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Enhancing the Verification-Driven Learning Model for Data Structures with Visualization

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Enhancing the Verification-Driven Learning Model for Data Structures with Visualization

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Abstract

The thesis aims at teaching various data structures algorithms using the Visualization Learning tool. The main objective of the work is to provide a learning opportunity for novice computer science students to gain a broader exposure towards data structure programming. The visualization learning tool is based on the Verification-Driven Learning model developed for software engineering. The tool serves as a platform for demonstrating visualizations of various data structures algorithms. All the visualizations are designed to emphasize the important operational features of various data structures. The learning tool encourages students into learning data structures by designing Learning Cases. The Learning Cases have been carefully designed to systematically implant bugs in a properly functioning visualization. Students are assigned the task of analyzing the code and also identify the bugs through quizzing. This provides students with a challenging hands-on learning experience that complements students' textbook knowledge. It also serves as a significant foundation for pursuing future courses in data structures.

Keywords: Data Structures, Visualization Learning tool, Verification-Driven Learning Model, Learning Cases.

1. Introduction

Learning programming concepts is often considered very challenging for novice students [1]. High attrition rate among students in data structures courses is a common phenomenon in computer science programs. The challenge is largely because students often fail to understand all the aspects of the algorithms and intricate code that implements them. In learning of data structures, it is imperative that students understand the abstract models and the algorithms in an intuitive and tangible manner at their initial learning stage.

The target group of people for this thesis is the computer science students enrolled in the data structures courses. Our selection of this target group is based on the fact that learning data structures is important as they take a pivotal position in programming. Textbooks are an important source to students that explains the working functionality of programming concepts such as data structures. However, recent studies have found that the usefulness of a textbook in exposing the entirety of a concept matter is very limited [2]. Students are often not able to identify the important features in programming for data structures. To prevent this, students need additional help in learning data structures.

Hands-on activities are regarded as an efficient means in helping students comprehend the programming concepts. Studies show that students who are encouraged to attend lab courses along with the classroom lectures have performed well in a definitive testing environment [3]. These lab courses use animations and other visual representations that bring the abstract concepts of the object oriented programming to the fore [3].

Our project is based on teaching data structures with the help of code visualization and operational animations. Failures in understanding the object-oriented programming occurs because of two major reasons: Misunderstanding of the concept itself and misunderstanding of the program code [4]. We believe that learning data structures poses similar challenges. To develop an efficient learning platform, it is necessary that these two issues are addressed. Students are given proper user interfaces to interact with the programs, and focus on the important aspects of the data structures that would otherwise be overlooked in just reading. To address the aforementioned issues, we have implemented learning cases based on the verification-based learning model for the students.

The project has enhanced the Verification-Driven learning model (VDL) with high-quality animations and code visualizations. The basic VDL learning procedure [5] has been adjusted to the process given below:

Step 1: Students begin the process by reviewing the functionalities of the data structures and understanding the goal of the operations.

Step 2: Students interact with the program by playing the animations of operations provided. These operations are based on a set of data structures.

Step 3: Students go through the task of analyzing the code and understand the code in an implementation point of view. They will be able to relate the code implementation to the actions of the animations.

Step 4: Students are challenged by multiple-choice questions that require the students to identify the bugs that are deliberately planted in the program.

Step 5: Students will make use of the code logic visualization provided along with the animations to identify the bugs.

With a successful implementation of the aforementioned process of steps, students will be able to identify the extent to which they understand the concepts implemented in the learning model. A VDL model for data structures supported by visualization consists of the following aspects. This list is a customization of the VDL model for general software engineering [5].

1. A working implementation of the set of subject data structures.
2. An explanation of the algorithms of the subject data structures.
3. Animations that visualize the specifications of data structures and their functionalities.
4. An interactive user interface that controls the animations.
5. Test cases that encourage the students to do critical thinking and analyze the algorithms implemented by the code
6. Multiple-choice questions that challenge the students' critical thinking.

2. Background

A brief description of the concepts, tools and development environments utilized in the project are given in this chapter.

2.1 Data structures

A data structure is a particular way of organizing data in a memory so that it can be used efficiently. Data structures are the foundation in programming and very often used as organized means of storing data in software design. Only a few data structures are involved in disk storage. For example, B-Trees are usually used for the implementing databases.

Array, Linked List, Stack, Hash Map, Heap, Queue, Tree, etc., are the most common used data structures in programming. In a broader sense, data structures are categorized under two types: Linear and Non Linear data structures. For the purposes of demonstration of animation and learning cases, we have implemented the animations for the following data structures: Array, Linked List, Doubly-Linked List, Circular-Linked List, Stack, Queue, Binary Tree, AVL Tree and Hash Table.

2.2 Adobe Flex

The Flex SDK in the visualization learning tool is used to provide a launching platform for both flex and flash enabled animations. The entire application layout and design is carried out through Flex.

Adobe Flex is a free, open source framework for building highly interactive, expressive web applications that deploy consistently on all major browsers, desktops, and operating systems. Flex includes a rich component library for creating rich Internet applications (RIAs). Flex applications considerably reduce the network burden and also provide fast rendering ability to the web applications. In a flex application, the client is always bound to the server. This makes it easy for the flex applications to render the web content. Typical HTML applications consist of multiple pages and as a user navigates between them, the application data must be passed along so the application itself (the collection of pages and functionality it consists of) can maintain state.

In contrast, Flex applications are stateful. A Flex application is embedded in a single HTML page that the user does not leave and is rendered by Flash Player. The Flex application can dynamically change views and send and retrieve data asynchronously to the server in the background, updating but never leaving the single application interface.

2.3 MXML

MXML is a convenience language which provides an alternate way to generate ActionScript using a declarative tag-based XML syntax. When an application is compiled, the MXML is parsed and converted to ActionScript in memory and then the ActionScript is compiled into byte code with swf file format.

2.4 Actionscript

Actionscript is used to write the design and layout implementation logic in Flex. Also, it is used to manipulate the timing aspects of the animation in the Flash Professional CS5. ActionScript code is compiled to swf file format which is then loaded in to the browser of the client and played using Adobe Flash Player.

2.5 Adobe Flash Builder

Flash Builder 4.0 is used to create the flex background for the learning tool. The use of Flash Builder for the flex applications makes it very convenient to manage, deploy and debug the flex project during the development process.

2.6 Adobe Flash Player

Adobe Flash Player is a browser plugin that is required to deploy the Flex/Flash swf files on the client side. It is an Active X control that has a much richer object model and rendering engine that allows developers to include more highly expressive and interactive content in web applications.

2.7 Flash Professional CS5

Adobe Flash Professional CS5 is used to design the animations necessary for the concept visualization of the data structure functionalities. The compiled swf files are deployed into the flex application layout to run the animations.

3. Teaching Data structures with Operational Animations and Code Visualization

The primary objective of the animations is to illustrate the algorithms of data structures in a visually appealing and intuitive manner. The final goal is to provide students with a sound knowledge through concrete examples.

3.1 Lab Design

The project implements various animations to illustrate the working processes of the data structure algorithms. To help the users understand the algorithms in an efficient way, the animations are illustrated along with the visualization of the code. Additionally, the play/pause and replay buttons allow students to control the animations while they are being visualized. The following are the brief descriptions of the data structures and their algorithm animations we have developed for the project.

3.1.1 Animation and Code Visualization for Array

An array is a data structure consisting of a group of elements occupying a contiguous area of memory. The applications of arrays are often mathematical vectors and matrices.

Our project implements animations for a number of algorithms including sorting, searching, insertion and deletion in arrays. We have implemented animations of quick sort, bubble sort, insertion sort and merge sort. Figure 1 shows the code that implements the quick sorting for an array.

```
public class QuickSort{
	public static void main(String a[]) {
		int i;
		int array[] = {50,33,70,20,40,90,10,30,55,34,23,12};
		quick_srt(array,0,array.length-1);
	}
	public static void quick_srt(int array[],int low, int n) {
		int lo = low;
		int hi = n;
		if (lo >= n)   {
			return;
		}
		int mid = array[(lo + hi) / 2];
		while (lo < hi) {
			while (lo<hi && array[lo] < mid) {
				lo++;
			}
			while (lo<hi && array[hi] > mid) {
				hi--;
			 }
			 if (lo < hi) {
				int T = array[lo];
				array[lo] = array[hi];
				array[hi] = T;
			}
		}
		if (hi < lo) {
			int T = hi;
			hi = lo;
			lo = T;
		}
		quick_srt(array, low, lo);
		quick_srt(array, lo == low ? lo+1 : lo, n);
	}
}
```

Figure 1

Figure 2 shows the snapshot of the quick sort animation. Each bar in the animation represents an individual element of the array. The bars highlighted in green indicate the items currently being compared for sorting. By showing the movement of the elements in the array, we visualize the actions of the algorithm. Each line of the code in the code visualization box is highlighted when the corresponding action happens in the animation.

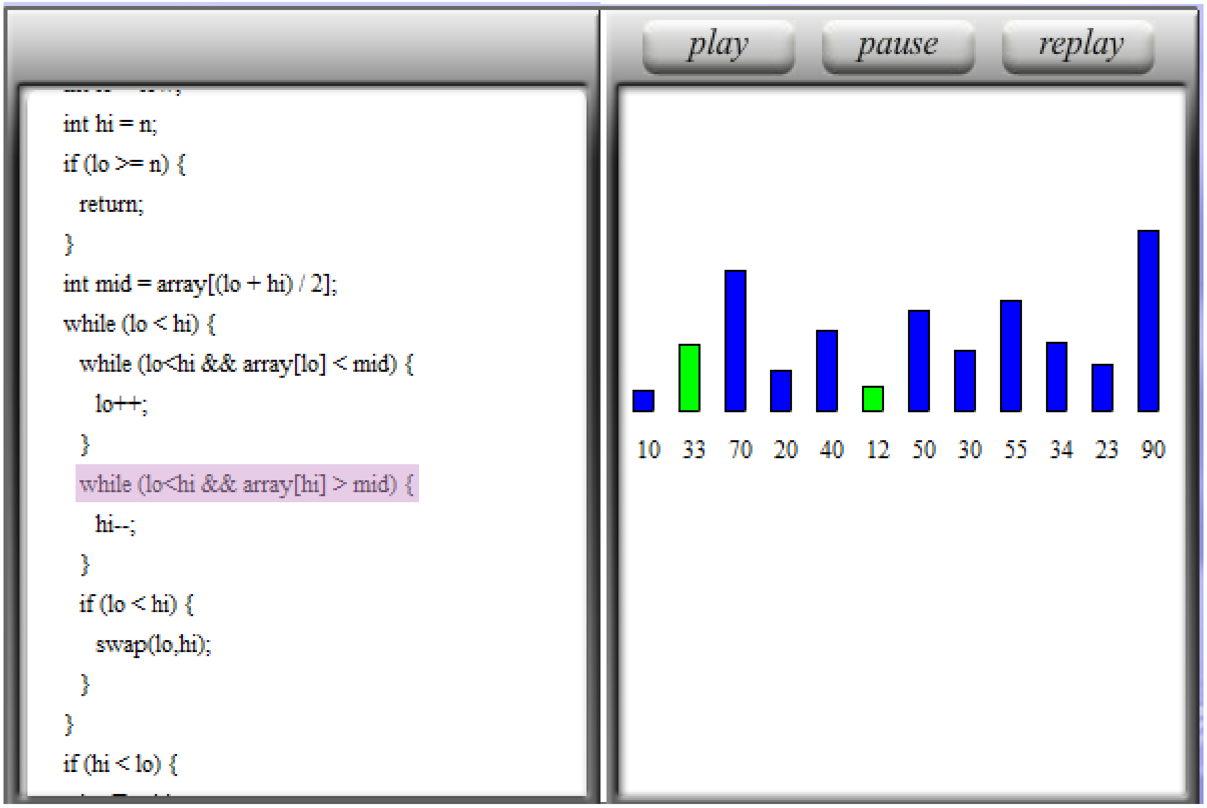


Fig 2

3.1.2 Animation and code visualization for Linked List

A linked list is a data structure that consists of a sequence of nodes each of which contains a reference to the next node in the sequence. A linked list data structure can be used to implement several other data structures such as stacks and queues. One major advantage of linked list is that the list elements can be easily added or removed without reallocation or reorganization of the entire structure.

A linked list contains nodes, each with a reference (a pointer) to its next node. The animations are carefully designed to resemble the structure. The major operations on a linked list are search, insert and delete. In an insert operation, after the new node is added, it is important to rearrange the references between the nodes.

```
class Node {
	public int iData;
	public Node next;
	public Node (int id);
	{
		iData = id;
	}
}
public Node searchNode (int id) {
	Node destNode = null;
	if (first !=null) {
		Node curNode = first;
		while (curNode !=null) {
			if (curNode.iData == id) {
				destNode = curNode;
				break;
			}
			curNode = curNode.next;
		}
	}
	return destNode;
}

public void deleteNode (int id) {
	Node destNode = searchNode (id);
	if (destNode !=null) {
		if (destNode == first) {
			first =first.next;
		}
		else {
			Node prevNode = searchNode (destNode);
			prevNode.next = destNode.next;
		}
	}
}
```

Figure 3

When a node is deleted, the references between the remaining nodes must be rearranged. Figure 3 shows the code that implements the delete operation in the linked list. Figure 4 shows a snapshot of the animation of the delete operation in a linked list.

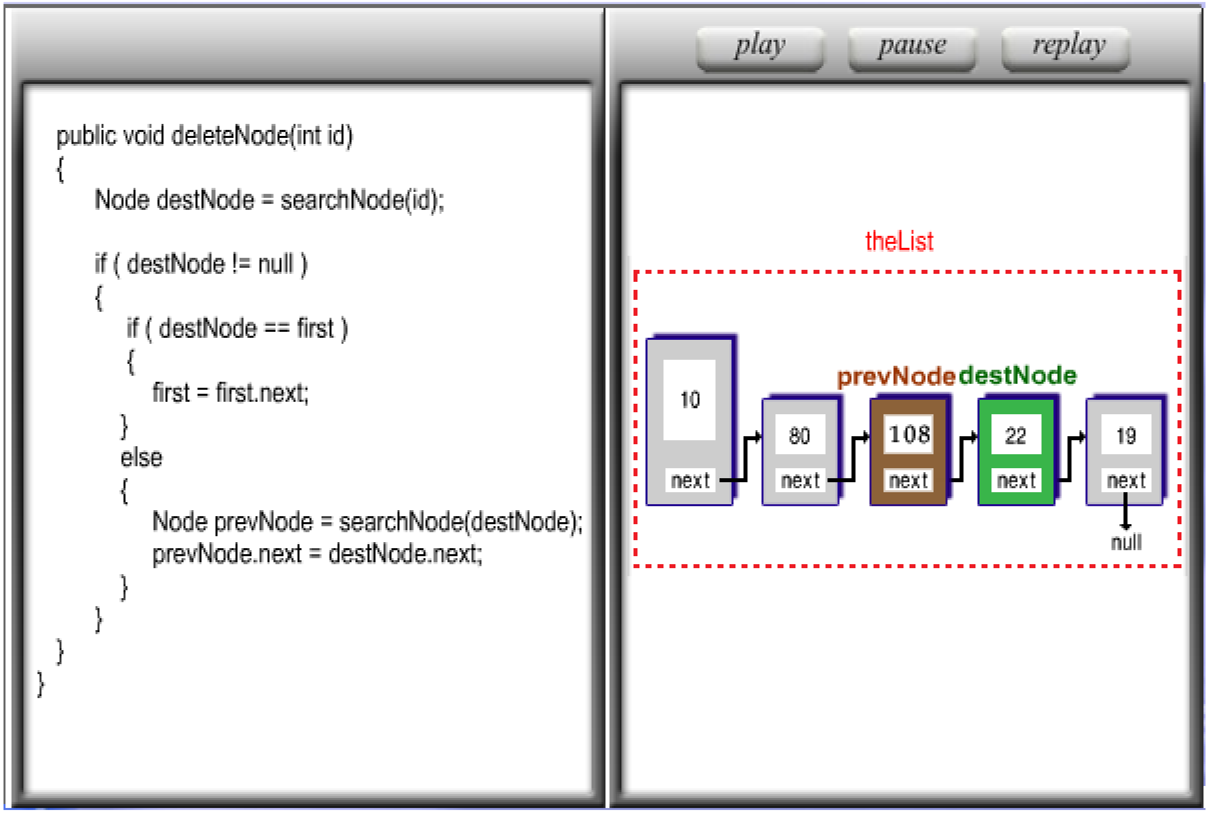


Fig 4

The objective of the animation in Fig 4 is to illustrate the deletion of node 22. The deletion of the node is accomplished by the change in the references to the nodes that are on either side of the deleted node. From the figure, the “next” reference of the node 108 is to be replaced by the reference pointing to node19.

3.1.3 Animation and code visualization for Doubly-Linked List

In a doubly-linked list, each node has two references: one reference points to its previous node and the other points to its next node. Though adding or deleting nodes in a doubly linked list requires more operations, there is neither need to keep track of the previous node during traversal nor no need to traverse the list to find the previous node. This makes node reference modifications easier. Fig 5 shows the code that implements the search operation in a Doubly-linked list. Figure 6 is a snapshot of the animation to search node 22.

```
class DoublyNode {
	public static void main (String[] args) {
		NodeList theList = args[0];
		Node destNode = theListsearchNode(22);
	}
}
public Node searchNode (int id) {
	Node destNode = null;
	if (first !=null) {
		Node curNode = first;
		while (curNode !=null) {
			if (curNode.iData == id) {
				destNode = curNode;
				break;
			}
			curNode = curNode.next;
		}
	}
	return destNode;
}
```

Figure 5

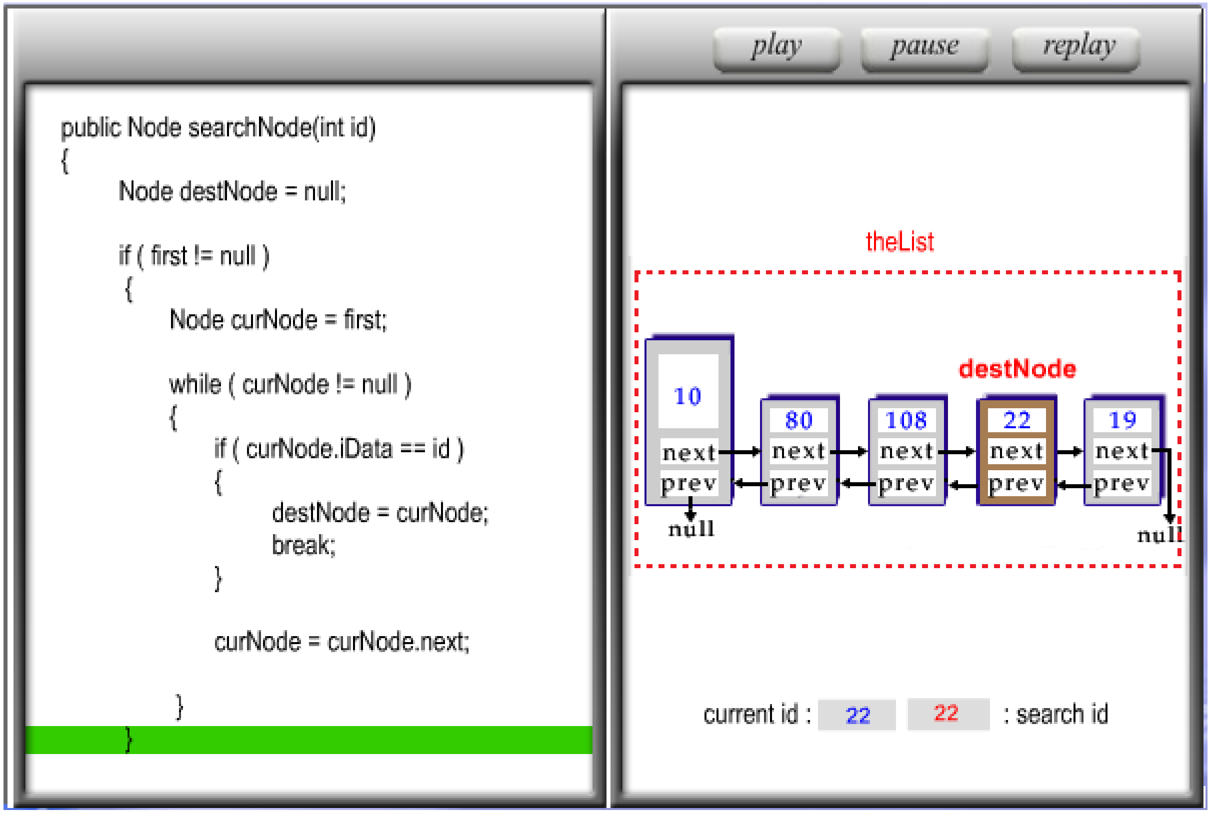


Fig 6

3.1.4 Animation and code visualization for Circular-Linked List

A circular-linked list is a linked list in which the "next" reference of the last node points to the first node. Hence, a pointer to the last node gives easy access also to the first node, by following one reference. Thus, in applications that require access to both ends of the list (e.g., in the implementation of a queue), a circular structure provides convenience. Figure 8 is a snapshot of the insert operation of node 20 in a circular-linked list. The animation also shows the rearrangement of the references of nodes 108 and 22 after inserting node 20. Figure 7 shows the code that implements the insert operation in a Circular-Linked list.

```
public Node searchPrvNode (Node destNode)  {
	Node prevNode = null;
	if (first !=null) {
		Node curNode = first;
		while (curNode !=first && curNode !==null) {
			if (curNode.next ==destNode) {
				prevNode = curNode;
				break;
			}
			curNode = curNode.next;
		}
	}
	return destNode;
}

public void insertNode  (int pos, int id) {
	Node newNode = new Node (id);
	Node destNode = searchNode (pos);
	if (destNode == null ||destNode == first) {
		newNode.next = first;
		first = newNode;
	}
	else if (destNode == last) {
		newNode.next =null;
		last = newNode;
	}
	else {
		Node prevNode = searchprvNode (destNode);
		newNode.next = destNode;
		prevNode.next = newNode;
	}
}
```

