

## Announcements

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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.

# Pre-Announcement

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Project Manager at Autonomous Underwater Vehicles at Berkeley here to say  
“Join us for sea robots.”

- Interest in AI, Machine Learning, etc.
- Email [auvs.at.berkeley@gmail.com](mailto:auvs.at.berkeley@gmail.com)
-

# Quick Note on Autograders / Debugging

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Autograder is not intended to be your debugging tool.

- It is a bad habit to rely on teacher provided tools for correctness.

Example: Your `LinkedListDeque` is failing in the autograder, but works fine when you run the provided `LinkedListDequeTest.java` file.

- Approach #0: Assume the autograder is broken (unlikely but possible).
- Approach #1: Visually inspect your code for errors. Sometimes works.
- Approach #2: Ask for help in office hours / Piazza. OK, but slow!
- Approach #3: Look inside `LinkedListDequeTest.java` to see how it works. Add your own tests that fail. Set breakpoints and use the visual debugger to figure out what's going wrong.
  - We'll be discussing this sort of approach today.



# CS61B: 2018

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## Lecture 7: Testing

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



# How Does a Programmer Know That Their Code Works?

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What evidence did you have for Project 0 in 61B?

- We gave you some tests.
- Running main and seeing if the planets move around in a proper planetary way.
- The real MVP: Autograder.

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 Program Know That This Is the Way?

What evidence did you see?

- We gave you some code.
- Running main and seeing the output in the console in the right way.
- The real MVP: Autocomplete!

In the real world, programs don't write themselves.

- Knowing that it works
- This will be our next challenge

That's Cool! What's Next?



# Sorting: The McGuffin for Our Testing Adventure

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

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

```
x = {"he", "is", "the", "agoyatis", "of", "mr.", "conchis"}
```



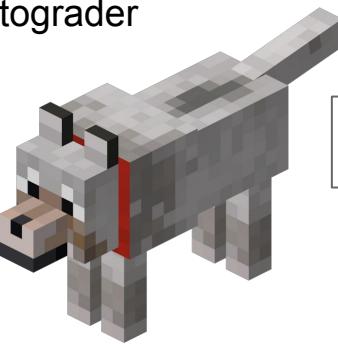
```
public static void  
sort(String[] x)
```



```
x = {"agoyatis", "conchis", "he", "is", "mr.", "of", "the"}
```

# The Old Way

Autograder



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

The screenshot shows the Autograder Results page for Project 0: NBody. The top navigation bar includes 'gradescope' and 'Project 0 : NBody'. Below the navigation are tabs for 'Results' (selected) and 'Code'. The main content area displays 'Autograder Output (hidden from students)' which is truncated. It also shows 'Results of the entire autograder run using autograder version 0.23 beta.' and 'Velocity Limiting (0.0/0.0)'. A message about tokens is present. The 'File Checking (0.0/0.0)' section shows 'Verifying that all required files have been submitted' with two entries: './NBody.java (ok)' and './Planet.java (ok)'. The bottom section is labeled 'Compilation'.

Autograder Results Results Code

Autograder Output (hidden from students)  
... (truncated)

Results of the entire autograder run using autograder version 0.23 beta.

Velocity Limiting (0.0/0.0)

To keep you from getting too reliant on the autograde submission to the AG will now use one "token". You will have 1 token remaining after any submission that consumes a token. Will be reset to 1 token every 1200 seconds. If you have 0 tokens, you will not be able to submit to the AG until you have tokens again.

Hi Open Sun: You have 1 tokens remaining out of a

- \* Submission at Friday January 27, 00:35:11 PST
- \* Submission at Friday January 27, 00:28:28 PST

If this current submission scores 0 points, you will lose 1 token.

Tokens recharge every 1200 seconds. Your next recharge will be at 00:35:11 PST.

