Supplementary TestVision Examples

1 Introduction

This document contains descriptions of three programs implemented in the TestVision interface. The programs are implementations of algorithms that are commonly taught in CS1 or introductory courses on algorithms and data structures, namely insertion into a binary search tree (BST), the sorting algorithm Bubble Sort, and depth-first search (DFS). The purpose of documenting them here is to help the reader better understand how users interact with the system and to demonstrate how it can be used to work with more complex programs than the Greatest Common Divisor and Dot Product examples presented in the paper. We showcase both how the underlying algorithms are implemented and how TestVision can be used to (i) test the program implementations and (ii) assess the quality of one's tests.

Each example is described in detail with illustrative screenshots. It is also possible to explore them directly as pre-configured examples with interactive tutorials on the TestVision website, which is linked in the paper:

https://testvision.algot.org/

In the system, the examples are presented as new "Challenges" and can be accessed in the "Workspace" tab, located below the existing tutorials, as shown in Figure 1.

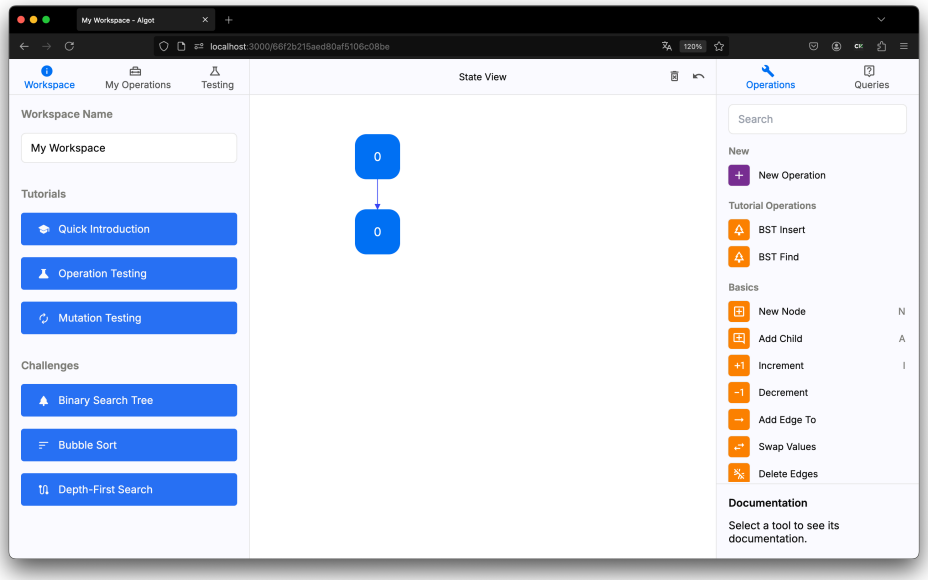


Figure 1: The "Challenges" containing more complex examples below the tutorial

2 Examples

2.1 Binary Search Tree Insertion

For this example, we consider an operation that inserts nodes into a Binary Search Tree (BST). The implementation is shown in Figure 2 and can be accessed in TestVision by opening the “Binary Search Tree” challenge.

The Binary Search Tree Insertion operation takes two nodes as inputs. The first node is expected to be the root of the BST, and the second node is the one to be inserted into the tree. These input nodes are represented by blue-colored nodes in Figure 2. The input also defines two possible children for the root, representing the rest of the BST, which are referred to as pattern nodes in Algot and are shown in pink in Figure 2. To define these pattern nodes, the programmer can apply the “Append Child” pattern to the root node, found in the “Patterns” tab of the operation editor.

Algot uses these pattern nodes to check whether the input matches the expected structure. If the input matches, all actions defined in the operation are executed. If actions are defined on nodes that do not exist during the actual execution, the operation simply returns. This behavior is useful, for example, when iterating over a list and stopping recursion once the end is reached.

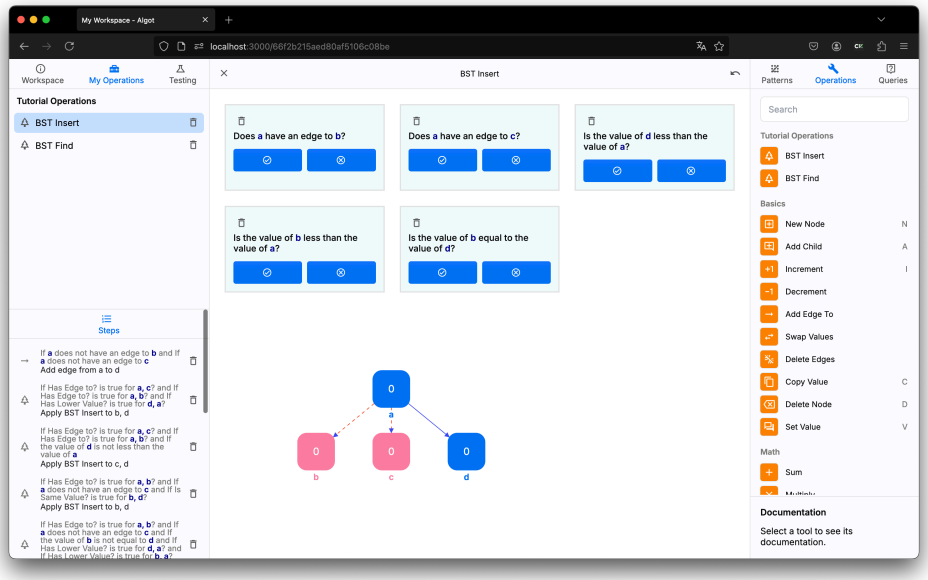


Figure 2: Implementation of the BST insert operation

The operation is defined with five queries (at the top of Figure 2), which serve as conditions for actions in the operation. The first two queries of the BST insert operation check whether the root node has no children. If this is the case, the new node is simply appended as a child of the root, and the operation terminates. If the root node has two children, the value of the node to be inserted is compared with the value of the root using the third query (at the top of Figure 2). If the new value is less than the root node’s value, the operation is recursively called on the left child of the root. If the value is greater than or equal to the root node, it is recursively inserted into the right subtree.

