Lab 02: Debugging

FAQ

Each assignment will have an FAQ linked at the top. You can also access it by adding “/faq” to the end of the URL. The FAQ for Lab 02 is located here.

Introduction

To debug a program, you must first know what’s wrong. In this lab, you’ll get some experience with using the debugger to see program state. When you run into a bug, the error is accompanied with a “stack trace” that details the method calls that caused the error in the first place. One of the focuses of this lab will be to get you used to reading these stack traces, because they can be **super** helpful in debugging your own code.

Setup

Follow the assignment workflow instructions to get the assignment and open it in IntelliJ.

Goals and Outcomes

In this lab, you will enhance your code debugging abilities by defusing a (programmatic) bomb and debugging a text adventure we have written. We’ll guide you through this process, but the intention is to make this a realistic debugging experience.

By the end of this lab, you will…

- Be able to use the debugger and visualizer to inspect program state.
- Be able to interpret test failure messages.
- Be able to interpret stack traces.
- Be better able to approach debugging code.
- Have learned about some common Java bugs and errors.

IntList Aside

Added to our implementation in Wednesday's lecture are two methods in the `IntList` class, `print` and `of`. The `of` method is a convenience method for creating `IntList`s. Here's a quick demonstration of how it works. Consider the following code that you've seen in lecture for creating an `IntList` containing the elements 1, 2, and 3.

```
IntList lst = new IntList(1, new IntList(2, new IntList(3, null)));
```

That's a lot of typing, and is quite confusing! The `IntList.of` method addresses this problem. To create an IntList containing the elements 1, 2, and 3, you can simply type:

```
IntList lst = IntList.of(1, 2, 3);
```

The other method `print` returns a `String` representation of an IntList.

```
IntList lst = IntList.of(1, 2, 3);
System.out.println(lst.print())

// Output: 1 -> 2 -> 3
```

These methods mostly provide convenient ways of creating and displaying `IntList`s, respectively. We use these convenience methods to make testing easier.

Bomb

The `BombMain` class calls the various `phase` methods of the `Bomb` class. Your job is to figure out what the passwords to each of these phrases is by *using the IntelliJ debugger*.

⚠ The code is written so that you can’t find the password just by reading it. For this lab, you are **forbidden** from editing the `Bomb` code, whether to add print statements or otherwise modify it.

The point of this exercise is to get comfortable using tools that will help you a lot down the road. Please take it seriously!

Interactive Debugging

So far, you might have practiced debugging by using using print statements to see the values of certain variables as a program runs. When placed strategically, the output from printing might help make the bugs obvious or narrow down their cause. This method is called **print debugging**. While print debugging can be very useful, it has a few disadvantages:

- It requires you to modify your code, and clean it up after.
- It’s tedious to decide and write out exactly what you want to print.
- Printing isn’t always formatted nicely.

In this lab, we’ll show you a new technique, **interactive debugging** – debugging by using an interactive tool, or a debugger. We’ll focus on IntelliJ’s built-in debugger.

