FootPrint

Motivation

The standard IDE debuggers such as those in IntelliJ and Eclipse do not offer the option of stepping backward through the execution. Occasionally, programmers set the breakpoint too far or step through the debugger too fast and miss the step they wanted to examine and have to restart. Having the option to view your variable's history throughout the debugging session would help solve these issues. This is what we are trying to achieve with FootPrint: a user-friendly, lightweight, and simple way for Java developers (specifically, students or beginning developers) to view the history of their variables.

For example, imagine a CS student who is trying to debug their program. They want to look at what is in their array at line 15, but they accidentally advance to line 16 when the array is discarded. With FootPrint, they could simply examine the state of the selected array by looking at the program state from line 15, which FootPrint would store for reference. Moreover, developers could have a better understanding of their code and the data structure by studying their variables' history.

Impact

FootPrint could be useful for Java programmers using IntelliJ. Even if someone doesn't overstep the debugger, viewing variable history would also allow for users to better understand what is going on in their code at a high level perspective. However, for beginner programmers who are more likely to overstep the debugger or who may not have as much intuition as senior programmers and would like to easily view what happened to their variables, FootPrint would be especially useful. Beginner-level programmers are also more likely to prefer using FootPrint over the more heavy-duty alternatives presented in the first section since FootPrint is very simple. Overall, this means less time and frustration spent on debugging. Since we are targeting beginner developers, we will focus on user-friendliness and practical use of our plugin and measure our success based on a user study.

Current Approach

Currently, time traveling debuggers and other plugins (e.g data visualization plugins) exist that allow one to go back and examine previous variable states, but they can be excessive for beginner programmers. Many existing programs store information such as stack frames, exceptions, method history, and logs. Chronon Time Travelling Debugger [1] is one such plugin also saves execution paths and time stamps for the program. Java Tutor is another tool visualizing the variables' states. Many existing plugins also store this information including JIVE [2] and UndoDB [3]. JIVE is a data visualization plugin for Java for Eclipse that also allows the user to see a history of their variables. While these tools may be useful for more sophisticated programs and experienced developers, we believe that intro-level programmers who simply wish they could look at their array from a line they stepped past would find these extra features and extra info unnecessary and perhaps overwhelming. It seems that recording the entire program with something like Chronon just to look at a variable a few steps back could be overkill in such cases.

Related works tend to take the following approaches: recording, using counters, or tracing. Recorders like Chronon, UndoDB, iReplay, etc., record the state of your program throughout the execution, and then allow you to go back and examine the states [4]. These have high overhead since the entire execution is recorded and can require gigabytes of logs per day [5]. For example, according to Chronon's performance guide, the recorder "is greatly affected by the amount of memory allocated to it".

At a minimum, it recommends users to allocate at least 1gb of memory during the recording process and 2-3gb during the unpacking or replaying process [13]. Kendo uses performance counters, which allow for a more low-level insight on program behavior in order to reproduce bugs for multithreaded programs without recording execution. However, Kendo only works for these multithreaded programs since the counters can only be used to reconstruct things such as lock acquisition order [5]. There is also the use of tracing in gdb's debugger and QIRA and strace. There is also the built-in feature of Watches and field watchpoints in IntelliJ. Watches allow you to monitor specific variables or expressions in the current stack frame, but do not store their history which is a large limitation; Watches is intended for evaluating expressions and not tracking variable history [11]. There are also field watchpoints, which allow the user to track a specific instance variable and suspends the debugger each time it changes. While these are useful, they do not actually store the history of the field so you cannot view the previous values of a field. Furthermore, these are only available for fields, not local variables [12].

Scientific and practical interest

There are three different types of debuggers: cyclic debuggers, record-replay debuggers, and reverse debuggers. As Engblom (2012) pointed out, reverse debugging has been discussed since the very beginning of computer programming. However, it was long ignored because of the difficulty in its implementations, such as the time management and reconstruction approach [8]. Since we are pursuing a similar feature of reverse debugging from the user end but with a simple and light-weighted backend, we came out the idea of extracting the information from debuggers and build a tool to track the footprint of variables [9].

