void add(Object o) {
    if (!inSet(o) && _size < MAX) {
        _items[_size] = o;
        ++_size;
    }
}
```

- ... re-run the tests, check for green, define our own exception...

SmallSetFullException

```
public class SmallSetFullException extends Error {}
```

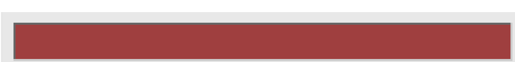
- ... re-run the tests, check for green, and...

Testing for Exceptions

- ... finally test for our exception:

SmallSetTest

```
@Test public void testAddTooMany() {
    SmallSet s = new SmallSet();
    for (int i=0; i < SmallSet.MAX; i++) {
        s.add(new Object());
    }
    try {
        s.add(new Object());
        fail("SmallSetFullException expected");
    }
    catch (SmallSetFullException e) {}
}
```

- The test fails as expected, 
  so now we fix it...

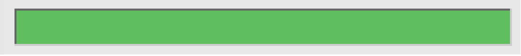
Testing for Exceptions

- ... so now we modify **add()** to throw:

SmallSet

```
public void add(Object o) {
    if (!inSet(o) && _size < MAX) {
        if (_size >= MAX) {
            throw new SmallSetFullException();
        }
        _items[_size] = o;
        ++_size;
    }
}
```

- All tests now pass, so we're done:



After all Tests are Passed

- Is the code is correct?
  - Yes, if we wrote the right tests.
- Is the code efficient?
  - Probably used simplest solution first.
  - Replace simple data structures with better data structures.
  - New ideas on how to compute the same while doing less work.
- Is the code readable, elegant, and easy to maintain?
  - It is very common to find some chunk of working code, make a replica, and then edit the replica.
  - But this makes your software fragile
    - Later changes have to be done on all instances, or
    - some become inconsistent
  - Duplication can arise in many ways:
    - constants (repeated “magic numbers”)
    - code vs. comment
    - within an object’s state
    - ...

"DRY" Principle

- Don't Repeat Yourself
- A nice goal is to have each piece of knowledge live in one place
- But don't go crazy over it
  - DRYing up at any cost can increase dependencies between code
  - "3 strikes and you refactor" (i.e., clean up)

Simple Refactoring

- Renaming variables, methods, classes for readability.
- Explicitly defining constants:

```
public double weight(double mass) {
  return mass * 9.80665;
}
```

```
static final double GRAVITY = 9.80665;

public double weight(double mass) {
  return mass * GRAVITY;
}
```

  - If your application later gets used as part of a Nasa mission to Mars, it won't make mistakes
  - Every place that the gravitational constant shows up in your program a reader will realize that this is what she is looking at
  - The compiler may actually produce better code

Extract Method

- A comment explaining what is being done usually indicates the need to extract a method

```
public double totalArea() {
   ...
   // now add the circle
   area += PI * pow(radius,2);
   ...
}
```

```
public double totalArea() {
   ...
   area += circleArea(radius);
   ...
}

private double circleArea(double radius) {
   return PI * pow(radius, 2);
}
```

- One of the most common refactorings

Extract Method

- Simplifying conditionals with Extract Method

before

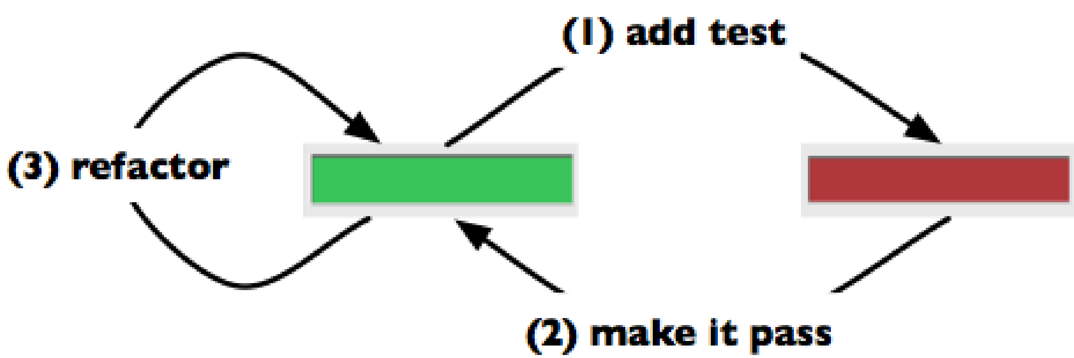
```
if (date.before(SUMMER_START) || date.after(SUMMER_END)) {
    charge = quantity * _winterRate + _winterServiceCharge;
}
else {
    charge = quantity * _summerRate;
}
```

after