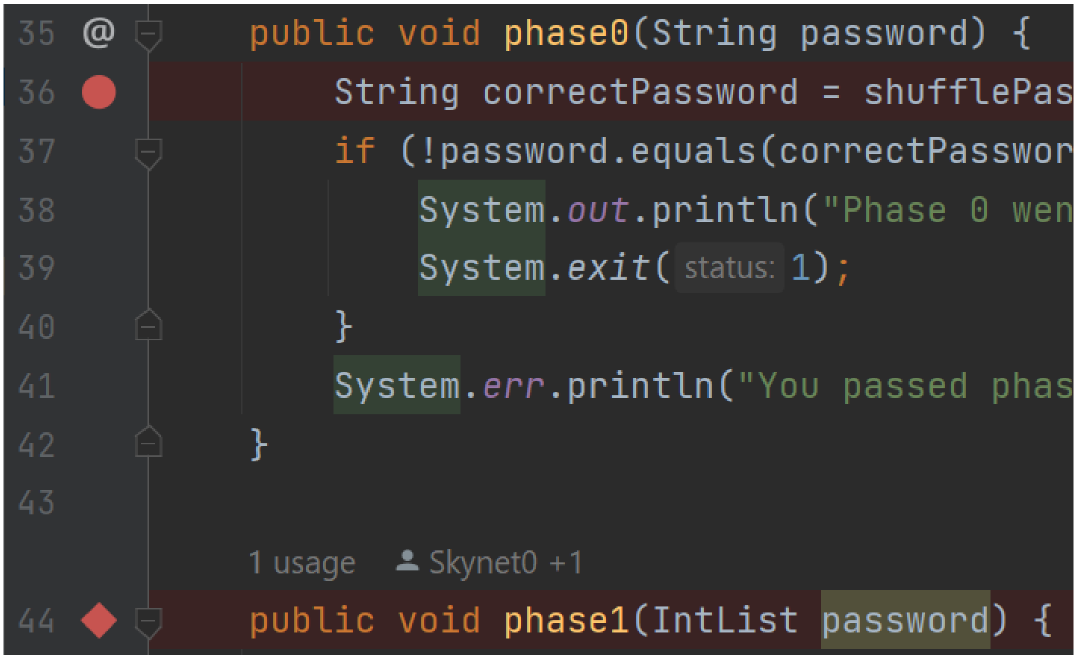
Debugger Overview

Breakpoints

Before starting the IntelliJ debugger, you should set a few **breakpoints**. Breakpoints mark places in your code where you can *suspend* the program while debugging and examine its state. This:

- Doesn’t require you to modify your code or clean it up after, since breakpoints are ignored in normal execution.
- Lets you see *all* the variables without needing to write print statements.
- Lets IntelliJ display everything in a structured manner

To set a breakpoint, click the area just to the right of the line number.



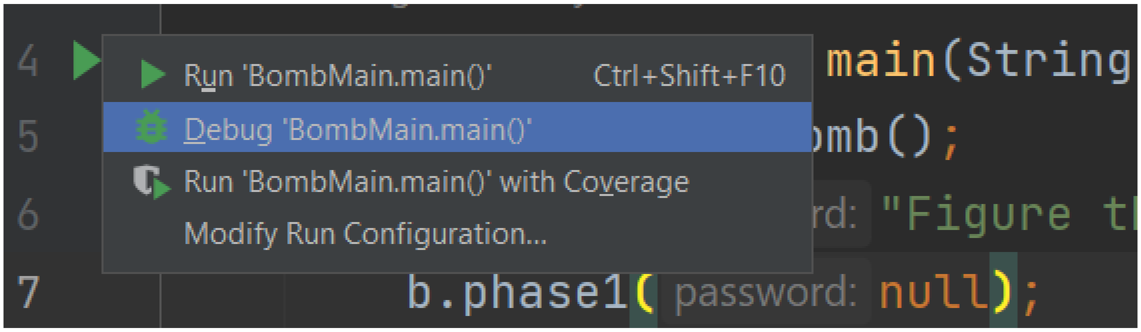
```
    public void phase0(String password) {
        String correctPassword = shufflePas
        if (!password.equals(correctPasswor
            System.out.println("Phase 0 wen
            System.exit( status: 1);
        }
        System.err.println("You passed phas
    }

    1 usage   Skynet0 +1
    public void phase1(IntList password) {
```

A red circle or diamond should appear where you clicked. If nothing appears, make sure that you click next to a line with code. When the debugger reaches this point in the program, it will pause **before** the execution of the line or method. Click the breakpoint again to remove it.