If the root node has one child, and the values of both the single child and the node to be inserted are either larger than, less than, or equal to the root node, the operation is recursively called on the single child to maintain the structure of the BST. These conditions are checked by the third, fourth, and fifth queries (at the top of Figure 2). In all other cases, the new node is simply added as a right child of the

root node. If the value of the new node is less than that of the left child, both nodes (and their subtrees) are swapped to maintain the BST structure. This step is not commonly used in BST implementations, but in Algot, it is not possible to add a right child without first adding a left child. This implementation works around the limitation by always appending the left child first and swapping the nodes if necessary to maintain the BST structure.

For this example, we assume that the user has written such a function and now wants to use TestVision's features to ensure the implementation is correct. As seen in Figure 2, the BST insert operation must cover multiple cases to ensure that new nodes are inserted in the correct location and that the structure of the BST is maintained, which makes the implementation more prone to errors and testing non-trivial.

To ensure that the operation is working as expected, the user can navigate to the testing tab and create new tests that cover different insertion scenarios, checking whether the nodes are inserted correctly and the properties of the BST are maintained. Each test is defined by creating an input graph, as seen in Figure 3, and an output graph, as seen in Figure 4, which is compared with the actual output of applying the operation to the input graph. However, the user might overlook adding tests that cover edge cases, potentially leading to undetected bugs.

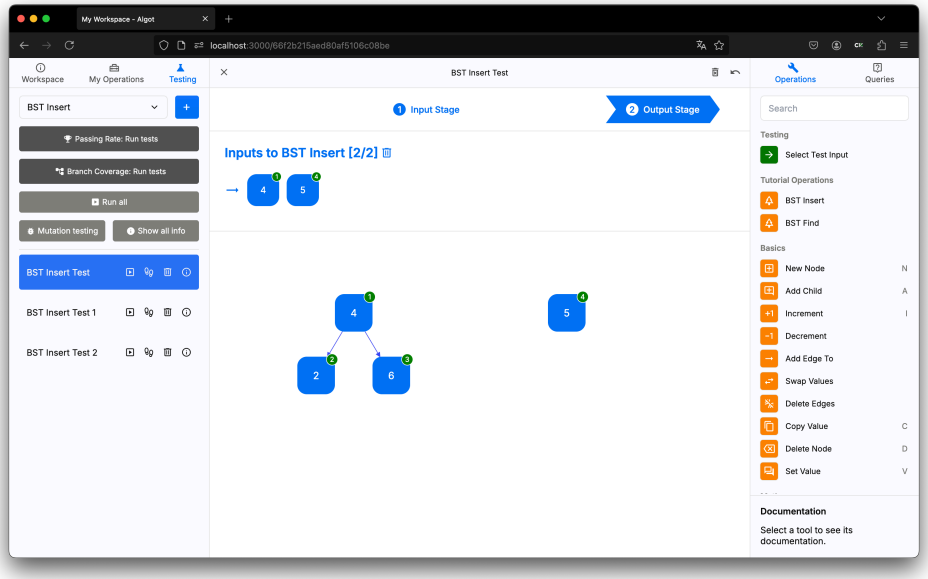


Figure 3: Input graph of a BST insert test

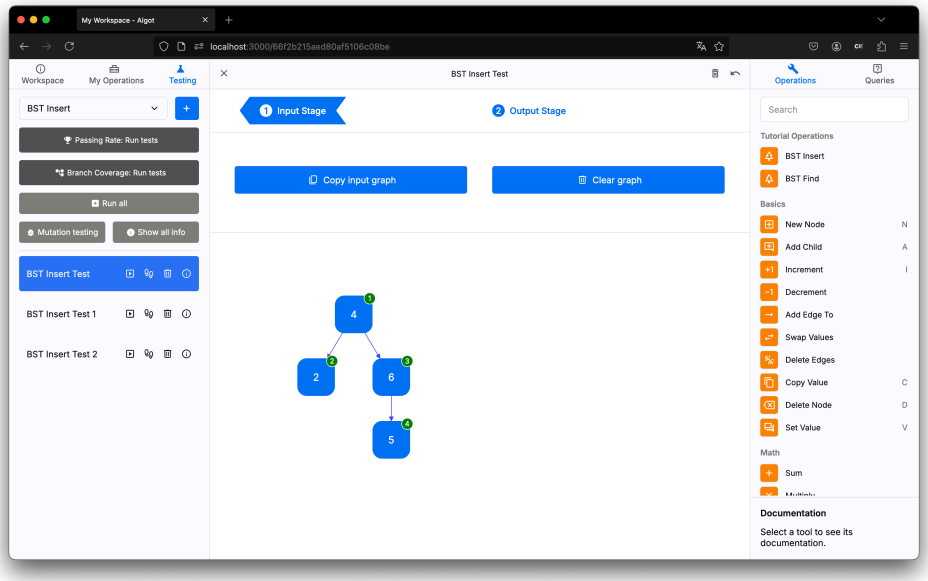


Figure 4: Output graph of a BST insert test

To assist with this, TestVision displays coverage metrics for individual tests as well as for the entire test suite, as shown in Figure 5. These metrics allow the user to determine whether all possible insertion scenarios are covered by tests and evaluate whether the test suite is comprehensive enough. By leveraging these metrics, the user can create new test cases and improve the overall quality of the test suite.

