CS 2110

Software Design Principles I

Recap from last time

- We were talking about the class hierarchy and inheritance of methods
- Basic idea was to have a parent class that implements some very general functionality and then a child class that specializes it.
- A parent class can also standardize an “interface” shared by child classes. For example: classes that support the same interface as an Array
  - X[i] = 17 + Y[j,k] / X[i]; // Is X *really* an array?

Array vs ArrayList vs HashMap (latter two from java.util)

- Array
  - Storage is allocated when array created; cannot change
  - Extremely fast lookups
- ArrayList (in java.util)
  - An “extensible” array
  - Can append or insert elements, access i’th element, reset to 0 length
  - Lookup is slower than an array

- HashMap (in java.util)
  - Save data indexed by keys
  - Can look up data by its key
  - Can get an iteration of the keys or values
  - Storage allocated as needed but works best if you can anticipate need and tell it at creation time.

HashMap Example

- Create a HashMap of numbers, using the names of the numbers as keys:

```
Map<String, Integer> numbers
                    = new HashMap<String, Integer>();
numbers.put("one", new Integer(1));
numbers["two"] = new Integer(2));
numbers.put("three", new Integer(3));
```

- To retrieve a number:

```
Integer n = numbers.get("two");   // Explicit method call
Integer n = numbers["two"];       // Array notation
```

- Returns null if the HashMap doesn't contain key
  - Can use numbers.containsKey(key) to check this

Generics and Autoboxing

- Is a number like 71 an Integer (an object) or a base type (an "int")?
- How do I create an array with an object, not a base type, in the entries?

- Java automatically “autoboxes” and also lets you use types as a kind of parameter

```
Map<String, Integer> numbers =  new HashMap<String, Integer>();
numbers.put("one", 1);        // Autobox converts 1 to new Integer(1);
int s = numbers.get("one");
```

What do these tell us?

- There is a great deal of power in “abstraction”
  - Here we’re seeing examples in which the abstract type is an array, but the values and even the index can be arbitrary objects!

- In Java we often also need special-purpose objects that add functionality, properties etc
  - For example, to make an array extensible, or to ensure that lookup will use a very fast method even if the index type isn’t an integer

Our challenge?

- We need to look at a computing problem, such as building software for cyclists, and learn to
  - See the most general abstractions, where they arise. For example “gosh, these are graphs”
  - Build powerful, general purpose solutions, such as a graph class supporting graph operations
  - But then also see how to map that general abstraction back to the real world
    - For example, creating bike routes that have GPS locations and times and other bike-specific properties

Mapping goes two ways

- You look at a problem and say “I see a more basic, general idea here”
  - These bike routes look like graphs to me
  - So I’ll build a graph class, and then I’ll specialize it to support graphs of bike data
- But sometimes you have an existing powerful class and think the opposite way
  - I already have a graph package. I’ll use it to implement bike routes

So how do people do this?

- One of the hardest questions in computing centers on finding the right abstractions
- We want them to be powerful, yet efficient
- We want ways to specialize them that seem as natural as possible

A journey of a thosand miles…

- … starts with a single step
- Most developers develop code partly by experimentation
- Don’t be afraid to experiment by writing little code fragments and seeing if they compile and what they do.
- But don’t write random code hoping that it might work by some miracle.

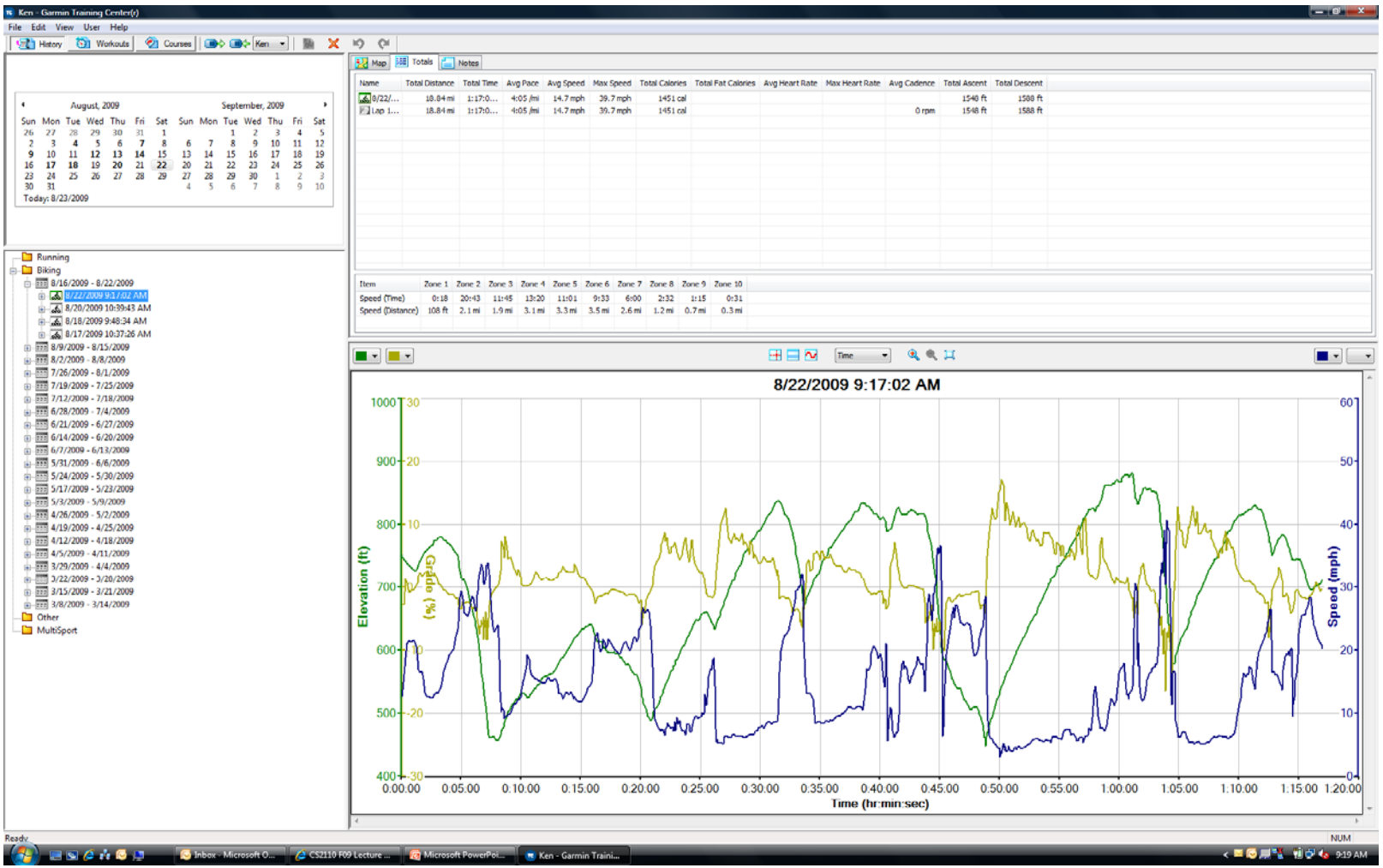
Mistakes will happen!