Our Approach

FootPrint integrates with IntelliJ's built in debugger to provide a familiar, yet enhanced debugging experience for IntelliJ's users. To use, the user would set breakpoints and start a debugging session as normal. Then, in addition to the debugging window that pops up, a FootPrint UI would also appear. At anytime, users can choose from the list of variables that are currently in the debugging window and add them to FootPrint in order to be tracked starting at where the program is currently paused. For each variable that we are monitoring, FootPrint will store all changes that happened to it (from beginning of the tracking period to the end). Consider this scenario:

```
Line 1    int sum = 0    ← set breakpoint
Line 2    for (int i = 0; i < 6; i++) {
Line 3          sum += i;
Line 4    }
Line 5    System.out.println(sum);
```

The user wants to see how the variables sum and i change throughout the for loop. He or she will set a breakpoint beginning at the place where they are interested in the changes. The user then steps through their code and debug as they would normally. During this time, FootPrint records the different values that sum and i were previously assigned to create the following output for their histories:

History:

```
sum:
line      value
```

1	0
3	1
3	3
3	6
3	10
15	3

i:

line	value
2	0
2	1
2	2
2	3
2	4
2	5

Notice how sum = 0 only gets recorded once but in the code, sum actually took on the value “0” twice (once during initialization and once during i = 0) but we would only record when the variable changes. This prevents us from storing duplicate information. Once tracked, users can re-access these histories anytime, even if the variable becomes out of scope.

Furthermore, our approach uses less memory because we are only storing information about variables (specifically, values and the line number where it was changed) as opposed to extra data such as stack frames, exceptions, method history, and logs of the entire program like current approaches. Our users are only given information that are relevant to them and are able to get a quick summary of how things change throughout the program.

Architecture & Implementation

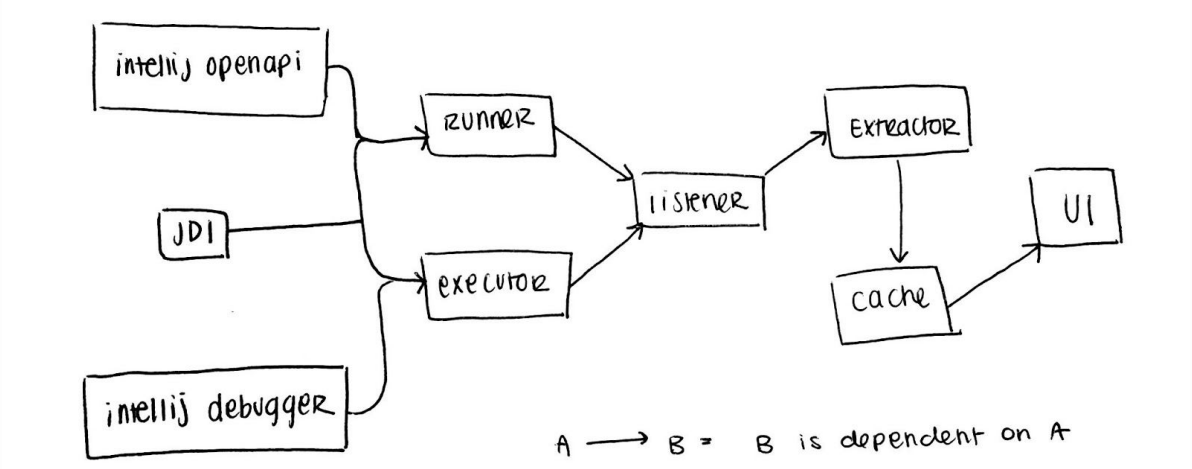


Figure 1.2. Architecture diagram illustrating the major components of FootPrint and their dependencies