File Checking (0.0/0.0)

Verifying that all required files have been submitted

- \* ./NBody.java (ok)
- \* ./Planet.java (ok)

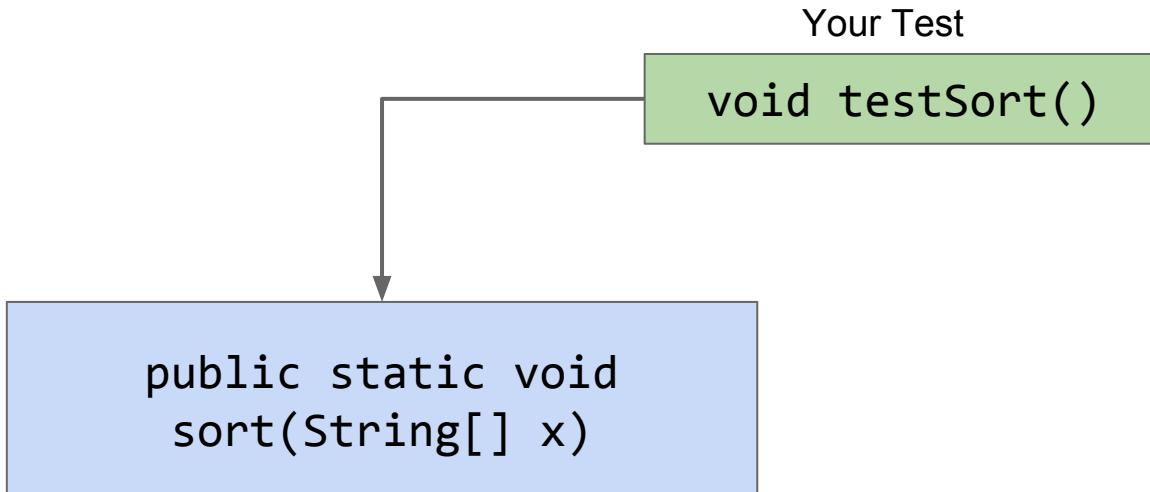
Compilation

# 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", "cows", "clouds", "dwell"};  
        Sort.sort(input);  
  
        org.junit.Assert.assertArrayEquals(expected, input);  
    }  
  
    public static void main(String[] args) {  
        testSort();  
    }  
}
```



# Selection Sort

# 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.

# 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 TDD helps.

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

6	3	7	2	8	1*
1	3	7	2*	8	6
1	2	7	3*	8	6
1	2	3	7	8	6*
1	2	3	6	8	7*
1	2	3	6	7	8

# The Evolution of Our Design

Created testSort:

`testSort()`

Created a sort skeleton:

`sort(String[] inputs)`

Created testFindSmallest:

`testFindSmallest()`

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.

Used Google to figure out how to compare strings.



# 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?

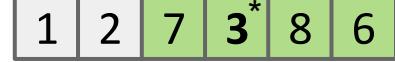
```
public static void sort(String[] x) {  
    sort(x, 0);  
}
```

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

# Major Design Flaw in findSmallest

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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()
```

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)
```

Added helper method:

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

Used debugger to realize fundamental design flaw in `findSmallest`

Used Google to figure out how to compare strings.



# The Evolution of our Design

Created testSort:

```
testSort()
```

Created a sort skeleton:

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

Created testFindSmallest:

```
testFindSmallest()
```

Created findSmallest:

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