- We call them bugs…
- To debug code, we need to think hard….
  - **Do not just make random changes, hoping something will work. This never works.**
  - Think about what could cause the observed behavior
  - Isolate the bug. Focus on the first thing that goes wrong.

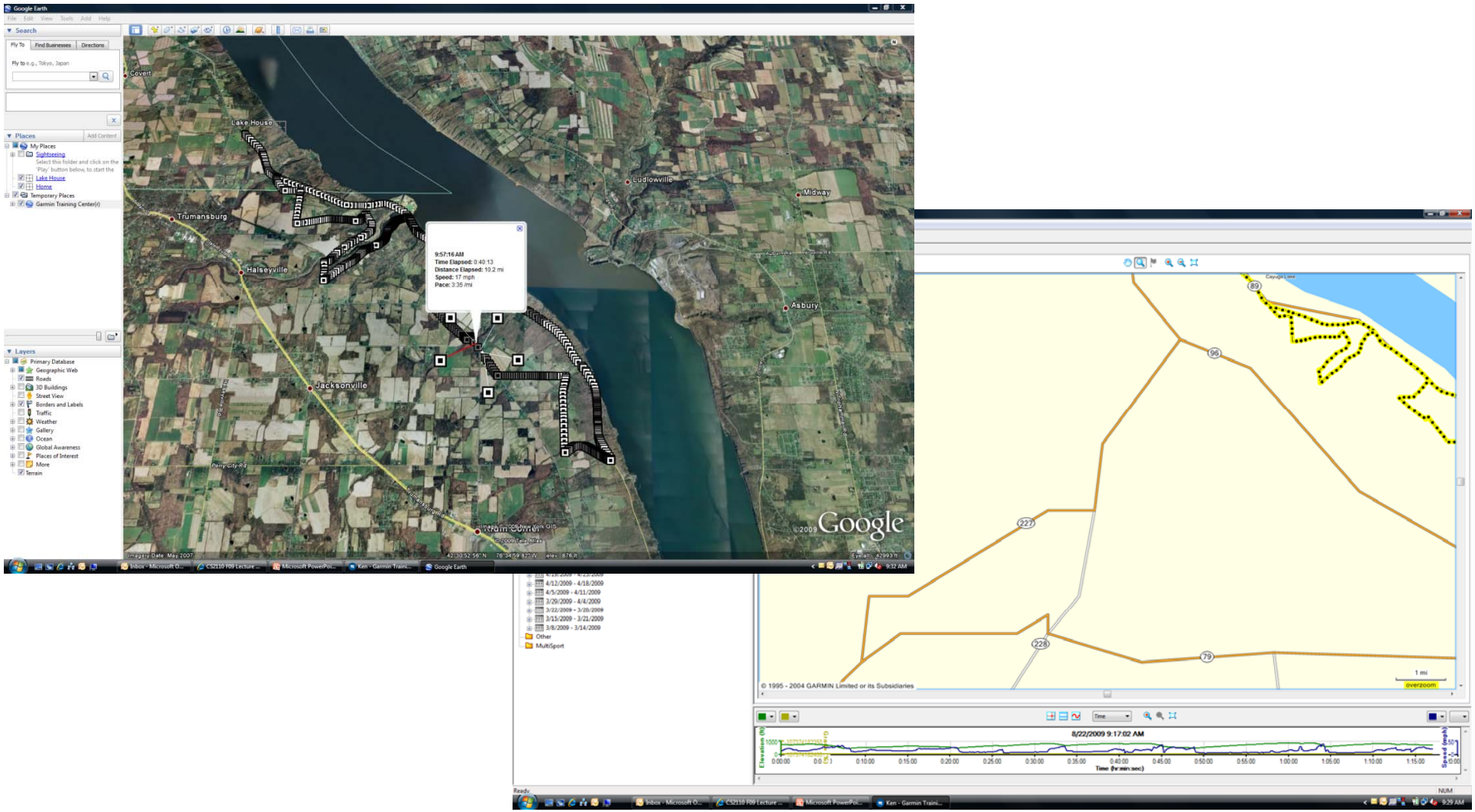
- An IDE helps by providing a *Debugging Mode*
  - Can set breakpoints, step through the program while watching chosen variables
  - When program pauses at breakpoint, or dies, can look at values of variables it was using

