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# Visualization and Comparative Simulation of Pathfinding, Searching and Sorting Algorithms

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**Abstract :**This study addresses the need for enhanced algorithms learning through the utilization of comparative simulation and visualization. Motivated by the challenge of comprehending complex algorithms, we emphasize the efficacy of visualization tools. Our research explores the real-time rendering of algorithms in a visual format, facilitating a deeper understanding of their underlying mechanisms. In addition, we introduce a novel comparative simulation feature within our Algorithm Visualizer e-learning application, enabling learners to contrast the performance of diverse algorithms, discern their strengths and weaknesses, and evaluate their applicability to different data sets. Specifically, this application accommodates various algorithms, including Dijkstra's algorithm, DFS, BFS, Binary Search, and more. Learners can employ this tool to scrutinize algorithmic differences and efficiency, exemplified through scenarios like comparing Dijkstra's algorithm and A* algorithm for pathfinding on a map. Furthermore, this feature extends to the evaluation of sorting algorithms, such as Quick Sort and Merge Sort, allowing users to visualize their performance on large data sets. In conclusion, the Algorithm Visualizer e-learning application serves as a valuable resource for learners, enhancing algorithmic comprehension through comparative simulation and visualization techniques.

**Keywords:** algorithm visualization; searching; sorting; pathfinding; digital learning; heuristic algorithms; educational technology.

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## 1. Introduction

In the vast landscape of computer science, the study of algorithms is often encapsulated as the "Design and Analysis of Algorithms." Proficiency in computational thinking and programming is a prerequisite for excelling in this field. Nevertheless, the intricate nature of algorithms can pose a formidable challenge, even to seasoned programmers. Conventional pedagogical methods employed to teach algorithms can often be tedious, failing to provide the essential tools required for efficient and effective learning. As such, there exists a conspicuous gap, waiting to be bridged by a visualization-centric approach to algorithm learning.

This study seeks to address this critical void in the realm of algorithm education by venturing into the realm of dynamic visualization. The foundational motivation for this research stems from an extensive exploration and dialogue with leading experts, all of whom concur on the pressing need for a robust, user-friendly application with dynamic visualization features. This demand has sparked our enthusiasm for a novel project that leverages contemporary tools such as ReactJs, its associated frameworks, and libraries to craft a much-needed educational tool. Our overarching objective is the creation of a cutting-edge algorithm visualization platform, designed to facilitate efficient and effective learning.

By manifesting algorithms in a visual format, this software implementation promises to elevate students' understanding of these intricate constructs. With dynamic visual representations of algorithms in action, we aim to revolutionize the pedagogical landscape, ushering in a more comprehensive and effective approach to teaching. The paramount importance of visualization in comprehending complex concepts, including algorithms, is championed by an array of prominent experts and educators, all of whom underscore the adage that "a picture is worth a thousand words." Indeed, extensive research underscores the profound impact of visualization in enhancing our grasp of intricate subject matter.

In summation, our commitment is unwavering in the development of an algorithm visualization platform that stands as a formidable asset for learners of all backgrounds and skill levels. By harnessing the formidable power of visualization and comparative simulation, our application is poised to democratize algorithmic comprehension, making it more accessible, enjoyable, and understandable to learners across the spectrum.

## 2. Literature Review

The realm of algorithm visualization has witnessed several notable contributions by researchers and developers in recent years, underscoring the profound impact of visualization in the understanding and learning of complex algorithms.

(Prabhakar et al. 2022) embarked on the development of an algorithm visualizer using the Tkinter Module in Python. Their creation was a desktop application, readily accessible through a user-friendly website. While their work laid the foundation for algorithm visualization, it also highlighted the growing need for more interactive and accessible learning tools.

(Yadav et al. 2021) introduced a path-finding visualizer that harnessed A*, Dijkstra, and DFS algorithms to calculate the shortest route between designated start and end nodes. The visual representation of this process proved instrumental in fostering an intuitive understanding of these algorithms, underscoring the value of visualization as an educational tool.

(Goswami et al. 2021) made a significant stride in the field by creating an innovative algorithm visualization tool. Their tool encompassed a diverse range of path-finding, sorting, and CPU scheduling algorithms. Notably, their research revealed a pivotal statistic: 60% of students preferred learning algorithms through visualization rather than traditional textbooks. This insight shed light on the growing appetite for interactive and visually engaging learning tools to facilitate comprehension of intricate algorithms.

(Senger et al. 2021) focused their efforts on the development of a visualizer aimed at BFS and Dijkstra's Algorithm, accentuating the need for comparisons and analysis between these two algorithms. (B. Nagaria et al 2021) stressed the necessity for an interactive teaching tool catering to visually inclined students. Their tool allowed students to submit path-finding formulas and receive visual feedback, further emphasizing the efficacy of visualization in the learning process.