IntelliJ's run actions for programs are as follows. First, a user will select a run configuration and an executor. From IntelliJ's documentation [10], a run configuration allows users to run certain types of external processes such as scripts. From IntelliJ's documentation [11], an executor is a specific way of executing any possible run configuration. IntelliJ has three built in executors: Run, Debug, and Run with Coverage. Footprint works with any run configuration, since we have created our own executor, extending the DefaultDebugExecutor. A program runner, which will actually execute the process, is then chosen from all registered program runners by asking whether they can run the given run profile with the given executor ID. Because we want access to the internal state of the running debug process and because we have created a custom executor, a custom program runner was necessary. Finally, ProgramRunner.execute() is called, starting the process. Thus, our custom executor and runner live on top of the existing architecture for IntelliJ's debugger.

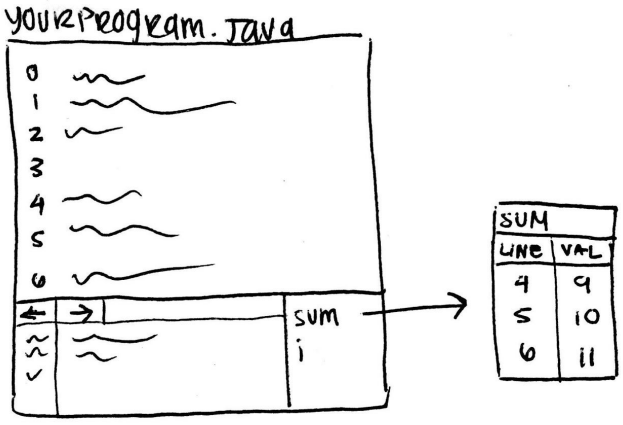
FootPrint uses three resources: IntelliJ's openapi, IntelliJ's debugger interface, and JDI (Java Debug Interface). Our own Runner and Executor classes use these resources in order to run IntelliJ's built-in debugger through our plugin. Our Listener class watches for changes in the program's variables. Our Extractor class extracts the contents of these variables when the Listener indicates a change. This data is stored in our Cache that we implement. The contents of this cache are then displayed through the UI.

The listener class work as follows. The custom runner will, as part of the initialization of the debug process, register with the virtual machine a number of breakpoints, either field or line, that will, when triggered, notify the listener class. The listener class will then notify the extractor class, passing along the necessary information including the stack frame, and will then resume the program. All of this will occur without the knowledge of the user, and will not affect the user's defined breakpoints.

In terms of API's and libraries, FootPrint will use JDI, IntelliJ's XDebugger, and IntelliJ's openapi. XDebugger, the built in underlying debug library used by IntelliJ, and openapi, IntelliJ's api for the editor, are used when implementing the runner and executor. Java Debug Interface (JDI) is used actually extract the variable data.

GUI's

Figure 1.3 Text-based GUI



Our UI will be text-based, the user would essentially select a variable and the UI would display its history altogether. This seems more useful if the user would like to see the variable history and line numbers all in one place to see how the variable changes. However, it is more difficult to see interactions between different variables this way. Despite this issue, we find it most reasonable to implement this particular UI due to time constraints. There is also the issue of how we handle objects. We will either simply call the object's toString() method or match how IntelliJ displays objects i.e. simply displaying field values and displaying arrays as "[a, b, c]."

Risks and Rewards

We expect the biggest challenge of this project is detecting when a variable is changed up until the breakpoint set by the user. In order to extract information about a variable, Java debuggers need an "event", such as a breakpoint, to pause the program's execution and get the information from the variable [6]. If we want to track the any changes that happened, we would need to set our own breakpoints at every line before the user's breakpoint in order to monitor those changes. However, doing so would defeat the purpose of creating a fast and lightweight plugin. An alternative is to use watchpoints instead, as a way to track specific variables which sounds much more efficient. We just have to figure out how to incorporate watchpoints into our implementation now. A major limitation is that there are only watchpoints offered for fields. There is also the alternative of just extracting all local variables each time the debugger is suspended, which we have already figured out how to do. However, there is still the issue of only getting data during suspension which we will have to work around. If we cannot get around this issue, then FootPrint will only store values during suspended states. We believe this could still be useful though, since it still can solve the issue of overstepping the debugger so long as you previously had the debugger paused on the line of interest.

