

# Towards Efficient Object-Centric Debugging with Declarative Breakpoints

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## Abstract

Debuggers are central tools in IDEs for inspecting and repairing software systems. However, they are often generic tools that operate on a low level of abstraction. Developers need to use simple breakpoint capabilities and interpret the raw data presented by the debugger. They are confronted with a large abstraction gap between application domain and debugger presentations. We propose an approach for debugging object-oriented programs, using expressive and flexible breakpoints that operate on sets of objects instead of a particular line of source code. This allows developers to adapt the debugger to their domain and work on a higher level of abstraction, which enables them to be more productive. We give an overview of the approach and demonstrate the idea with a simple use case, and we discuss how our approach differs from existing work.

## 1 Introduction

Debuggers are important tools for finding and correcting software defects, but are also used by programmers for code comprehension [8]. Conventional debuggers often follow the same static structure, where IDEs like Eclipse<sup>1</sup> or IntelliJ IDEA<sup>2</sup> provide ways to set static breakpoints that will halt the execution when reached. The programmer is presented with a view of the source code where the program has halted, a view of the current call stack, and various means to access run-time information, such as a browser for variables and their values in the current scope. The operations *step into*, *step over*, and *step out* are used to navigate through the stack and continue stepwise execution until a certain point of interest is reached (which again is visible by viewing the call stack and the corresponding source code).

When working with large, object-oriented projects with a complex inheritance structure, exploring the execution of a program can be hard to follow since there are many different locations in the source code involved. Using the debugger operations frequently results in a context switch. Often, using the *step* operations exclusively is too fine-grained. Instead, developers need to place multiple breakpoints (which can be tedious and error prone in larger projects) to obtain more meaningful (in the context of the current debugging task) *units of execution*. Furthermore, traditional debuggers do not provide a good interface for exploring the evolution of objects of interest, i.e., they do not provide a way to browse the state of objects at an earlier point in the execution. Conditional breakpoints can be used to halt execution at a certain line of code when a certain condition is satisfied. For example, they can be used to only stop execution when a certain object is involved. However, they only

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<sup>1</sup><https://www.eclipse.org/>

<sup>2</sup><https://www.jetbrains.com/idea/>

limit whether execution is halted at that particular line and cannot result in halting at different locations in the source code.

Several alternative techniques and tools for debugging object-oriented software exist. Ressia et al. [7] propose a debugger methodology called *Object-Centric Debugging*, which focuses on (live) objects instead of source code and the execution stack. During run time, one can specify dynamic breakpoints for individual objects with a set of operations (e.g., *halt on write*, *halt on call*, *halt on object in call*) in order to track its evolution with respect to certain properties of interest. These operations focus on individual objects, while we plan to extend the idea to sets of objects.

Lienhard, Fierz et al. present *Object-Oriented Back-in-Time Debugging* [6] and *Compass* [4], where they track object states at run time and provide tools for inspecting their evolution in the past. In their work, they depart from the traditional stack-based view during halted execution and provide views for analyzing side effects of method invocations (e.g., by presenting at which point in time a variable pointed to a certain value) and visualizing method executions. Data is collected for all objects that are reachable when halting the execution. In contrast, we plan to only track objects that are of interest in the debugging task by manually selecting, at run time, the objects that need to be tracked.

Chiş et al. make debuggers more dynamic by providing a framework that allows programmers to easily build custom debugger views for their specific domain [2]. They show by example how domain-specific debuggers can be created to improve comprehension and productivity. For example, a debugger for the SUnit testing framework is presented that provides a diff view of the expected and actual values of an `assert (a = b)` expression, which is automatically opened when the debugger interrupts the program. Apart from the custom views however, the debugger remains in the traditional form with stack trace and source code view.

Stateful Breakpoints [1], proposed by Bodden, are built on runtime monitors for creating complex, temporal breakpoints. These allow developers, for example, to specify breakpoints in the form of “break here if one particular file is read after it has been closed already”. This approach is similar to conditional breakpoints, since the possible places where the breakpoint can fire are fixed at compile time. We will explore different possibilities and existing work for specifying our proposed breakpoints. This includes regular-expression like languages, the Object Constraint Language<sup>3</sup>, and path expressions.

Phang et al. [5] present a trace-based debugging environment that provides a scripting language based on Python. In their approach, the authors provide ways to create execution traces for parts of the program execution. The traces can then be used to detect consistency errors in one’s code. Their approach requires one to manually specify the points at which data (i.e., traces) are recorded, something that we aim to solve differently by specifying the data that need to be tracked at one single point only.

