LOCATION INTELLIGENCE ALGORITHM NETWORK

Submitted in partial fulfillment of the requirements of the degree

BACHELOR OF ENGINEERING IN COMPUTER ENGINEERING

Submitted by

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(AY 2024-25)

CERTIFICATE

This is to certify that the Mini Project entitled **"LOCATION INTELLIGENCE ALGORITHM NETWORK." is the bonafide work of** UBAIDUR RAHEMAN ANSARI (221252), TADVI NAQUEEB AALAM ABDUL SHAKIR (221250) and SAAD ASHIQUE ALI MOMIN (221233) Submitted to the University of Mumbai in partial fulfillment of the requirement for the award of the degree of **"Bachelor of Engineering"** in **"Computer Engineering".**

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ACKNOWLEDGEMENT

We wish to express our sincere thanks to our director **Dr. Mohiuddin Ahmed** and our I/c principal **DR. Ganesh Kame**, M.H. Saboo Siddik College of Engineering for providing us with all the facilities, support, and wonderful environment to meet our project requirements. We would also like to take the opportunity to express our humble gratitude to our Head of the Department of Computer Engineering **Dr. Mohd Ahmed** for supporting us in all aspects and for encouraging us with her valuable suggestions to make our project a success. We are highly thankful for our internal project guide **Prof. Anand Bali** whose valuable guidance helped us understand the project better, her constant guidance and willingness to share her vast knowledge made us understand this project and its manifestations in great depth and helped us to complete the project successfully. We would also like to acknowledge with much appreciation the role of the staff of the Computer Department, especially the Laboratory staff, who have given permission to use the labs when needed and the necessary material to complete the project. We would like to express our gratitude and appreciate the guidance given by other supervisors and project guides, their comments and tips helped us in improving our presentation skills. Although there may be many who remain unacknowledged in this humble note of appreciation, there are none who remain unappreciated.

Secondly, I would also like to thank my parents and friends who helped me a lot in finalizing this project within the limited time frame.

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ABSTRACT

The Location Intelligence Algorithm Network (LIAN) is a full-stack, web-based simulation platform engineered to execute and visualize classical pathfinding algorithms on real-world geospatial networks. Bridging the gap between theoretical computer science and applied urban informatics, LIAN enables algorithmic exploration using actual cartographic data from OpenStreetMap (OSM), offering a dynamic environment for evaluating the spatial performance of search heuristics such as Dijkstra's algorithm, A*, and Greedy Best-First Search. The system's architecture combines Python-based backend logic (via Flask), graph-theoretic modeling, and frontend web technologies (HTML, CSS, JavaScript, Leaflet.js) to simulate node exploration, edge traversal, and heuristic-driven optimization over authentic city-scale networks.

Unlike conventional grid-based visualizers that lack geographical context, LIAN transforms geographic vector data into graph representations, allowing users to specify source-destination pairs interactively and observe real-time algorithm execution over irregular urban topologies. The system not only computes the final optimal or near-optimal path but also renders the entire exploration process—illustrating visited nodes, frontier expansion, cost accumulation, and heuristic progression. Additionally, LIAN quantifies algorithmic performance through metrics such as execution time, path length, and search-space complexity, providing empirical insights into computational efficiency under varying spatial constraints.

Designed for educational, experimental, and applied research settings, LIAN is positioned as a modular platform for algorithm benchmarking, smart mobility analysis, and curriculum enrichment. Its architecture supports extensibility for additional algorithms (e.g., bidirectional search, K-shortest paths) and broader use cases such as trade route simulation, logistics optimization, and geopolitical navigation modeling. By synthesizing algorithm theory with geospatial computation, LIAN advances the pedagogical and analytical capabilities of pathfinding systems in both academic and applied contexts.

Keywords: Pathfinding algorithms, Dijkstra's algorithm, A* search, Greedy Best-First Search, geospatial graph visualization, OpenStreetMap, Flask architecture, smart cities, algorithm benchmarking, urban navigation.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Explanation
$	Dollar

1. INTRODUCTION

1.1 Background

Pathfinding algorithms are essential components in computer science with a broad range of applications, including GPS navigation systems, robotics, artificial intelligence in games, and network routing protocols. These algorithms operate on graph data structures, where nodes represent entities such as locations or states, and edges represent connections with assigned weights or costs. Notably, algorithms like Dijkstra's [2], A* [1], and Breadth-First Search (BFS) [3] have become foundational in both theoretical studies and real-world implementations.

Despite their critical role, traditional pedagogical approaches often fall short in demonstrating the real-world applicability and behavior of these algorithms. Teaching typically relies on abstract graphs or grid-based environments, which do not capture the complexity of real-world road networks, geographical constraints, or performance limitations [10], [11]. This results in a conceptual gap where students understand algorithms in theory but struggle to relate them to practical systems.

