Announcements

The slides for this lecture are particularly unhelpful without consulting either the textbook or the web videos. If you feel like you're missing something, you are. See those resources instead.

CS61B, 2021

Lecture 3: Testing

- A Simple JUnit test
- Testing Philosophy
- Selection Sort
- Simpler JUnit Tests

How Does a Programmer Know That Their Code Works?

In prior programming classes, you most likely knew your code worked because it passed some autograder tests.

In the real world, programmers believe their code works because of **tests they write themselves**.

- Knowing that it works for sure is usually impossible.
- This will be our new way.

How Does a Progra

In prior programming
passed some autograd

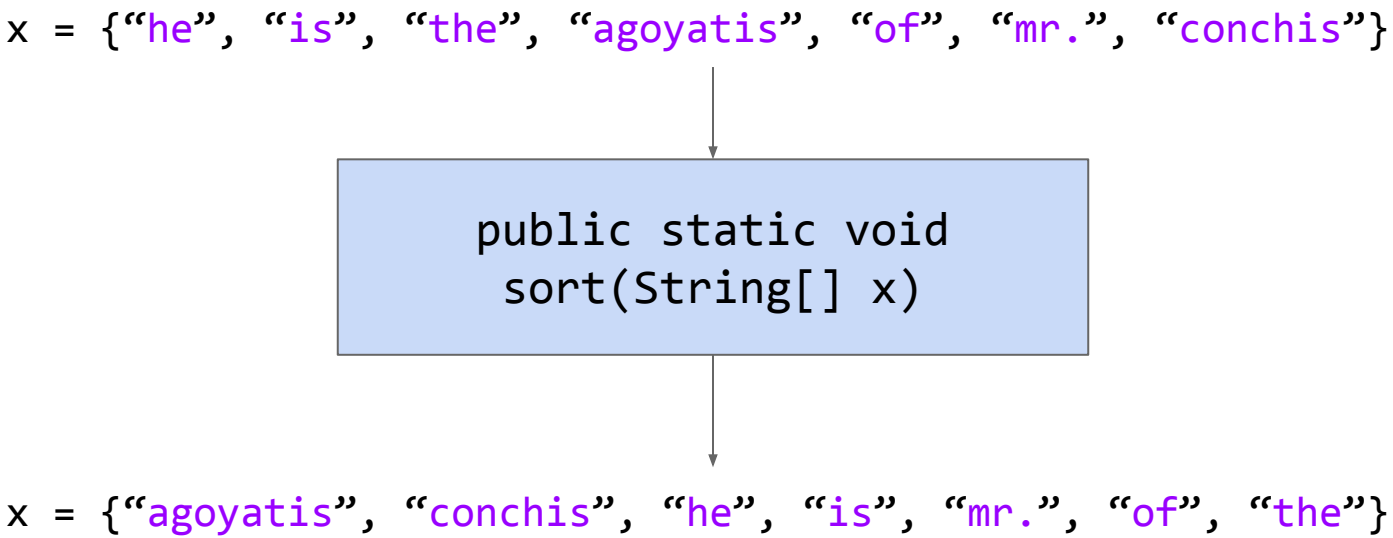
In the real world, prog
write themselves.