So let's look at how all this works

- Garmin GPS unit tracks your bike ride

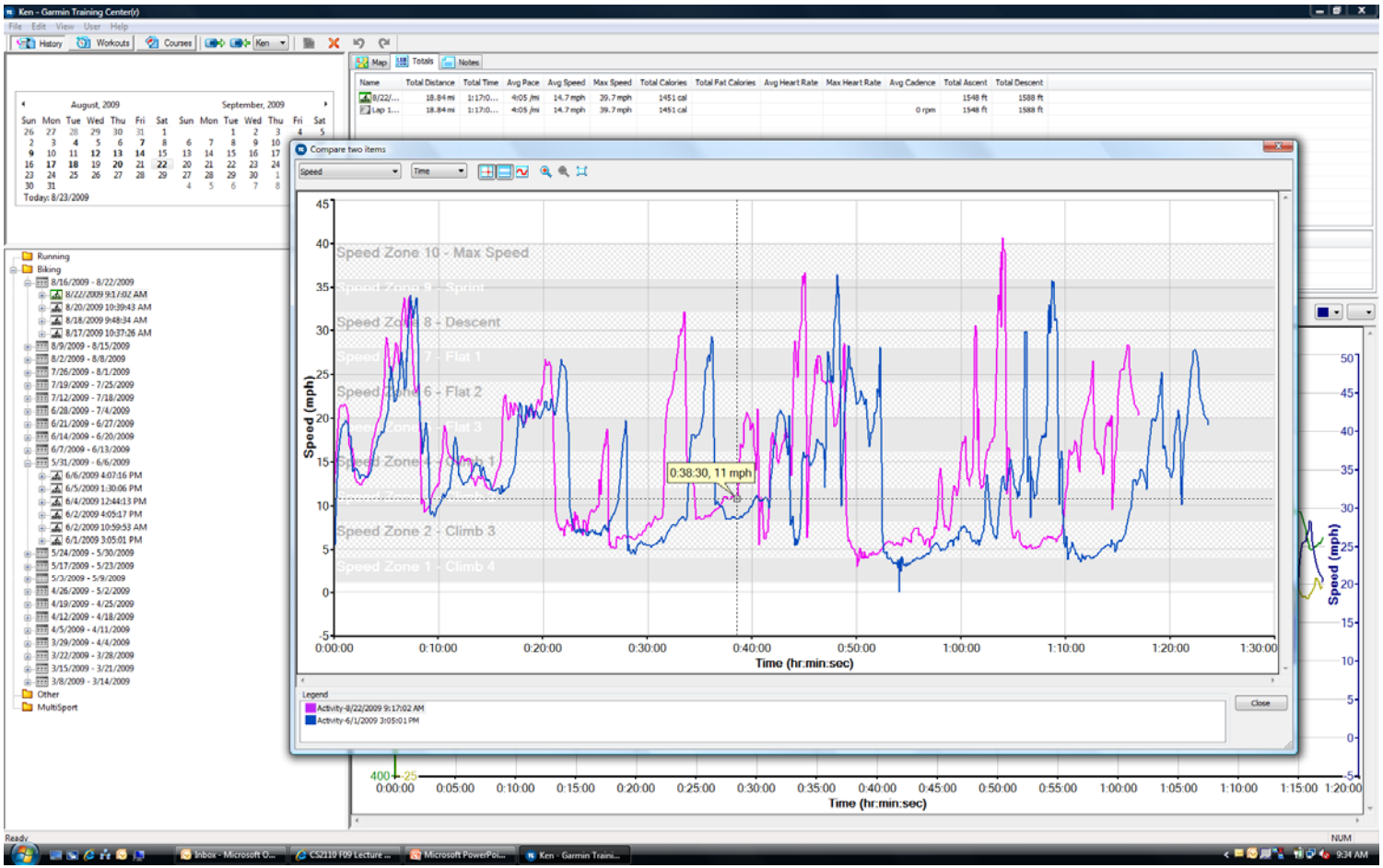


… displays match one graph (of the ride) with another graph (the map)



… comparisons also match two graphs

- Which parts of my ride gained time verus last time? Which lost time?