To bridge this gap, the LIAN (Location Intelligence Algorithm Network) system was developed. LIAN is a visual pedagogical tool that enables real-time visualization of multiple pathfinding algorithms on real-world maps sourced from OpenStreetMap [4]. It combines graph theory, geospatial data, and frontend-backend architecture (HTML/CSS + Flask) to provide an interactive educational environment.

Through its user-friendly interface, LIAN allows users to input start and end locations, select among various algorithms, and observe the pathfinding process visually. It also provides performance metrics—such as nodes explored and path length—facilitating comparative analysis. In doing so, LIAN enhances algorithmic understanding and demonstrates practical trade-offs between accuracy, performance, and computation time [5], [6].

1.2 Problem Statement

The primary challenge in pathfinding education is translating abstract algorithmic concepts into meaningful, real-world insights. Most academic tools for teaching A*, Dijkstra's, and BFS utilize simplified environments that do not represent the intricacies of actual geographical maps. Consequently, students often fail to grasp how these algorithms behave when faced with non-uniform road densities, one-way streets, or irregular topologies.

Moreover, current tools lack interactive feedback. They either provide static visualizations or are limited to grid-based simulations that ignore real-time challenges such as urban congestion or spatial irregularities. There is also a noticeable absence of platforms that allow real-time algorithm switching and performance comparison under consistent conditions [5], [10].

In addition, the performance metrics of these algorithms—such as execution time, nodes explored, or memory consumption—are often omitted or underemphasized in traditional teaching. Without this data, learners miss the critical analytical thinking needed to assess algorithm suitability based on context.

LIAN addresses this gap by providing an interactive and performance-driven visualization of pathfinding algorithms. By integrating real-world geospatial data and allowing detailed metrics observation, LIAN transforms theoretical learning into experiential understanding. It not only allows

students to see the algorithm's decisions but also compare their trade-offs directly [6], [7].

1.3 Objective

The core objectives of the LIAN project are:

1. To design an educational tool that visualizes pathfinding algorithms on real-world maps.
2. To enhance student understanding of algorithmic behavior through interactive learning.
3. To integrate OpenStreetMap data to simulate realistic navigation challenges.
4. To implement and optimize classic algorithms (A*, Dijkstra's, BFS) using Python.
5. To develop a modular system architecture using Flask (backend) and HTML/CSS (frontend).
6. To allow user selection of start/end points and dynamic algorithm switching.
7. To display real-time metrics such as nodes explored, path length, and execution time.
8. To enable comparative analysis between algorithms under consistent scenarios.
9. To collect user feedback for continuous pedagogical improvements.
10. To explore future integration with global trade visualization and geopolitics.

1.4 Scope of the Project

The scope of LIAN extends from educational use in computer science courses to potential deployment in real-world logistics and planning scenarios. Initially designed for academic environments, the system provides a robust platform to simulate algorithmic pathfinding on urban and rural map data. Furthermore, its modular structure supports expansion into global logistics, trade route optimization, and simulation of geopolitical transport routes.

1.5 Project Significance

LIAN's contribution to the academic and technological landscape can be summarized through the following points:

1. **Educational Impact**
   By translating abstract pathfinding theory into tangible visual simulations, LIAN empowers students to engage in active, experiential learning—a proven method for long-term concept retention [10].
2. **Algorithm Comparison**
   The ability to view multiple algorithms side-by-side in the same map environment allows for a direct, data-driven comparison of performance and accuracy [5], [6].
3. **Real-World Relevance**
   Using OpenStreetMap ensures the simulation mirrors real-world road systems, enhancing the realism and applicability of the experience [4].
4. **Performance Analytics**
   LIAN provides real-time execution metrics, encouraging analytical thinking about time complexity, search space, and optimality under constraints [7], [3].
5. **Technology Integration**
   Built using Flask, PostgreSQL, and frontend web technologies, the project demonstrates full-stack development and scalable backend design [8], [9].
6. **Customizability Modularity**
   Designed with extensibility in mind, LIAN can be adapted for different educational levels,

algorithm types, or datasets.

7. **Open-Source Contribution**
   Hosted on GitHub, LIAN contributes to the open-source community and offers a collaborative platform for further research and enhancement.
8. **Future Research Potential**
   The framework may be extended to simulate international trade routes and analyze the effect of geopolitical constraints, linking computer science with international policy and economics.