Fig 7

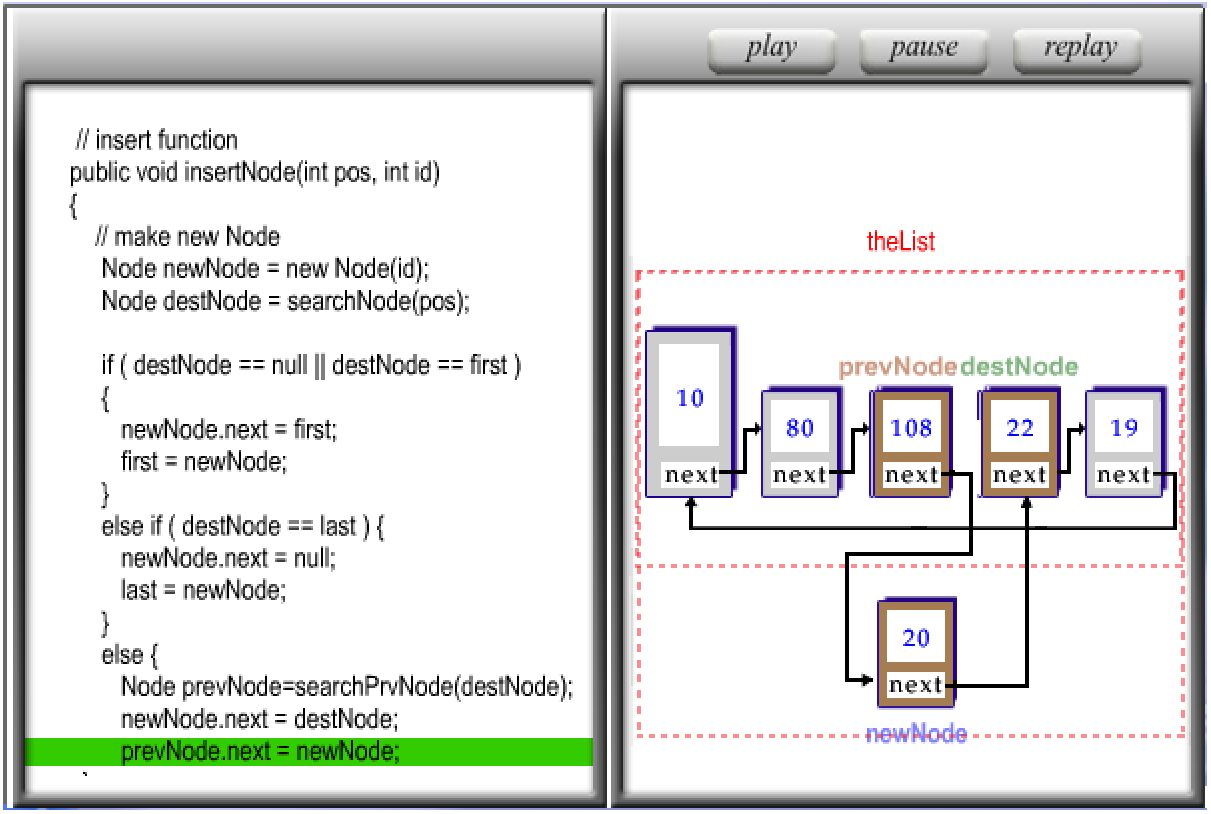


Fig 8

3.1.5 Animation and code visualization for Stack

Stack is a data structure that stores its data values in a FILO manner. Each data entry is stacked on the top of the previous entry. A Stack data structure usually implements two functionalities: PUSH and POP. Figure 10 is a snapshot of the animation of the application of a stack theStack.

```
Class stackPop {
        public static void main (String [] args) {
                Stack theStack  = new Stack();
                theStack.push(20);
                theStack.push(30);
                theStack.push(40);
                while (!theStack.isEmpty ()) {
                        double value = theStack.pop ();
                        System.out.println (value);
                        System.out.println (",");
                }
        }
}
```

(figure continued)

```
class Stack    {
        private int maxSize;
        private double [] stackArray;
        private int top;
        private int front;
        public Stack (int s) {
                maxSize = s;
                stackArray = new double [maxSize];
                top = -1;
                front = 0;
        }
        public void push (double j) {
                stackArray [++top] = j;
        }
        public double pop ()  {
                return stackArray [top--];
        }
}
```

Fig 9

Figure 9 shows the code that performs the applications of the stack. The animation in Figure 10 shows that since the value 20 is added first in to the stack, it will be the last item to be popped out. With each pop operation, exactly one item (on top of the stack) is removed.

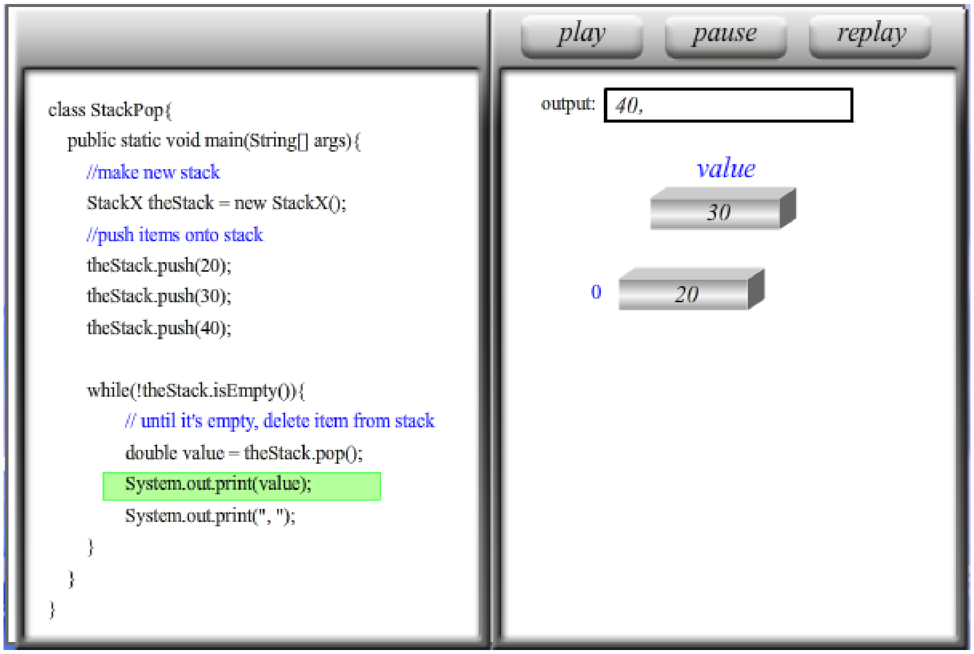


Fig 10

3.1.6 Animation and code visualization for Binary Tree Traversal

Traversal of a tree structure means visiting all the nodes of a tree exactly once. For the purpose of illustration, inorder, preorder and postorder tree traversals have been implemented. The following is a snapshot of the inorder traversal of the binary tree.

In an Inorder traversal, the left child, root node and the right child are traversed in the respective order. The traversal is programmed with a recursive style of implementation.

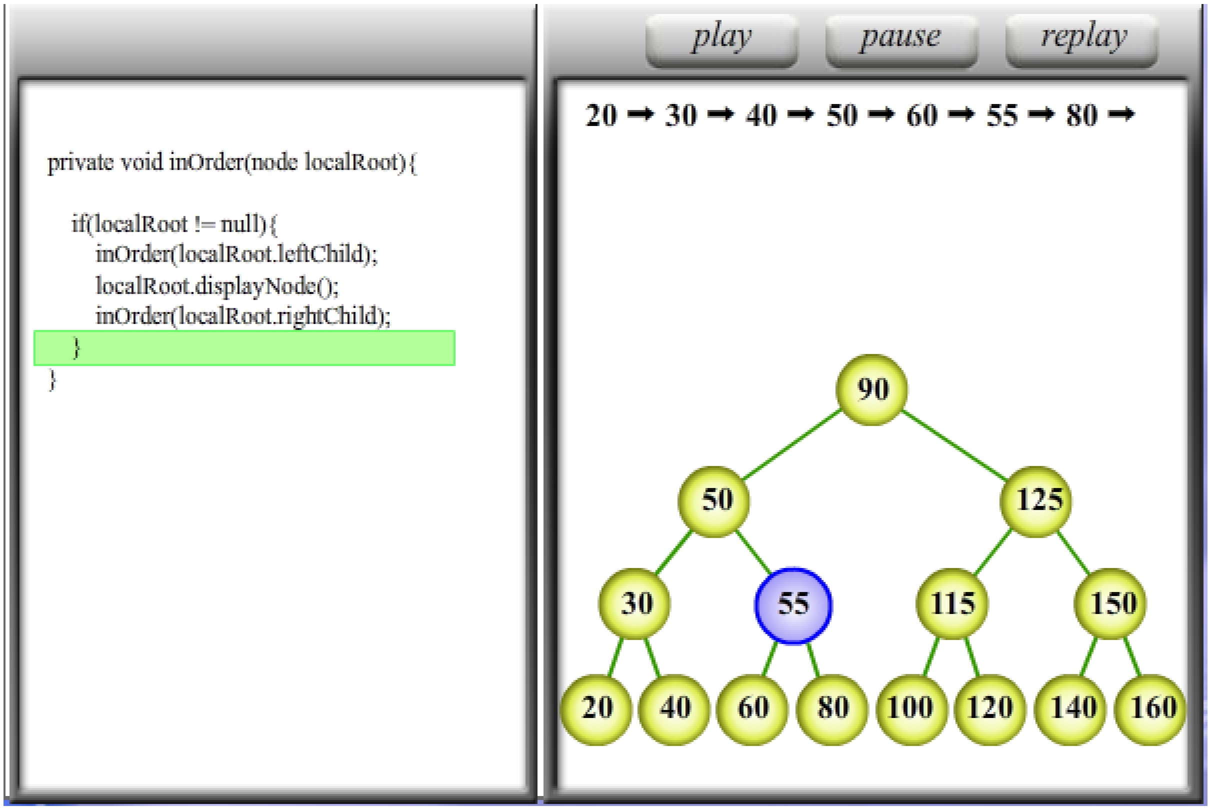


Fig 11

3.1.7 Animation and code visualization for Hash Table

A Hash Table uses a key-value pair to store information in a table. The hash function operates on the key and the result of the hash function determines the location where the data value has to be stored. To deal with hash collisions, we applied the linear probing technique to store the data records. If the intended location to store a key is unavailable, the immediate next slot is attempted until an empty slot is found to store the data. Figure 12 is a screenshot of the insert operation in a hash table.

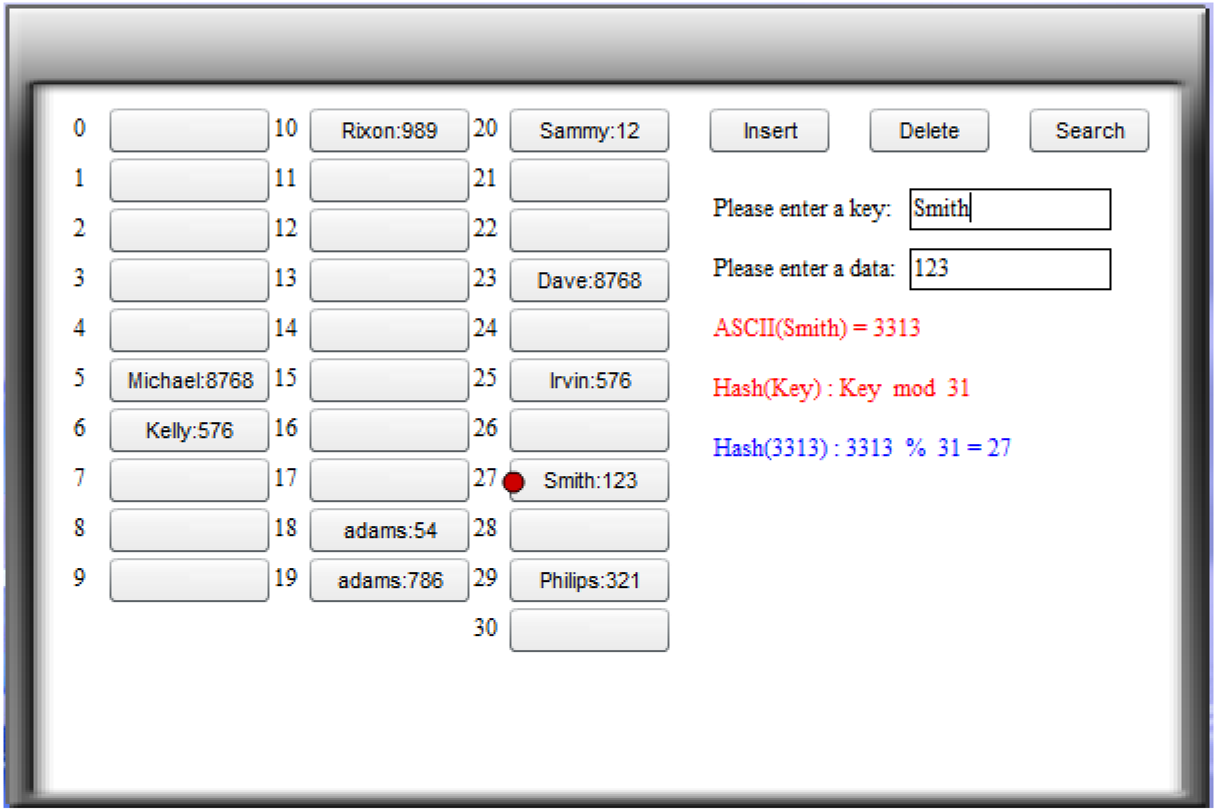


Fig 12

As shown in figure 12, the key-value pair entered by the user is stored in the location determined by the hashing function. The hashing function is:

Hash (key) = key mod 31

The numeric equivalent value of the text key is determined by the customized ASCII conversion. The numeric value is operated upon by the hashing function to determine the location where the data needs to be stored. The maximum number of characters for the key is constrained to 24.

3.1.8 Animation and code visualization for AVL tree

An AVL tree is a nearly balanced binary search tree. The maximum difference between the heights of the left and right sub trees of any node cannot be greater than 1. Imbalance in the sub-trees of a node arises when a new node is added to the tree. We implement the animation for the double rotation that adjusts the imbalanced tree. To illustrate the double rotation in the AVL tree, we insert node 70 into the tree. Figure 13 shows the Avl tree before adding node 70.

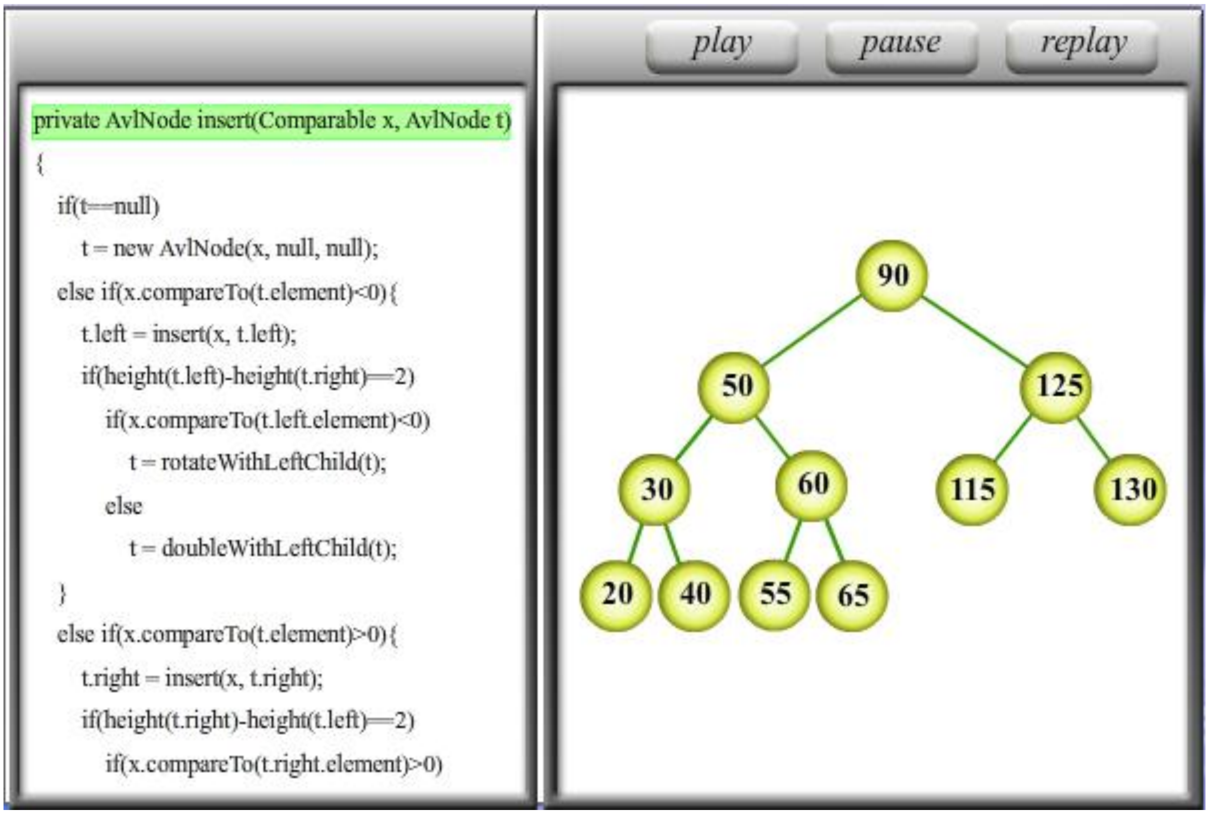


Fig 13

When we add node 70 as the right child to node 65, the tree becomes imbalanced at node 90. This is because the height of the left sub-tree of node 90 is now increased to 4 while the height of its right sub-tree is to 2. The resulting imbalanced tree is shown in Figure 14.

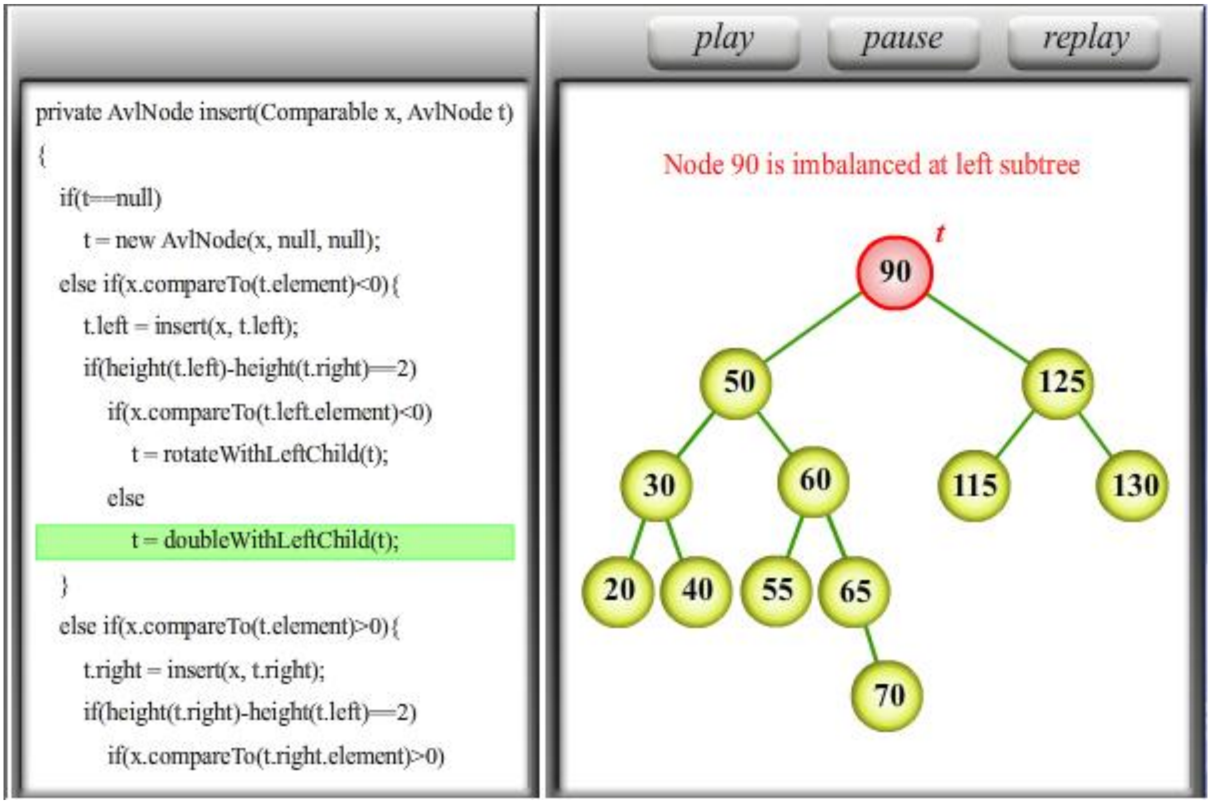


Fig 14

To balance the tree, we need to perform double rotation. In the animation, Double rotation is achieved by two single rotations. First, we perform single rotation at node 50 by rotating it to the left. Figure 15 shows a snapshot of the animation after rotating the tree at node 50.