Despite this, we think that our solution is feasible since IntelliJ does provide open APIs that allows us to interact with its built in debugger [7] . We will take advantage of this and build our solution upon existing resources. To minimize risks, we will implement basic features first and then add more as time permits.

Cost and Time

Since FootPrint will build on some of the functionalities from IntelliJ's debugger (like extracting variable states), we expect to be able to finish this project within 6 weeks. The first four weeks will be spent on building and testing the backend of extracting and caching information while the remaining two weeks will be spent on building and testing a user interface.

Checks for Success

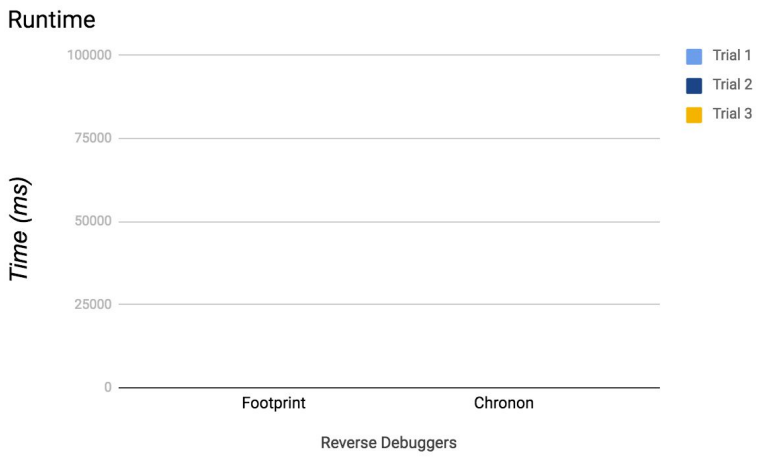
The midterm to measure FootPrint project is to finish the building process of FootPrint's backend. At this point, we will have fully implemented and tested the storage of debugging information. The final exam to check for success will be after the UI design of FootPrint and the launch of the project. We will do experiments with the users for feedbacks to further improve FootPrint, as well as run a performance experiment that focuses on runtime.

Experimental Methodology

Performance Experiment:

We will run FootPrint and Chronon on our sample program in debugging mode. We will measure how long each plugin takes to record/prepare for user interaction. For Chronon, this means we will measure the recording time. For FootPrint, we will set a breakpoint at the end of the program and measure how long it takes for FootPrint to collect and display the variable histories. Since FootPrint will set breakpoints under the hood in order to get a full record of variable history (in addition to user breakpoints), measuring this preprocessing time is analogous to Chronon's recording time since both processes have to be complete before the user can begin debugging. The plugin that takes the least amount of time to preprocess will be the one with better runtime. We chose to run FootPrint against Chronon because Chronon seems to be the most popular Java rewind debugger that is compatible with Intellij. We also considered testing JIVE which is also made for Java, but it is focused on data visualization so we thought it was too different to be compared. Since our project is aimed towards students, we will choose likely choose an example problem or homework solution from an intro CSE class here at UW to most accurately reflect what our target audience will use FootPrint on.