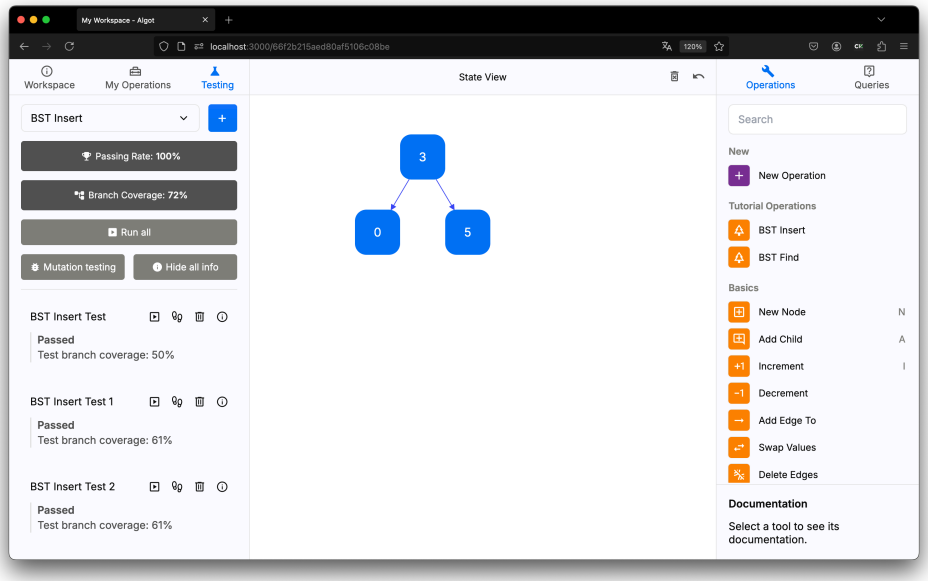


Figure 5: An incomplete test suite for the BST insert operation, reaching 72% branch coverage

2.2 Bubble Sort

In this example, we consider an implementation of Bubble Sort. The implementation is shown in Figure 6 and can be inspected in TestVision by starting the Bubble Sort challenge and reviewing the added operations. To create a simple interface that only requires the head of the list, this implementation uses two

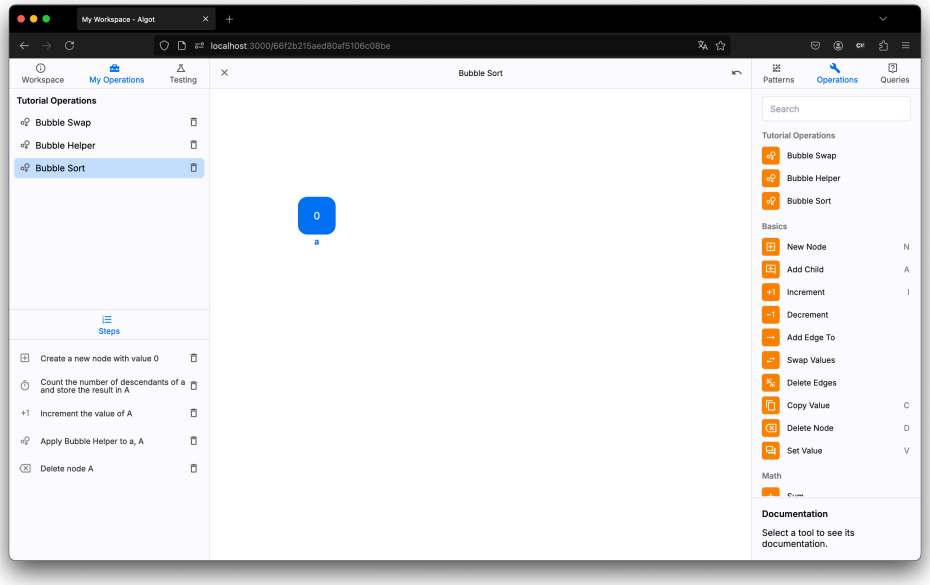
helper functions. The use of helper functions is a common pattern in the Algot programming language and serves as a realistic example of implementing more complex functions in Algot.

The Bubble Sort operation creates a new node and stores the length of the list in it, then calls the Bubble Helper operation on the head of the list to be sorted along with the length of the list. This simplifies the interface for users, as they only need to call the operation on the head of a list without providing multiple arguments.

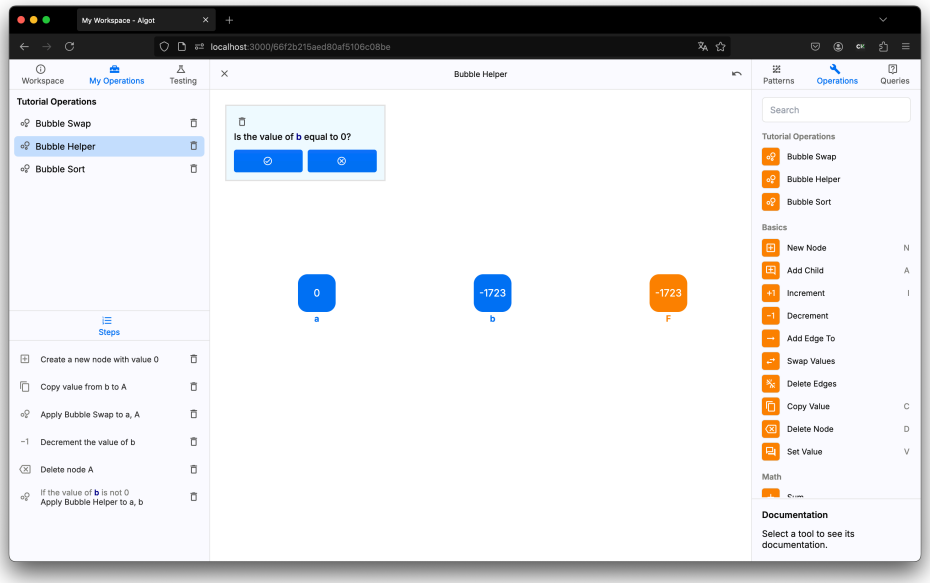
The Bubble Helper function uses the second argument, which contains the length of the list, as a counter and decreases it by one. It then calls the Swap operation on the list and a copy of the counter, ensuring the counter's value is not modified by the Swap operation. If the counter is not equal to 0, the Bubble Helper operation recursively calls itself.

The Swap operation takes two nodes as inputs: the first is a node (from the list) that potentially has a child, and the second is a counter. The child is defined as a pattern node, meaning the operation terminates when the end of the list is reached, and no child node exists. The operation first decreases the counter by one, then swaps the values of the first node and its child if the child's value is smaller. It then recursively calls itself on the child and the decreased counter. In this implementation, the counter is used to terminate the recursion before the end of the list is reached, as with each iteration, one more element at the end of the list is already in its correct, sorted position.