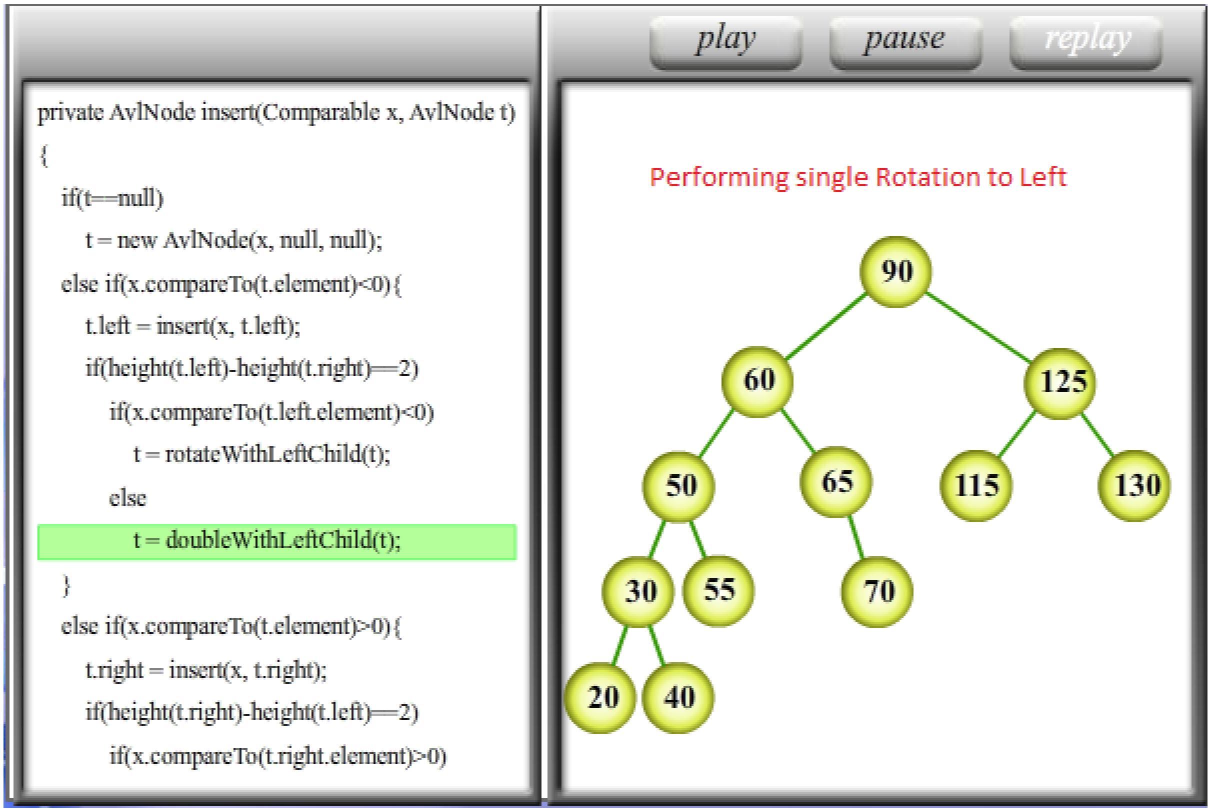


Fig 15

Since the tree is still not balanced, we perform single rotation at node 90 by rotating it to the right. Figure 15 shows a snapshot of the animation after the tree is rotated at node 90. From the Figure 16, it can be seen that the tree is now balanced with the highlighted sub-tree shifting to the right side of the root node. The code to perform the tree rotation in the tree is given in Figure 17.

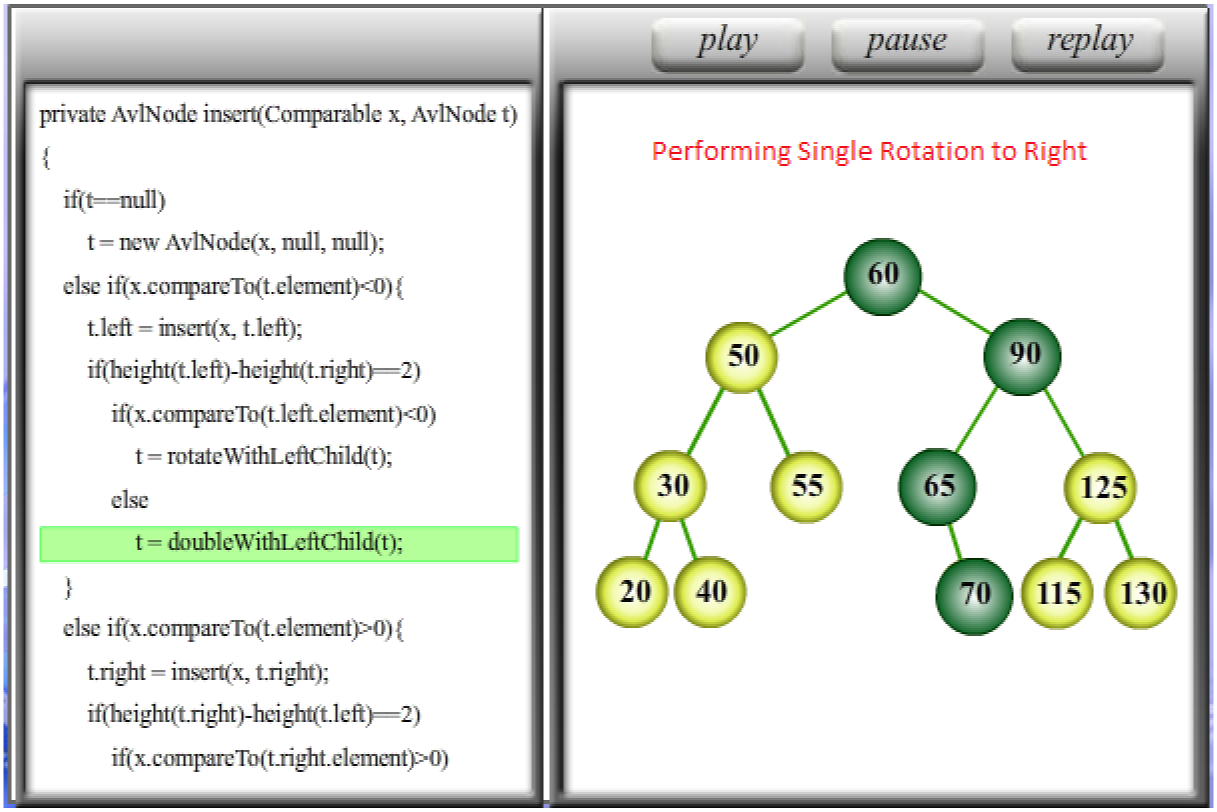


Fig 16

```
//x – the new node to insert
// t – the node that roots the tree

private AvlNode insert (Comparable x, Avl Node t) {
        if (t == null)
                t = new AvlNode (x, null, null);
        else if (x.compareTo (t.element) <0) {
                t.left = insert (x, t.left);
                if ( height (t.left ) – height (t.right) == 2)
                        if (x.compareTo (t.left.element) < 0 )
                                t = rotateWithLeftChild (t);
                        else
                                t = doubleWithLeftChild (t);
        }
```

(figure continued)

```
        else if (x.compareTo (t.element) >0) {
                t.right= insert (x, t.right);
                if ( height (t.right ) – height (t.left) == 2)
                        if (x.compareTo (t.right.element) < 0 )
                                t = rotateWithRightChild (t);
                        else
                                t = doubleWithRightChild (t);
        }
        else ;
        t.height = max ( height (t.left ), height (t.right)) +1;
        return t;
}
```

Fig 17

3.2 Visualizing Program Execution by Highlighting Code

Dynamically highlighting the currently executing code has been a common feature of most program debugging tools. To demonstrate the actions of the code, we have implemented the feature of dynamic code highlighting along with animations. When each action happens in the animation, the corresponding line of code is highlighted. Students can replay and pause to trace the relationship between the actions and code to the most detailed level.

The snapshot in Figure 18 illustrates the code highlighting feature in the Push algorithm of a stack. Students can use the pause and replay buttons to understand the animation and analyze the current line of code that the animation is implementing. The figure shows the push operation on the stack by adding the new value 40, along with the corresponding code line being highlighted in the code visualization box.

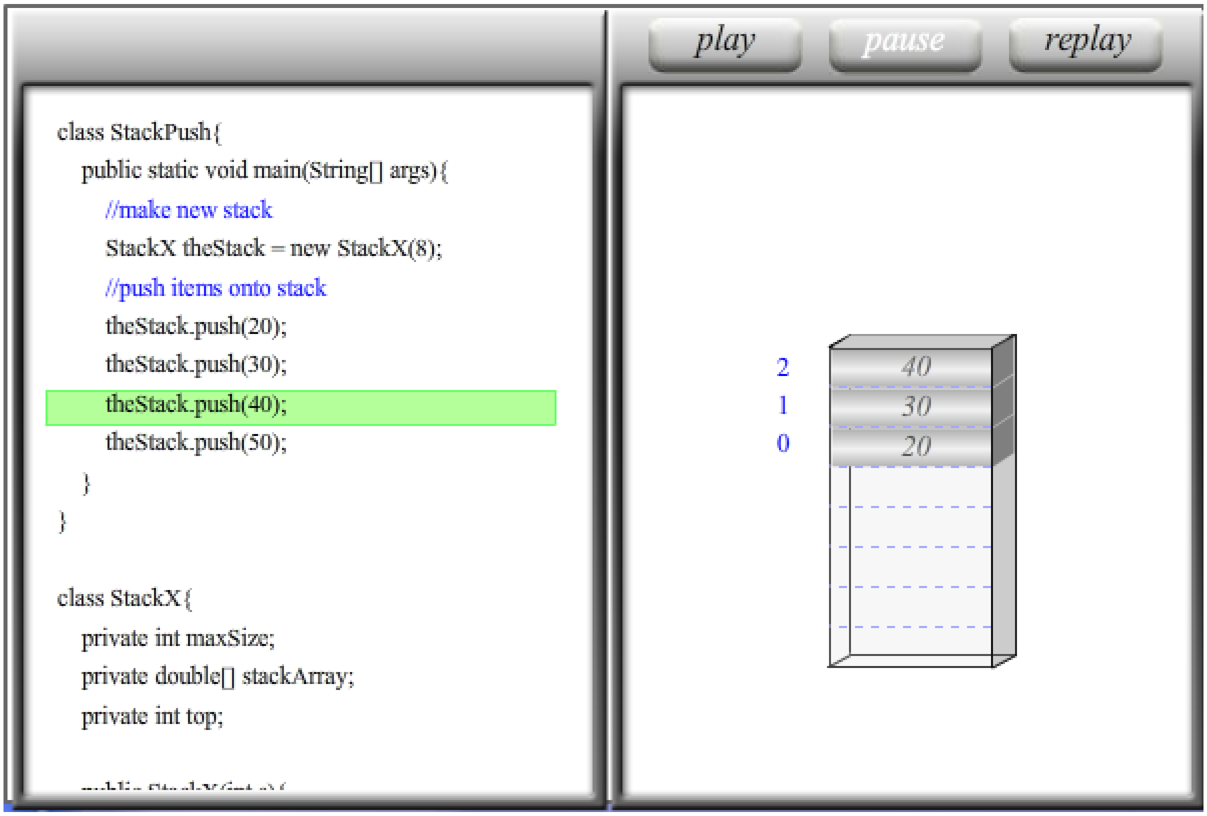


Fig 18

By helping students simultaneously co-relate the code with the actions in the animation, we hope to provide them a good visualization tool for learning actual implementation.

The learning tool has two modes: The Learning Mode and the Quiz mode. The Learning mode employs all the functionally correct animation visualizations. The debug mode employs the animations that are deliberately tweaked to implant errors in the animations. Students are assigned the task of identifying the problems in these animations and are asked to answer the multiple choice questions. The multiple-choices questions pose a challenge to the students that require thorough study of the algorithm and a clear understanding of the functionality of the animated operation.

4. Applying Algorithm Animations and Code Visualization to VDL Learning Cases

The thesis aims at teaching students various data structures algorithms. All the algorithms are illustrated in the form of animations. The following data structures are implemented for the project – Array, Linked list, doubly linked list, Circular linked list, Stack, Queue, Binary Tree, AVL tree, Hash Table. The animations in the thesis are presented in 2 modes: Learning mode and Debug mode.

Learning mode illustrates all the animations for all the algorithms implemented for the respective data structures. A total of 28 animations, constituting all the data structures, are presented in the Learning mode. Students are provided with Play, Pause and Replay buttons to control the animations for better and clear understanding of the concepts presented.

Table 1 lists all the algorithm animations implemented for the project in the Learning mode for each data structure:

The Debug mode poses various challenges to the students. Students are encouraged to analyze the animations carefully and participate in interactive quizzing and bug identification exercises. Basing on the animations presented in the Learning mode, bugs are planted in selected algorithms from all the data structures. The code for these animations are tweaked and implanted with bugs to result in erroneous animations. These bug animations are interspersed with correct animations and listed in the Debug mode. Students are then challenged to identify the code changes responsible for the errors and also identify a possible solution through multiple choice questions. Each error/bug animation is developed in to an individual Learning case inside the Debug mode. A total of 20 learning cases are developed for the project.

Animation No.	Data Structure	Algorithm
1	Array	Merge Sort
2	Array	Insertion Sort
3	Array	Quick Sort
4	Array	Bubble Sort
5	Array	Binary Search
6	Array	Insert element
7	Array	Delete element
8	Linked List	Search Node
9	Linked List	Insert Node
10	Linked List	Delete Node
11	Doubly Linked List	Search Node
12	Doubly Linked List	Insert Node
13	Doubly Linked List	Delete Node
14	Circular Linked List	Search Node
15	Circular Linked List	Insert Node
16	Circular Linked List	Delete Node
17	Stack	Push
18	Stack	Pop
19	Queue	Enqueue
20	Queue	Dequeue
21	Binary Tree	In-order Traversal
22	Binary Tree	Pre-order Traversal
23	Binary Tree	Post-Order Traversal
24	AVL Tree	Single Rotation
25	AVL Tree	Double Rotation
26	AVL Tree	Insert Node
27	AVL Tree	Delete Node
28	Hash Table	Lookup, Insert, Delete

Table 1

Students are provided with additional features such as "Show the Animation" and "Pinpoint to Error" buttons that help them to compare the erroneous animations with the actual animations and identify the possible cause of error in the code.

Table 2 lists all the Learning Cases implemented for the project in the Debug mode for each data structure:

Learning Case No.	Data Structure	Algorithm	Learning Case Description
1	Array	Merge Sort	This Learning Case teaches students the sorting of elements during merge sorting algorithm.
	Array	Insertion Sort	-
	Array	Quick Sort	-
2	Array	Bubble Sort	This Learning Case teaches students the sorting of elements during Bubble sorting algorithm.
	Array	Binary Search	-
	Array	Insert element	-
	Array	Delete element	-
	Linked List	Search Node	-
3	Linked List	Insert Node	This Learning Case teaches students how to insert a new node in a linked list.
	Linked List	Delete Node	
4	Doubly Linked List	Search Node	This Learning Case teaches students the search algorithm in a Doubly linked list.
	Doubly Linked List	Insert Node	
5	Doubly Linked List	Delete Node	This Learning Case teaches students how to delete a node in a Doubly linked list.
	Circular Linked List	Search Node	-
	Circular Linked List	Insert Node	-
6	Circular Linked List	Delete Node	This Learning Case teaches students how to delete a node in a Circular linked list.
7	Stack	Push	This Learning Case teaches students the implementation of Push algorithm in a Stack.
8	Stack	Pop	This Learning Case teaches students the implementation of Pop algorithm in a Stack.
9	Queue	Enqueue	This Learning Case teaches students the implementation of Enqueue algorithm in a Queue.
10	Queue	Dequeue	This Learning Case teaches students the implementation of Dequeue algorithm in a Queue.

11	Binary Tree	In-order Traversal	This Learning Case teaches students the implementation of In-order traversal in a Binary tree.
12	Binary Tree	Pre-order Traversal	This Learning Case teaches students the implementation of Pre-order traversal in a Binary tree.
	Binary Tree	Post-Order Traversal	-
13	AVL Tree	Single Rotation	This Learning Case teaches students the implementation of single rotation in an AVL tree.
14	AVL Tree	Single Rotation	This Learning Case teaches students the implementation of single rotation in an AVL tree.
15	AVL Tree	Double Rotation	This Learning Case teaches students the implementation of Double rotation in an AVL tree.
16	AVL Tree	Double Rotation	This Learning Case teaches students the implementation of Double rotation in an AVL tree.
17	AVL Tree	Double Rotation	This Learning Case teaches students the implementation of Double rotation in an AVL tree.
18	AVL Tree	Double Rotation	This Learning Case teaches students the implementation of Double rotation in an AVL tree.
	AVL Tree	Insert Node	-
	AVL Tree	Delete Node	-
19	Hash Table	Lookup, Insert, Delete	This Learning Case teaches students the implementation of delete operation in a Hash table.
20	Hash Table	Lookup, Insert, Delete	This Learning Case teaches students the implementation of delete operation in a Hash table.

Table 2

All the learning cases are presented in the data structure visualization learning tool in which we have designed a Learner's Corner. We have implemented algorithm animations and code visualization for both correct code and programs having planted bugs. The students' task is to identify the planted bug. This kind of task places the students on the spot where concentration and critical thinking are highly demanded. We hope such a setting can simulate students' interests and sharpen their analysis capability.

The learning cases provide an opportunity for students to dig into the implementation of the algorithms. The following learning cases are implemented in various data structure to assist students' learning. Table 1 shows the list of learning cases developed for the project

Learning Case #1

This learning case is designed to teach students the insert operation in a linked list data structure. When node 20 is added to the linked list, the pointer references for nodes 108 and 22 must be altered. The result of inserting node 20 before node 22 is shown in Figure 19. The code visualization box in the Figure 20 shows the portion of the code used to rearrange the pointer references to the nodes in the linked list after inserting the new node. This portion of the code is deliberately changed. A bug is implanted in the program. Figure 21 shows the changes made to the code.

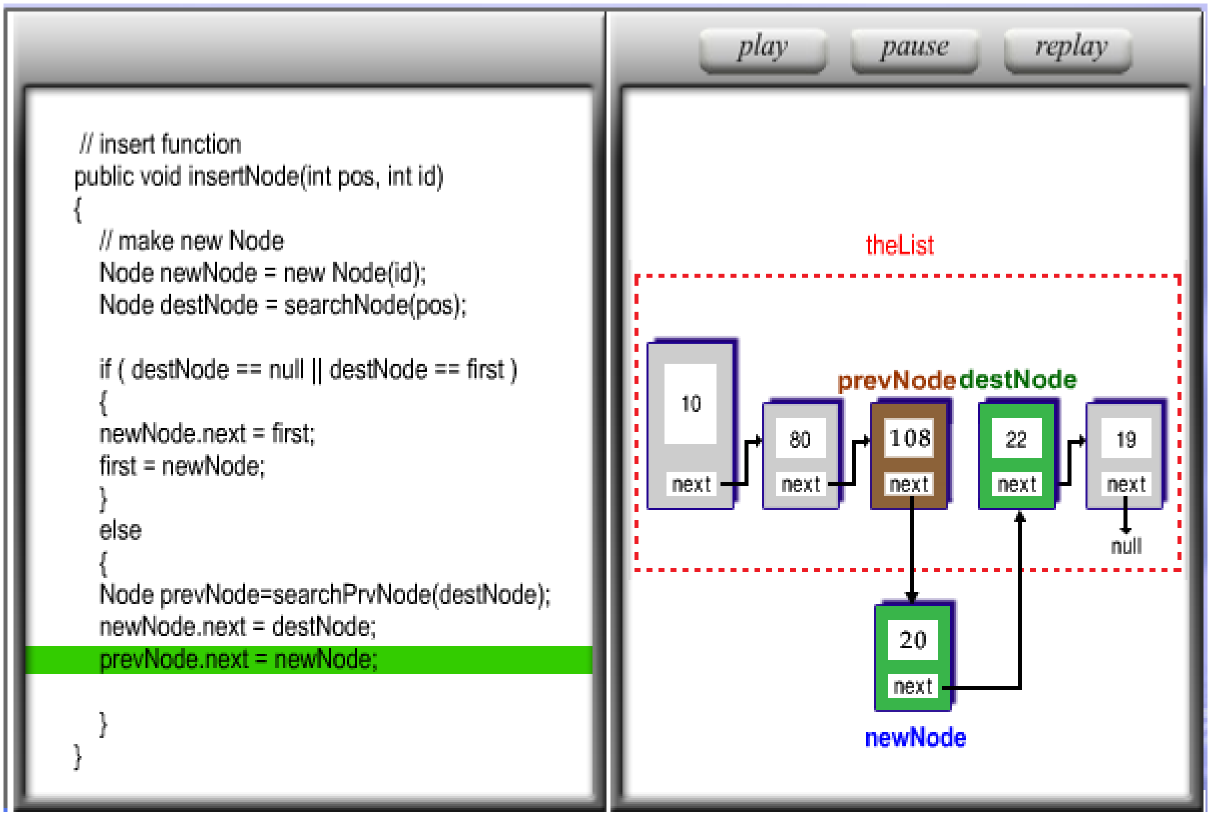


Fig 19

```
public void insertNode ( int pos, int id) {
        Node newNode= newNode (id);
        Node destNode = searchNode (pos);
        if (destNode ==null | | destNode ==first)  {
                newNode.next = first;
                first = newNode;
        }
        else {
                Node prevNode = searchPrvNode (destNode);
                newNode.next = destNode.next;
                destNode.next = newNode;
        }
}
```

Fig 20

```
public void insertNode ( int pos, int id) {
        Node newNode= newNode (id);
        Node destNode = searchNode (pos);
        if (destNode ==null || destNode ==first)  {
                newNode.next = first;
                first = newNode;
        }
        else {
                Node prevNode = searchPrvNode (destNode);
                newNode.next = destNode.next;
                destNode.next = newNode;
        }
}
```

Fig 21

Because the pointer references are wrongly defined, the new node with id 20 is inserted between nodes 22 and 19, while a correct implementation would have inserted the new node between the nodes with ids 108 and 22 as shown in Figure 19.

Figure 22 shows the wrongful insertion result. The student should examine the insert operation and identify that the node references have been wrongly assigned, resulting in the node being added with incorrect position. After the animation is complete, a challenging multiple choice question is presented to the student inside the description box. Figure 23 shows the multiple-choice question for the test case.

To help the student answer the question, the button “Show the Animation” calls the animation deployed with the correct code. This gives the student to understand a comparison between the animations created based on the correct code and that based on the wrong code.