We continue in the next section by presenting our ideas using a simple use case. We argue why there is a need for our proposed debugger and point out benefits over other approaches.

## 2 Efficiently Debugging Object-Oriented Programs

Let us consider a custom implementation (in Pharo Smalltalk) of a linked list, where `LinkedList` objects contain a method `first` that returns the first element. These are simple objects of type `Element` and have a method `value`, which returns the value the element represents, and a method `next`, which returns another `Element` instance (or `nil` if the receiver of the message is the last element in the list). Finally, a method `size` returns the number of elements that are currently in the list.

We write a unit test to make sure the `size` method works as intended (and wrongly assume that the methods for adding elements work as intended):

```
testSize
  l := LinkedList new.
  l add: '1'; add: '2'; add: '3'; add: '4'.
  l insertAfter: 2 value: '2.5'.
  self assert: (l size = 5).
```

The methods `size` and `insertAfter:value:` are defined in the class `LinkedList` as follows:

```
size
  "Count the elements by iterating through the list."
```

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<sup>3</sup><http://www.omg.org/spec/OCL/>

```

    | count element |
    count := 0.
    element := first.
    [ e isNotNil ] whileTrue: [
        count := count + 1.
        element := element next.
    ].
    ^ count

insertAfter: anIndex value: aValue
    "Insert a new element after the element at index anIndex."
    | count element newElement |
    count := 1.
    element := first.
    [ count < anIndex ] whileTrue: [
        count := count + 1.
        element := element next.
    ].
    newElement := Element new: aValue.
    newElement next: (element next next). "Bug! Should be 'element next' only."
    element next: newElement.

```

When trying to find this bug with a traditional debugger, one would usually first find out what the actual `size` method invocation in the assertion returns. Here, the return value is still 4, meaning that either the `size` implementation contains a bug, or one of the methods that modify the list. The debugger would now require you to step through the list operations and look at the code that is executed. In particular, one would want to inspect the methods `add:` and `insertAfter:value:`. In this example, there are only two methods that alter the structure of the list. However, there are more cases where objects are interconnected and have complex structures. An example is that of GUI frameworks, where elements can be nested within each other and children know about their parents and vice versa. The structure of these systems can often be modified in a large number of places in the source code, e.g., when user input is handled or business logic is executed and the GUI is updated. Locating a bug in such a system with a traditional debugger can be very challenging, as a large number of possible sources of the errors have to be considered. Stepping through the source code line by line is time consuming, as is adding breakpoints at each location that modifies the structure.

To provide an efficient and high level approach to finding bugs, we propose to develop a debugger that addresses the mentioned drawbacks of other approaches and allows developers to explore complex object structures (examples include data structures, design patterns, and GUI programs) in the context of their domain. The amount of code that needs to be inspected in order to locate the bug can be minimized and is only required at a late stage of the debugging process. Our envisioned debugger is rooted in the methodology of object-centric debuggers, i.e., a debugger that allows a set of objects to be inspected and answer questions like “*When is this object used as a parameter in a message send?*” or “*When is this object modified?*”. We aim to allow developers to define domain-specific properties at which the execution should halt. We call these *declarative breakpoints* and propose to express them either by using arbitrary source code or by providing a domain-specific language. This way, a developer is able to express breakpoint conditions in his domain. In our example, we want to be able to specify expressions like: “*In this list instance, halt execution whenever the next instance variable of one of its elements is accessed or modified*”. (Note that this differs from simply adding a breakpoint at the setter and getter of `next`, since execution is only halted if the element is actually part of the list we are interested in. However, this should also apply for future list elements that may not exist yet when specifying the halting conditions.) What we aim for is a way to specify debugging operations in the context of live objects, with the possibility to express complex conditions that can be applied to one’s domain. Our proposal differs from conditional breakpoints, since we can break at different locations in the execution, while conditional breakpoints can only be used to not break at the same specified point in the source code. It differs from object-centric debugging, since declarative breakpoints operate on groups of objects.

We propose a debugger that can support, for example, the following workflow to fix the presented bug.