Ghandge et al. 2021) presented AlgoAssist, a comprehensive platform with integrated features that enhanced students' coding abilities and facilitated teachers' assessments of student work. A notable feature of AlgoAssist was its emphasis on "Algorithm Visualization" to elucidate the flow and operations of algorithms, consolidating lab functionality into a single accessible platform.

(Jain 2021) contributed to the landscape of algorithm visualization with a Sorting Algorithms Visualizer. This tool facilitated the visualization of various sorting algorithms, such as Insertion Sort, Bubble Sort, and Selection Sort. It provided users with the ability to generate random arrays for visualization and to control the sorting speed and array size, enhancing user engagement and understanding.

(Abedalrahim et al. 2020) focused their efforts on a desktop-based application developed using Java, which centered on the simulation of various sorting algorithms. However, this application had limitations as it could only be used on standalone PCs.

## 3. Proposed System

The research paper proposes a system for visualizing and simulating searching and sorting algorithms, with a focus on comparative analysis. The system is designed to provide a user-friendly interface that allows users to compare the performance of different algorithms under various conditions.

The selection of searching and sorting algorithms for this system is grounded in extensive literature research and prior research findings. Researchers such as (Prabhakar et al. 2022), (Yadav et al. 2021), (Goswami et al. 2021), (Senger et al. 2021), and (Ghandge et al. 2021) have demonstrated the value of algorithm visualization in enhancing understanding. These studies provide a strong justification for the inclusion of specific algorithms, including linear search, binary search, bubble sort, insertion sort, merge sort, quicksort, and heapsort. These algorithms have proven their significance in both educational and practical contexts, and their selection is informed by the broad applicability and relevance they hold.

The central research question guiding this work is: "How can we provide a comprehensive and accessible platform for users to visualize, simulate, and compare searching and sorting algorithms to facilitate algorithmic comprehension and evaluation?"

A. Objectives

The primary objectives of this research project encompass several key facets:

1. The development of a user-friendly web-based platform that offers dynamic visualizations and simulations of searching and sorting algorithms. The aim is to make these algorithms more engaging and comprehensible to a diverse audience.

2. Enabling side-by-side comparisons of different algorithms under various conditions, empowering users to assess the relative performance of these algorithms. This feature is vital in allowing users to make informed choices in algorithm selection for their specific tasks.

3. Providing customization options that allow users to adjust algorithm parameters and observe their impact on algorithm performance. Customization fosters deeper insights into algorithm behavior and empowers users to tailor algorithms to specific needs.

4. Offering comprehensive performance metrics, including comparisons, swaps, time complexity, and space complexity. This level of detail equips users with a deeper understanding of algorithm efficiency and resource usage.

5. Implementation of a modern and intuitive user interface that allows users to personalize their experience, making the platform accessible and enjoyable for learners, researchers, students, and developers alike.

The motivation for this research is rooted in the desire to make algorithmic concepts more accessible and enjoyable. Existing literature, exemplified by the work of Prabhakar et al. [1], Yadav et al. [2], Goswami et al. [3], and Ghandge et al. [6], underscores the effectiveness of algorithm visualization in enhancing the understanding of algorithms. This work also addresses the challenge of understanding and comparing pathfinding algorithms, such as Dijkstra's algorithm and A*, without visual aids. The web-based application aims to bridge this gap by providing interactive simulations and visualizations of different pathfinding algorithms.

In conclusion, this web-based application seeks to provide a user-friendly platform for comparative simulation and visualization of various searching, sorting, and pathfinding algorithms. It leverages modern web development technologies and tools to ensure a responsive and interactive user experience, empowering users on their journey to master and evaluate these algorithms effectively.

B. Features

The system will have the following features:

1. Auto-Generation and User Input: The system will allow users to auto-generate data or enter their data for visualization.

2. Side-by-Side Comparison: The application allows users to run two algorithms simultaneously for a side-by-side comparison. This feature enables users to compare the performance of different algorithms under various conditions.

3. Algorithm Selection: The system will include the

following searching algorithms:

a. Linear Search

b. Binary Search

c. Depth First Search

d. Breadth First Search

4. The following sorting algorithms will also be included:

a. Bubble Sort

b. Selection Sort

c. Insertion Sort

d. Quick Sort

e. Heap Sort

f. Merge Sort

5. Visualization Tools: The system will provide a variety of visualization tools to help users understand the behavior of each algorithm. Users can choose from several types of visualizations such as bar graphs, line graphs, or pie charts to display the results of each algorithm.