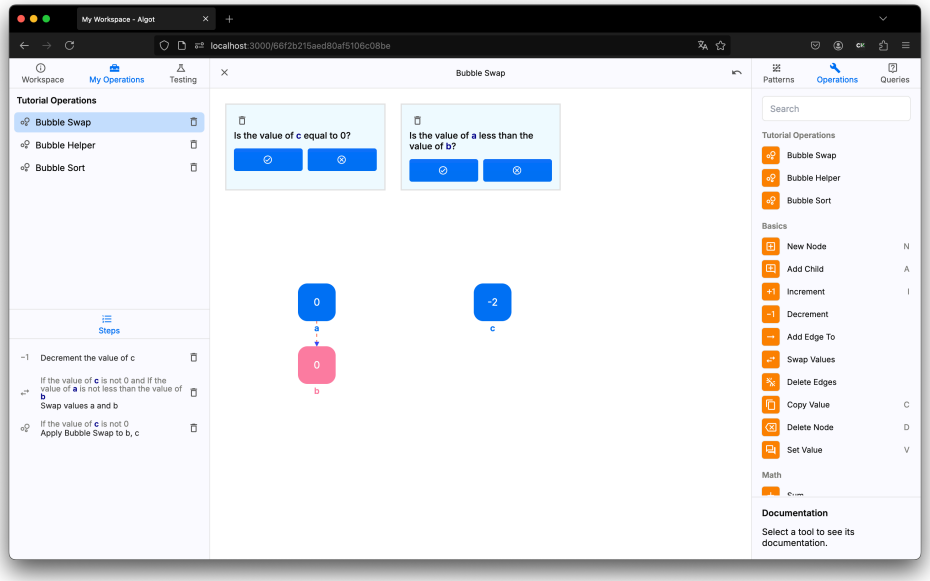
For simplicity, this implementation does not terminate early if no swaps are made during a call of the Bubble Helper operation.



a) Bubble Swap Operation



b) Bubble Helper Operation



c) Swap Operation

Figure 6: Implementation of Bubble Sort using two helper operations

We now assume that the user creates a simple test, as shown in Figure 7. This test passes and achieves 100% branch coverage. However, the user may want to further assess the adequacy of this single test and opens the mutation testing screen to do so. Next, a suitable mutation operator must be selected. Since the operation only takes a single input and does not operate on a tree, operators from the "Input Mutation" or "Pattern Mutation" categories would not be appropriate. Additionally, as the operation does not use any mathematical operators, the "Math operation mutation" and "Absolute value insertion" options are also unsuitable. In this example, we consider the "Operation mutation" option, which swaps operations called by the function with other operations of the same arity.

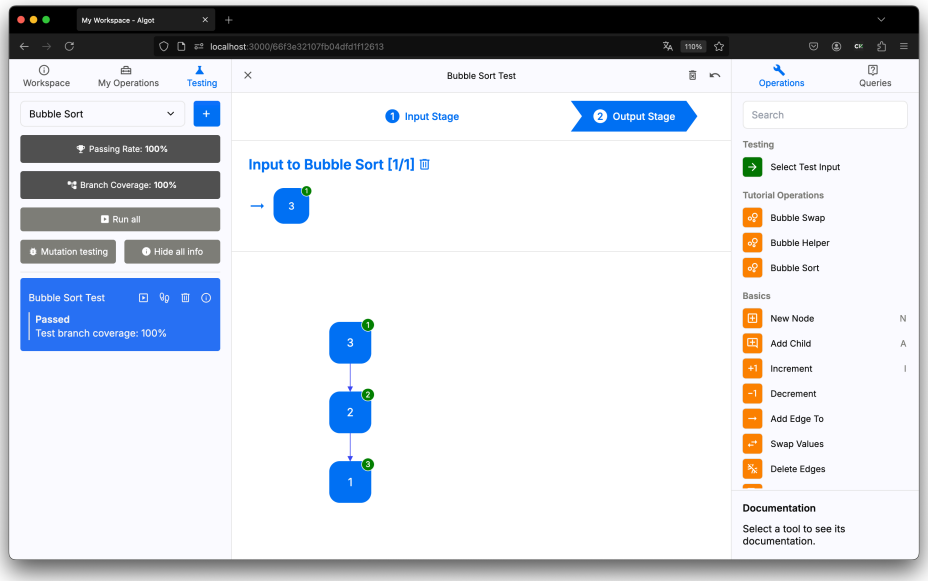


Figure 7: Input of a passing test for the Bubble Sort operation

This generates 34 mutants, which are displayed in the list on the right-hand side of the screen, as seen in Figure 8. After running the mutation test, we observe that all but 3 mutants are killed, resulting in a mutation score of 91%. By inspecting the first mutant, shown in Figure 9, we can see that the "Count descendants" operation was swapped with the "Copy value" operation. Using the step-through debugger, we find that the head of the list in the test we wrote has 3 descendants, which is equal to its value. Because of this, our test is unable to kill the mutant, even though it is not equivalent to the original operation.