1. Since we encounter the bug in the `testSize` method, we insert a conventional breakpoint after the

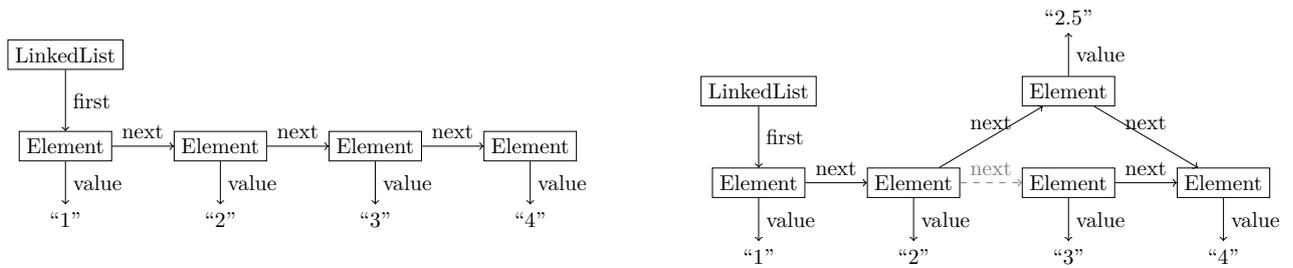


Figure 1: Tracked states before (left) and after (right) `insertAfter:value:` is executed. In the latter, the old `next` reference is shown as a dashed gray edge, akin to the side effect browser in Compass [4].

`LinkedList` instance is created. Once the debugger opens, we need to set up the data that needs to be tracked. Here, we should be able to track the list itself, but also all elements that are reachable. We will explore different ways to do this. Initial ideas include a domain-specific language that can express reachable objects (here, we could write an expression like `list first next*` to select objects that are reachable through `list first`, followed by an arbitrary number of `next` messages). Alternatively, we could imagine that arbitrary code can be used to collect the objects. Either way, we aim to provide a simple, straightforward way to select these objects. We will take existing work into account, including path expressions and Object Constraint Language in general, and Expositor [5] and Stateful Breakpoints [1] in particular. By manually specifying the set of relevant objects, we can keep track of the data that is of interest and use the obtained data in visualizations.

2. We continue execution until we reach the (failing) assertion, where we open the debugger again. At this point, the recorded information is available and should be presented in a way similar to what Ressia et al. are doing. Furthermore, we may be able to take advantage of moldable debuggers, in particular of custom renderers and presentations of objects in Chiş' work [2]. Figure 1 shows possible visualizations of the recorded data before and after the execution of `insertAfter:value:`.
3. Since we can browse the evolution of the relevant objects, we now realize that one of the elements has become unreachable. We go back to the initial breakpoint and create a declarative breakpoint for whenever a list element that *belongs to the list instance we are inspecting* updates the `next` reference. Note that we can define this breakpoint even if the list is empty; execution will nevertheless be halted at some future point when list elements are involved. Finding a simple way to define the breakpoints is closely related to defining the objects that should be tracked in the previous step. Once we find a suitable way to do this, we intend to use it for both tasks.
4. We execute the test once again and halt at several points. Thanks to the flexibility of declarative breakpoints, we step through high level units of execution, namely whenever a successor of a list element is updated. In the example, this happens in the `add:` and `insertAfter:value:` methods. Once the debugger interrupts program execution at a specified point, we want to present the obtained data to the programmer. As opposed to the generic views seen in previous work, we think that customized debugger views as seen in the Moldable Debugger Framework can be combined with the presentations that show the history of objects from the back-in-time debugger. Initially, we want this to be done manually, meaning that a programmer has to specify the particular views he wants to see either when interrupting the program execution or when specifying the data that is being tracked. In a later stage, we should consider techniques that can automatically select views and visualizations based on the available data. An example where this has been successfully achieved is the work of Cross et al. [3]. The authors present a classroom environment that can detect certain data structures and provide suitable visualizations for a large array of common structures with high precision.

In the example, we can use the same visualization as in the previous steps. We can follow the evolution of the list and realize that the bug is inside the `insertAfter:value:` method. We now take a look at the source code of `insertAfter:value:` for the first time and fix the bug (e.g., by using the traditional debugger operations to step through the execution in a more fine-grained fashion).

### 3 Conclusion

We give an overview of existing approaches to object-oriented debugging and point out shortcomings of existing breakpoint facilities and presentation issues. We outline an idea and possible debugging workflow that allows developers to define expressive breakpoints—called *declarative breakpoints*—that can be used to define halting conditions on the structure within a set of related run-time objects. The proposed approach provides developers with a higher level of abstraction and minimizes the required interaction with traditional debugger facilities to navigate the call stack and program execution. We illustrate the workflow by discussing a simple example where we locate and fix a bug in a linked list implementation. Declarative breakpoints are useful for programs where many methods modify the state of a set of objects, since we can avoid setting breakpoints in all places in the source code where the modifications take place.

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