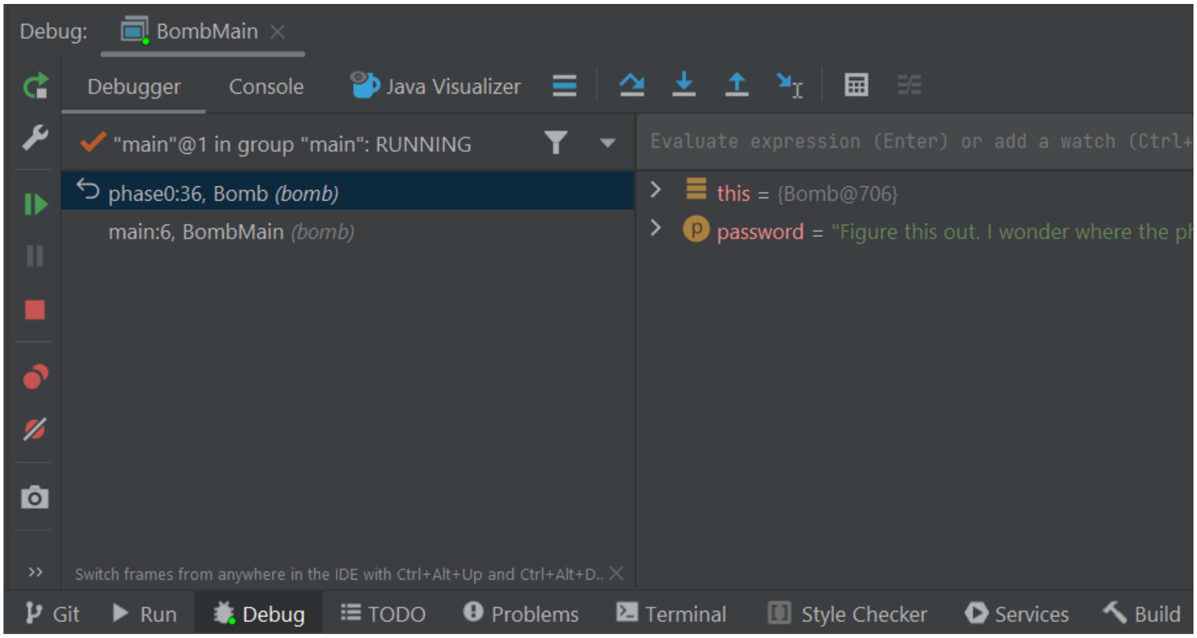
Running the Debugger

Once you've set some breakpoints, you're ready to start a debugging session! Click on the green triangle next to the class or test you want to debug (in test files there may be two green triangles). Instead of clicking the green triangle to run, click the 🐞 debug option:


Run 'BombMain.main()' Ctrl+Shift+F10
Debug 'BombMain.main()'
Run 'BombMain.main()' with Coverage
Modify Run Configuration...

```
main(String
mb();
rd: "Figure t
b.phase1( password: null);
```

The selected program should run until it hits its first breakpoint. A debugger window should also appear on the bottom of the interface, where the console was.



"main"@1 in group "main": RUNNING

phase0:36, Bomb *(bomb)*
main:6, BombMain *(bomb)*

this = {Bomb@706}
password = "Figure this out. I wonder where the ph

Switch frames from anywhere in the IDE with Ctrl+Alt+Up and Ctrl+Alt+D..

On the left, you will be able to see all current method calls and on the right, you will be able to see the values of instantiated variables at this point in the program (they will also be shown in gray text in the editor). For instances of classes, you can click the dropdown to expand them and look at their fields.

In the debugger, you have a few options:

- Learn something from the displayed values, identify what's wrong, and fix your bug! Click ■ to stop the debug session.
- Click ▶ to resume the program (until it hits another breakpoint or terminates).
- Click ↷ to advance the program by one line of code.
  - ↓ does something similar, but it will step into any method called in the current line, while ↷ will step over it.
  - ↑ will advance the program until after it returns from the current method.
- If you accidentally step too far and want to start the session over, click ↻.

To see the console output (and type into the console) while debugging, click the "Console" tab next to "Debugger" in the top left of the debug window, just above the frames. If you want to see everything simultaneously (while being more compressed), you can drag the console tab to the far right of the bottom panel. Here's a GIF from a previous semester that shows this (IntelliJ looks different, but the action is the same.)

Bomb Introduction (Phase 0)

For this lab, we will be providing hints. Please **only use them if you're stuck!** You'll get much more out of the exercises if you try to solve them on your own first.

Task: Set a breakpoint at `phase0` and use the debugger to find the password for `phase0` and replace the `phase0` argument accordingly in `bomb/BombMain.java`.

Once you've found the correct password, running the code (not in debug mode) should output "You passed phase 0 with the password <password>!" instead of "Phase 0 went BOOM!"

▶ **`phase0` Method Breakdown**

Visualizer (Phase 1)

While being able to see variable values is great, sometimes we have data that's not the easiest to inspect. For example, to look at long `IntList`s, we need to click a lot of dropdowns. The Java Visualizer shows a box-and-pointer diagram of the variables in your program, which is much better suited for `IntList`s. To use the visualizer, run the debugger until you stop at a breakpoint, then click the "Java Visualizer" tab.

The password for phase 1 is an `IntList`, not a `String`. You may find the `IntList.of` method helpful.

Task: Set a breakpoint at `phase1` and use the Java Visualizer to find the password for `phase1` and replace the `phase1` argument accordingly in `bomb/BombMain.java`.

▶ **`phase1` Method Breakdown**

Conditional Breakpoints (Phase 2)

Sometimes you may want to have your program pause only on certain conditions. To do so, create a breakpoint at the line of interest and open the “Edit breakpoint” menu by right-clicking the breakpoint icon itself. There, you can enter a boolean condition such that the program will only pause at this breakpoint if the condition is true.