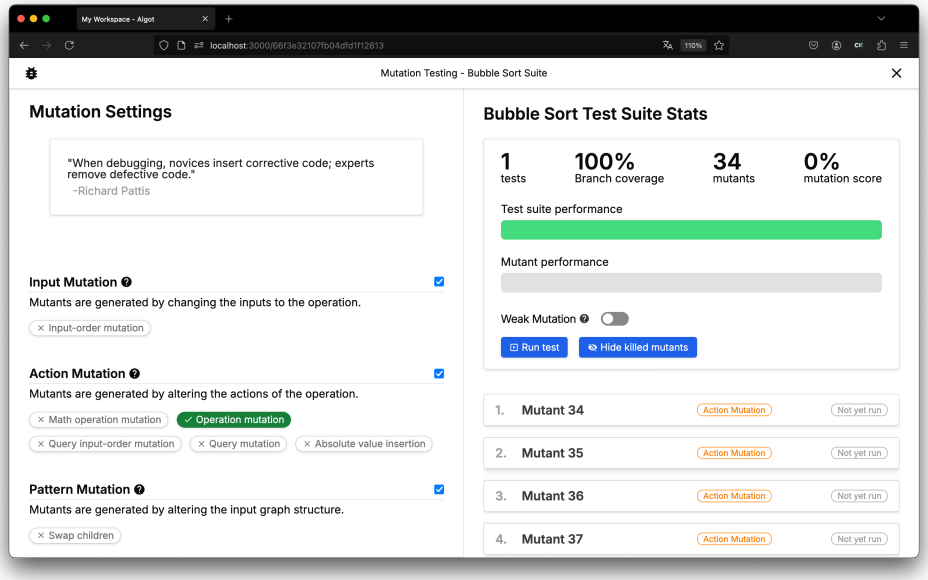


Figure 8: Mutation testing screen with "Operation mutation" selected

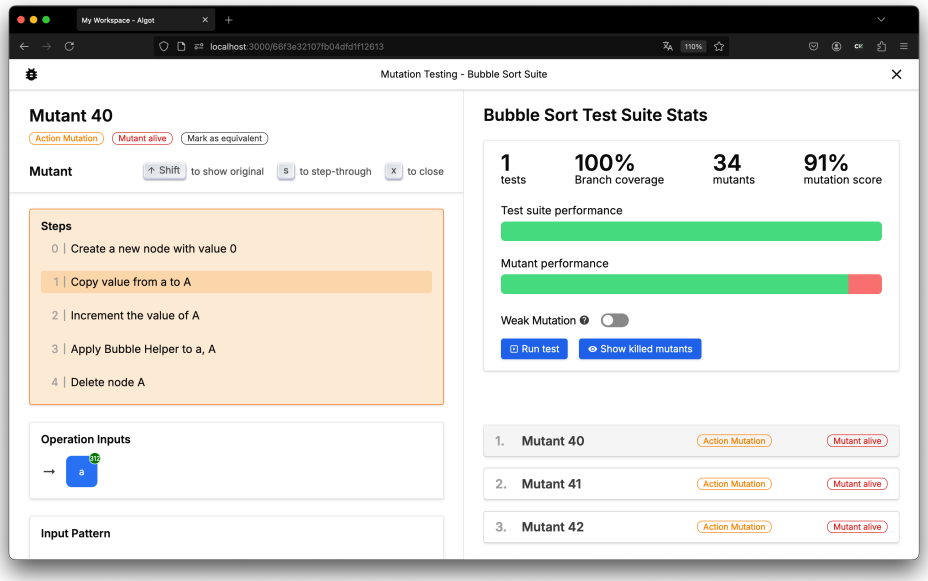


Figure 9: Mutant for the Bubble Sort operation that is not killed by the test suite

To address this issue, we create a new test case where the number of descendants of the head of the list is not equal to its value, as shown in Figure 10. After re-running the mutation tests, we observe that all but one mutant are killed after adding this new test case.

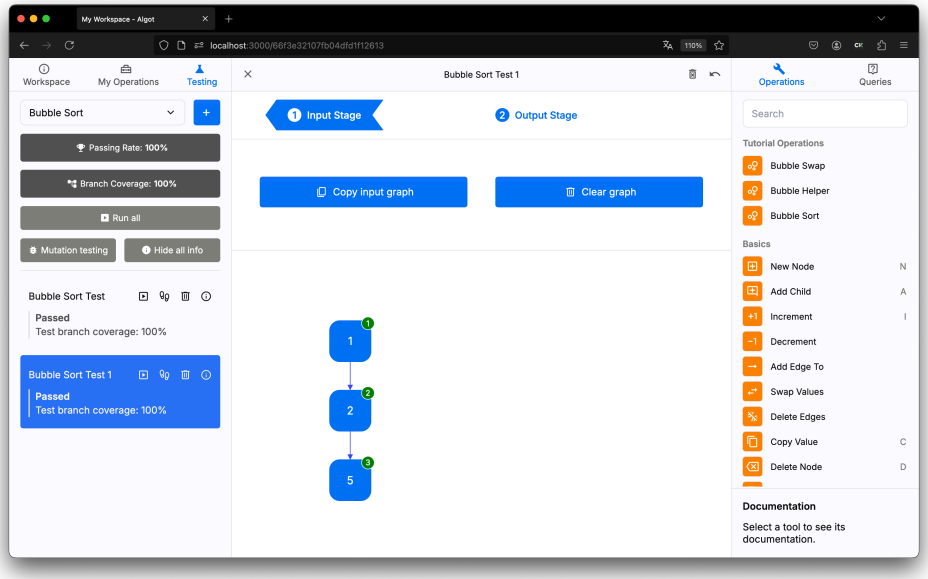


Figure 10: New test that kills the mutant from Figure 9

If we inspect the last remaining mutant, as seen in Figure 11, we observe that the "Count descendants" operation was swapped with the "Get tree height" function. However, in the case of a list, both operations are equivalent, making it impossible to kill this mutant. To address this, we can mark the mutant as equivalent, which allows us to achieve a mutation score of 100%.

We can now iteratively enable more mutation operators and create new tests to kill any surviving mutants, continuously improving our test suite.