- Knowing that it w
- This will be our ne

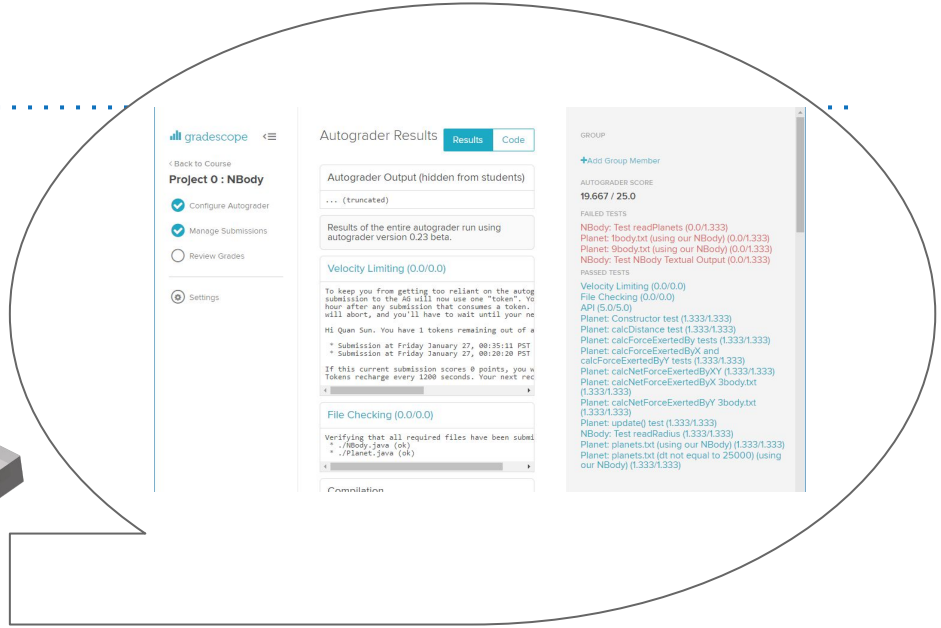
Sorting: The McGuffin for Our Testing Adventure

To try out this new way™, we need a task to complete.

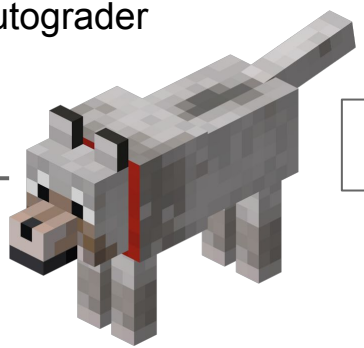
- Let's try to write a method that sorts arrays of Strings.



The Old Way



Autograder

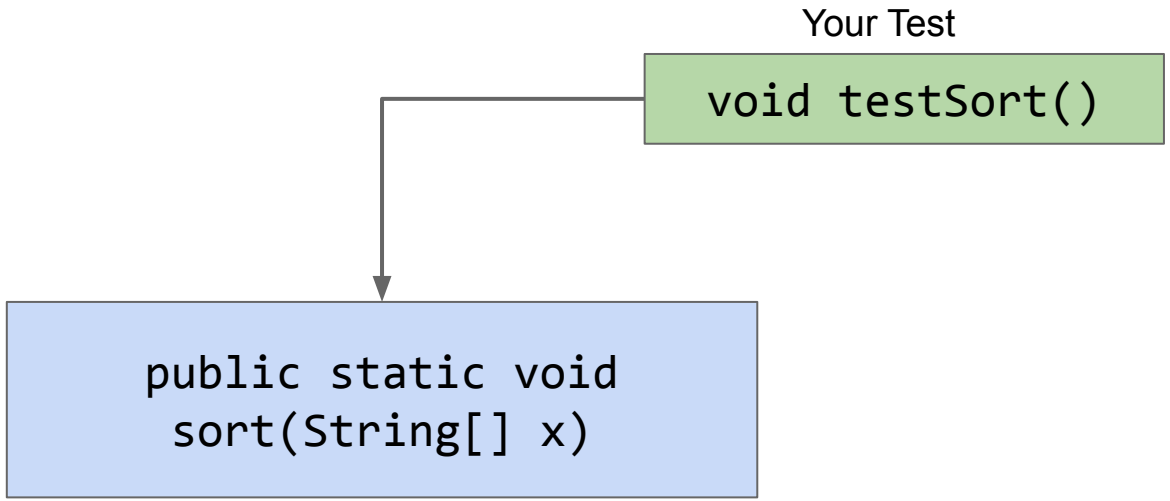


```
public static void
sort(String[] x)
```

The New Way

In this lecture we'll write `sort`, as well as our own test for `sort`.

- Even crazier idea: We'll start by writing `testSort` first!