6. Performance Metrics: The system will provide detailed performance metrics for each algorithm. Users can view the number of comparisons, swaps, and other operations performed by each algorithm, as well as the time and space complexities of each algorithm.

7. Data Set and Algorithm Configuration Saving: The application will have a feature for users to save their data sets and algorithm configurations for future use. Users can save their results and compare them with previous runs to track their progress over time.

8. User Interface: The system will have a modern and intuitive user interface that is easy to navigate. Users will be able to choose from several color schemes and themes to customize the appearance of the application.

The proposed system will be an excellent tool for researchers, students, and developers to evaluate the performance of searching and sorting algorithms and gain a deeper understanding of their behavior. The application's user-friendly interface and visualization tools make it easy for users to compare algorithms and analyze their performance.

The proposed web application aims to provide a platform for comparative simulation and visualization of various pathfinding algorithms. Pathfinding is a common problem in computer science, and there are several algorithms available to solve it. However, it can be difficult to understand and compare these algorithms without visual aids. This web application aims to bridge that gap by providing users with interactive simulations and visualizations of different pathfinding algorithms.

The website will allow users to select from a variety of pathfinding algorithms, such as Dijkstra's algorithm, A* algorithm, and other variations. Users can create maps with different obstacles and terrain types to test the algorithms' performance in a 2D space. The application will simulate the pathfinding algorithm selected by the user on the map created by them. It will visualize the algorithm's progress and show the path found by the algorithm. Users can also compare the performance of different algorithms side by side on the same page.

Customization options will be available, allowing users to customize different parameters of the algorithms, such as the heuristic function, to see how it affects the algorithm's performance. The website will also provide learning resources to help users understand the algorithms' underlying principles, including tutorials and articles.

Overall, the website aims to provide a user-friendly platform for comparative simulation and visualization of pathfinding algorithms, using modern web development technologies and tools to ensure a responsive and interactive experience for users.

C. System Architecture

The visual representation of the major components of our application, depicted in Fig. 1, provides an at-a-glance overview of the system's architecture, highlighting the core functionalities that have been carefully designed to provide an intuitive and user-friendly experience.

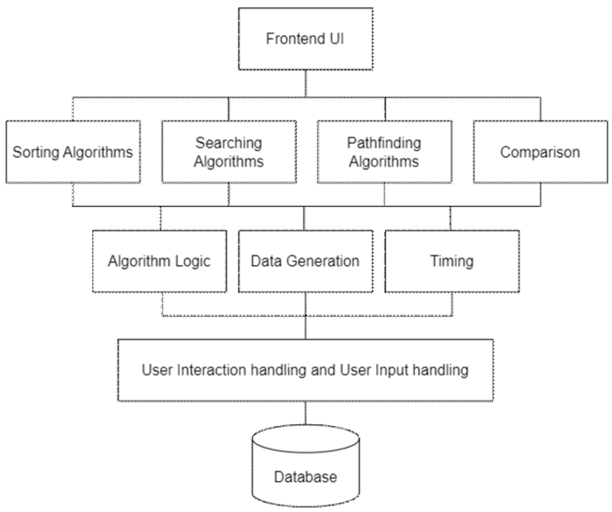


**Fig. 1 : System Architecture**

The system's three main components, Pathfinding Algorithms, Searching Algorithms, and Sorting Algorithms, have been thoughtfully designed to offer users an intuitive and engaging way to explore the fascinating world of algorithms.

The Pathfinding Algorithms component allows users to interact with a grid-based visualization where they can create a maze and set their starting and ending points. By selecting an algorithm, users can watch as the system employs a series of techniques to find the shortest path between these two points. The algorithm can be customized by adjusting the speed, adding barriers, or clearing the board. Additionally, the system provides an interactive feature where users can add a bomb to the maze as a barrier, making the visualization even more dynamic and exciting.

The Searching Algorithms component provides a comprehensive view of various algorithms used in searching, such as Linear Search and Binary Search. The system generates blocks that represent an array's size, and each block contains a specific value. Users can interact with these blocks and observe how each algorithm works to find a particular value within the array. To make the visualization more interactive, the system also offers an option to drag the blocks to reorder them, providing a more hands-on experience.

For DFS and BFS algorithms, the system generates circles to represent nodes and lines that represent the edges of a graph or tree. Users can interact with these circles and lines by adding new nodes and connecting them with lines to form edges. This interactive feature allows users to gain a deeper understanding of how these algorithms work to traverse the graph or tree and discover all of its nodes.