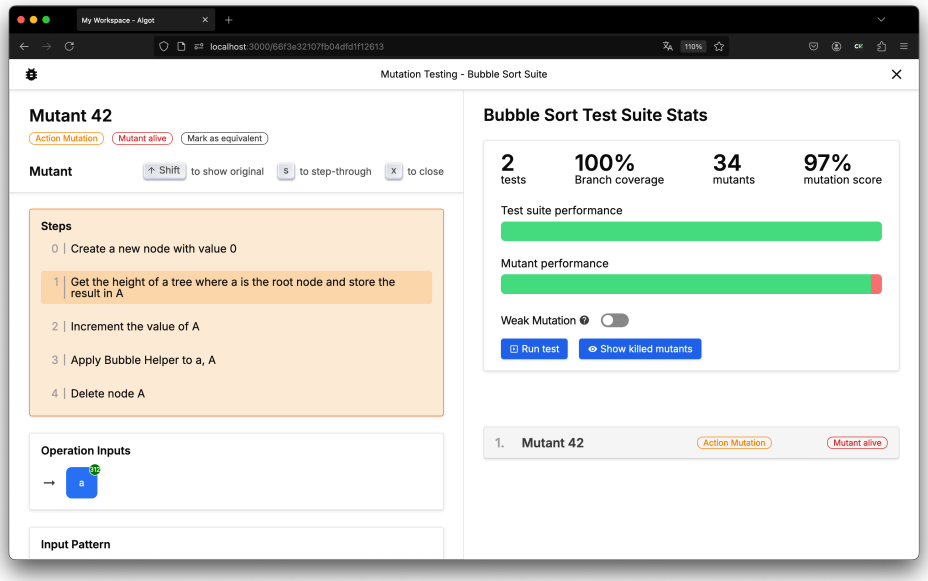


Figure 11: Equivalent mutant of the Bubble Sort operation

2.3 Depth-first Search

For the final example, we consider an implementation of Depth-first Search (DFS) that numbers the nodes in the order they are visited. An example of how the operation numbers the nodes in a graph can be seen in Figure 12.

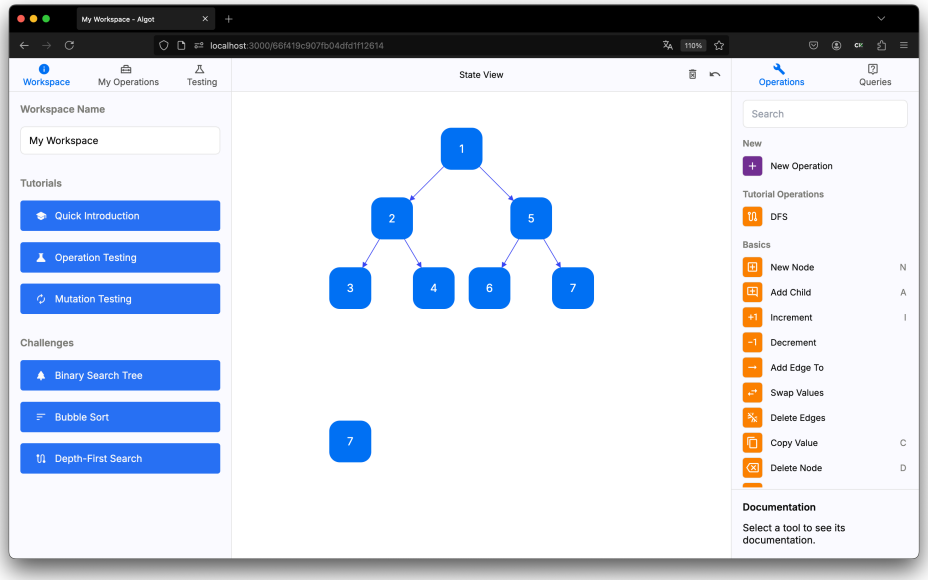


Figure 12: Execution of the DFS operation on a binary tree of height 2

The operation takes two nodes as inputs: first, the current node being traversed by the DFS, and second, a node containing a counter. The precondition for the operation is that every node of the tree being searched has a value 0, indicating it has not yet been visited. The value of the second node (the counter) should be 0 on the initial call if the user wants the numbering to start at 1. In the operation definition, the currently visited node may have one child node, and the parent of the current node may also have

another child, as shown in Figure 13. This demonstrates how operations in Algot can work on inputs with specific graph structures.

If the value of the current node is 0 (i.e., it has not been visited), the counter is increased by one and copied to the current node. If the child node's value is also 0, DFS is recursively called on it with the updated counter. Next, if the sibling node's value is 0, the function is recursively called on the sibling with the updated counter.

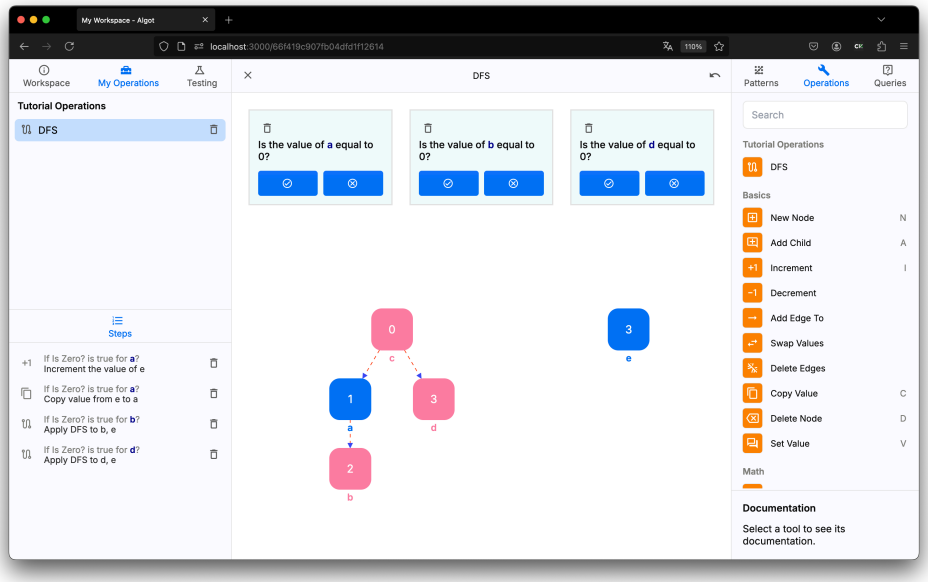


Figure 13: Implementation of the DFS operation

By starting the "Depth-first Search" challenge in TestVision, the DFS operation is added to the sidebar and can be inspected. In this example, we consider a user who wants to test whether this function works on different kinds of graphs. To do this, the user creates new tests for the DFS operation. For the first test, we consider a binary tree, as shown in Figure 14. After running it, we observe that it passes as expected.