Another thing you can do is to set breakpoints for exceptions in Java. If your program is crashing, you can have the debugger pause where the exception is thrown and display the state of your program. To do so, click ● in the debugger window and press the plus icon to create a “Java Exception Breakpoint”. In the window that should appear, enter the name of the exception that your program is throwing.

Task: Set a breakpoint at `phase2` and use the debugger to find the password for `phase2` and replace the `phase2` argument accordingly in `bomb/BombMain.java`. Remember, don’t edit `Bomb.java`!

Note: The password isn’t given explicitly like in the previous phases. Rather, your task is to construct an input so that the `boolean correct` variable is set to `true` after `phase2` is run.

▶ **Hint 1**

▶ **Hint 2**

▶ **Hint 3**

▶ **Hint 4**

▶ `phase2` **Method Breakdown**

At this point, you should be able to run the tests in `tests/bomb/BombTest.java` and have all of them pass with a green checkmark.

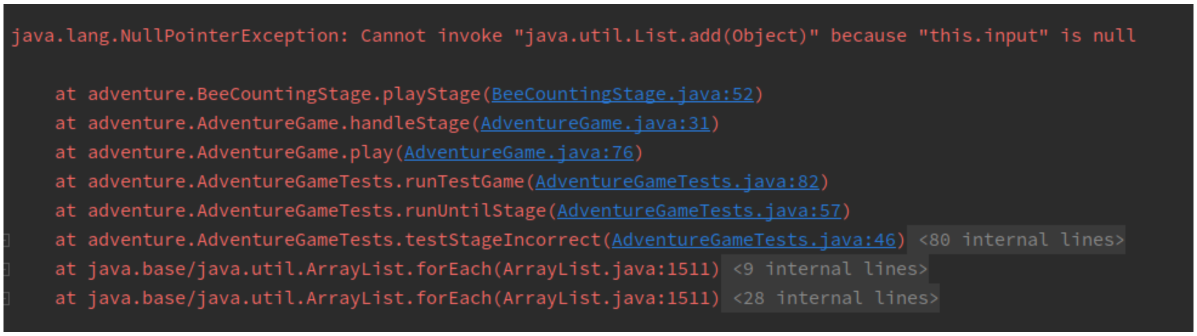
Adventure

Running the Game and Tests

The very first thing you should do is run the `main` method in `AdventureGame` to run through the game. This will give you a sense of what the program you are debugging is actually supposed to do. Then, after you've run the game, run the tests in `tests/adventure/AdventureGameTests`. They should fail on `BeeCountingStage` which will lead you into debugging the first error below.

Reading Stack Traces

When a *runtime error* occurs in Java, a stack trace is printed to the console to provide information on where the error occurred and what steps the program took to get there. When running `Adventure` for the first time, your stack trace will look something like this:



```
java.lang.NullPointerException: Cannot invoke "java.util.List.add(Object)" because "this.input" is null

    at adventure.BeeCountingStage.playStage(BeeCountingStage.java:52)
    at adventure.AdventureGame.handleStage(AdventureGame.java:31)
    at adventure.AdventureGame.play(AdventureGame.java:76)
    at adventure.AdventureGameTests.runTestGame(AdventureGameTests.java:82)
    at adventure.AdventureGameTests.runUntilStage(AdventureGameTests.java:57)
    at adventure.AdventureGameTests.testStageIncorrect(AdventureGameTests.java:46) <80 internal lines>
    at java.base/java.util.ArrayList.forEach(ArrayList.java:1511) <9 internal lines>
    at java.base/java.util.ArrayList.forEach(ArrayList.java:1511) <28 internal lines>
```

The first thing to note is what kind of error occurred; this is shown at the first line of the stack trace. In this case, our code threw a `NullPointerException`.

For some exceptions, including `NullPointerException`s, Java will give you an explanation. Here, `this.input` is `null`, so we can't invoke (call) a method on it.

The lines beneath it represent the sequence of methods the program took to arrive at the error: the first line in the list is where the error occurred and the line beneath it represents the line of code that called the method which threw the error, and so on.

You can click on `blue text` to navigate to that file and line.

For each of the following stages, **only change what is necessary**! You should not be rewriting entire blocks of code unless otherwise specified. We've included how many lines we changed as a guideline.

Note: You can run through the adventure game each time if you'd like to validate correctness, but you don't need to - feel free to debug through the tests directly. This can be done by setting a breakpoint in `playStage` for the appropriate stage file you'd like to debug, then debugging `AdventureGameTests`.

Debug BeeCountingStage

Task: Fix the `NullPointerException` that occurs in `BeeCountingStage` by analyzing the stack trace. You can ignore the lines with `<XX internal calls>`; these are from test framework or library code and usually won't help you find errors.