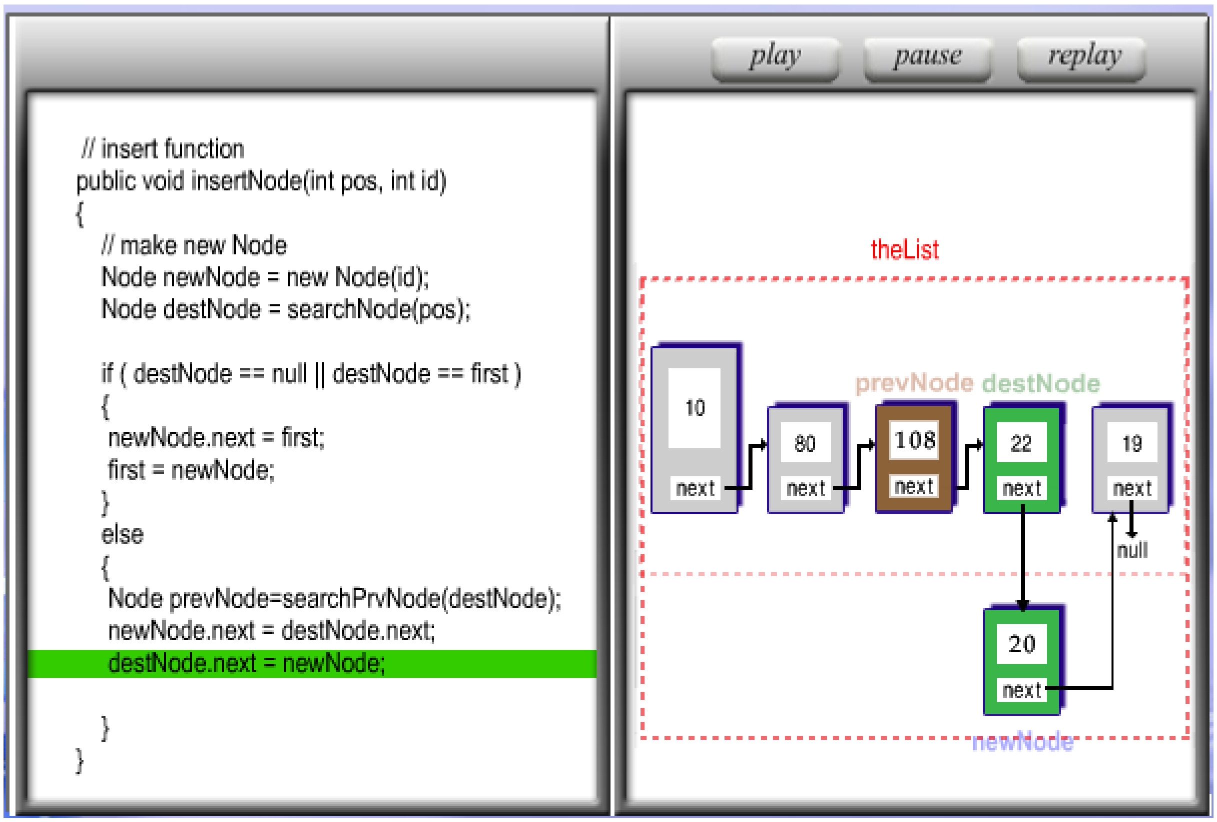


Fig 22

Ultimately the student will analyze the code responsible for the error. The student can also attempt the multiple choice question at any point later in the debug mode by clicking the "What's wrong" button.

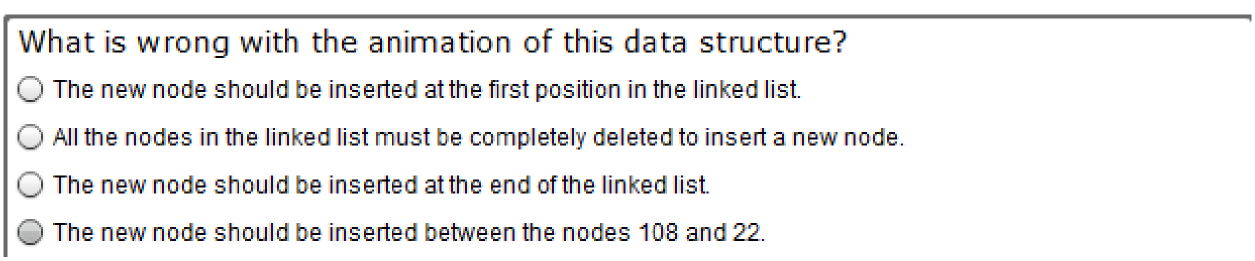


Fig 23

Learning Case #2

This test case is implemented to demonstrate the implementation of the search operation in the doubly-linked list. A doubly-linked list has three main operations: Find, insert and delete. Figure 24 shows a snapshot of a successful implementation of the search operation in a doubly linked list. The animation for the find operation shows node 22 successfully returned as the search result.

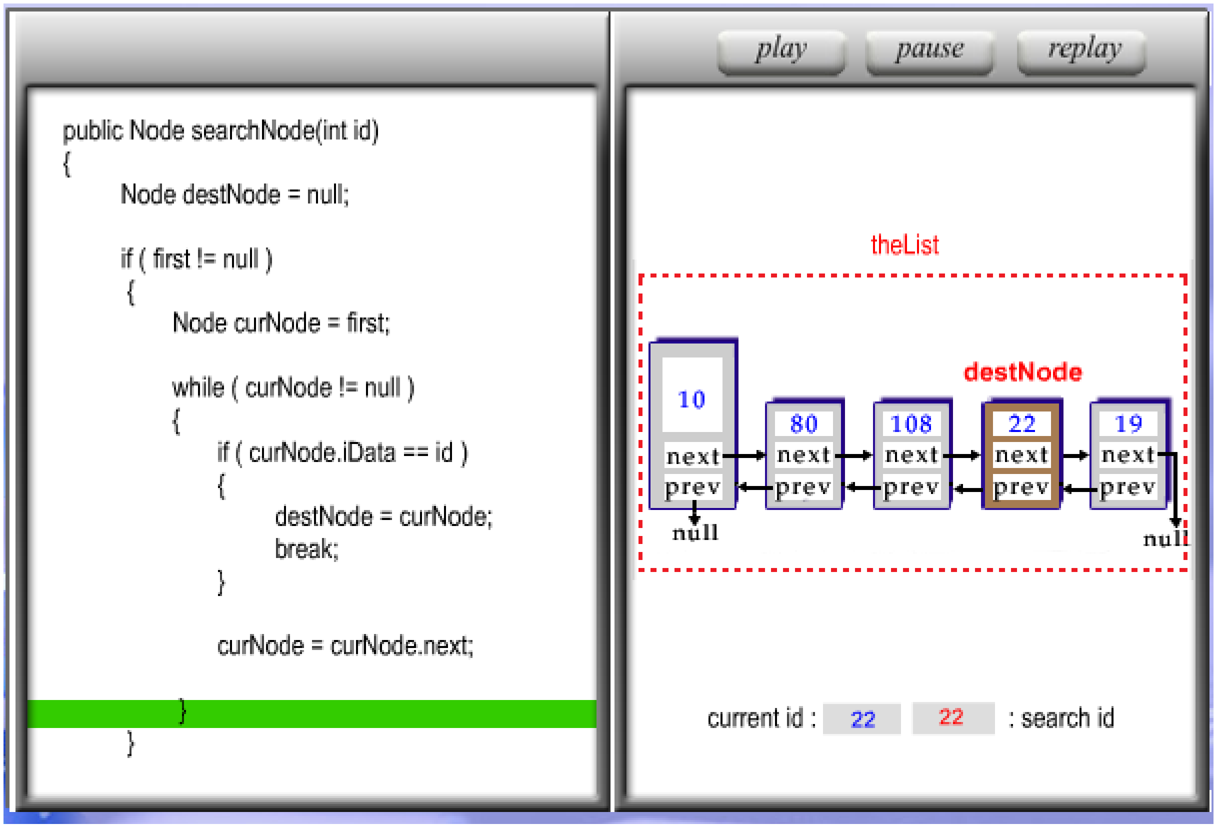


Fig 24

To create a test case, we have modified the code of the find operation on the doubly-linked list. The modified code can be seen in Figure 25 below.

```
publicNode searchNode (int id) {
        Node destNode = null;
        if (first ! = null) {
                Node curNode =first;
                while (curNode != null)   {
                        if (curNode.iData == id) {
                                destNode = curNode.next;
                                break;
                        }
                        curNode = curNode.next;
                }
        }
        return destNode;
}
```

Fig 25

As seen in Figure 25, the code statement that determines the search result node is modified. Due to the change in the code, the search result always returns the node next to the original node that is being search for. Hence the animation now returns node 19 instead of node 22 as the search result. Figure 26 shows a snapshot of the animation with the planted error.

The student should examine the animation and identify that the search result statement has been modified to give a wrong result. After the animation is complete, a challenging multiple choice question is presented to the student inside the description box. Figure 27 shows the multiple-choice question presented for this test case.

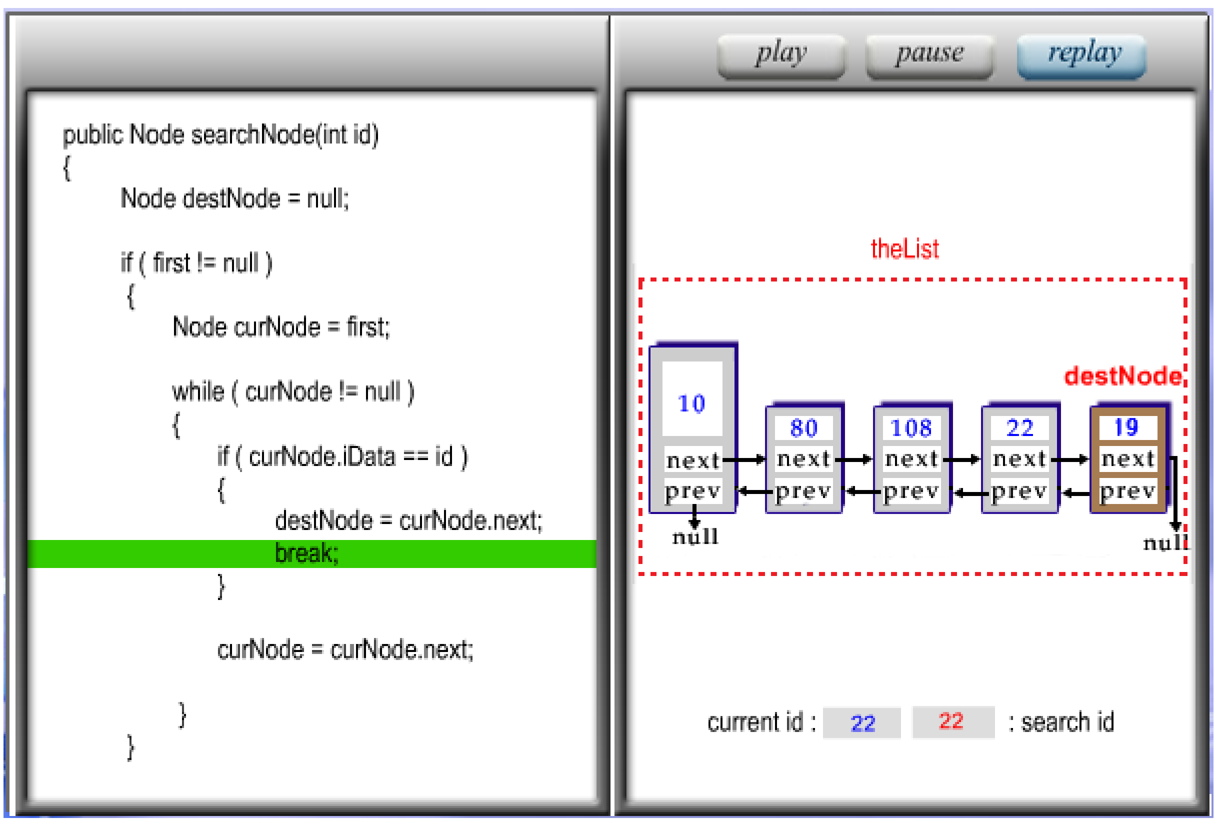


Fig 26

To help the student answer the question, the button “Show the Animation” calls the animation deployed with the correct code. This gives the student to understand a comparison between the animations created based on the correct code and that based on the wrong code. Ultimately the student will analyze the code responsible for the error.

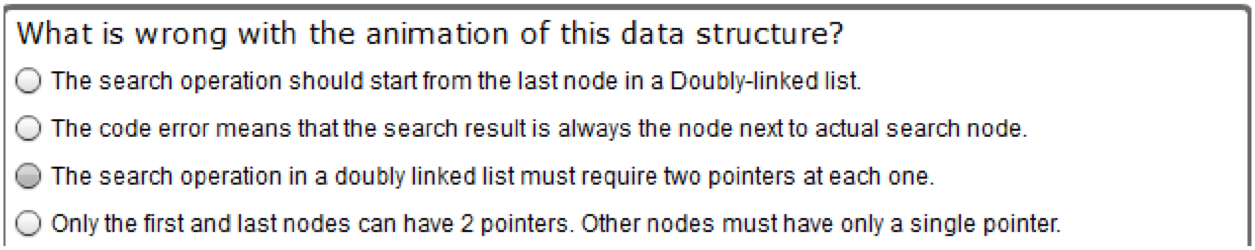


Fig 27

Learning Case #3

This test case is implemented to demonstrate the delete operation in a doubly-linked list. The successful operation deletes the node 22 and reassigns the node pointer from node 108 to node 19. Figure 28 shows a snapshot of the animation in the doubly-linked list.

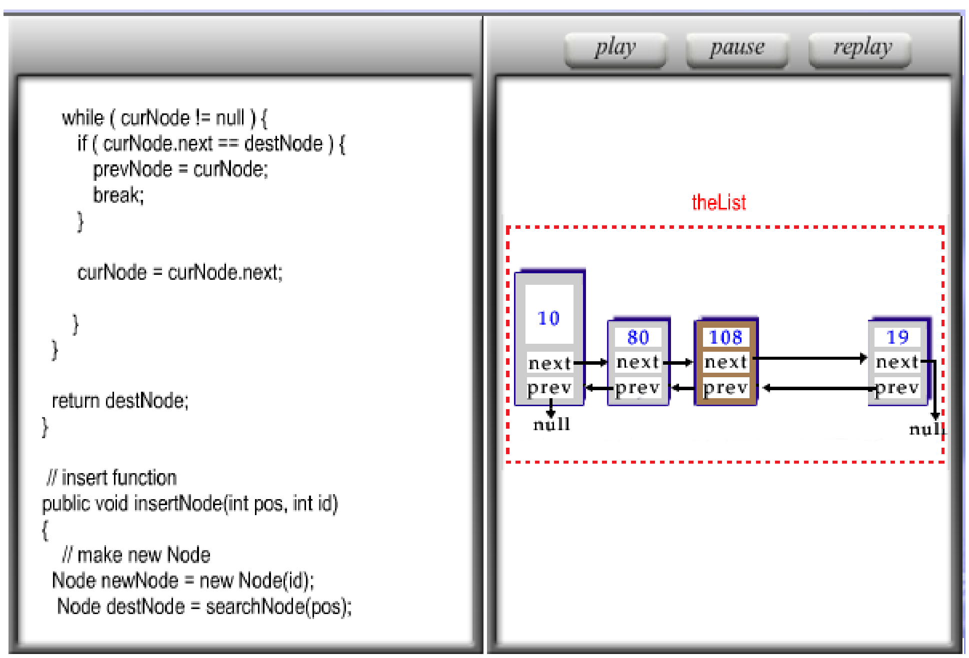


Fig 28

To implement the test case, we have implanted the bug in the code for the delete method. Figure 29 shows the code changes made to the delete operation of the doubly-linked list. As seen in Figure 29, the code statement that identifies the node to be deleted (node 22) is deliberately modified to delete node 108 instead of node 22. Figure 30 shows a snapshot of the doubly-linked list delete operation with the planted error.

```
public void deleteNode (int id) {
        Node destNode = searchNode (id);
        Node nxtNode = searchNode(destNode.next);
        if (destNode != null )  {
                if (destNode == first ) {
                        first = first.next;
                        first.prev = last;
                }
                else if (destNode == last)  {
                        Node prNode = searchNode (destNode.prev);
                        prNode.nxt =  null;
                }
        }
        else {
                Node prNode = searchNode (destNode.prev);
                Node oNode = searchNode(prNode.prev);
                destNode.prev = prNode.prev;
                oNode.next = destNode;
        }
}
```

Fig 29

After the animation is complete, a challenging multiple choice question is presented to the student inside the description box. Figure 31 shows the multiple-choice question. To help the student answer the question, the button “Show the Animation” calls the animation deployed with the correct code. This gives the student to understand a comparison between the animations created based on the correct code and that based on the wrong code.

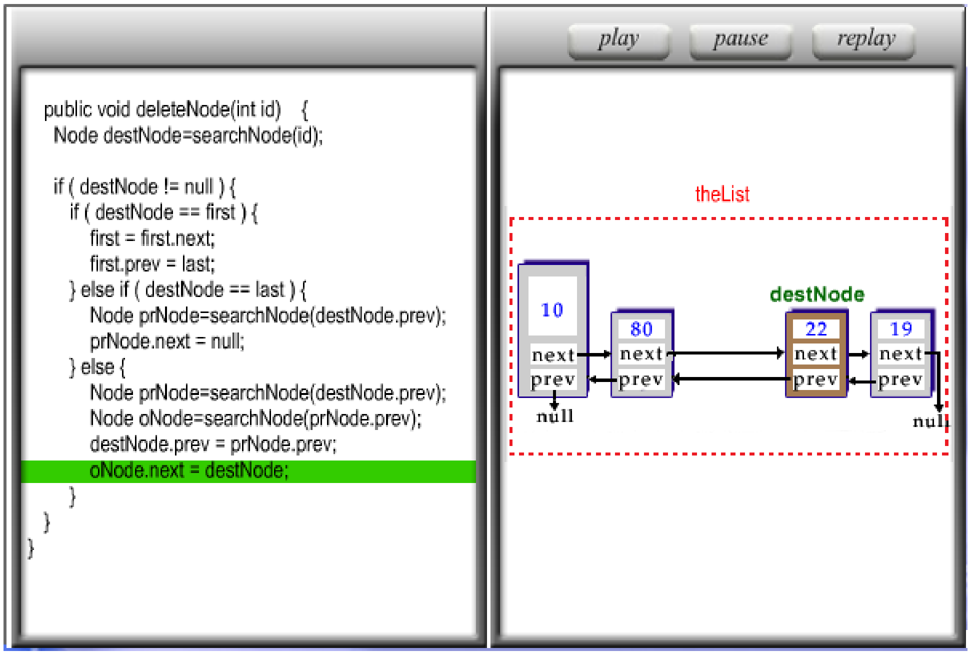


Fig 30

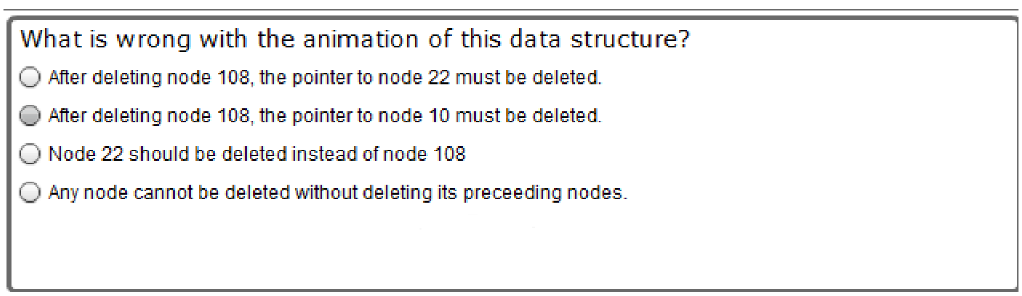


Fig 31

Ultimately the student will analyze the code responsible for the error. The student can also attempt the multiple choice question at any point later in the debug mode by clicking the "What's wrong" button.

Learning Case #4

This test case is implemented to demonstrate the delete operation in a circular-linked list. The successful operation deletes the node 22 and reassigns the node pointer from node 108 to node 19. Figure 32 shows a snapshot of the animation in the circular-linked list.

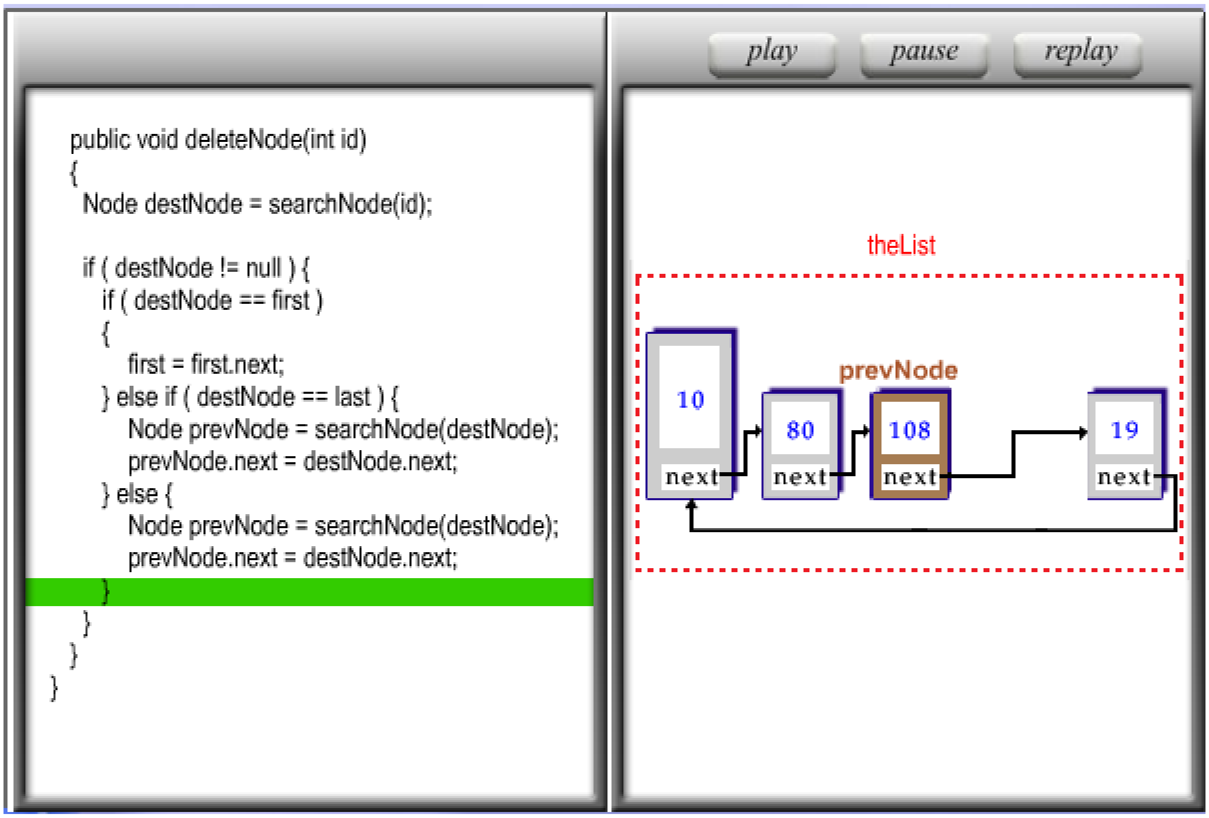


Fig 32

```
public void deleteNode (int id) {
        Node destNode = searchNode (id);
        if (destNode != null ) {
                if (destNode == first ) {
                        first = first.next;
                }
                else if (destNode == last) {
                        Node prevNode = searchNode (destNode);
                        prevNode.next = destNode.next;
                }
        }
        else {
                Node prevNode = searchNode (destNode);
                prevNode.next = prevNode;
        }
}
```

Fig 33

To implement the test case, we have implanted the bug in the code for the delete method. Figure 33 shows the code changes made to the delete operation of the circular-linked list. As seen in Figure 38, the code statement that must reassign the pointer from node 108 to the next node (node 19) after deleting node 22 is deliberately modified to point to node 108 itself. Figure 34 shows a snapshot of the circular-linked list delete operation with the planted error.