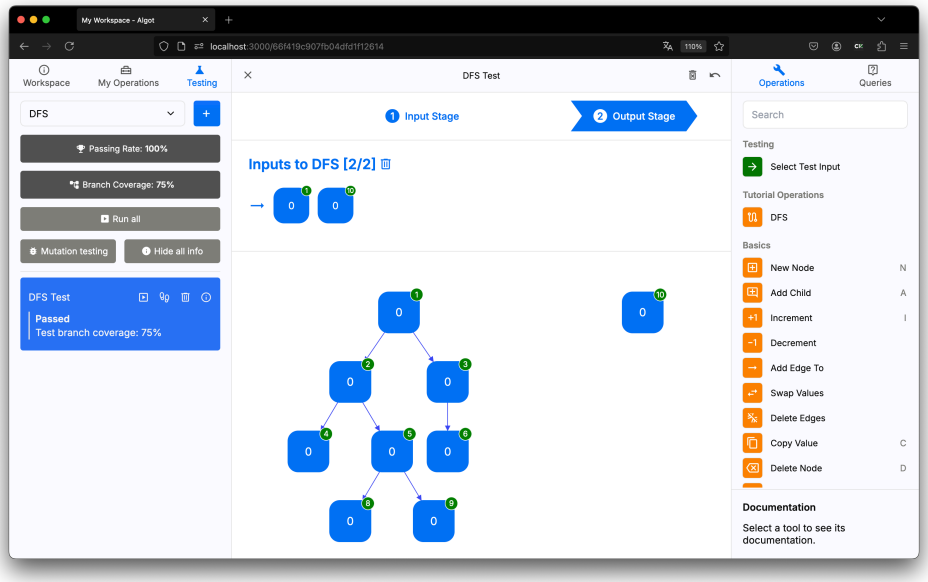


Figure 14: Binary tree test input for the DFS operation

For the next test, the user might introduce multiple paths leading to the same node. An example of this is shown in Figure 15.

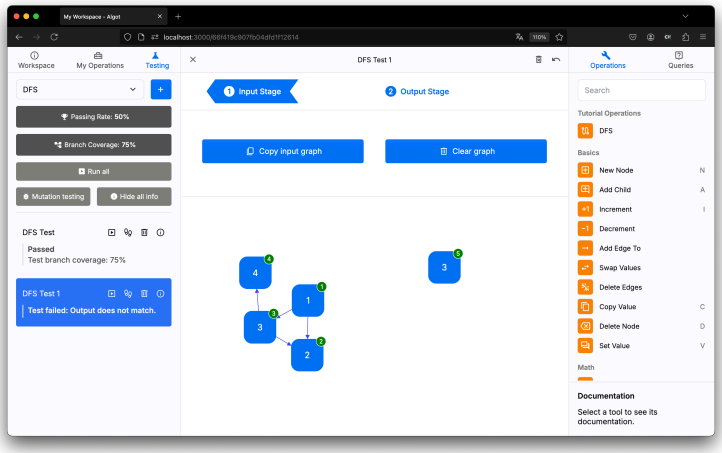


Figure 15: Expected output of a failing test that introduces multiple paths to the same node

After running all tests, we observe that the new test fails: not all nodes are visited by the DFS implementation. The issue is that the operation checks the first child of a node and only recurses over the other children if the first child has not been visited yet. However, by introducing multiple paths to the same node, the first child may have already been visited in a previous iteration, causing the DFS to terminate even though there may still be unvisited children.

The user can observe this in more detail by opening the step-through debugger for the failing test by clicking on the footsteps icon, as shown in Figure 15. In the step-through debugger, all executed actions and their order can be stepped through, revealing why the recursion terminates early. An example of the step-through debugger on the failing test is shown in Figure 16.

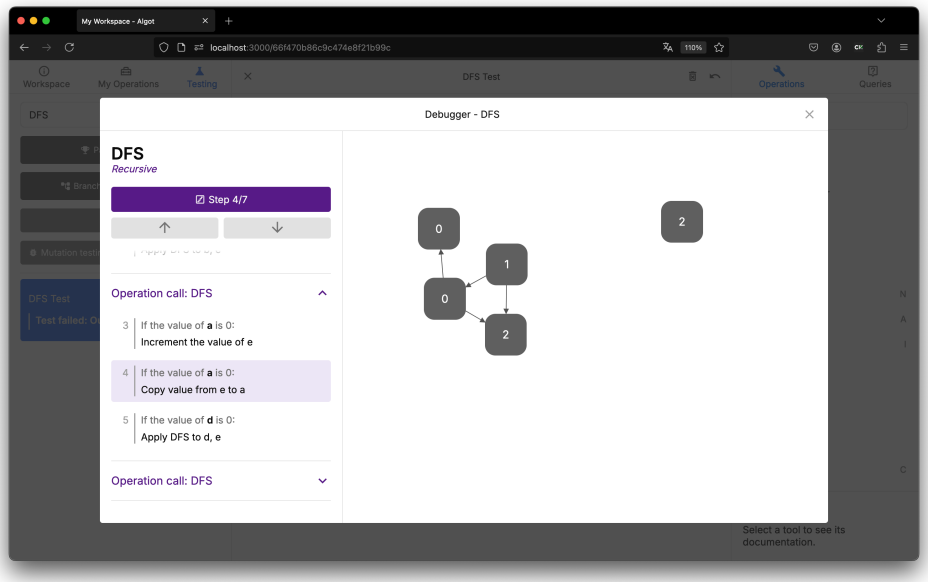


Figure 16: The step-through debugger opened on a failing DFS test

			Novelty				Usefulness				intuitive use				clarity				
ID	Age	Gender	creative	inventive	leading edge	innovative	useful	helpful	beneficial	rewarding	easy	logical	plausible	conclusive	well grouped	structured	ordered	organized	Average
1			7	5	6	7	7	5	7	5	3	6	7	6	5	7	5	5	5.8125
2			6	7															6.5
3			6	4	4	5	4	5	5	5	4	6	5	6	6	4	5	4	4.875
4			6	6	5	6	6	6	7	6	6	7	7	7	6	6	6	6	6.1875
5			6	6	6	7	5	6	6	6	5	5	6	5	6	5	5	6	5.6875
6			7	7	7	7	5	7	7	5	7	7	7	6	7	7	7	7	6.6875
7			6	6	5	6	7	7	7	5	4	5	7	7	6	6	6	6	6
8			6	4	2	5	5	4	5	3	7	1	2	3	6	7	6	6	4.5
9			7	7	6	6	5	6	6	7	6	6	6	6	5	5	6	5	5.9375