Expected lines modified: 1

It turns out that this isn't the only error in `BeeCountingStage`!

Task: Fix the `IndexOutOfBoundsError` that occurs in `BeeCountingStage`.

Note: Ignore the grey links to `Objects.java` and `ArrayList.java` at the top of the stack trace. The error may have *occurred* in code that was not yours, but the root cause was probably something *your code* tried to do.

Expected lines modified: 1

▶ **Hint 1**

▶ **Hint 2**

Optional for This Week Only

> **Note**: Due to the Project 0 deadline and the length of this lab, the following tasks are optional *for this week only*. We still recommend you complete them for more practice debugging before finishing Project 0, but they will each be worth 0 points for Lab 02. They will be required and worth points for Lab 03.

Debug `SpeciesListStage`

> **Task**: Fix the error(s) in `SpeciesListStage`. If you don't see what the issue is inside the method where the exception occurred (the top line of the stack trace), it's often a good idea to look at the second line to see where the method is being called from, and with what arguments.

Expected lines modified: 3-4

▶ **Hint**

Debug `PalindromeStage`

> **Task**: Sometimes, IntelliJ will tell you something that it thinks is wrong. Hover over the yellow / orange highlights in the method with the bug. Does that give you any useful information?
>
> Use this feature to address the error(s) in `PalindromeStage`.

Note: If the debugger feels unresponsive, it is usually due to an infinite loop somewhere in your code. If you set a breakpoint and it is never reached, then you know an infinite loop occurs before the breakpoint! Use this in combination with stepping to isolate the problem.

Expected lines modified: 3

Debug MachineStage

The `sumOfElementwiseMax` method in `MachineStage` is supposed to take two arrays, compute the element-wise max of those two arrays, and then sum the resulting maxes. For example, for two arrays `{2, 0, 10, 14}` and `{-5, 5, 20, 30}`, the element-wise max is `{2, 5, 20, 30}`. In the second position, the larger of `0` and `5` is `5`. The sum of this element-wise max is $2 + 5 + 20 + 30 = 57$.

There are two different bugs that make the method return an incorrect result. You can assume the input parsing code in `playStage` works correctly.

To find the bugs, you should not step into the `mysteryMax` or `mysteryAdd` functions, or even try to understand what they are doing. That is, you should use ↷ to *only see the result*. These are ***mysterious*** functions that are deliberately obfuscated. If you find yourself having accidentally stepped into one of these two functions, use the ↥ button to escape.

Even without stepping INTO these functions, you should be able to tell whether they have a bug or not. That's the glory of abstraction! Even if I don't know how a fish works at a molecular level, there are some cases where I can clearly tell that a fish is dead.

Task: Fix the two bugs so that `sumOfElementwiseMax` returns a correct result.

If you find a bug in `mysteryMax` or `mysteryAdd`, rewrite the method entirely instead of trying to fix it. Don't rewrite code unnecessarily, though – be sure that it's broken first!

Expected lines modified: 2-5

▶ **Hints**

Still Broken…?

At this point, the test for correct inputs should pass. That test is testing a **correct** input to the adventure game. The second test checks an **incorrect** input (meaning one that gets something wrong at some point during the game). You should have gotten an error this time which tells you that the output the game gave did not match the output we expected. Click on `<Click to see difference>`, and IntelliJ will tell you where and how the long `String` outputs differed. Specifically, in this case, `SpeciesListStage` has a bug.

> **Task**: Go back to `SpeciesListStage` to find and fix the bug (if you didn't find it before). You may find what you learned in `PalindromeStage` helpful.

Expected lines changed: 0-1

After completing this task, all of the tests should pass.

▶ **Hint**

Deliverables and Scoring

The lab is out of 256 points. There are no hidden tests on Gradescope. If you pass all the local tests, you will receive full credit on the lab.

- Find all the passwords in `BombMain.java`. (3 parts, 64 pts each)
- Fix the bugs in `BeeCountingStage` for correct inputs. (1 part, 64 pts)
- (Optional, but required for Lab 03) Fix all bugs in the remaining adventure game stages for correct inputs. (3 parts, 0 pts each)
- (Optional, but required for Lab 03) Fix the bug in the adventure game for incorrect inputs. (1 part, 0 pts)

Submission

Just as you did in Lab 1, add, commit, then push your Lab 2 code to GitHub. Then, submit to Gradescope to test your code. If you need a refresher, check out the instructions in the Lab 1 spec and the Assignment Workflow Guide.

Acknowledgements

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