After the animation is complete, a challenging multiple choice question is presented to the student inside the description box. Figure 35 shows the multiple-choice question. To help the student answer the question, the button “Show the Animation” calls the animation deployed with the correct code. This gives the student to understand a comparison between the animations created based on the correct code and that based on the wrong code.

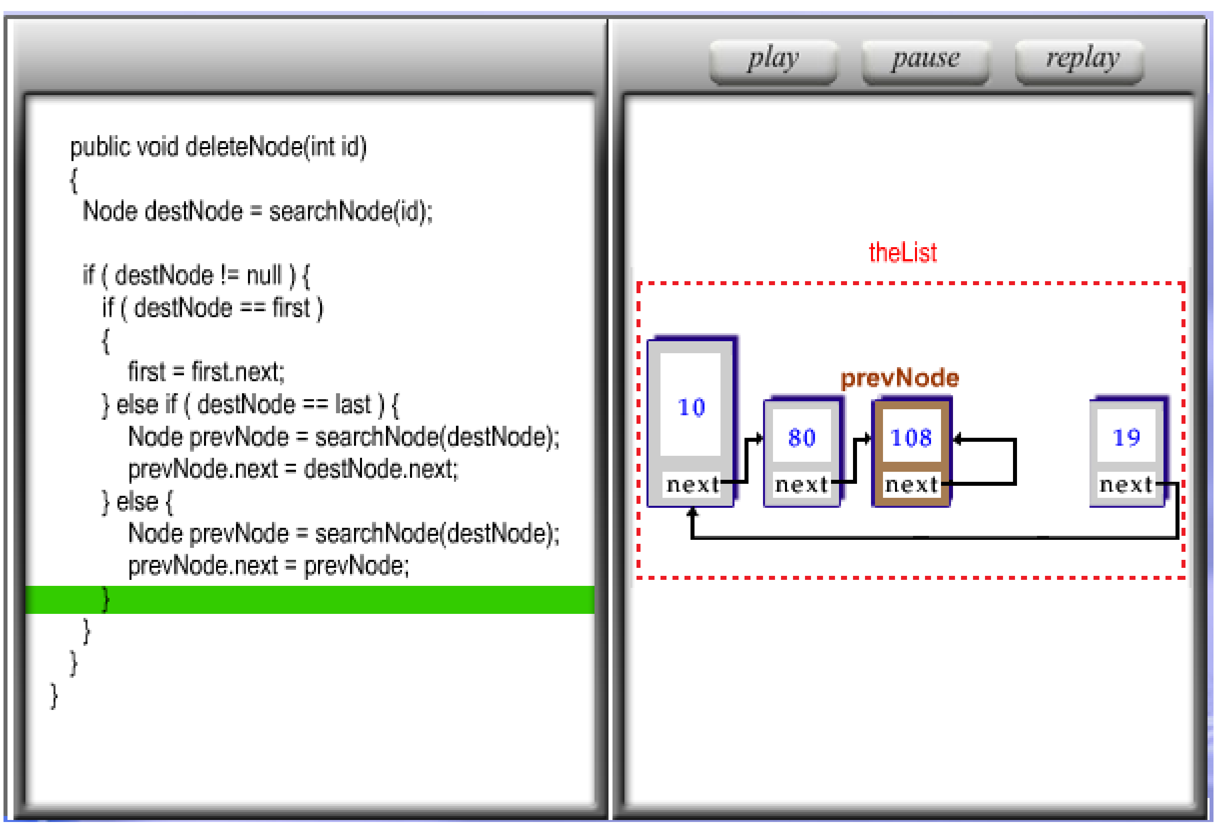


Fig 34

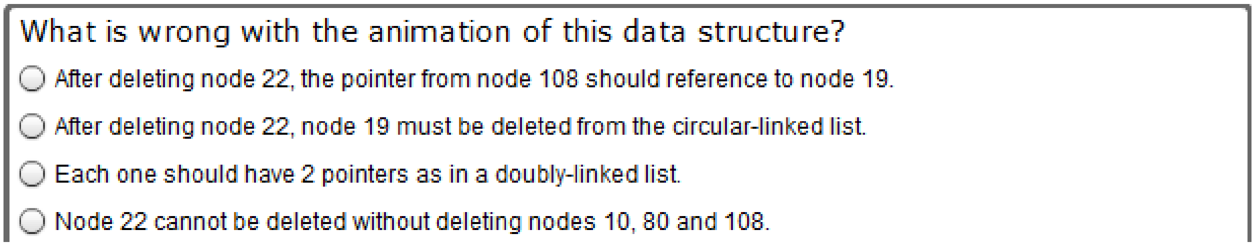


Fig 35

Ultimately the student will analyze the code responsible for the error. The student can also attempt the multiple choice question at any point later in the debug mode by clicking the "What's wrong" button.

Learning Case #5

A stack data structure has two main operations: PUSH and POP. The push operation inserts the new record on top of the previous records. The pop operation deletes the top record from the stack. Hence a stack is a FIFO data structure. We have implemented a learning case to demonstrate the implementation of the stack.

The code to implement a stack can be presented as in the Figure 36. In order to implant an error to show the functioning of the stack in an incorrect manner, we replace the correct code with the erroneous code inside the pop method.

```
Class stackPop {
	public static void main (String [] args) {
		Stack theStack  = new Stack();
		theStack.push(20);
		theStack.push(30);
		theStack.push(40);
		while (!theStack.isEmpty ()) {
			double value = theStack.pop ();
			System.out.println (value);
			System.out.println (",");
		}
	}
}


Class Stack {
	private int maxSize;
	private double [] stackArray;
	private int top;
	private int front;
	public Stack (int s) {
		maxSize = s;
		stackArray = new double [maxSize];
		top = -1;
		front = 0;
	}
	public void push (double j) {
		stackArray [++top] = j;
	}
	public double pop () {
		return stackArray [top--];
	}
}
```

Fig 36

Using the PUSH operation, values 20, 30, 40 are pushed into the stack respectively. Hence the value 20 will be at the bottom of the stack. For the value 20 to be able to be popped, it is needed that the top most records with values 30 and 40 be popped first. However, with the erroneous code in the POP method, the animation will show that the values 20, 30 and 40 are popped in the same order as they are pushed on to the stack. This animation hence will contradict the FILO ordering of the stack data structure. Figure 37 shows the snapshot of the animation resulted from the wrongful implementation of the POP method.

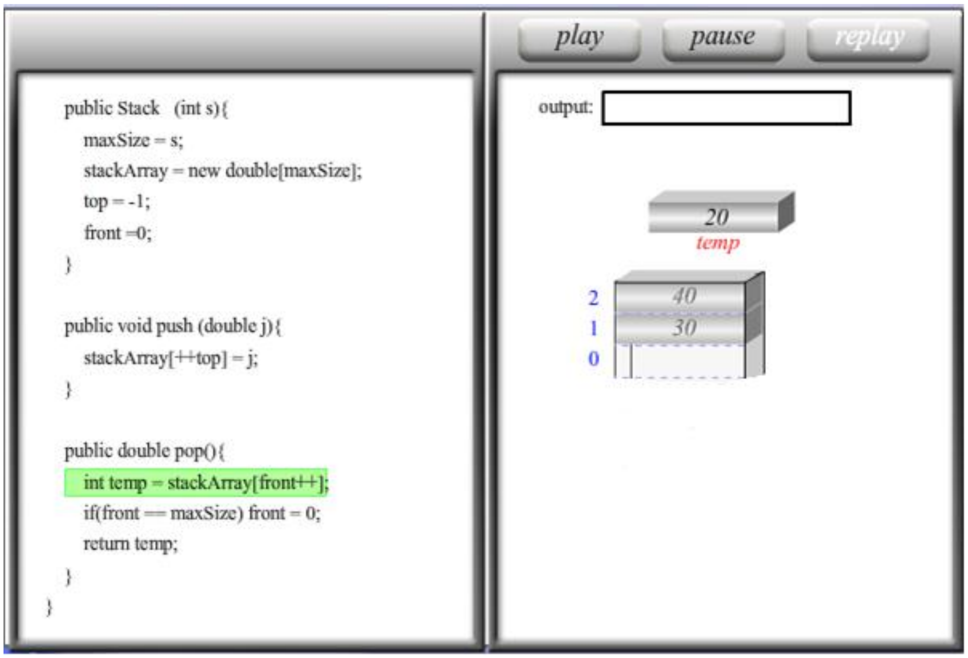


Fig 37

It shows the instant when the first value in the stack is popped. The animation will show that value 20 is popped first. This is an erroneous animation since this value at the bottom of the stack, and that the first value to be popped must be value 40 according to FILO ordering of stack data structure.

The student should identify the error in the stack implementation of the Pop method. We challenge the student with the multiple choice question presented in the description box. Figure 38 shows the multiple-choice question.

What is wrong with the animation of this data structure?

- ◯ A single pop operation in a stack must delete all the records in the stack.
- ◯ A pop operation must be performed in a LIFO order. Here it is demonstrated in FIFO order.
- ◯ A pop function must only read the lastest value entered in to the stack.
- ◯ A pop operation must be performed in a FIFO order. Here it is demonstrated in LIFO order.

Fig 38

To help the student answer the question, the button "Show the Animation" calls the animation deployed with the correct code. This gives the student to understand a comparison between the animations created based on the correct code and that based on the wrong code. Ultimately the student will analyze the code responsible for the error.

Learning Case #6

This learning case demonstrates the implementation of the PUSH operation in a stack. Using the push operation, values 20, 30, 40 are pushed into the stack respectively. Initially the size of the stack is Zero. As the value 20 is added to the stack, the size of the stack is incremented by 1 and the value 20 is stored at the top of the stack. As the values 30, 40 and 50 are added respectively, the size of the stack is incremented by 1 each time and the values in it are pushed downwards with the latest value to be added placed at the top of the stack.

In order to show the functioning of the stack in an incorrect manner, we replace the correct code with the erroneous code inside the push method. Due to this deliberately planted bug, the stack is shown to have a predefined size and the newly added values are added to the bottom of the stack instead of being added at the top. This is a wrong implementation of the stack data structure. Figure 39 shows the snapshot of the successful push operation in a stack.

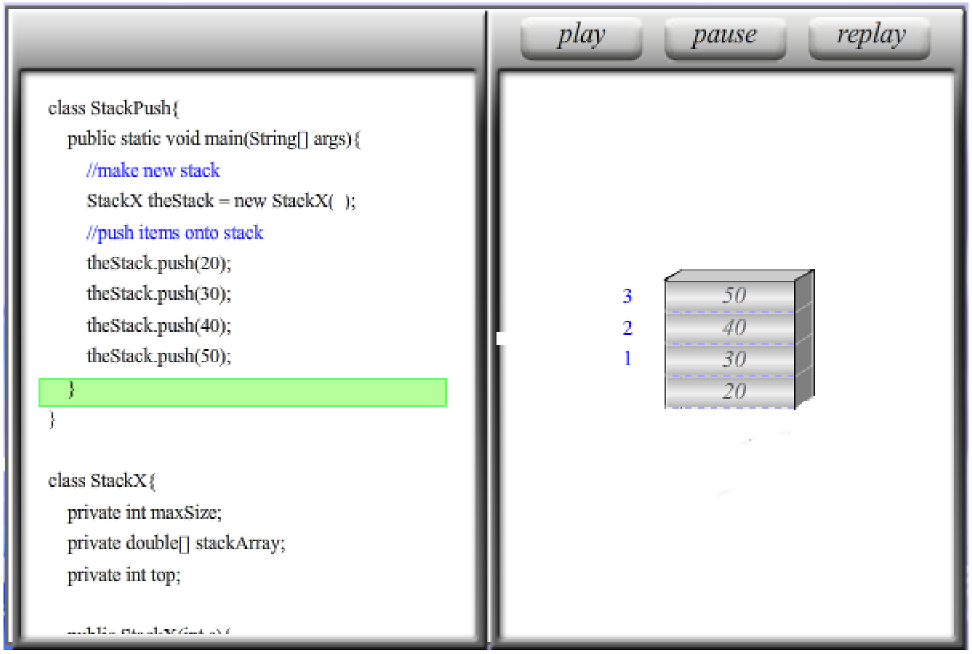


Fig 39

Figure 39 shows the animation at the instant when the value 50 is being added to the stack.

The animation resulting due to the planted error is shown in figure 40. As shown in the figure, the values have been added to the bottom of the stack instead of being added at the top.

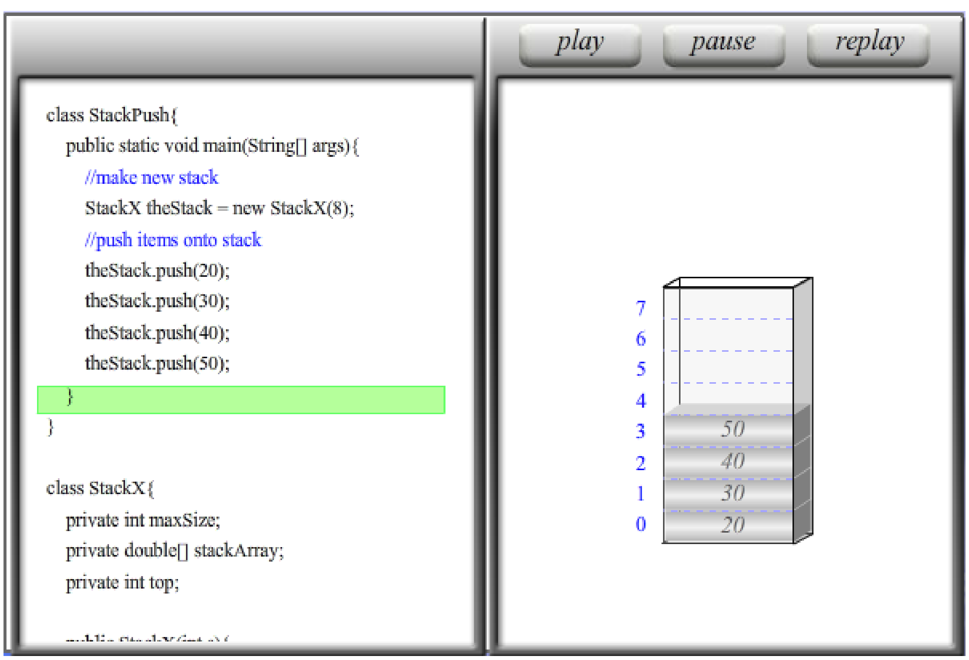


Fig 40

The student should identify the error in the stack implementation of the Push method. We challenge the student with the multiple choice question presented in the description box. Figure 41 shows the multiple-choice question.

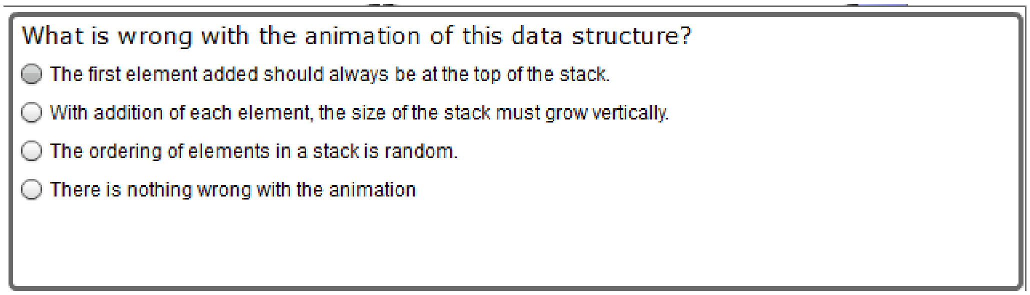


Fig 41

To help the student answer the question, the button "Show the Animation" calls the animation deployed with the correct code. This gives the student to understand a comparison between the animations created based on the correct code and that based on the wrong code. Ultimately the student will analyze the code responsible for the error.

Learning Case #7

This Learning Case demonstrates the preorder depth-first traversal algorithm in a binary tree. In preorder traversal technique, the root node, the left child and the right child are traversed in the respective order. The code to represent the Preorder traversal of a binary tree is given in Figure 42:

```
private void preOrder(node localRoot) {
        if(localRoot !=null) {
                localRoot.displayNode();
                preOrder(localRoot.leftChild);
                preOrder(localRoot.rightChild);
        }
}
```

Fig 42

The order of the statements that control the traversal routes through the child nodes is modified.

The animation hence traverses through the right child before traversing through the left child.

The code of the traversal algorithm modified deliberately to plant the bug is shown in Figure 43:

```
private void preOrder(node localRoot) {
                                        if(localRoot !=null) {
                localRoot.displayNode();
                preOrder(localRoot.rightChild);
                preOrder(localRoot.leftChild);
        }
}
```

Figure 43

A snapshot of the animation with the wrong implementation of the traversal order is shown in Figure 44.

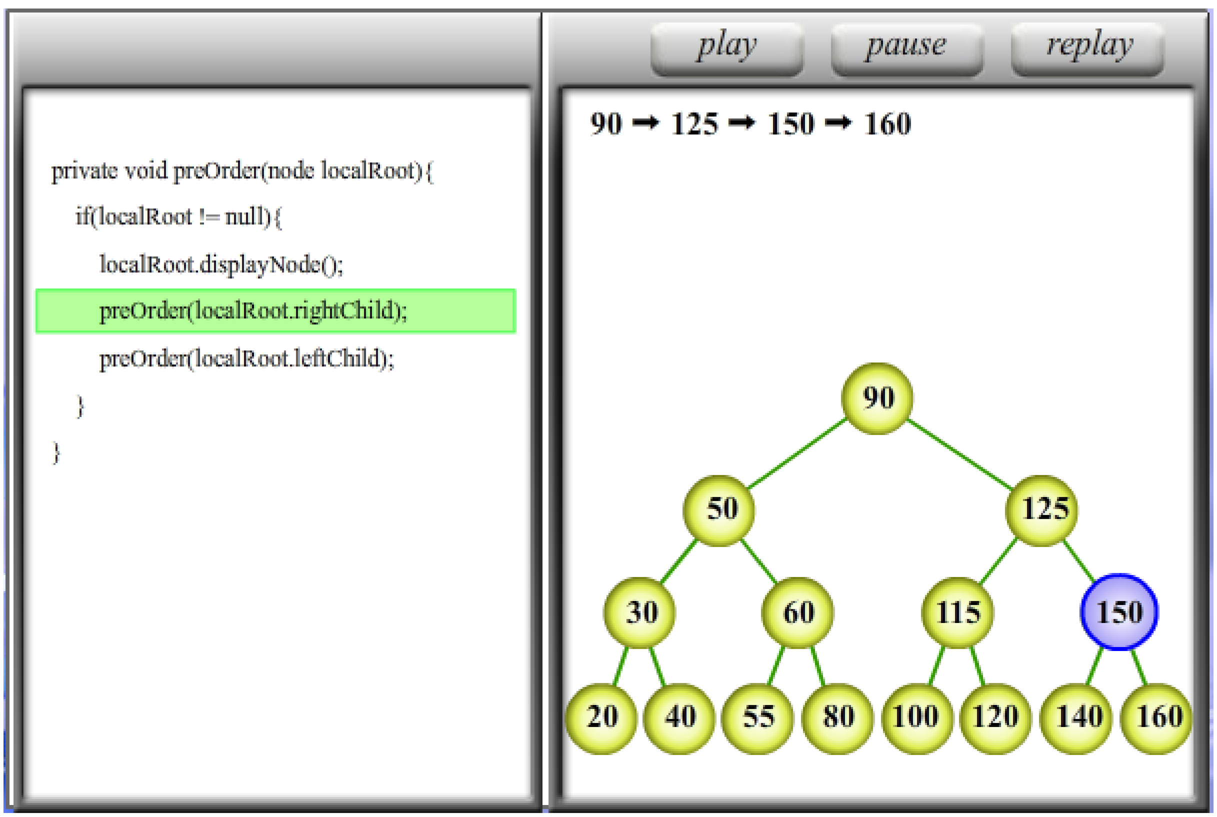


Fig 44

In this case, the animation is critical to students' understanding because the problem is in the process of computing rather than the output. We use the following multiple choice question to challenge the student.

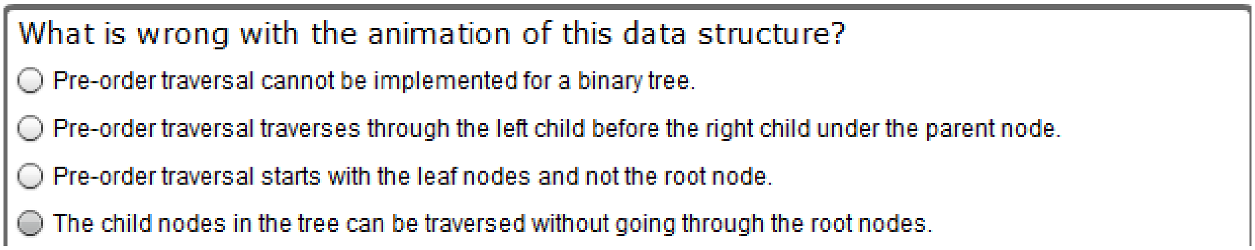


Fig 45

The correct implementation of the traversal order is presented to the student when the "Show the animation button" is clicked.

Learning Case #8

By implementing this learning case, we would like to illustrate the single and double rotations in an Avl tree. The code to implement the single and double rotations in an Avl tree is given in Figure 46.

```
//x – the new node to insert
// t – the node that roots the tree

private AvlNode insert (Comparable x, Avl Node t) {
        if (t == null)
                t = new AvlNode (x, null, null);
        else if (x.compareTo (t.element) <0) {
                t.left = insert (x, t.left);
                if ( height (t.left ) – height (t.right) == 2)
                        if (x.compareTo (t.left.element) < 0 )
                                t = rotateWithLeftChild (t);
                        else
                                t = doubleWithLeftChild (t);
        }
```

(Figure continued)

```
            else if (x.compareTo (t.element) >0) {
                        t.right= insert (x, t.right);
                        if ( height (t.right ) – height (t.left) == 2)
                                    if (x.compareTo (t.right.element) < 0 )
                                                t = rotateWithRightChild (t);
                                    else
                                                t = doubleWithRightChild (t);
            }
            else ;
            t.height = max ( height (t.left ), height (t.right)) +1;
            return t;
}
```

Fig 46

By using the above code, we add nodes 65 and 70 in to the avl tree in the respective order. Since the addition of node 65 imbalances the tree at node 55, the code performs single rotation at node 55 to its right, thus balancing the tree. The addition of node 70 imbalances the tree at node 90. So the code rotates the tree twice to perform double rotation. The first rotation is made at node 50. The tree is rotated to the left at the node 50. The second rotation is made at node 90. The tree is now rotated to right at node 90. Hence the avl tree is balanced using single and double rotations. Figure 45 shows a snapshot of the animation of the code implementation.