Ad Hoc Testing vs. JUnit

Ad-Hoc Testing is Tedious

```
public class TestSort {
    /** Tests the sort method of the Sort class. */
    public static void testSort() {
        String[] input = {"beware" , "of", "falling", "rocks"};
        String[] expected = {"beware" , "falling", "of", "rocks"};
        Sort.sort(input);

        for (int i = 0; i < input.length; i += 1) {
            if (!input[i].equals(expected[i])) {
                System.out.println("Mismatch at position " + i + ", expected: '" + expected[i] +
                                   "', but got '" + input[i] + "'");
                return;
            }
        }
    }

    public static void main(String[] args) {
        testSort();
    }
}
```

JUnit saves us the trouble of writing code like this (and more!).

JUnit: A Library for Making Testing Easier (example below)

```
public class TestSort {
  /** Tests the sort method of the Sort class. */
  public static testSort() {
    String[] input = {"cows", "dwell", "above", "clouds"};
    String[] expected = {"above", "clouds", "cows", "dwell"};
    Sort.sort(input);

    org.junit.Assert.assertArrayEquals(expected, input);
  }

  public static void main(String[] args) {
    testSort();
  }
}
```

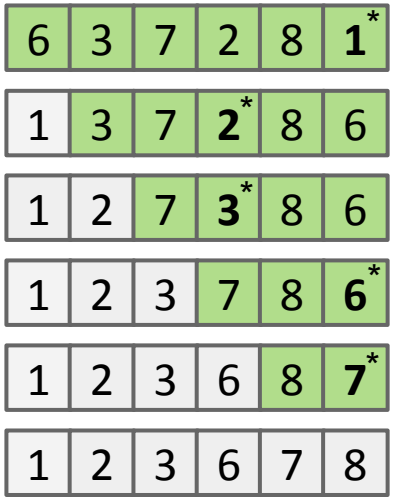
Note: An earlier version of this slide had clouds and cows backwards.

Selection Sort: Find Smallest

Back to Sorting: Selection Sort

Selection sorting a list of N items:

- Find the smallest item.
- Move it to the front.
- Selection sort the remaining N-1 items (without touching front item!).



As an aside: Can prove correctness of this sort using invariants -- see lecture 4.

Back to Sorting: Selection Sort

Selection sorting a list of N items:

- Find the smallest item.
- Move it to the front.
- Selection sort the remaining N-1 items (without touching front item!).

Let's try implementing this.

- I'll try to simulate as closely as possible how I think students might approach this problem to show how "test driven development" (TDD) helps.

Not shown in details in these slides. See lecture video.

Simpler JUnit Tests

(using two new syntax tricks)

Simple JUnit

New Syntax #1: `org.junit.Assert.assertEquals(expected, actual);`

- Tests that `expected` equals `actual`.
- If not, program terminates with verbose message.

We've already seen this throughout today.

JUnit does much more:

- Other methods like `assertEquals` include `assertFalse`, `assertNotNull`, etc., see https://junit.org/junit5/docs/5.0.1/api/org/junit/jupiter/api/Assertions.html
- Other more complex behavior to support more sophisticated testing.
- See lab2.

Better JUnit

The messages output by JUnit are kind of ugly, and invoking each test manually is annoying.

Yes this is weird, as it implies you'd be instantiating TestSort.java. In fact, JUnit runners do this. I don't know why.

New Syntax #2 (just trust me):

- **Annotate** each test with `@org.junit.Test`.
- Change all test methods to non-static.
- Use a JUnit runner to run all tests and tabulate results.
  - IntelliJ provides a default runner/renderer. OK to delete `main`.
  - There are ways to run JUnit tests from command line. Not taught in our class.
  - Rendered output is easier to read, no need to manually invoke tests!

There is a lot of black magic happening here! Just accept it all for now.

Even Better JUnit

It is annoying to type out the name of the library repeatedly, e.g. **org.junit.**Test and **org.junit.Assert.**assertEquals.

New Syntax #3: To avoid this we'll start every test file with:

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

This will magically eliminate the need to type '`org.junit`' or '`org.junit.Assert`' (more after the midterm on what these imports really mean).

Selection Sort: Continued

Progress Roadmap

Created testSort: `testSort()`

Created a sort skeleton: `sort(String[] inputs)`

Created testFindSmallest: `testFindSmallest()`

Created findSmallest: `String findSmallest(String[] input)`

Used Google to figure out how to compare strings.

After verifying findSmallest worked, we simplified our code by importing `org.junit.Test` and `org.junit.Assert.*`.