ID	What part of the course material do you consider to be the most challenging or difficult?
1	- Symbolic execution (Klee in particular, not very intuitive results). - Data Flow Analysis (difficult content)
2	I think recursion is hard to grasp. Especially for new students of programming or math. This needs a deeper introduction I think.
3	I think the design of the dot product algorithm is the most challenging one.
4	Mutation testing. How to compute mutation score and how to efficiently find the test cases that are useful.
5	The fundamental of software testing as there was little experience prior to taking the course.
6	I found the abstract interpretation lecture a bit confusing. The rest was fine, especially after doing the exercises
7	Most of the concepts were ppretty straightforward. Some homeworks were difficult to setup. The project is a bit challenging to practically apply the concepts we learnt in lecture.
8	Mutation testing
9	Symbolic execution
	Could the material be presented in a different way to help you meet your learning goals?
1	Data Flow Analysis could be presented initially from a more practical perspective (examples, etc).
2	It is a good complement to the learning material in the lectures.
3	It's pretty clear in my opinion.
4	I think it is a good introduction. By demonstrating mutation testing in a visual way, we can understand it easily. I think it would be better by discussing more details about different kinds of mutants.
5	not sure, more time
6	Nothing comes to mind. I like the exercises and assignments to help with understanding.
7	Yes, we learnt everything in a very theoretical way. I would appreciated some concepts to be shown practically used in the lecture.
8	Mutations were only explained after having been mentioned numbee of times in examples. Having explained what mutatinos are would have helped.
9	digestible shorter videos with quizzes in the middle in general weekly quizzes on moodle for better comprehension.
	Please describe your impression with the software
1	Very nice idea to offer a visual language. The interface is modern and clear. Sometimes it's difficult to navigate around the different functionalities of the language.
2	I think it is a good software with a clear UI. Great with hover information on buttons. Nice overview of test cases easy to follow.
3	The software is usable, but there can be improvements such as when designing an operation, the close button "x" can be more obvious. It took me long to find where it is. Also, adding children can be done pressing "A" repeatedly instead of having to click on the newly ad
4	It is a very fancy software. It's my first time to use it, yet I find it quite easy to start with. It's useful to learn new knowledge by experimenting with this software.
5	Design very good, minimal and easy to understand. User functionality: everything is strate forward and implemented in a user friendly way
6	It looks good and easy to navigate.
7	At first glance, the software seems very helpful to solve/understand problems before coding them eg in intro to programming
8	Nice to see visually what happens during mutation testing.
9	It seems very well thought out and beautifully designed. It just seems to have some hiccups.
	Could you describe any challenges you can identify with the software?
1	It is not possible to give names to nodes ("variables" naming). There should be more explanations describing the different functionalities (on the interface). It coudl be difficult to implement more complex operations.
2	Not immediately.
3	The challenge I can identify is how to deploy the written program in Algot to real life.
4	Add more tutorials, it's still a little confusing about how to use this software, like how to add inputs to testcases.
5	not right of the bat, but some at the short cuts and case of user flow could be improved with more information but that could also waste it harder on the user
6	No.
7	I found it difficult to understand. There was an introduction but it was fast and then when working with it, I forgot how to do multiplication operation.
8	People unfamiliar with Algot may need some time to wrap their head around all of these interfaces
9	General usability kinks, like placement of nodes, being able to delete nodes from the input graph in demonstration node without making it an operation
	Do you think that the software can help you with your learning goals?
1	Yes it can be useful to learn recursion for beginners and the feature about mutation testing is very well done and I would us it to actually understand better how mutation testing works.
2	It is for sure easier to grasp mutation testing visually. Also equivalent test cases are easier to understand and compare.
3	Yes. The visual nature of the software helps a lot with that.
4	Yes.
5	haveing a state stepper is a good learning tool to see how these tests are implemented so yes it could help
6	Yes, especially the mutation testing part. The visualizations are nice to understand the operations done by the mutations.
7	Yes.
8	Unsure. I'd have to really dig deep to try it myself to me
9	I think it is very nice to learn about testing with it. It helped me clear up oen questions on mutation testing and solidify my course knowledge
	What improvements or additional features could improve the software?
1	Name to variables; make testing section clearer; documentation; visualization of branch coverage and other types of coverage metrics; clearer separation between phase of operation definition and actual use of it
2	Algot in general ctrl+z for regret.
3	More features such as OOOP and floating points.
4	Maybe more testing technics could be added. Such as dataflow testing.
5	A guiding hand for users that are finding this on there own to get them up to speed with usage
6	Being able to name the nodes would be nice. If this is alread possible I don't see how.
7	Maybe have a user guide that I can click on when I get stuck.
8	A some sort of "guided form." I would never have figured out how to use it without the verbal explanation.
9	* Further testing concepts like symbolic execution * Sometimes the demonstration node tends to make some assumptions, e.g. what input for nodes match what graphs, and these seem to be made super explicit in the software, which is confusing
	Do you have any other comments regarding the software that you would like to share?
1	I've noticed that there are diffferent releases of the software, it would be nice to know what is the difference between them :)
2	Really good implementation at east on the front end. Hopefully backend is good as well.

3	The tutorial is really clear and the software only needs minor adjustments.				
4	It's very good!				
5	Slower a bit, getting last could be a problem and going over more tests in a creative way. P.S. the tutorial was really good				
6					
7	In the testing part. When it adds a node at the bottom and I repeatedly click on it, it labels 'a, b, c... usually clicking the background exists from that. However, for these nodes, I had to click the background at the top near the other nodes to exit from the labelling.				
8	Ton of material to cover within 15 minutes, especially to people who have never heard of Algot before				
9					