```
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)
```

Used Google to figure out how to compare strings.



# 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.

# 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  
<http://junit.org/junit4/javadoc/4.12/org/junit/Assert.html>
- Other more complex behavior to support more sophisticated testing.
- See lab3.

# 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.
  - If you want to use the command line instead, see the jh61b runner in the lab 3 supplement. Not preferred.
  - 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

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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).

# **Testing Philosophy (Web Video Only)**



# Correctness Tool #1: Autograder

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Idea: Magic autograder tells you code works.

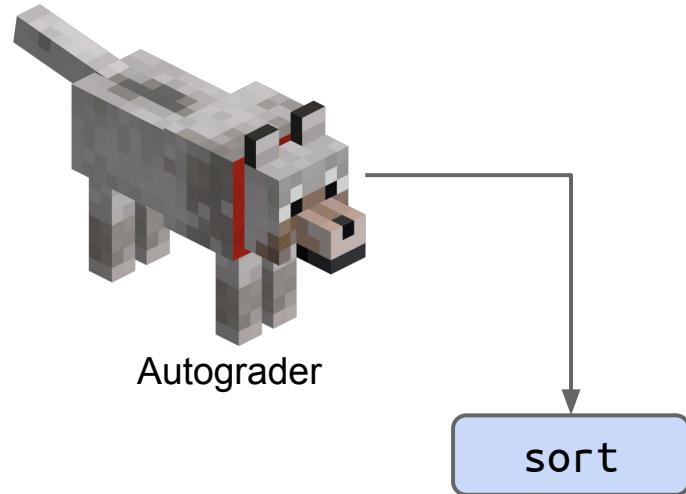
- We use JUnit + jh61b libraries.

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”.

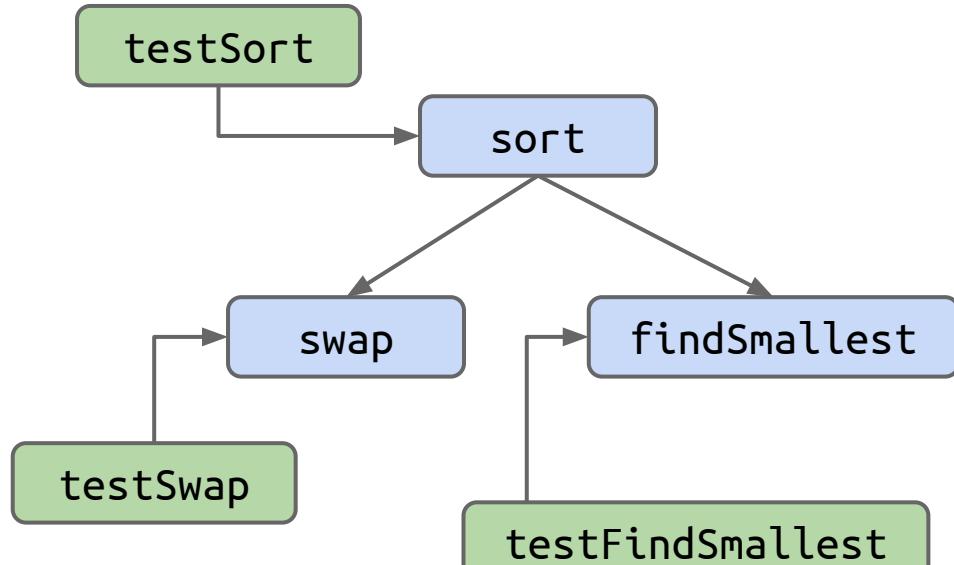
- JUnit makes this easy!

Why?

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

Why not?

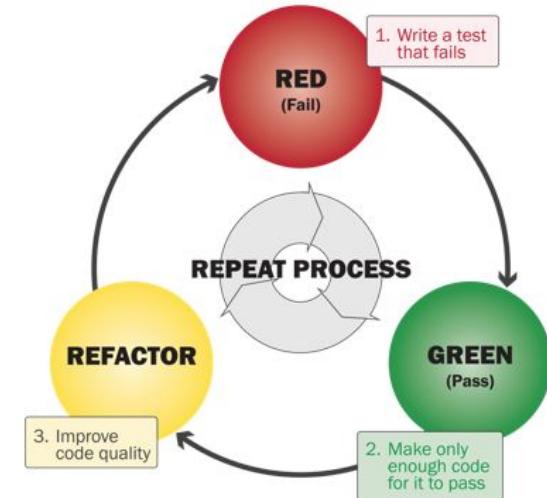
- Building tests takes time.