- Next, we'll write `testSwap` and `swap` methods.

Created testSwap: `testSwap()`

Created swap: `swap(String[] input, int a, int b)`

Progress Roadmap

Created testSort:

```
testSort()
```

Created a sort skeleton:

```
sort(String[] inputs)
```

Created testFindSmallest:

```
testFindSmallest()
```

Used Google to figure out how to compare strings.

Created findSmallest:

```
String findSmallest(String[] input)
```

Created testSwap:

```
testSwap()
```

Used debugger to fix.

Created swap:

```
swap(String[] input, int a, int b)
```

Now that we've got

Progress Roadmap

Created testSort:

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testSort()
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Created a sort skeleton:

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Used Google to figure out how to compare strings.

Created findSmallest:

```
String findSmallest(String[] input)
```

Created testSwap:

```
testSwap()
```

Used debugger to fix.

Created swap:

```
swap(String[] input, int a, int b)
```

Changed findSmallest:

```
int findSmallest(String[] input)
```

Now we have all the helper methods we need, as well as tests that make us pretty sure that they work! All that's left is to write the `sort` method itself.

Very Tricky Problem

method signature

Without changing the signature of `public static void sort(String[] a)`, how can we use recursion? What might the recursive call look like?

```
public static void sort(String[] x) {
  int smallest = findSmallest(x);
  swap(inputs, 0, smallest);
  // recursive call??
}
```

Very Tricky Problem: Bad But Tempting Solution

method signature

Without changing the signature of `public static void sort(String[] a)`, how can we use recursion? What might the recursive call look like?

```
public static void sort(String[] x) {
  int smallest = findSmallest(x);
  swap(inputs, 0, smallest);
  sort(x[1:]); ← Would be nice, but not possible!
}
```

Some languages support sub-indexing into arrays. Java does not.

- Bottom line: No way to get address of the middle of an array.

Very Tricky Problem: Good Solution

method signature

Without changing the signature of `public static void sort(String[] a)`, how can we use recursion? What might the recursive call look like?

```
public static void sort(String[] x) {
  sort(x, 0);
}
```

```
/** Destructively sorts x starting at index k */
public static void sort(String[] x, int k) {
  ...
  sort(x, k + 1);
}
```

Major Design Flaw in findSmallest

We didn't properly account for how `findSmallest` would be used.

- Example: Want to find smallest item from among the last 4:

- We need another parameter so that it's actually useful for sorting.

The Evolution of our Design

Created testSort:

```
testSort()
```

Created a sort skeleton:

```
sort(String[] inputs)
```

Created testFindSmallest:

```
testFindSmallest()
```

Used Google to figure out how to compare strings.

Created findSmallest:

```
String findSmallest(String[] input)
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Created testSwap:

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Used debugger to fix.

Created swap:

```
swap(String[] input, int a, int b)
```

Changed findSmallest:

```
int findSmallest(String[] input)
```

Added helper method:

```
sort(String[] inputs, int k)
```

Used debugger to realize fundamental design flaw in `findSmallest`

The Evolution of our Design

Created testSort:

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Used Google to figure out how to compare strings.

Created findSmallest:

```
String findSmallest(String[] input)
```

Created testSwap:

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testSwap()
```

Used debugger to fix.

Created swap:

```
swap(String[] input, int a, int b)
```

Changed findSmallest:

```
int findSmallest(String[] input)
```

Added helper method:

```
sort(String[] inputs, int k)
```

Used debugger to realize fundamental design flaw in `findSmallest`

Modified findSmallest:

```
int findSmallest(String[] input, int k)
```

And We're Done!

Often, development is an incremental process that involves lots of task switching and on the fly design modification.

Tests provide stability and scaffolding.

- Provide confidence in basic units and mitigate possibility of breaking them.
- Help you focus on one task at a time.

In larger projects, tests also allow you to safely **refactor**! Sometimes code gets ugly, necessitating redesign and rewrites (see project 2).

One remaining problem: Sure was annoying to have to constantly edit which tests were running. Let's take care of that.