Figure 1.4. Potential runtime graph



Follow this link to find out how to reproduce the tests and figures above:
https://github.com/hangbuiii/FootPrintTest

User Study:

We will gather a small sample of beginner developers (e.g. our friends) who have never been exposed to Chronon and have them test use Footprint and Choronon on the same program (the one from the performance experiment). Afterwards, we will gather data via surveys and measure our goal of being "user friendly" through their feedback to see which one they think offers the most intuitive and understandable UI. Essentially just letting people we know test out FootPrint and seeing if they think our UI is reasonable. Through the results of the feedbacks, we can see if FootPrint achieves its goal of being more user-friendly than current solutions on the market. As suggested by Mortensen, we will create a well-designed user study by reducing bias and ask explorative questions [14]. In order to reduce an bias, we will have users record their answers in an environment where FootPrint team members are not present. We want to ensure that participants do not feel pressured to answer in certain ways due to our influence

(e.g. the tone in which we ask questions). We will include follow-up sub-questions such as “why?” or “which ones?” to prompt the participants for more info.

For each of the plugins (Chronon and FootPrint), we will ask the following questions:

1) Was there anything that was difficult to view? E.g. fonts being too small, buttons being hidden
2) Did you encounter any bugs? If so, what were they?
3) Did you have trouble finding the controls?
4) If you had any issues, was the user manual or documentation sufficient to solve your issues?
5) Was the plugin efficient? Did you find yourself waiting for the plugin to load?
6) Would you use this product again? In what context and why?

We plan to refine our questions when the experiment approaches and we have a better idea of what FootPrint will be capable of.

Initial Results

Currently, we have implemented the basic extraction and storage of data as well as a simple text-based UI. We have unit tests for instantiable classes such as the DebugCache and VariableInfo. At the moment, FootPrint will automatically load/track any fields of the current object, and any local variables within the current method. For objects that are included in java.util, their values are displayed through their respective toString() method and for others, we display their fields. If the object’s field references another field, this field’s fields are also viewable. Our UI currently displays each value in a single line, which can be a bit hard to read, especially when displaying multiple fields within an object. We are working on refining the UI to make the values more readable. Our biggest hurdle is still finding a way to track all changes, and not just the ones that occur when the debugger is suspended by the user. Right now, we are looking into utilizing IntelliJ’s Program Structure Interface in order to parse the source file to find assignments, constructors, and mutators so we can set additional breakpoints at these lines. We are also trying to research the implementation of field watchpoints so that we can possibly mimic this with local variables.

Because FootPrint’s main purpose of displaying variable’s full histories has yet to be achieved, we have put off our user study and performance experiment until next week since we feel that such experiments will be of less use at this point. Instead, the FootPrint team has been testing FootPrint ourselves in order to find bugs, test the UI, etc.

Team Assignments

UI: Eric, Derek
Cache & Extracting information: Audrey, Hang

Week-by-week schedule

Underlined items are complete.

<u>Week 5: Architecture and Implementation plan</u>

We will outline the architecture plan for Footprint. We will decide on a UI and give a mockup. Furthermore, since we are extracting info from the built-in debugger, we will research the architecture of that. We will also decide on what data structures to use for our backend.

Week 6: User manual + begin implementation
User manual - ReadMe.MD (Sections: About, How to Download, How to Use)
Implementation - Finish and test module that will extract variable states from the debugger. Finish and test module that will store the variable states.

Week 7: Build and Test
We will complete and do testing of the UI. Further, we will create a user survey to determine usability and stability of FootPrint. At this point, FootPrint's basic features should be usable (basic data extraction and storage).

Week 8: Initial Results
We will do some basic preliminary testing of FootPrint ourselves and fix bugs that we find. We will continue to work on FootPrint's features, particularly, tackling the setting of breakpoints so that we can acquire the full histories of variables.

Week 9: Draft Final Report
We will run and compile results of user feedback survey and previous test results. Based on these, we will add to the test suite and fix any apparent bugs. We will run the outlined experiments to gauge the runtime of FootPrint compared to other products.We may add more example programs to run FootPrint on, but otherwise coding should be complete and fully tested.

Week 10: Finalize Project Report
Finish final commits on Git and finalize the report.

Feedback

We believe we have addressed all feedback.

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