Actual data is an XML document containing a list of “track points”

```
<?xml version="1.0" encoding="UTF-8" standalone="no" ?>
<TrainingCenterDatabase xmlns="http://www.garmin.com/xmlschemas/TrainingCenterDatabase/v2" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.garmin.com/xmlschemas/TrainingCenterDatabase/v2 http://www.garmin.com/xmlschemas/TrainingCenterDatabasev2.xsd">

 <Activities>
  <Activity Sport="Biking">
   <Id>2009-08-22T13:17:02Z</Id>
   <Lap StartTime="2009-08-22T13:17:02Z">
    <TotalTimeSeconds>4625.0800000</TotalTimeSeconds>
    <DistanceMeters>30319.2753906</DistanceMeters>
    <MaximumSpeed>17.7600002</MaximumSpeed>
    <Calories>1451</Calories>
    <Intensity>Active</Intensity>
    <Cadence>0</Cadence>
    <TriggerMethod>Manual</TriggerMethod>
    <Track>
     <Trackpoint>                                          (Time=2009-08-22T13:17:03Z,Latitude=42.5619387, Longitude=- 76.6450787,Altitude=229.4117432)
      <Time>2009-08-22T13:17:03Z</Time>
      <Position>
       <LatitudeDegrees>42.5619387</LatitudeDegrees>
       <LongitudeDegrees>-76.6450787</LongitudeDegrees>
      </Position>
      <AltitudeMeters>229.4117432</AltitudeMeters>
      <DistanceMeters>9.2514458</DistanceMeters>
      <SensorState>Absent</SensorState>
     </Trackpoint>
     <Trackpoint>
      <Time>2009-08-22T13:17:06Z</Time>
      <Position>
       <LatitudeDegrees>42.5618390</LatitudeDegrees>
       <LongitudeDegrees>-76.6449268</LongitudeDegrees>    (Time=2009-08-22T13:17:06Z,Latitude=42.5618390, Longitude=-76.6449268,Altitude=227.4891357)
      </Position>
      <AltitudeMeters>227.4891357</AltitudeMeters>
      <DistanceMeters>26.0653191</DistanceMeters>
      <SensorState>Absent</SensorState>
     </Trackpoint>
      .....
  </Track>
  …
```

But the data didn’t “start” as a graph

- Applications like this often need to get their data from some other format
- For example, the Garmin bike device actually creates a file in which it records the GPS data
- The analysis program runs separately on my PC

Each ride is in a separate file

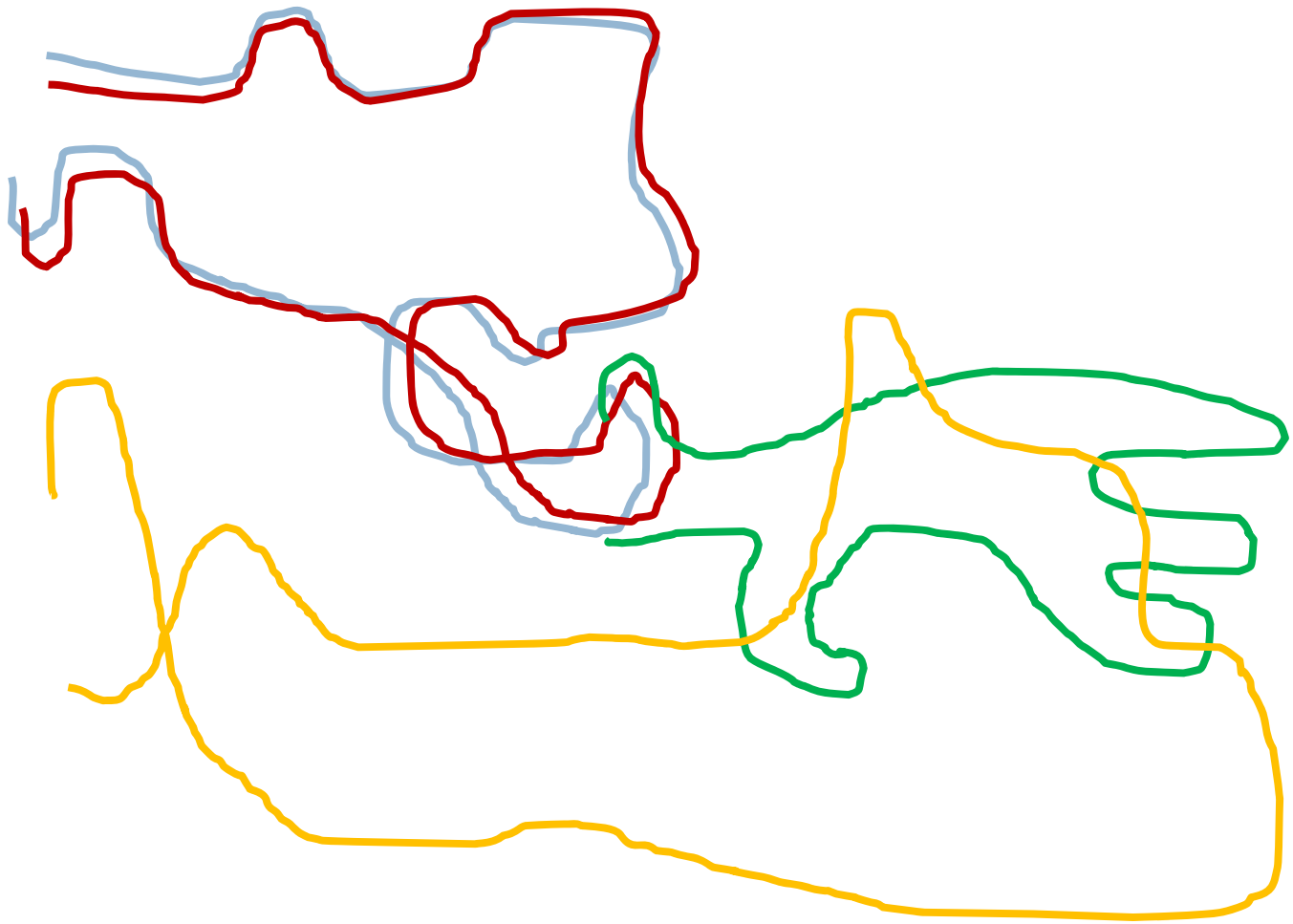
- Sort of like a set of documents
- I want to find the ones that “describe” the same route – the same list of roads in the same order, turns at the same place, etc
- But the GPS unit won’t have collected snapshots at identical spots