To deliberately plant the bug inside the code of the avl tree insert algorithm, we alter the condition for implementing the single and double rotation methods. The implications of the resulting code change means that the rotation methods would not be invoked unless the height difference between the left and right sub trees of any given node exceeds 3. The code modified to deliberately plant the bug in the single and double rotation methods is shown in Figure 47.

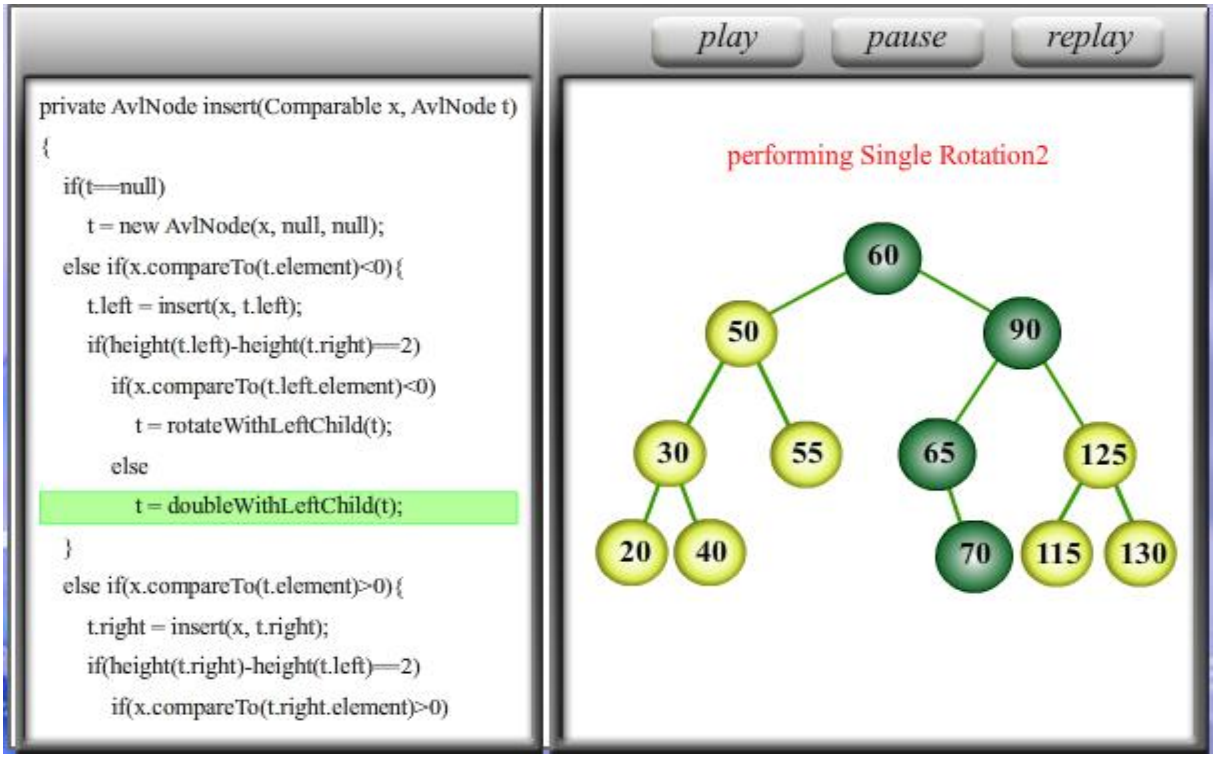


Fig 47

```
//x – the new node to insert
// t – the node that roots the tree

private AvlNode insert (Comparable x, Avl Node t) {
        if (t == null)
                t = new AvlNode (x, null, null);
        else if (x.compareTo (t.element) <0) {
                t.left = insert (x, t.left);
                if ( height (t.left ) – height (t.right) == 4)
                        if (x.compareTo (t.left.element) < 0 )
                                t = rotateWithLeftChild (t);
                        else
                                t = doubleWithLeftChild (t);
        }
        else if (x.compareTo (t.element) >0) {
                t.right= insert (x, t.right);
                if ( height (t.right ) – height (t.left) == 4)
                        if (x.compareTo (t.right.element) < 0 )
                                t = rotateWithRightChild (t);
                        else
                                t = doubleWithRightChild (t);
        }
        else ;
        t.height = max ( height (t.left ), height (t.right)) +1;
        return t;
}
```

Fig 48

As seen in the Figure 48, the statements that check for the imbalance of the tree are modified and hence the tree would not perform single or double rotations when node 65 and 70 are added.

After node 65 is inserted, the tree gets imbalanced at node 55 as the height difference between its left and right sub trees becomes 2. However, the tree is left imbalanced and followed by the insertion of node 70. Figure 49 shows the snapshot of the animation resulting from the wrongful code implementation.

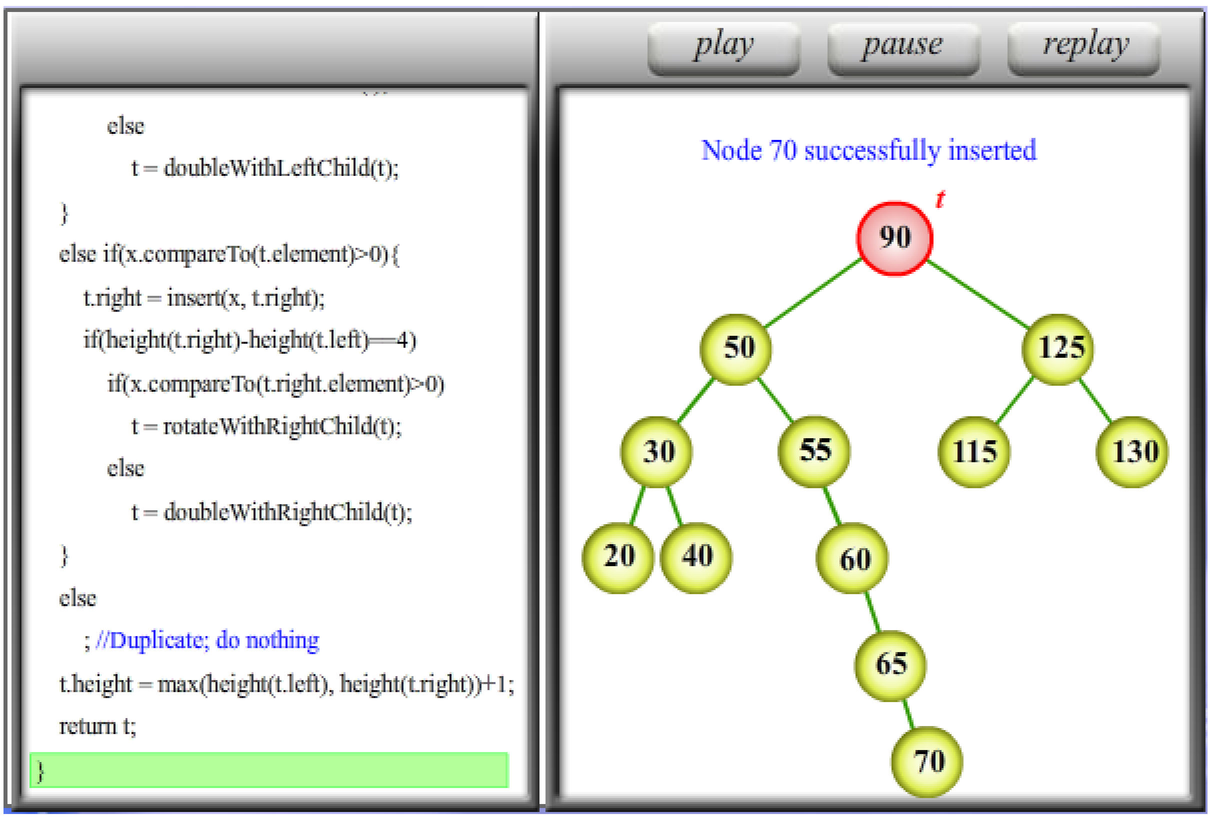


Fig 49

The student must identify that the code does not perform any rotation when either node 65 or 70 are inserted. After the animation is complete, a challenging multiple choice question is presented to the student inside the description box. Figure 50 shows the multiple-choice question.

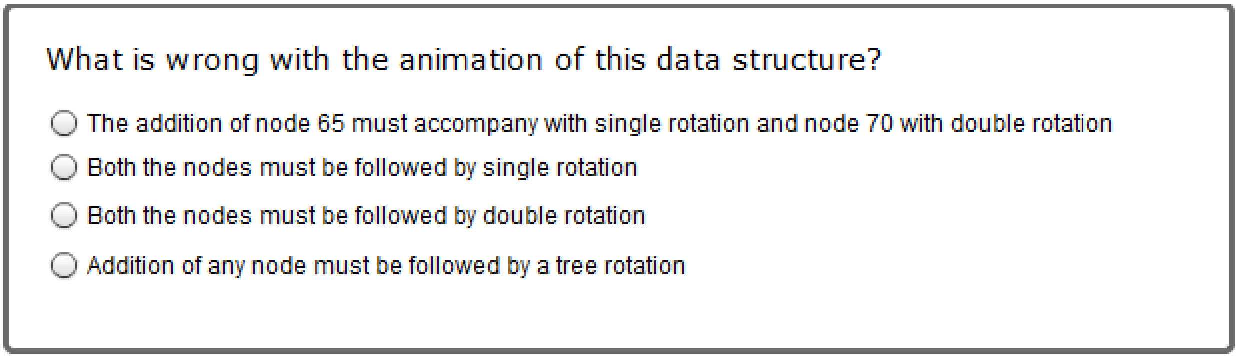


Fig 50

By looking at the correct implementation of the single and double rotations, students can understand and analyze the tree rotation in an Avl tree.

Learning Case #9 (a)

This learning case is implemented to teach students the implementation of double rotation in an Avl tree. As explained in learning case #8, to balance the tree after adding node 70, we need to rotate the tree in left and right directions respectively. This test case is implemented by altering the code so that the tree rotates in left and left directions respectively instead of rotating in left and right directions. Figure 51 shows a snapshot of the animation with the error in the implementation.

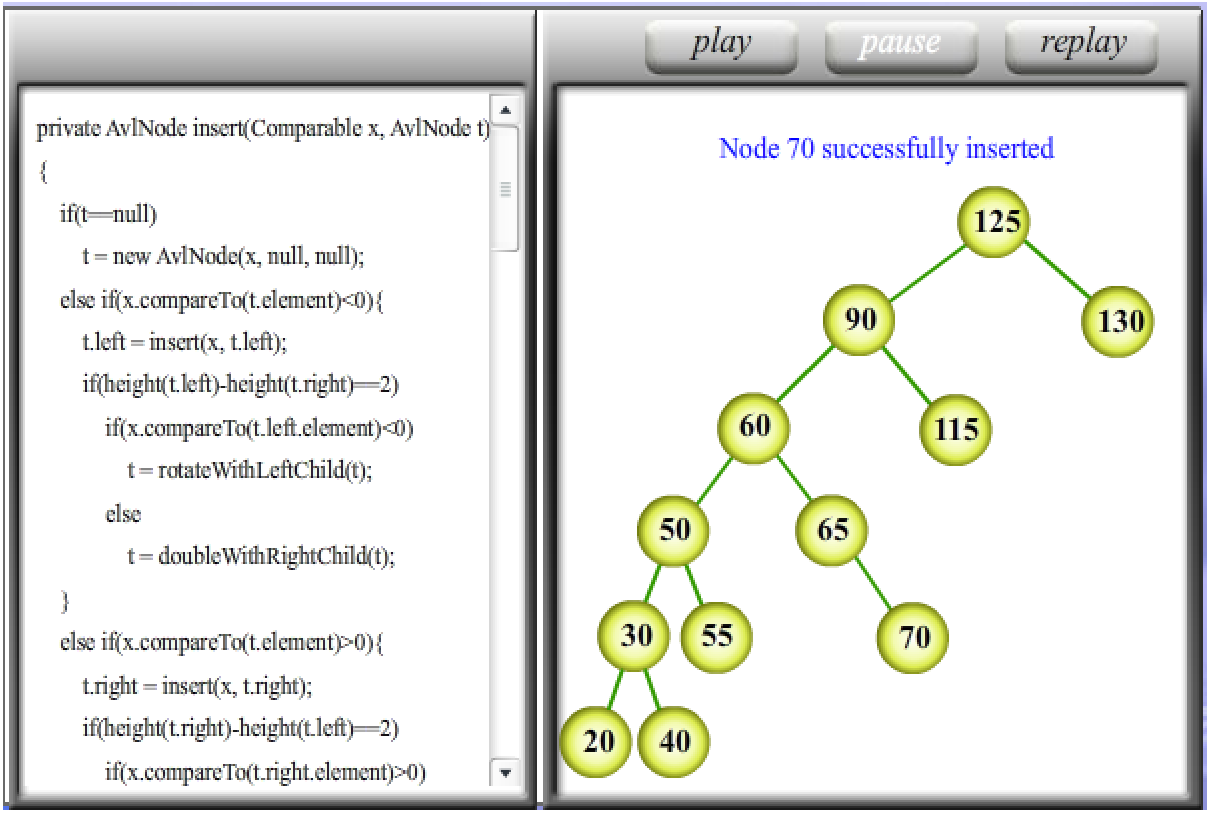


Fig 51

After the animation is completely over, the student is challenged with a multiple choice question that tests his understanding of the tree rotations in the animations. Figure 52 shows the multiple-choice question presented to the student after the animation is played.

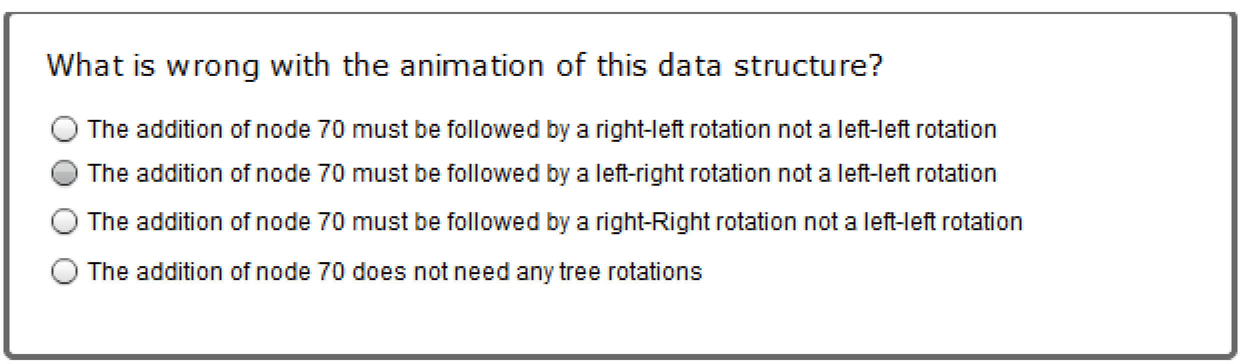


Fig 52

In order to help the student identify the error, the “Show the animation” button calls the correct animation. Student can hence understand the comparison between the correct and wrong implementation of the directions in the tree rotations.

Learning Case #9 (b)

This learning case is implemented to teach the students the implementation of double rotation in an Avl tree. This test case is implemented by altering the avl tree code so that the tree rotates in right and right directions respectively instead of rotating in left and right directions. Figure 53 shows a snapshot of the animation with the error in the implementation.

After the animation is completely over, the student is challenged with a multiple choice question that tests his understanding of the tree rotations in the animations. Figure 54 shows the multiple-choice question presented to the student after the animation is played.

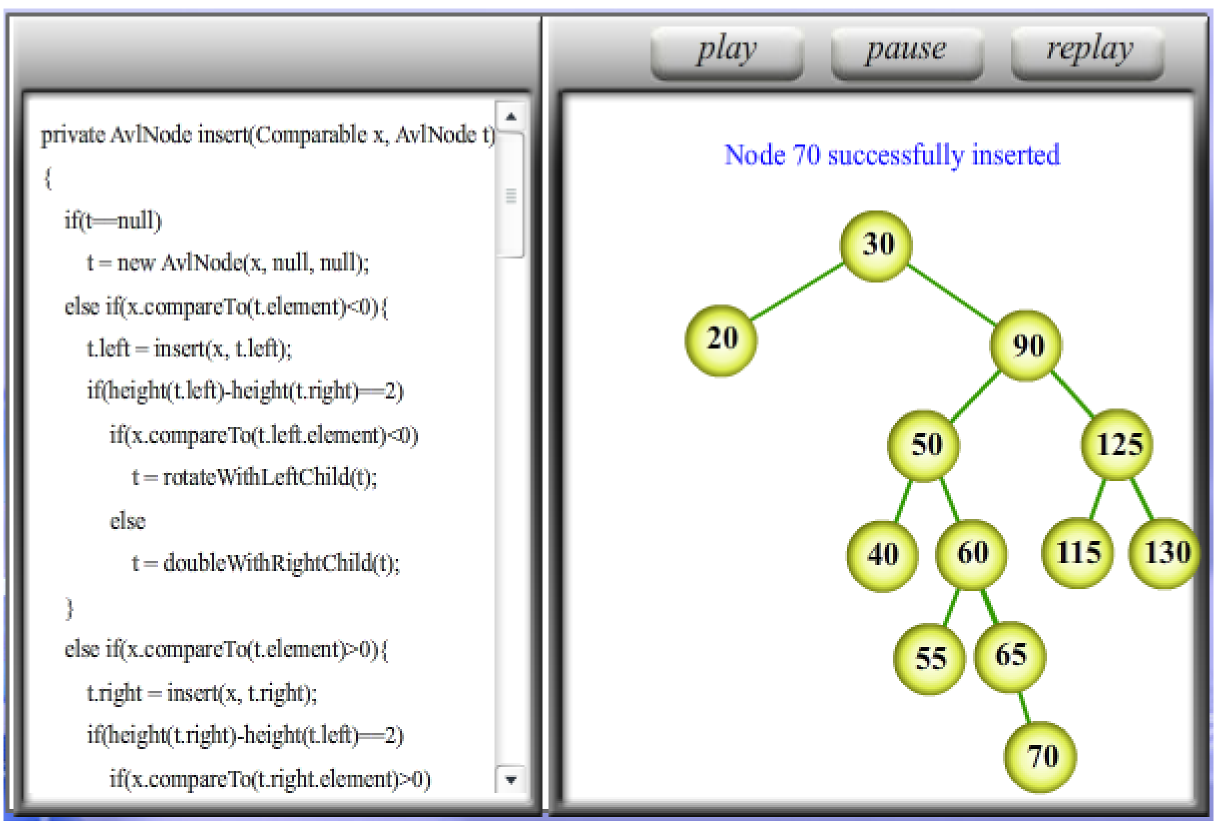
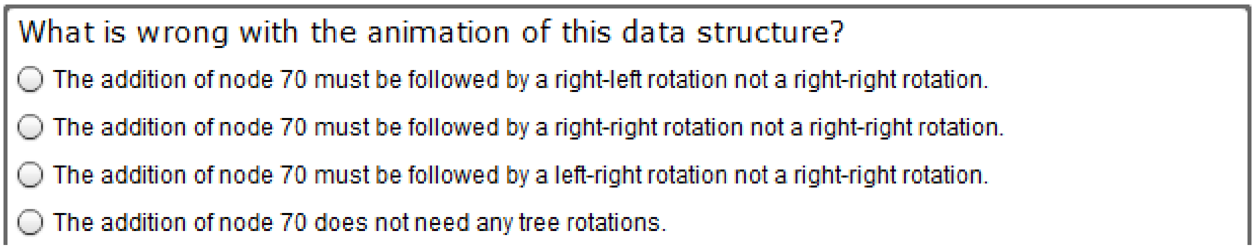


Fig 53

In order to help the student identify the error, the “Show the animation” button calls the correct animation. Student can hence understand the comparison between the correct and wrong implementation of the directions in the tree rotations.


What is wrong with the animation of this data structure?

- ◯ The addition of node 70 must be followed by a right-left rotation not a right-right rotation.
- ◯ The addition of node 70 must be followed by a right-right rotation not a right-right rotation.
- ◯ The addition of node 70 must be followed by a left-right rotation not a right-right rotation.
- ◯ The addition of node 70 does not need any tree rotations.

Fig 54

Learning Case #9(c)

This learning case is implemented to teach the students the implementation of double rotation in an Avl tree. This test case is implemented by altering the avl tree code so that the tree rotates in right and left directions respectively instead of rotating in left and right directions.

After the animation is completely over, the student is challenged with a multiple choice question that tests his understanding of the tree rotations in the animations. Figure 55 shows the multiple-choice question presented to the student after the animation is played.