Finally, the Sorting Algorithms component offers an excellent way for users to observe how different sorting algorithms work. The system generates bars that represent an array's size, and each bar's height indicates its value. Users can generate random arrays or insert their arrays to visualize how each algorithm sorts the array. With this visualization, users can gain a deeper understanding of how algorithms such as Merge Sort, Quick Sort, and Bubble Sort work to arrange an array's elements in ascending or descending order.

Overall, the system's components offer a diverse range of interactive features that allow users to learn and explore algorithms in an engaging and accessible way. By providing a user-friendly interface and interactive elements, users can gain a deeper understanding of how algorithms work and their applications in real-world scenarios.

D. Additional Features

Upon examining numerous similar projects, it was observed that certain characteristics are absent, which, if integrated, can augment the visualizer's allure, user-friendliness, and overall user experience. Our application endeavors to overcome these shortcomings by incorporating the following additional features:

1. A superior and captivating User Interface (UI) is incorporated to enhance the overall User Experience (UX) of the application. Furthermore, the application is designed to be responsive, facilitating a seamless and excellent user experience on both desktop and mobile devices, thereby ensuring accessibility for all users.

2. To facilitate better visual comparisons, two algorithms can be executed simultaneously on the screen. Furthermore, the application analyzes algorithms' performance by conducting a comprehensive analysis of factors such as run times, complexity, and memory consumption, and comparing them to other algorithms to determine their efficacy and performance.

3. The application also features a slider that enables users to adjust the visualization speed, thus facilitating better comprehension of the

algorithm's operations. Furthermore, pause and play controls of the visualization are integrated into the application, enabling users to analyze each step of the algorithm in detail.

4. The application includes a dark mode option, which not only adds aesthetic value but also reduces eye strain and enhances visual appeal in low-light conditions.

## 4. Results

The implementation of our project has yielded significant results, which we are excited to share with you. Following are the results achieved after the implementation of the project.


**Fig. 2 : Sorting Visualization Page**

The Sorting Visualization Page, shown in Fig. 2, comprises the following elements:

- Array Text field that displays the Array to be visualized.
- Generate Button, which generates a random array of random lengths when clicked.
- Speed Slider, used to set the speed of Visualization.
- Algorithm Drop Down, used to select the Algorithm to be Visualized.
- Visualize Button, which initiates the visualization.
- Reset Button, used to reset the visualization.
- Timer, that counts the time required for visualization to be completed.
- Visualization Area, comprising Bars that represent the values of the array.


**Fig. 3 : Sorting Visualization Comparison Page**

In Fig. 3, we can see the Sorting Visualization Comparison Page, which includes the following elements:

- Array Text field: shows the array to be visualized.
- Generate Button: generates a random array of random lengths when clicked.
- Speed Slider: sets the speed of visualization.
- Algorithm Drop Down: Select the type of algorithm to be visualized.
- Visualize Button: starts the visualization.
- Reset Button: resets the visualization.
- Two Timers: count the time required for visualization of respective algorithms to be completed.
- Two Drop-Downs: select two algorithms of the selected type to be visualized and compared.
- Two Visualization Areas: consist of bars that represent the values of the array.

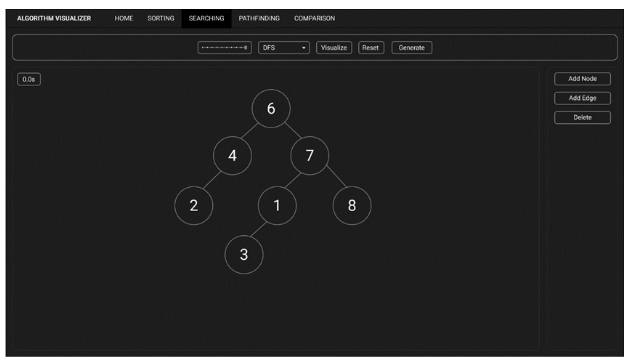


**Fig. 4 : Searching Visualization Page**

The Searching Visualization Page, shown in Fig. 4, comprises the following elements:

- Add Node Button to add a new Node.
- Add Edge Button to add a new Edge.
- Delete Button to delete an edge or a node.
- Generate Button, which generates a random tree when clicked.
- Speed Slider, used to set the speed of Visualization.
- Algorithm Drop Down, used to select the Algorithm to be Visualized.
- Visualize Button, which initiates the visualization.
- Reset Button, used to reset the visualization.
- Timer, that counts the time required for visualization to be completed.
- Visualization Area, consisting of Nodes and Edges that represent a Tree.