- May provide false confidence.
- Hard to test units that rely on others.
  - e.g. how do you test addFirst?



# Test-Driven Development (TDD)

Steps to developing according to TDD:

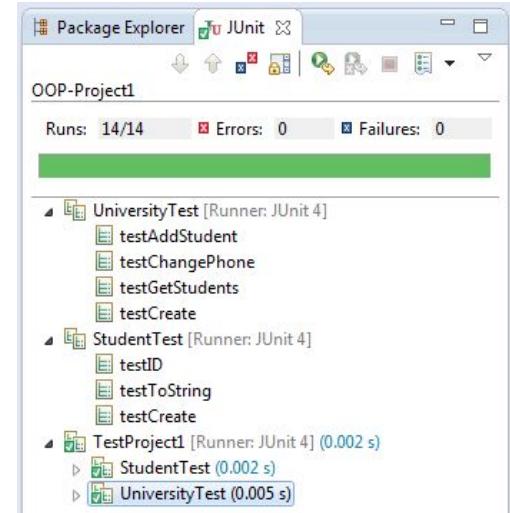
- Identify a new feature.
- Write a unit test for that feature.
- Run the test. It should fail. (**RED**)
- Write code that passes test. (**GREEN**)
  - Implementation is certifiably good!
- Optional: Refactor code to make it faster, cleaner, etc.



Not required in 61B. You might hate this!

- But testing is a good idea.

Interesting perspective: [Red-Shirt, Red, Green, Refactor.](#)

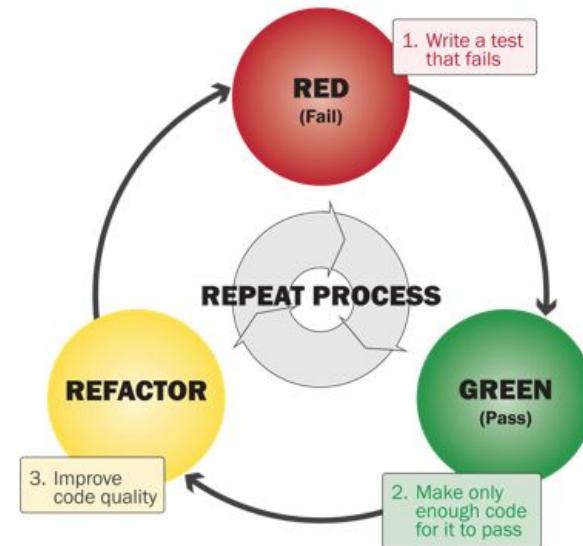


# A Tale of Two Workflows

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.

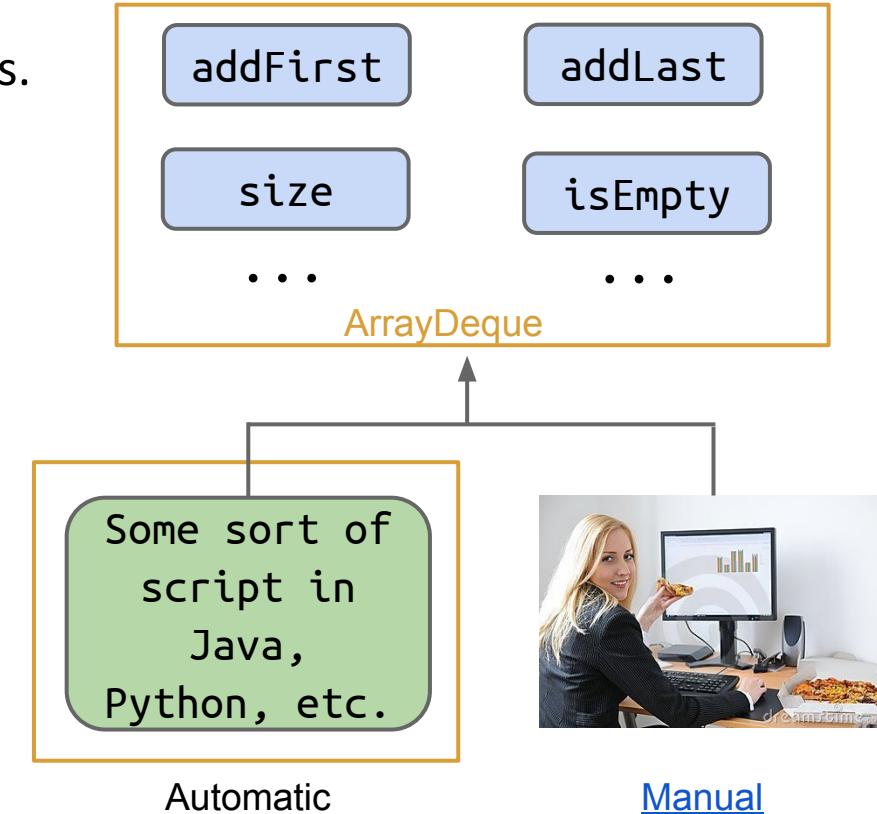
- Not JUnit's focus, but JUnit can do this.

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.



Automatic

[Manual](#)

# Parting Thoughts

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- 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?

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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

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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...