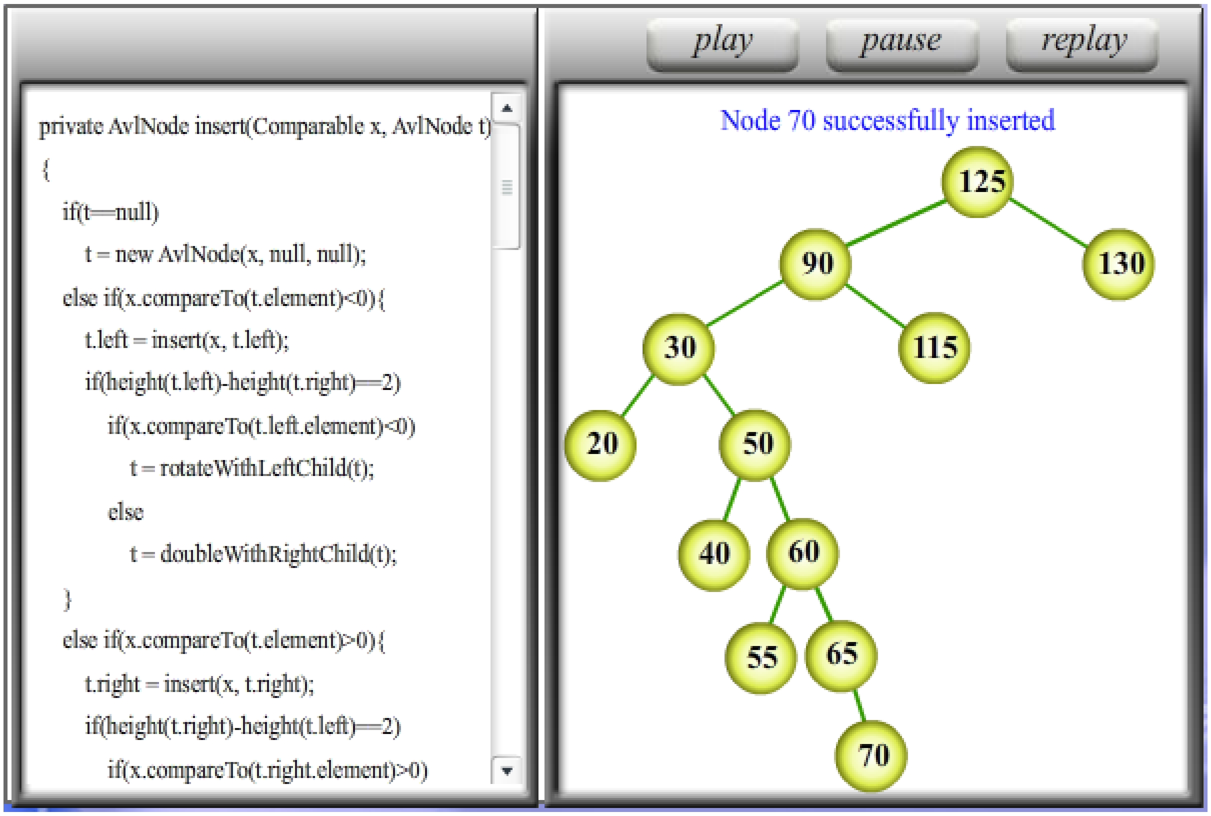


Fig 55

In order to help the student identify the error, the "Show the animation" button calls the correct animation. Student can hence understand the comparison between the correct and wrong implementation of the directions in the tree rotations.

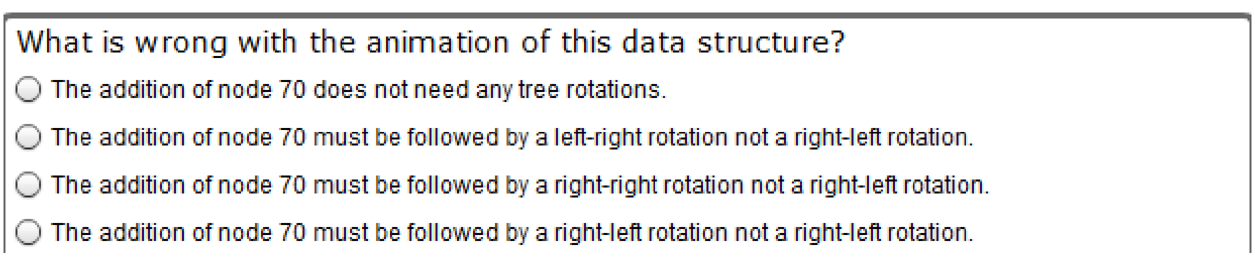


Fig 56

Learning Case #10

This learning case is implemented to illustrate the dequeue operation in a Queue. A queue follows a FIFO ordering for its operations. Figure 57 shows a snapshot of the animation of the Dequeue operation in a queue. Using the enqueue operation, values 20, 30 and 40 are added to the queue. The snapshot shows the value 20 currently being dequeued.

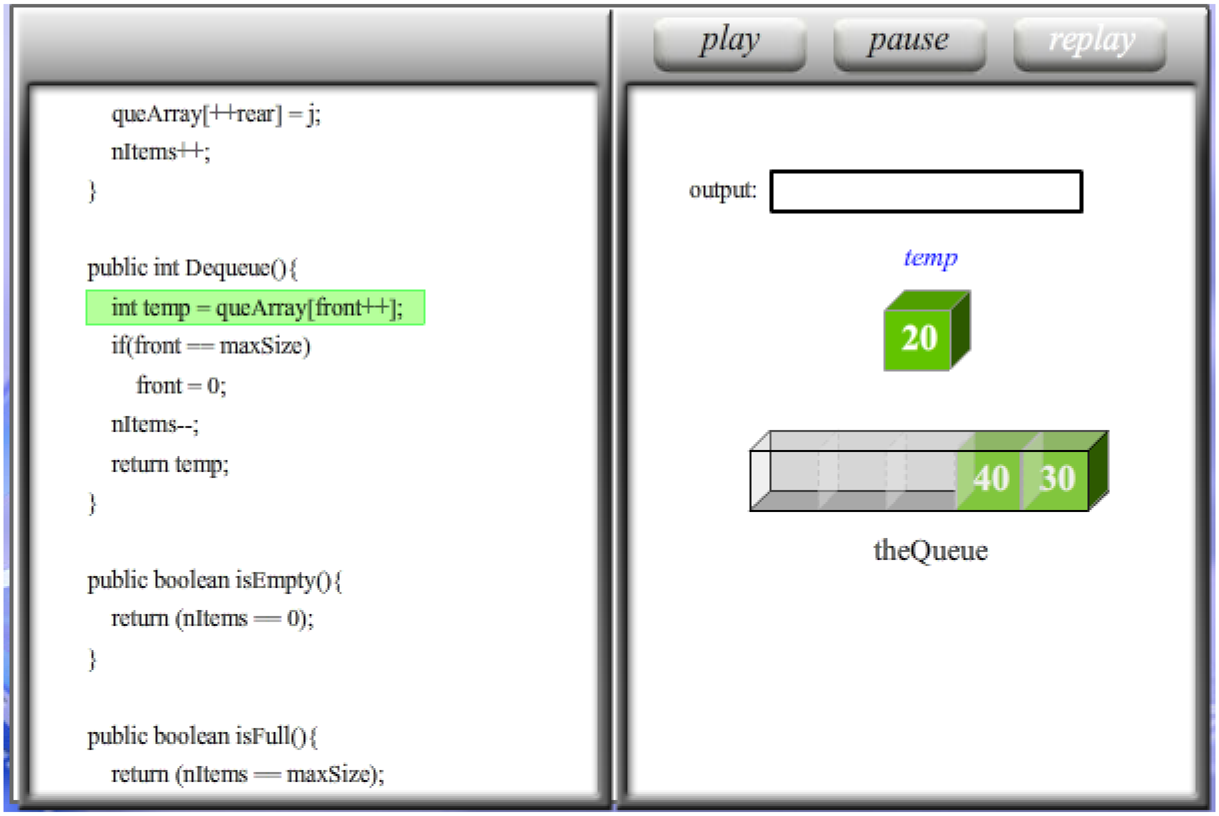


Fig 57

To implement the test case, the code used to implement the Dequeue operation is changed. The resulting code is shown in Figure 58.

```
class Queue
  {
    private int maxSize;
    private int[] queArray;
    private int front;
    private int rear;
    private int nItems;
    public Queue (int s)
      {
        maxSize = s;
        queArray = new int [maxSize];
        front = 0;
        rear = -1;
        nItems = 0;
      }
    public void Enqueue (int j)
      {
        if (rear == maxSize – 1)
        rear = -1;
        queArray[++rear] = j;
        nItems++;
      }
    public int Dequeue()
      {
        int temp = queArray [rear--];
        nItems--;
        return temp;
      }
  }
```

Fig 58

Due to the change in the code, the values from the queue are dequeued in the FILO order. Figure 59 shows the resulting animation with the planted error.

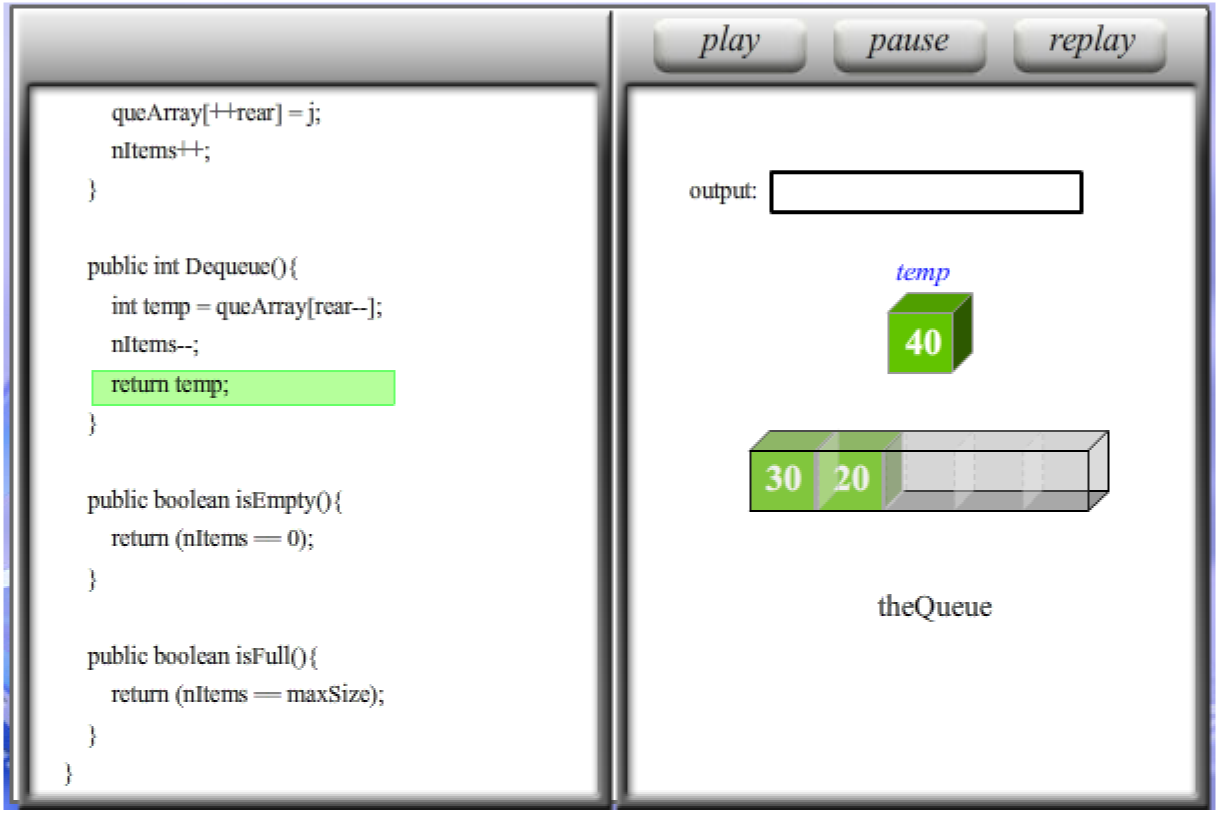


Fig 59

Figure 59 shows the value 40 being dequeued from the queue. Since value 20 is the first value to be enqueued to the queue, it should be dequed first. However, due to the planted error in the code, the elements are dequeued in the FILO order. The student must identify the code change that is responsible for the error in the implementation of the Dequeue method. The student is presented with a challenging multiple-choice question. Figure 60 shows the multiple-choice question.

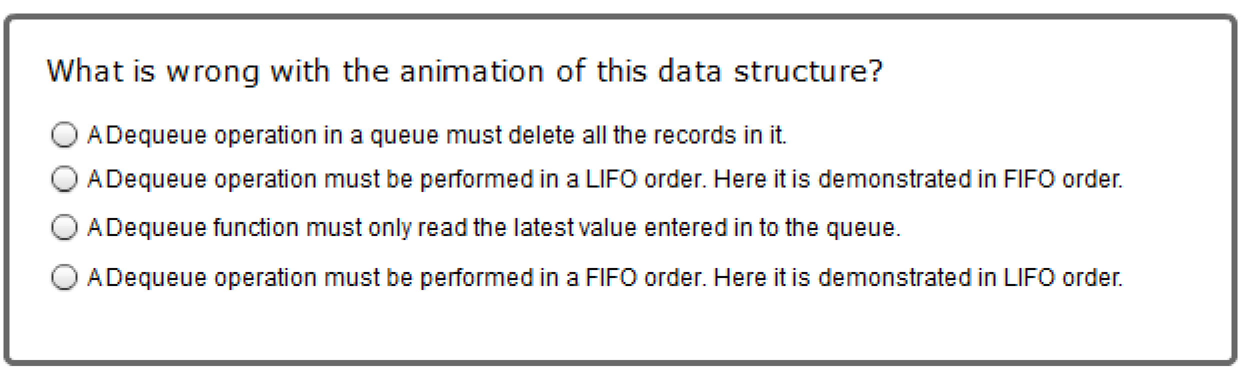


Fig 60

These sequences of steps require the full attention from the student. We believe getting students' complete concentration is important for their efficient learning.

Learning Case #11

A Hash Table uses a key-value pair to store information in a table. The key-value pair entered by the user is stored in the location determined by the hashing function. The hashing function that we have implemented for the hash table is:

$$\text{Hash (key)} = \text{key mod } 31$$

To deal with hash collisions, we applied linear probing technique to store the data records. This learning case demonstrates the implementation of lookup, insert and delete operations in a hash table. In this learning case, we have deliberately planted a bug to alter the delete operation in the hash table.

In a hash table, whenever a data record is deleted, the corresponding empty index is considered as empty for future insert operations and occupied for lookup operations. As seen in Figure 61, when the data record at the index 18 is deleted, it will not leave any unwarranted consequences for future insert/lookup operations. Figures 61 and 62 show a successful lookup operation in the hash table. The key-value pair adams:125 is just deleted, but it is considered as occupied for future search operations. Hence when we search for the record adams:567, it results in a successful operation.

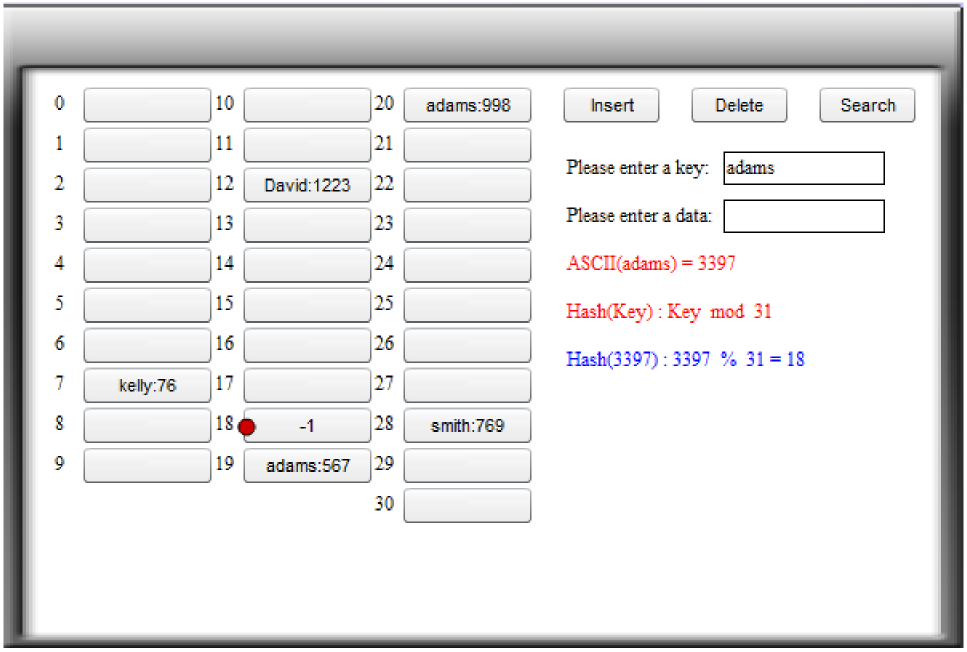


Fig 61

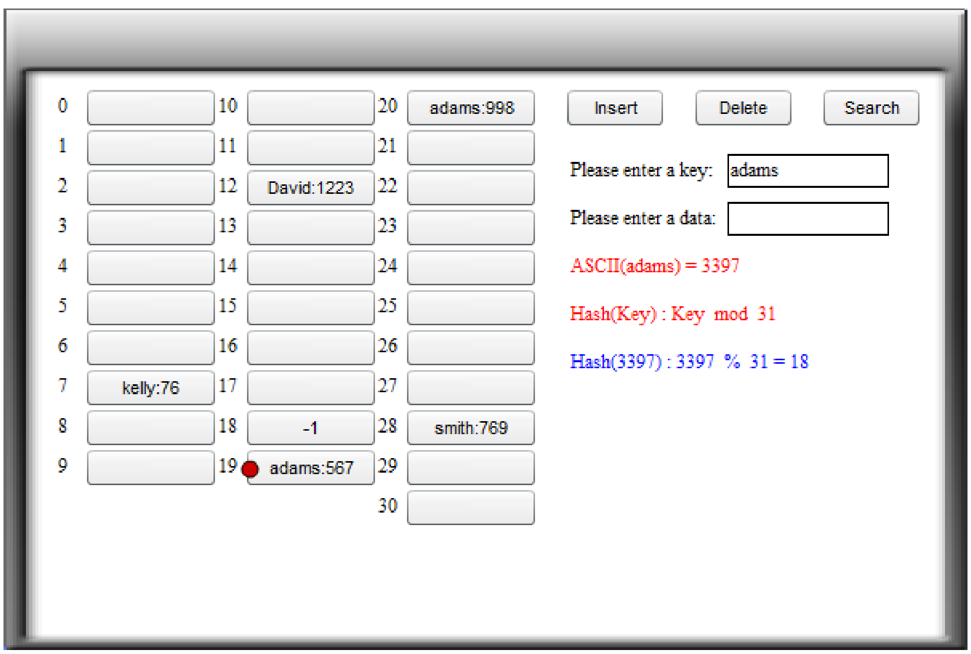


Fig 62

In the learning case, by planting the bug, we create an error during the delete process of a record. As shown in figure 63 and 64, the delete operation on key value pair adams:125 results in a vacant record that prevents successful results for the next search operations. Hence when the key-value pair is queried for lookup, it results in an empty result.

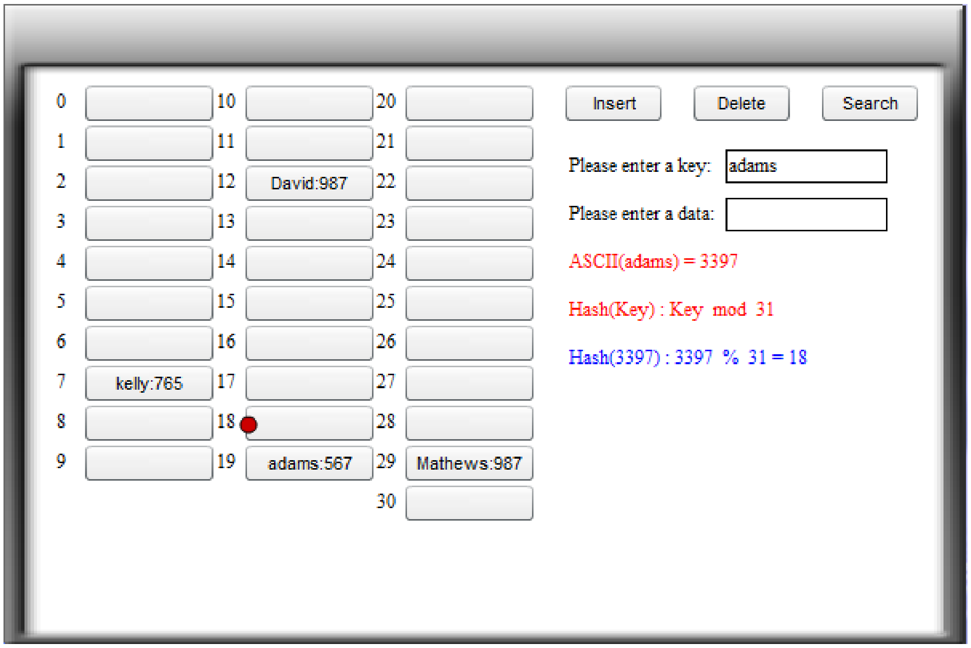


Fig 63

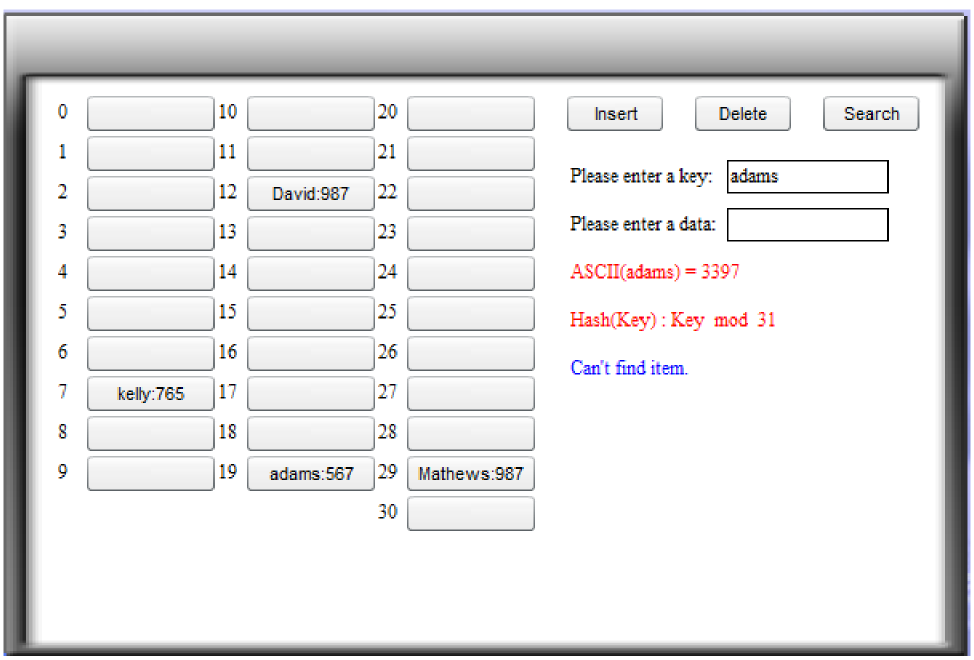


Fig 64

The student is challenged with a multiple choice question that tests his understanding of the operations performed in the hash table. Figure 65 shows the multiple-choice question presented to the student.