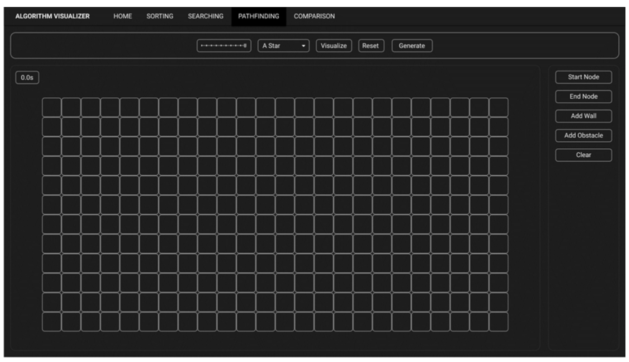


**Fig. 5. Pathfinding Visualization Page**

The Pathfinding Visualization Page, shown in Fig. 5, comprises the following elements:

- Start Node Button to set the start node in the Grid.
- End Node Button to set the end node in the Grid.
- Add Wall Button to add walls to the Grid.
- Add Obstacle Button to add obstacles in the Grid.
- Generate Button, which generates a maze when clicked.
- Speed Slider, used to set the speed of Visualization.
- Algorithm Drop Down, used to select the Algorithm to be Visualized.
- Visualize Button, which initiates the visualization.
- Reset Button, used to reset the visualization.
- Timer, that counts the time required for visualization to be completed.
- Visualization Area, comprising of a Grid that shows a maze.

Our project's advanced visualization features and algorithmic capabilities enable users to easily analyze and compare various pathfinding, searching, and sorting algorithms. With the ability to visualize and compare algorithms, users can gain a deeper understanding of their functions and operations, enabling them to make more informed decisions when selecting algorithms for specific tasks. This functionality is especially useful in the field of educational technology in higher education, where algorithmic understanding and proficiency are essential for success.

The implementation of our project has yielded significant technical results, and the addition of user experience and feedback further reinforces its practical value. Throughout the development process, we conducted extensive testing within our college community, inviting classmates and friends to interact with the application. The overwhelming response was positive, with users praising the project as a valuable tool for the study of Data Structures and Algorithms (DSA).

Most users found the interface intuitive, and the visualization features instrumental in enhancing their understanding of sorting, searching, and pathfinding

**Table 1 : Average Scores Given by Teachers and Students**

| Characteristics | Average Score (Students) | Average Score (Teachers) |
|---|---|---|
| User Interface | 9.1 | 8.7 |
| Ease of Use | 8.8 | 8.6 |
| Functionality | 9.2 | 9.1 |
| Education Value | 8.7 | 8.8 |
| Overall | 8.95 | 8.8 |

algorithms. Notably, teachers who evaluated the application also commended its potential for educational use, stating that with further development and additional features, it could be effectively employed in classrooms to teach students about algorithmic concepts. The combination of positive user experiences and constructive feedback positions our project as not only a robust technical solution but also a promising educational resource in the field of DSA.

## 5. Conclusion

In conclusion, our web application represents a valuable step in the realm of e-learning, offering users a powerful tool for visualizing and comprehending complex algorithms. The application is designed to be accessible to users of all levels, making it an effective educational resource.

As we look to the future, there are exciting possibilities for expanding our application's capabilities. One area of development that we envision is the creation of a mobile application that can operate offline, allowing users to access algorithm visualizations anytime and anywhere. The mobile application will encompass all the features available in the web version, ensuring users can visualize and compare algorithms conveniently on their mobile devices.

Moreover, we plan to incorporate more advanced algorithms based on algorithmic strategies like Divide and Conquer and Greedy Strategy. These advanced algorithms are fundamental in tackling complex problem-solving tasks, and their inclusion in our application will provide users with a deeper understanding of algorithmic strategies.

While we acknowledge the potential for our application to contribute to e-learning, it's important to emphasize that our work focuses on facilitating algorithm understanding and comparison. The ongoing development of our application aims to enhance the educational experience and make algorithmic concepts more accessible to learners.

In summary, our application is an innovative educational tool with the potential to impact how users learn about algorithms, and we are committed to further development to meet the evolving educational needs of our audience.

## Acknowledgment

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Additionally, we would like to thank our colleagues and other experts who provided us with their valuable feedback and insights throughout the development of this project. Their suggestions and constructive criticism have been instrumental in refining our ideas and making the project more effective, user-friendly, and innovative.

Lastly, we would like to thank the wider community of learners and educators who have shown an interest in our project. It is your enthusiasm and feedback that will continue to inspire us to work towards enhancing the project's capabilities and making it an even more valuable resource for everyone.

Once again, we extend our heartfelt appreciation to everyone who played a role in bringing this project to fruition, and we hope that our efforts will continue to benefit and inspire learners for years to come.

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