Testing Philosophy

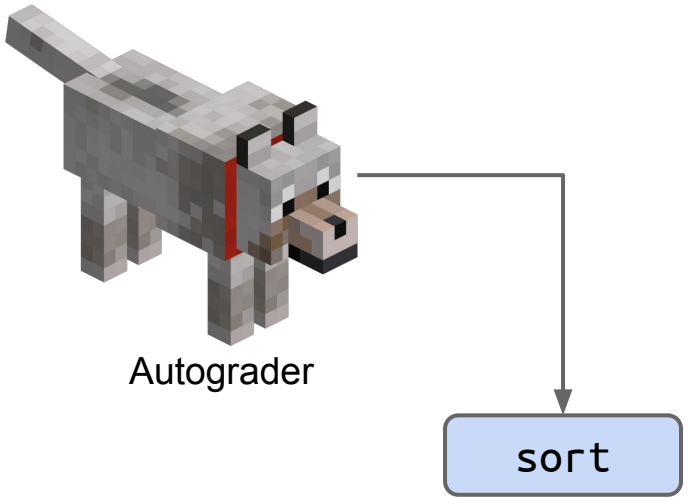
Correctness Tool #1: Autograder

Idea: Magic autograder tells you code works.

- We use JUnit + jh61b libraries.

Why?

- Less time wasted on “boring” stuff.
- Determines your grade.
- Gamifies correctness.



Why not?

- Autograders don’t exist in real world.
- Errors may be hard to understand.
- Slow workflow.
- No control if grader breaks / misbehaves.

Autograder Driven Development (ADD)

The worst way to approach programming:

- Read and (mostly) understand the spec.
- Write entire program.
- Compile. Fix all compilation errors.
- Send to autograder. Get many errors.
- Until correct, repeat randomly:
  - Run autograder.
  - Add print statements to zero in on the bug.
  - Make changes to code to try to fix bug.

```
[63, 12, 91, 5, 0]
got to this spot, lt is: 1
got to this spot, lt is: 2
got here!
[63, 12, 0, 5, 91]
got to this spot, lt is: 3
got to this spot, lt is: 4
got here!
[5, 12, 0, 63, 91]
Test Failed. Expected: ...
```

This workflow is slow and unsafe!

Note: Print statements are not inherently evil. While they are a weak tool, they are very easy to use.

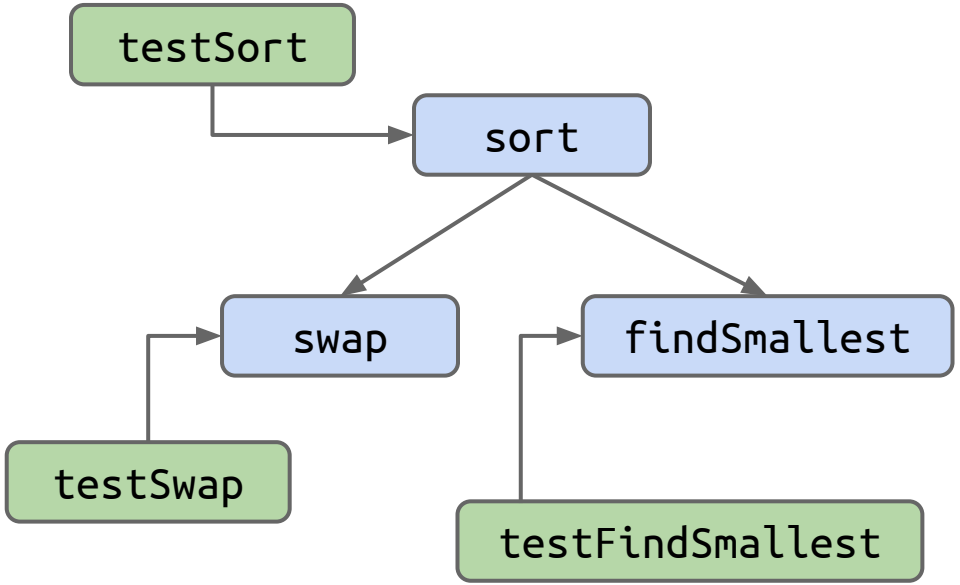
Correctness Tool #2: Unit Tests

Idea: Write tests for every “unit”.