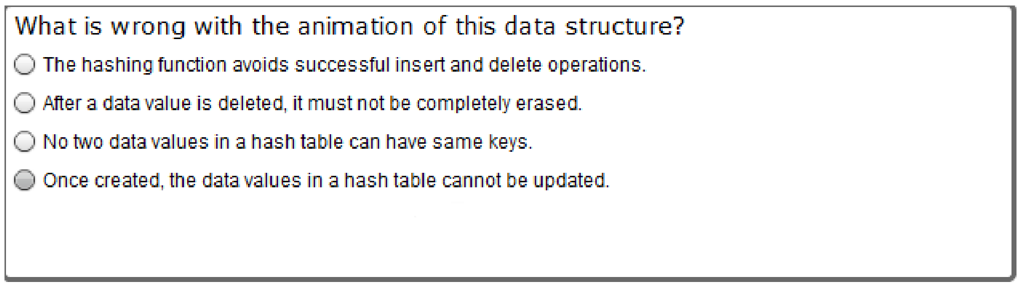


Fig 65

Learning Case #12

With this learning case, we intend to help students understand merge sorting algorithm. In merge sorting, elements should be recursively be divided in to sub lists of half the size of the parent sub list. This effectively means that the array must be divided to form sub lists of 2 elements each (with only 1 group containing a single element in case total number of elements is odd). The elements should then be sorted within their sub lists and then merged back and then sorted again to finally give a sorted array of elements. Figure 66 shows the correct implementation of merge sorting algorithm.

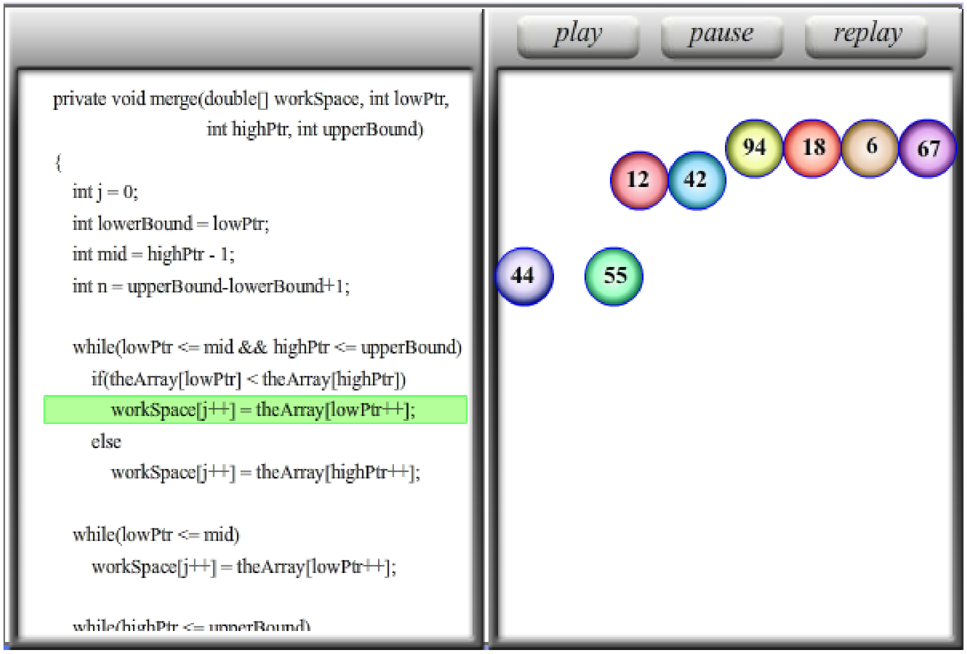


Fig 66

In order to utilize this algorithm as a learning case, we have deliberately planted a bug in the code. Due to this deliberately implanted bug, the unsorted list is divided only once resulting in two sub lists of 4 elements each. Elements are then sorted within the respective sub lists and merged back in to one sorted list of array.

This method of implementation does not reflect complete merge sorting. Figure 67 shows the animation at the instant where the elements are divided in to two sub lists of 4 elements each and sorted. This is an erroneous implementation of merge sorting because elements can only be sorted after they are divided in to sub lists of 2 elements each.

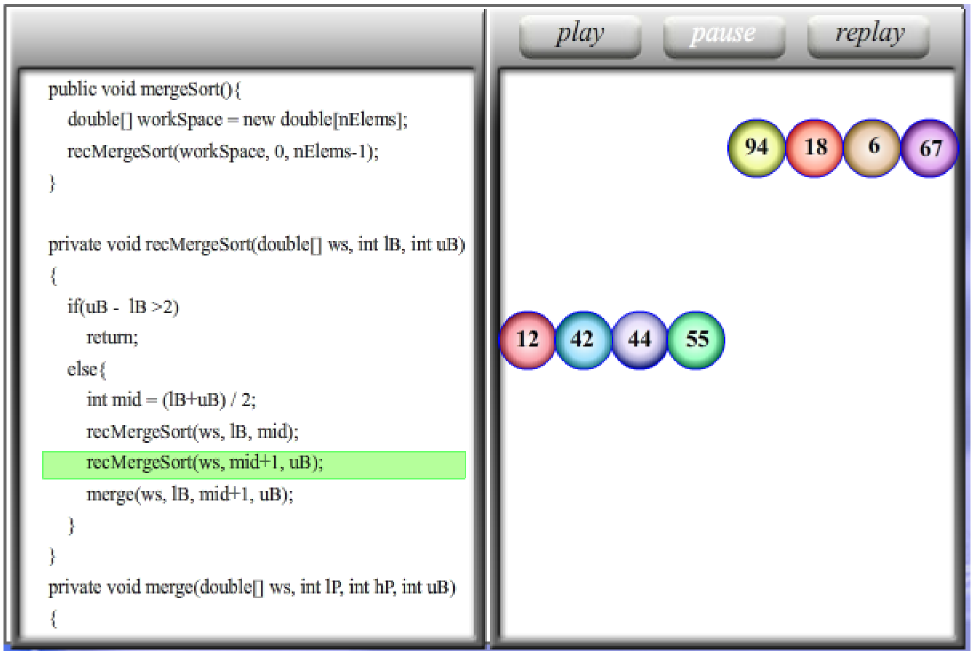


Fig 67

After the student examines the sorting animation, he must identify that the elements of the array are not recursively divided in to sub lists of 2 elements each before being sorted. After the animation is complete, a challenging multiple choice question is presented to the student inside the description box. Figure 68 shows the multiple-choice question presented to the student after the completion of the animation.

To help the student answer the question, the "Show animation" button calls the animation deployed with the correct code. This gives the student a comparison between the animations created based on the correct and that based on the wrong code and will also help the student analyze the code responsible for the error.

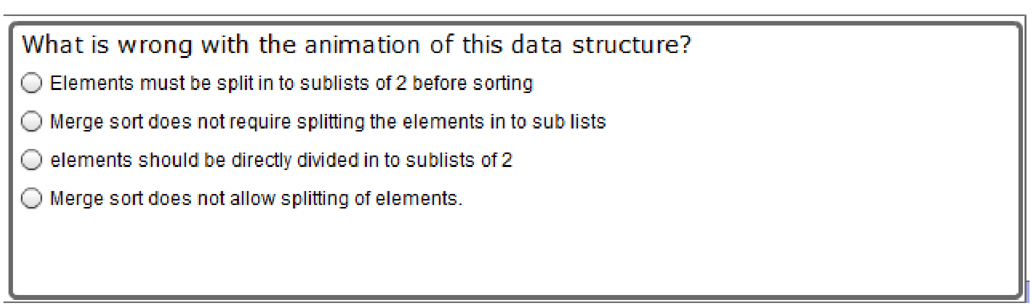


Fig 68

The student can also attempt the multiple choice question at any point later in the debug mode by clicking the “What’s wrong” button.

4.2 Code Highlighting for Bug identification:

To assist students’ learning of algorithms through the animations and code visualization, we have also implemented the code highlighting feature that allows the users to identify the bug in the code.

In the debug mode, when the student analyzes the animation and finds a problem of the animation, he can click the “Pinpoint to error” button and highlight the code lines that he thinks are the reason for the error in the animation. Then he clicks “Check My Answer”. The animator compares the highlighted code to the actual planted bug. If the user successfully identifies all the lines of code that are responsible for the bug, the animator will give a success solute. Otherwise, if he identifies the error partially, the animator alert says that he is partially correct. If he is not able to identify the bug correctly, the animator shows the student the exact lines of bug code.

Figure 66 shows the user interface of this feature for the pop operation in a stack. After the student analyzes the animation, he clicks the “Pinpoint to error” button and selects the lines that he thinks are modified to plant the bug as shown in Figure 69.

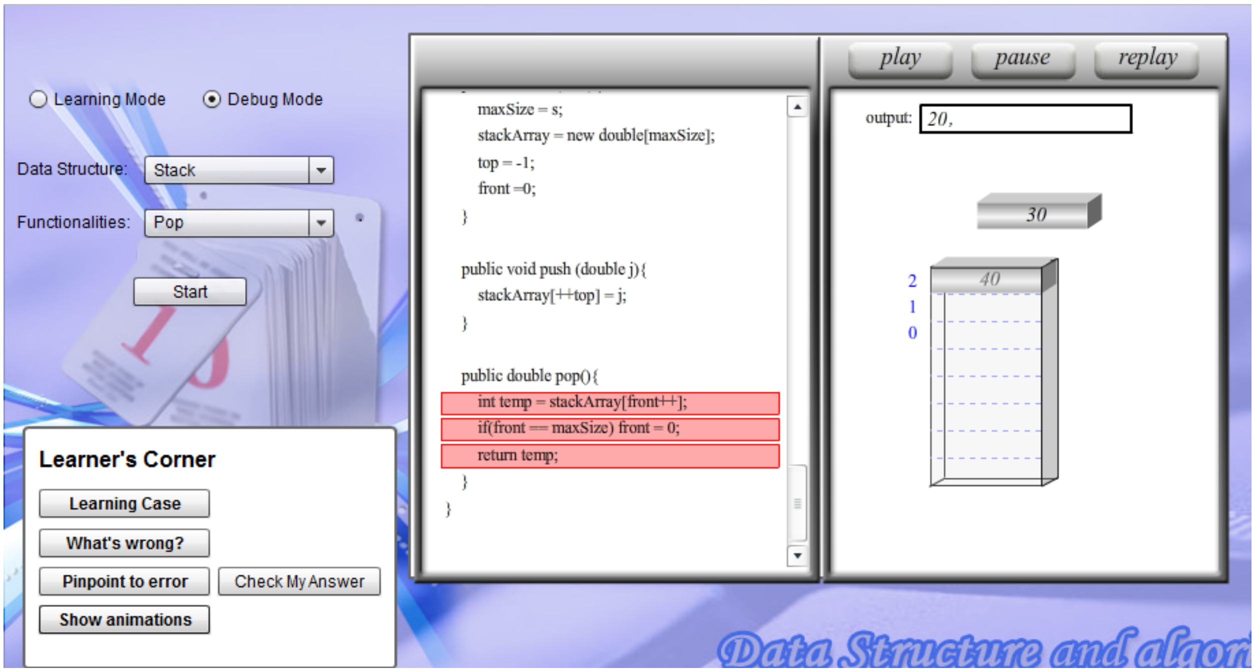


Fig 69

Once the user selects the erroneous lines, he then clicks "Check my answer" to find out if he has successfully identified the error. In this example, since the user has identified all the erroneous code lines, the animator gives him a success message as shown in Figure 70:

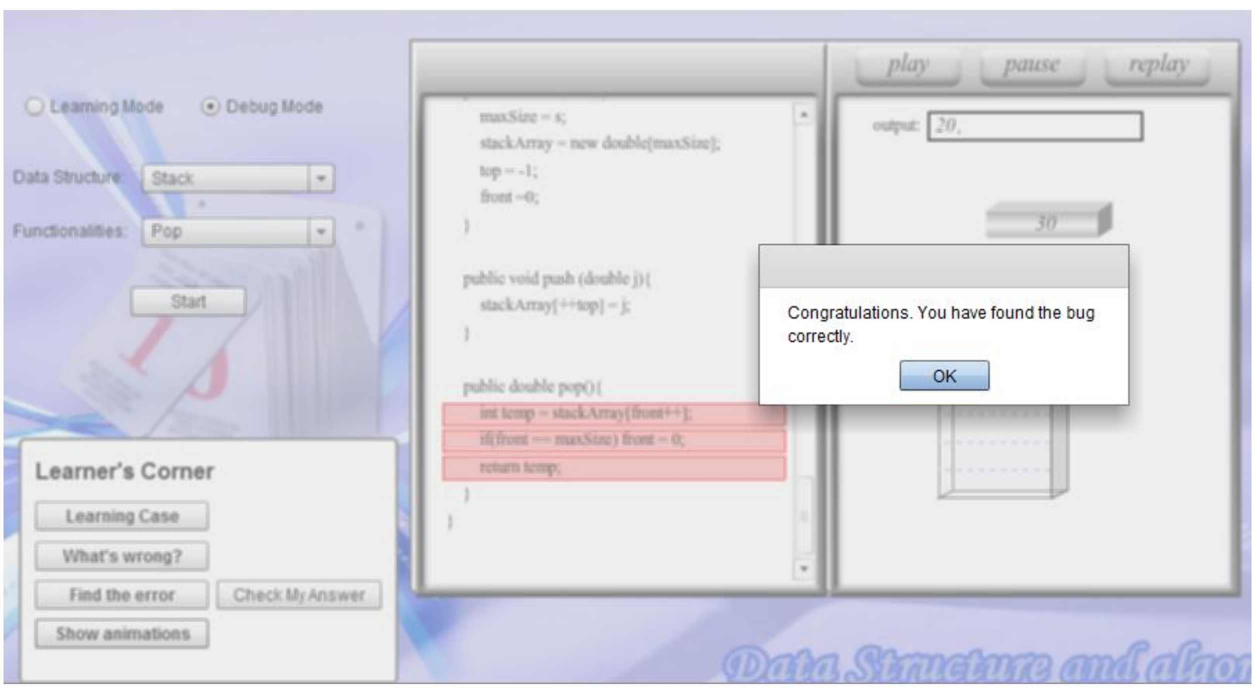


Fig 70

By providing this feature, we attempt to sharpen students' capability in code analysis. This feature hence provides a hands-on experience for the students to learn data structures programming with a greater attention to the details in the code.

5. Learning Tool Implementation

The basic platform for the learning tool is the visual representations of the data structures algorithms. The animations are designed in Adobe Flash environment using a combination of Flash components and action script code. The compiled animation files (with .swf extension) are dynamically loaded in to the Flex development environment. Each algorithm of the chosen data structure is designed using Flash based components discretely using Adobe Flash professional CS5. The animations are created using the frame based implementations. The Action script code in Flash is used to adjust the timing and the interactive nature of the animations to the user inputs. The motion implemented in the animations is defined using the motion tweening feature available in FLASH.

The Flex AlgorithmAnimation.mxml serves as the main application which orchestrates various animation files on the web server side. On the client side, the flash animation files are loaded in the browser and are played using Adobe Flash Player plugin. The use of a combination of Flash and Flex components in the development provides great advantages, especially in presenting the animations in a swift and appealing manner.

Designing animations in Flash Professional CS5

In a frame-based animation, each frame can be manipulated using the layout controls in the properties pane. ActionScript code snippets are used to guide and control the direction and motion aspects of the animation. Additionally, changes to the timing aspects can be performed by using the ActionScript.

Figure 71 shows the development of the visualization through Frame based animation of a stack data structure. The figure shows the exact snapshot of the animation at frame 50. The combination of such individual frames at various instances generates a continuous animation.

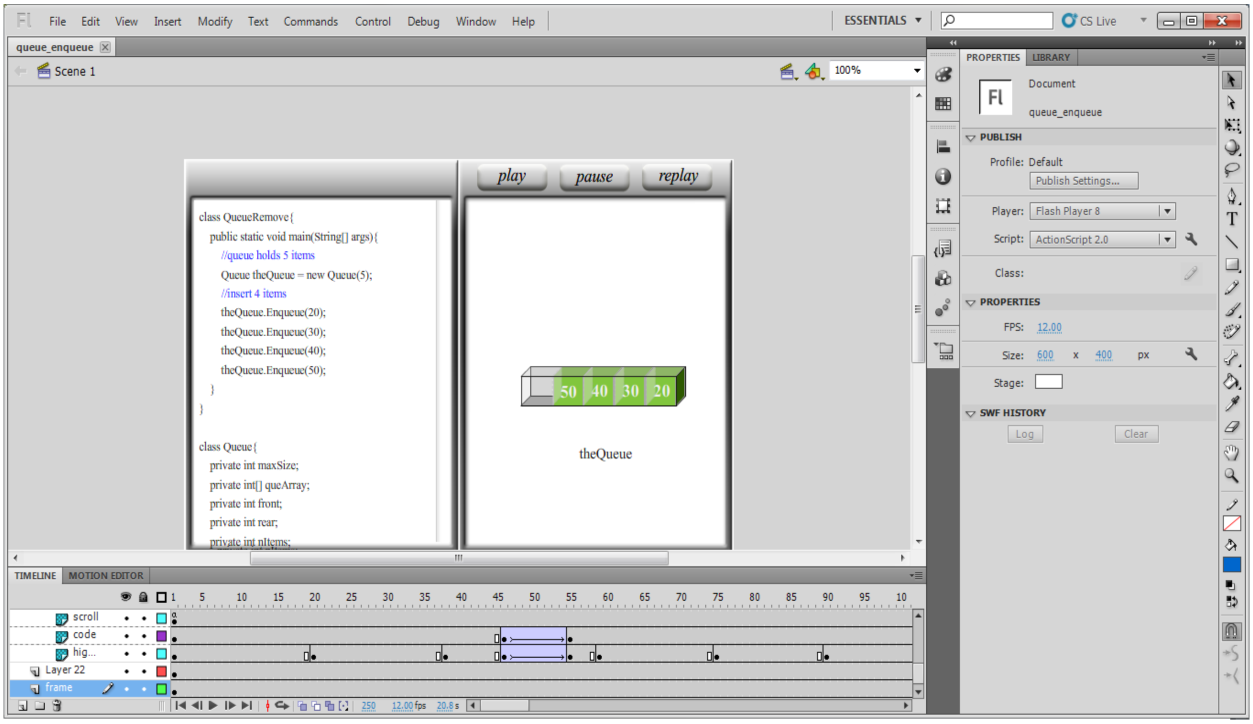


Fig 71

In order to make the animations run according to the controls used by the student, we need to access the motion tween at the code level. The primary use of the stop() method is to stop the animation from running continuously. During the visualization of the animations, since the students are provided the play, pause and replay buttons to control the animations, event listener objects are added to the code. These event listener objects detect the input from the students and call the respective methods to show the animations. We have taken the advantage of these code snippets to make the textual objects move along during the animations. Figure 72 shows a code snippet used for the stack PUSH animation.

```
code_sb._visible = false;
code_view.visible = false;
code.bg._visible = false;
stop();
code_sb.setScrollProperties (150,0,700);
//create listener object.
var sbListner:object = new object;
sbListner.scroll = function (evt_obj:object) {
//insert code to handle the scroll event.
//trace (code_sb.scrollPosition);
        code_view._y = 51.3-code_sb.scrollPostion;
}
//Add listener
code_sb.addEventListner ("scroll", sbListener);
```

Fig 72

Implementation of Flex components to visualize animations:

Flex components have been used to implement the visualization of the animations in the browser. All the components are assigned with trigger events that perform certain action.

Figure 73 shows a snippet of the XML based Flex code for the layout components.

```
<s:Panel width="100%" height="100%" title="Data Structures and algorithm animations."
horizontalCenter="0" verticalCenter="0" >

<mx:Image source="@Embed('animations/back.jpg')"   x.start="0" y.start="0"/>

<s:Label text="Data Structure:&#xd;"  x="10" y="25" height="26" width="85" x.start="10"
y.start="115"/>

<s:DropDownList id="dataStrList" dataProvider="{dataStructures}" labelField="algorithm"
prompt="Select one" change= "dataStrList_changeHandler(event)" x="103" y="20"
width="139"  x.start="103" y.start="110" width.start="160"/>

<s:Label x="10" y="64" text="Functionalities:" width="85" height="20" x.start="10"
y.start="154"/>
```

(Figure continued)

```
<s:DropDownList id="functionsList" x="103" y="58.5" dataProvider="{functions}"
prompt="Select function" labelField= "functionName” change=
"functionsList_changeHandler(event)"  width="139" x.start="103" y.start="148.5"
width.start="160"/>

<s:BorderContainer id="learnerCorner" visible="false" x="20" y="350"
borderVisible="true" borderWeight="2" cornerRadius="3" width="222" height="136"
height.start="178" y.start="308" width.start="274" x.start="14">

<s:Label  text="Learner's Corner" fontSize="16" fontWeight="bold"  width="165" x="10"
y="16"/>

<s:Button x="10" y="41" label="Learning Case" width="125" fontWeight="bold"
click="learningCaseHandler(event)" x.start="10" y.start="44" width.start="125"
height.start="21"/>

<s:Button x="10" y="70" label="What's wrong?" width="125" fontWeight="bold"
x.start="10" y.start="73" width.start="125" height.start="21"/>

<s:Button x="10" y="101" label="Show animations" width="125" fontWeight="bold"
click="showAnimationHandler(event)" x.start="10" y.start="129"/>
```

Fig 73

The code shown in Figure 70 is an XML code that initializes the layout components and assigns events to the components for a particular event. For example, the dropdown lists “Data structures” and “Functionalities” are controlled by the events FunctionsList_ChangeHandler and dataStrlist_ChangeHandler respectively. The multiple choices for corresponding test cases are manipulate using the method LearningCaseHandler. These events are triggered by various actions, for example, the student clicking a button. The pinpoint to error functionality is manipulated using the handler event – findErrorHandler.

6. Discussion & Conclusion

The primary objective of the Data Structures Visualization Tool is to help the computer science students understand the basics of data structures algorithms and implementation. The tool has adopted the Verification-Driven Learning Model and strives to illustrate the data structures in an interactive manner to help students' learning. In order to achieve the best results from this learning tool, it is necessary that more research be done towards the development of the tool to make sure it is enhanced in to a complete learning tool with more illustrations of various concepts. The tool has provided the students with richer interactive environment for learning. The process of prototyping this learning tool has shown that a combination of the Flex programming and the Flash technology is a viable platform for development of algorithm animation and code visualization for the learning tool.

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Vita

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