So suppose we want to compare two “rides”

- We’ve been thinking of each ride as a graph
- If we also consider the GPS data the ride is a curve in 3-D “space” (nodes are GPS data, edges link successive points)
- If two rides were on the same route, then these curves should match closely, provided we *ignore the timestamp*

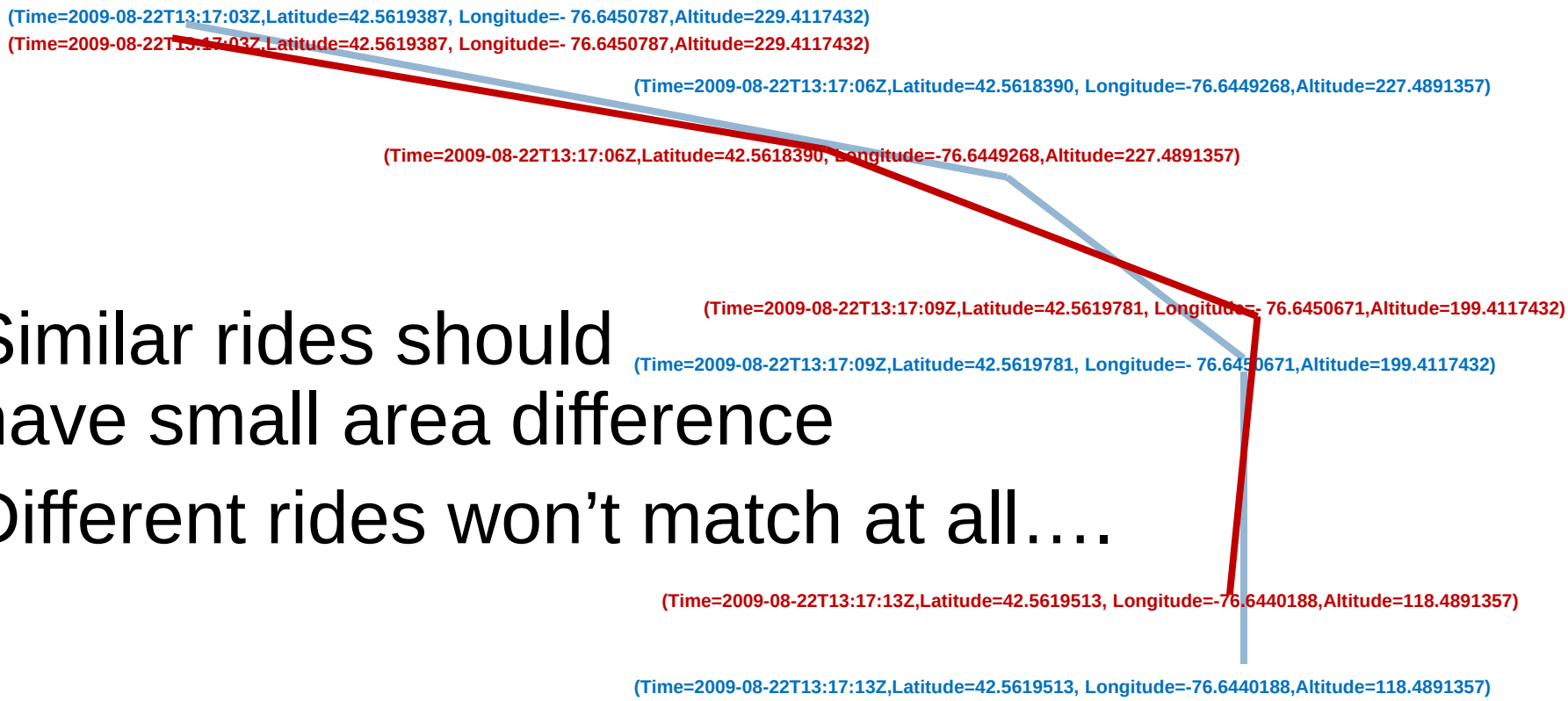
  - After all, my rides weren’t at identical speeds, which is my reason for wanting to compare them

Which rides were similar?



Which rides were similar?

- Could match the curves “edge by edge” and compute area between them….



- Similar rides should have small area difference
- Different rides won’t match at all….

What makes it tricky?