- JUnit makes this easy!

Why?

- Build confidence in basic modules.
- Decrease debugging time.
- Clarify the task.



Why not?

- Building tests takes time.
- May provide false confidence.
- Hard to test units that rely on others.
  - e.g. how do you test `addFirst`?

Test-Driven Development (TDD)

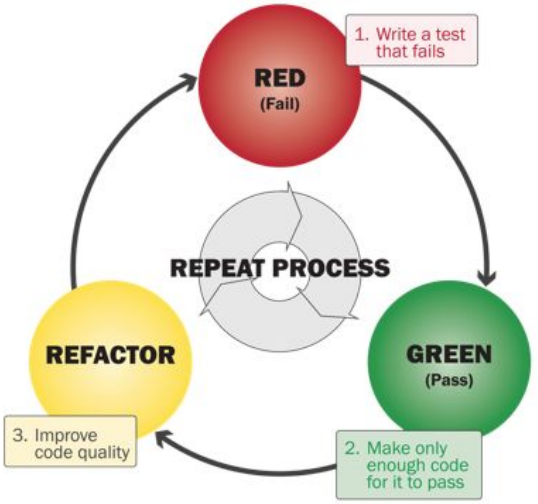
Steps to developing according to TDD:

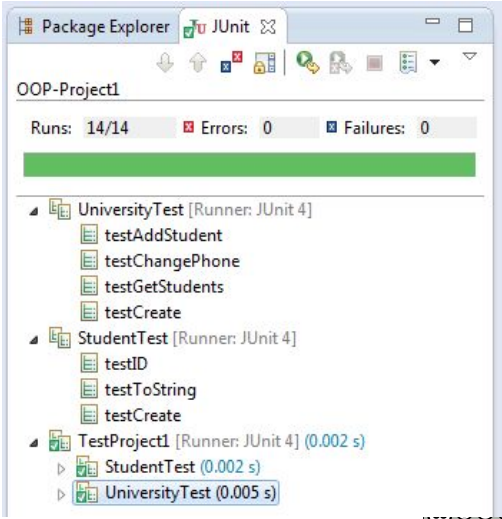
- Identify a new feature.
- Write a unit test for that feature.
- Run the test. It should fail. (RED)
- Write code that passes test. (GREEN)
  - Implementation is certifiably good!
- Optional: Refactor code to make it faster, cleaner, etc.

Not required in 61B. You might hate this!

- But testing is a good idea.

Interesting perspective: Red-Shirt, Red, Green, Refactor.



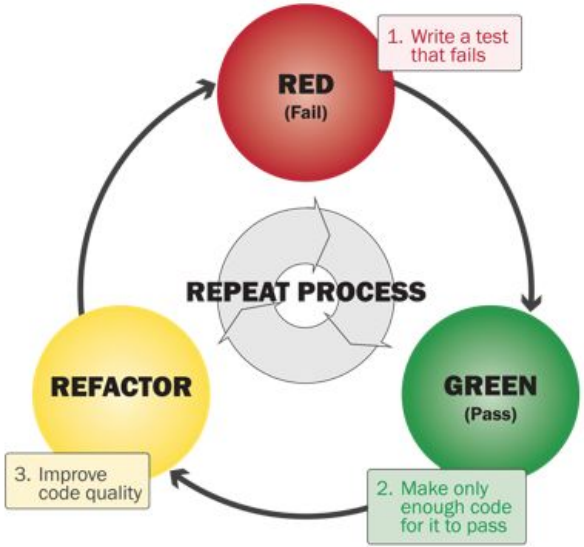


A Tale of Two Workflows

TDD is an extreme departure from the naive workflow.

- What's best for you is probably in the middle.

```
$ python sort.py
[63, 12, 91, 5, 0]
got to this spot, lt is: 1
got to this spot, lt is: 2
got here!
[63, 12, 0, 5, 91]
got to this spot, lt is: 3
got to this spot, lt is: 4
got here!
[5, 12, 0, 63, 91]
```



Correctness Tool #3: Integration Testing

Idea: Tests cover many units at once.