```
if (isSummer(date)) {
     charge = summerCharge(quantity);
}
else {
    charge = winterCharge(quantity);
}
```

Review

- Started with a "to do" list of tests / features
  - could have been expanded
    as we thought of more tests / features
- Added features in small iterations



- "a feature without a test doesn't exist"

Is testing obligatory?

- When you write code in professional settings with teammates, definitely!
  - In such settings, failing to test your code just means you are inflicting errors you could have caught on teammates!
  - People get fired for this sort of thing!
  - So… in industry… test or perish!
- But what if code is just “for yourself”?
  - Testing can still help you debug, and if you go to the trouble of doing the test, JUnit helps you “keep it” for re-use later.
  - “I have never written a program that was correct before I tested and debugged it.” Prof. Joachims

Fixing a Bug

- What if after releasing we found a bug?

Famous last words: "It works!"

A bug can reveal a missing test

- … but can also reveal that the specification was faulty in the first place, or incomplete
  - Code “evolves” and some changing conditions can trigger buggy behavior
  - This isn’t your fault or the client’s fault but finger pointing is common
- Great testing dramatically reduces bug rates
  - And can make fixing bugs way easier
  - But can’t solve everything: Paradise isn’t attainable in the software industry

Reasons for TDD

- By writing the tests first, we
  - test the tests
  - design the interface by using it
  - ensure the code is testable
  - ensure good test coverage
- By looking for the simplest way to make tests pass,
  - the code becomes “as simple as possible, but no simpler”
  - may be simpler than you thought!

Not the Whole Story

- There's a lot more worth knowing about TDD
  - What to test / not to test
    - » e.g.: external libraries?
  - How to refactor tests
  - Fixtures
  - Mock Objects
  - Crash Test Dummies
  - ...

* Beck, Kent: *Test-Driven Development: By Example*

How people write really big programs

- When applications are small, you can understand every element of the system
- But as systems get very large and complex, you increasingly need to think in terms of interfaces, documentation that defines how modules work, and your code is more fragmented
- This forces you into a more experimental style

Testing is a part of that style!

- Once you no longer know how big parts of the system even work (or if they work), you instead begin to think in terms of
  - Code you've written yourself. You tested it and know that it works!
  - Modules you make use of. You wrote experiments to confirm that they work the way you need them to work
  - Tests of the entire complete system, to detect issues visible only when the whole thing is running or only under heavy load

Junit testing isn't enough

- For example, many systems suffer from "leaks"
  - Such as adding more and more objects to an ArrayList
  - The amount of memory just grows and grows
- Some systems have issues triggered only in big deployments, like cloud computing settings
- Sometimes the application "specification" was flawed, and a correct implementation of the specification will look erroneous to the end user
- But a thorough test plan can reveal all such problems

The Q/A cycle

- Real companies have quality assurance teams
- They take the code and refuse to listen to all the long-winded explanations of why it works
- Then they do their own, independent, testing
- And then they send back the broken code with a long list of known bugs!
- Separating development from Q/A really helps

Why is Q/A a cycle?

- Each new revision may fix bugs but could also break things that were previously working
- Moreover, during the lifetime of a complex application, new features will often be added and those can also require Q/A
- Thus companies think of software as having a very long “life cycle”. Developing the first version is only the beginning of a long road!

Even with fantastic Q/A…

- The best code written by professionals will still have some rate of bugs
  - They reflect design oversights, or bugs that Q/A somehow didn’t catch
  - Evolutionary change in requirements
  - Incompatibilities between modules developed by different people, or enhancements made by people who didn’t fully understand the original logic

- So never believe that software will be flawless
- Our goal in cs2110 is to do as well as possible
- In later CS courses we’ll study “fault <u>tolerance</u>”!