- Lance and Pantani didn’t follow the identical route (they were on the same road, but obviously didn’t exactly follow each other)
- They may have been separated in time here and there, even if at the end of the day they were side by side on the climb
- Sometimes Lance was faster, sometimes Pantani was faster

The idea of abstraction

- Our goal is to learn to think very abstractly
  - A “ride” that followed some “route”
  - The ride may differ (faster, slower, paused to wait for a car to pass) and yet the “route” is essentially the same
  - Yet even the route won’t be identical (depends on how you define identical…)

Software Engineering

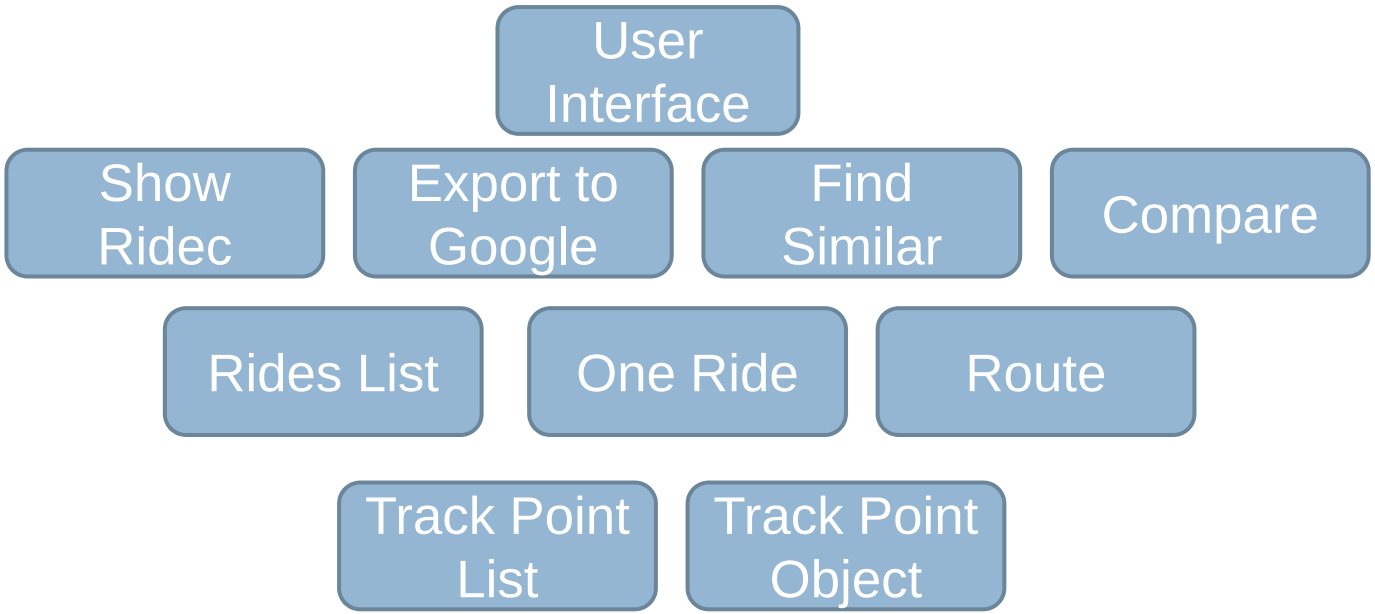
- The art by which we start with a problem statement and gradually evolve a solution
- There are whole books on this topic and most companies try to use a fairly uniform approach that all employees are expected to follow
- The IDE can help by standardizing the steps

The software design cycle

- Some ways of turning a problem statement into a program that we can debug and run
  - Top-Down, Bottom-Up Design
  - Software Process (briefly)
  - Modularity
  - Information Hiding, Encapsulation
  - Principles of Least Astonishment and “DRY”
  - Refactoring

Top-Down Design

- Garmin GPS software



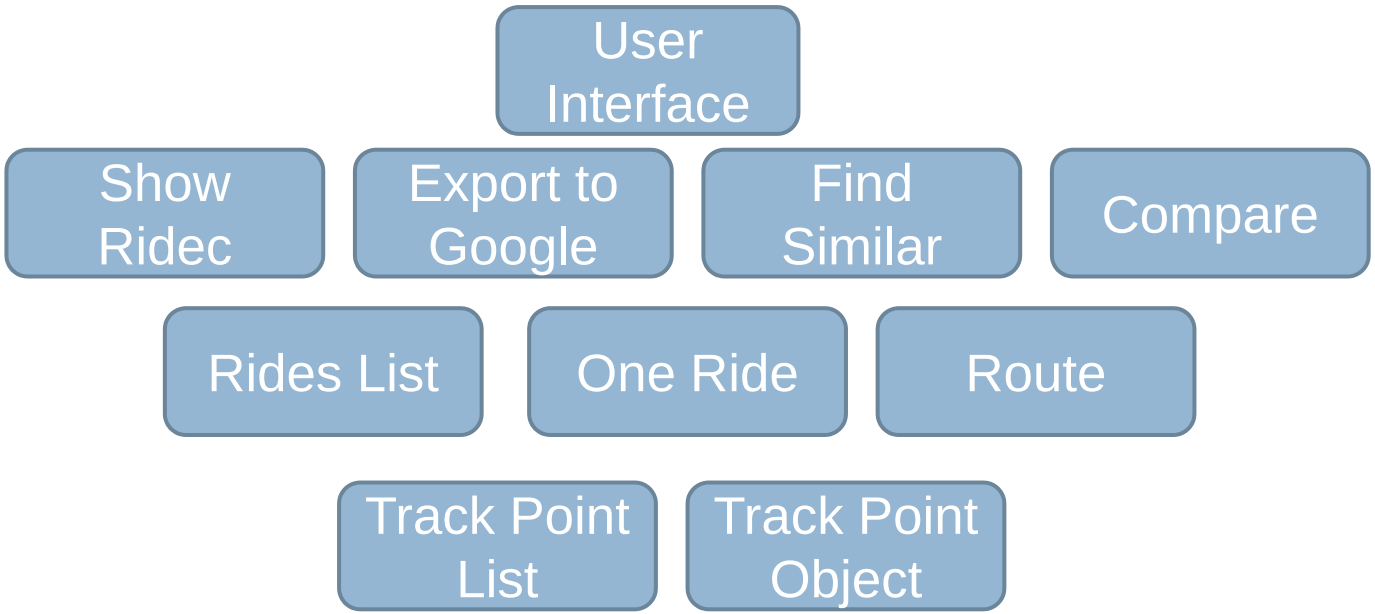
- Refine the design at each step
- Decomposition / “Divide and Conquer”