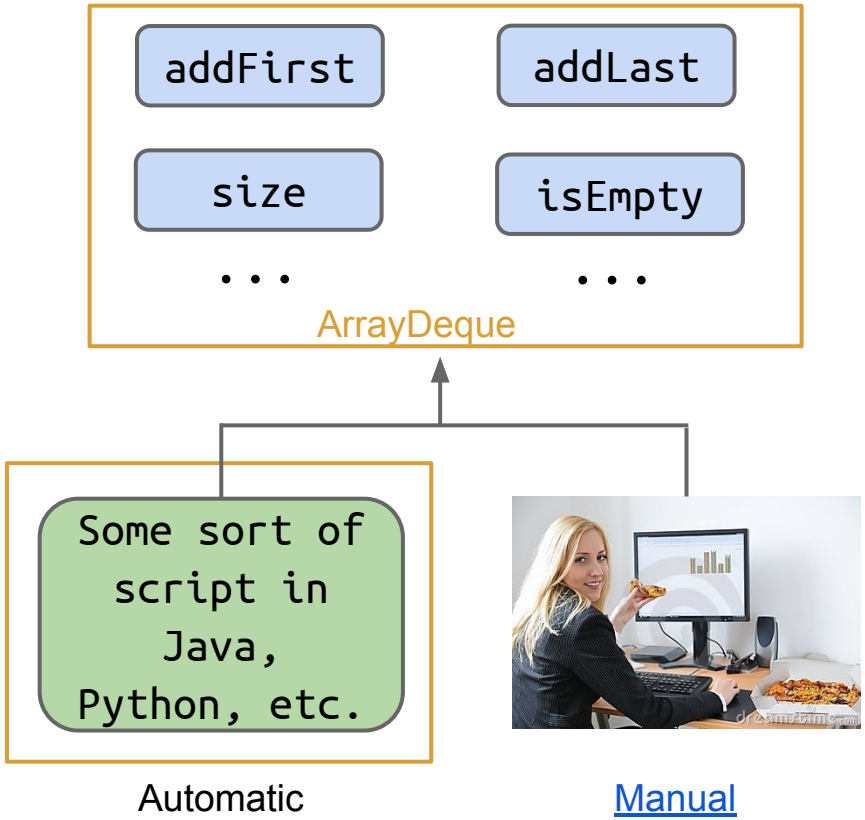
- Not JUnit's focus, but JUnit can do this.

Why?

- Unit testing is not enough to ensure modules interact properly or that system works as expected.

Why not?

- Can be tedious to do manually.
- Can be challenging to automate.
- Testing at highest level of abstraction may miss subtle or rare errors.



Parting Thoughts

- JUnit makes testing easy.
- You should write tests.
  - But not too many.
  - Only when they might be useful!
  - Write tests first when it feels appropriate [I do this a lot].
  - Lab 3, Project 1B, and Project 2 will give you practice!
  - Most of the class won't require writing lots of tests (to save you time).

- Some people really like TDD. Feel free to use it in 61B.
  - See today's optional reading for thoughts from the creator of Ruby on Rails and others.

More On JUnit (Extra)

Bonus Slide: What is an Annotation?

Annotations (like org.junit.Test) don't do anything on their own.

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

Runner uses reflections library to iterate through all methods with "Test" annotation. Pseudocode on next slide.

Sample Runner Pseudocode

Runner uses reflections library to iterate through all methods with “Test” annotation.

```
List<Method> L = getMethodsWithAnnotation(TestSort.class,
                                          org.junit.Test);
int numTests = L.size();
int numPassed = 0;
for (Method m : L) {
    result r = m.execute();
    if (r.passed == true) { numPassed += 1; }
    if (r.passed == false) { System.out.println(r.message); }
}
System.out.println(numPassed + “/” + numTests + “ passed!”);
```

Citations

Training montage: Wet Hot American Summer

Creepy hand picture (title slide):
http://www.automatedtestinginstitute.com/home/images/stories/Functional.jpg

Red-Green-Refactor image courtesy of a guy who has had issues with TDD:
http://ryantablada.com/post/red-green-refactor---a-tdd-fairytale

How It Usually Goes...