Not a perfect, pretty picture

- Boxes at lower levels are “more concrete” and contain things like GPS records, actual strings
- Boxes at higher levels are more abstract and closer to dealing with the user
- In between are “worker bees” that do things like file storage and waking up Google Earth
- But don’t take the hierarchy too seriously
  - Most things don’t fit perfectly into trees

Bottom-Up Design

- Just the opposite: start with parts



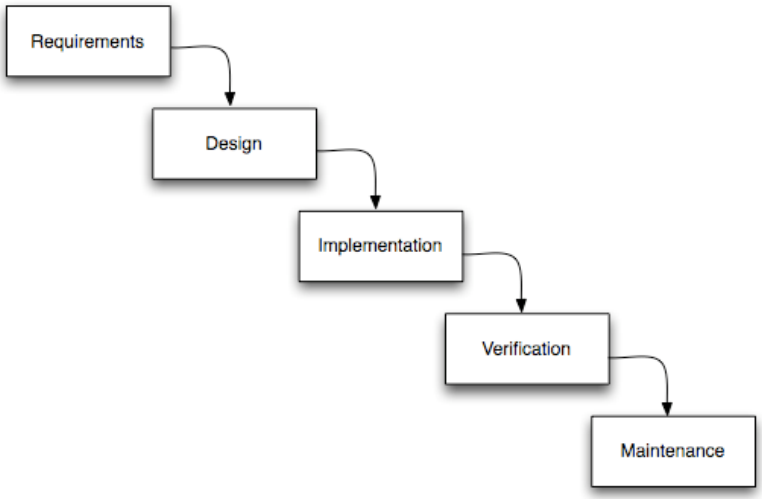
- Composition
- Build-It-Yourself (e.g. IKEA furniture)

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…

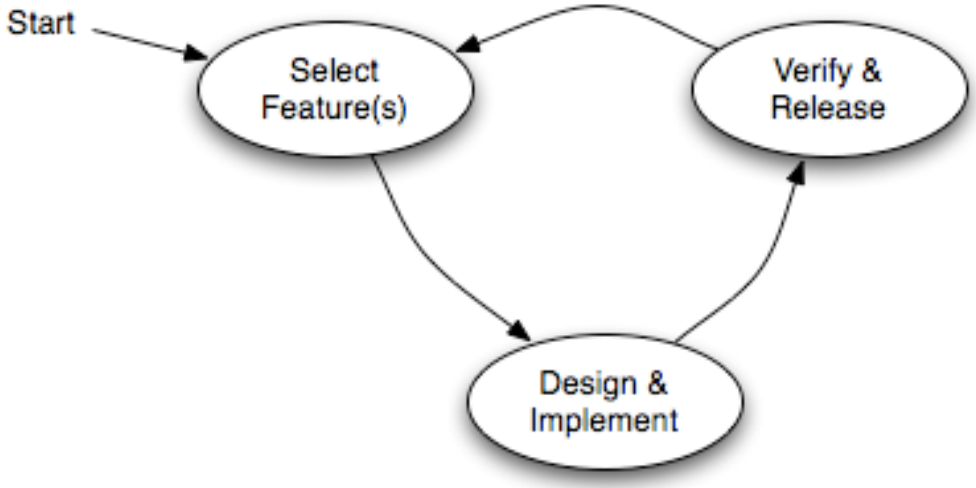


"Waterfall"

- 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

Modularity

- Module: component of a system with a well-defined interface. Examples:
  - Tires in a car (standard size, many vendors)
  - Cable adaptor for TV (standard input/output)
  - External storage for computer
  - ...
- Often includes more than one class
- Modules “hide information” behind their interfaces

A module isn't just an object

- *We're using the term to capture what could be one object, but will often be a larger component constructed using many objects*

- In fact Java has a module subsystem for this reason (we won't use it in cs2110)
  - A module implements some "abstraction"
  - You think of the whole module as a kind of big object

Information Hiding

- What "information" do modules hide?
  "Internal" design decisions.

```
class Set {
      ...

   public void add(Object o) ...

      public boolean contains(Object o) ...

      public int size() ...
}
```

- A class's interface is everything in it that is externally accessible

Encapsulation

- By hiding code and data behind its interface, a class encapsulates its "inner workings"
- Why is that good?
  - Lets us change the implementation later without invalidating the code that uses the class

```
class LineSegment {
  private Point2D _p1, _p2;

  ...
  public double length() {
    return _p1.distance(_p2);
  }
}
```

```
class LineSegment {
  private Point2D _p;
  private double _length;
  private double _phi;

  ...
  public double length() {
    return _length;
  }
}
```

Encapsulation

- Why is that good? (continued)
  - Sometimes, we want a few different classes to implement some shared functionality
  - For example, recall the “iterator” construct we saw in connection with collections:

```
Iterator it = collection.iterator();

while (it.hasNext()) {
   Object next = it.next();
   doSomething(next);
}
```

```
for (String s: args) {
   System.out.println("Argument "+s);
}
```

- To support iteration, a class simply needs to implement the Iterable interface

Degenerate Interfaces

- Public fields are usually a Bad Thing:

```
class Set {
      public int _count = 0;

   public void add(Object o) ...

      public boolean contains(Object o) ...

      public int size() ...
}
```

- Anybody can change them; the class has no control

Interfaces vs. Implementations

- This says “I need this specific implementation”:

```
public void doSomething(LinkedList items) …
```

- This says “I can operate on anything that supports the Iterable interface”

```
public void doSomething(Iterable items) …
```

- Interfaces represent higher levels of abstraction (they focus on “what” and leave out the “how”)

Use of interfaces?

- When a team builds a solution, interfaces can be very valuable!
  - Rebecca agrees to implement the code to extract GPS data from files
  - Tom will implement the logic to compare bike routes
  - Willy is responsible for the GUI
- By agreeing on the interfaces between their respective modules, they can all work on the program simultaneously

Principle of Least Astonishment

- A interface should “hint” at its behavior

Bad:

```
public int product(int a, int b) {
    return a*b > 0 ? a*b : -a*b;
}
```

Better:

```
public int absProduct(int a, int b) {
    return a*b > 0 ? a*b : -a*b;
}
```

- Names and comments matter!

Principle of Least Astonishment

- Unexpected side effects are a Bad Thing

```
class Integer {
   private int _value;
   ...
   public Integer times(int factor) {
      _value *= factor;
      return new Integer(_value);
   }
}
...
Integer i = new Integer(1
Integer j = i.times(10);
```

Developer was trying to be clever. But what does this code do to i?

Duplication

- 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, when the code you copied needs to be revised, either
  - The person doing that changes 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 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)

Refactoring

- Refactor: to improve code's internal structure without changing its external behavior
- Most of the time we're modifying existing software
- "Improving the design after it has been written"
- Refactoring steps can be very simple:

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

```
static final double GRAVITY = 9.80665;

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

- Other examples: renaming variables, methods, classes

Why is refactoring good?

- 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

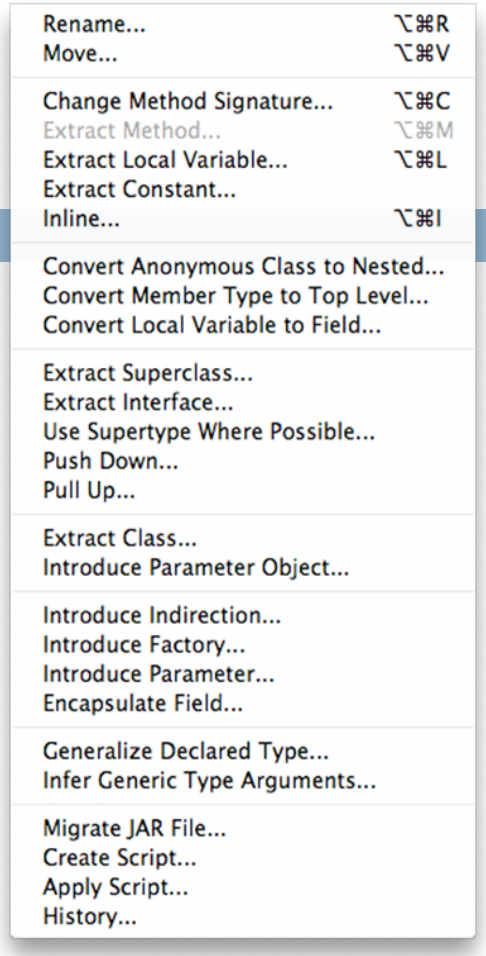
```
if (date.before(SUMMER_START) || date.after(SUMMER_END)) {
   charge = quantity * _winterRate + _winterServiceCharge;
}
else {
   charge = quantity * _summerRate;
}
```

after

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

Refactoring & Tests

- Eclipse supports various refactorings
- You can refactor manually
  - Automated tests are essential to ensure external behavior doesn't change
  - Don't refactor manually without retesting to make sure you didn't break the code you were "improving"!
- More about tests and how to drive development with tests next week



Summary

- We've seen that Java offers ways to build general classes and then to created specialized versions of them
  - In fact we saw several ways to do this
- Our challenge is to use this power to build clean, elegant software that doesn't duplicate functionality in confusing ways
- The developer's job is to find abstractions and use their insight to design better code!