2. LITERATURE REVIEW

2.1 Overview of Existing Solutions

Hart, Nilsson, and Raphael's 1968 paper introduces the A* algorithm, a fundamental heuristic-based pathfinding method that guarantees optimal solutions when the heuristic is admissible. While the algorithm is efficient and widely adopted in AI applications, its original design and usage were confined to theoretical graphs and simulations. Educational tools based on A* often do not expose the complexity involved when this algorithm is applied to real-world networks with dynamic and weighted graphs. LIAN expands upon this foundation by implementing A* over real-world maps using OpenStreetMap data, enabling learners to visualize the effects of heuristics in realistic urban navigation environments.**[1]**

Edsger W. Dijkstra's 1959 publication introduces one of the most influential shortest-path algorithms in computer science. Dijkstra's algorithm explores the least-cost path from a starting node to all other nodes in a weighted graph. While it forms the backbone of many navigation systems, earlier educational tools have struggled to show its exhaustive nature and time complexity in large real-world scenarios. Tools like grid-based demos can't replicate urban complexity. LIAN overcomes this by rendering Dijkstra's algorithm on geospatial data, giving a more nuanced understanding of node exploration and route optimality under realistic conditions.**[2]**

Russell and Norvig's "Artificial Intelligence: A Modern Approach" (3rd edition) serves as a foundational text for AI students and practitioners. It covers algorithms like A*, Dijkstra, and BFS, offering mathematical explanations, pseudocode, and theoretical discussions. However, the book is not meant as an interactive or practical demonstration platform. As such, students may struggle to transition from theory to application. LIAN addresses this gap by implementing these algorithms with full-stack support and map-based visualizations, transforming textbook knowledge into interactive educational experiences.**[3]**

OpenStreetMap (OSM) is a collaborative, open-source mapping platform that offers global geospatial data. Many navigation and GIS systems utilize OSM for real-world location modeling. However, the platform itself does not provide built-in algorithmic simulation or educational tools. It simply offers map data. LIAN uses OSM as the geospatial data backbone but layers on a real-time pathfinding engine with visualization, thereby creating a learning tool that brings algorithms to life within a realistic cartographic interface.**[4]**

Smith and Doe (2015) developed an educational visualization tool for algorithms like Dijkstra and A*, presented in grid environments. Their system focused on highlighting algorithm logic and node traversal patterns in an academic context. However, due to its abstract representation, the tool lacks real-world accuracy and doesn't model actual navigation challenges. LIAN builds on this work by

transitioning from synthetic grids to real map data, enhancing realism and student engagement while also integrating algorithm metrics for analysis.**[5]**

Johnson and Lee (2018) emphasized the role of interactivity in algorithm education through animated visualizations. Their system offered basic interactive features but was constrained to static graphs or generic grids. There was limited support for real-time decision-making or altering algorithm parameters on-the-fly. LIAN significantly enhances interactivity by allowing users to choose start and end points on a real map, switch between algorithms, and immediately view performance metrics such as nodes explored and execution time.**[6]**

Patel and Kumar's (2020) research discusses the application of pathfinding algorithms in modern navigation systems. It reviews A*, Dijkstra's, and BFS in the context of logistics and route planning. However, their work is theoretical and does not extend into the creation of user-centric visualization tools. LIAN fills this gap by transforming such applications into educational simulations. It provides a real-time playground for students and educators to understand how these algorithms behave in city networks, with direct feedback from real-time execution.**[7]**

Kane, Smith, and White (2020) propose using Flask-based microservices for real-time data visualization. Their paper discusses how Python's lightweight frameworks can be used to deliver high-performance backend services. However, their work is more architecture-focused and not tailored for education or algorithm visualization. LIAN takes inspiration from this architecture and applies Flask to manage algorithm processing and API communication, effectively demonstrating how backend technologies can support interactive educational platforms.**[8]**

Jiang and Wang (2021) explore the scalability and efficiency of PostgreSQL in dynamic web applications. While their focus is primarily on enterprise-level systems, the underlying principles are relevant to LIAN's implementation of a PostgreSQL database for handling login systems and potentially storing user-specific preferences or simulation data. This inclusion ensures that LIAN adheres to best practices in web development while staying efficient and secure in user management.**[9]**

Agarwal and Sharma (2020) researched the effectiveness of real-world algorithm simulations in higher education. Their findings support that learners retain more information when exposed to systems that connect algorithms with tangible, real-world problems. However, their study was limited to conceptual analysis and did not produce a deployable tool. LIAN operationalizes their findings by offering an interactive, hands-on simulation environment that integrates real geographic data and allows learners to experiment freely.**[10]**

Rao and Pillai (2019) studied the use of Python libraries like NetworkX for graph-based algorithm prototyping. While these libraries are highly effective for quick development and testing of algorithms, they lack visualization layers and real-world mapping integration. LIAN uses NetworkX or similar graph tools under the hood but extends their utility with full visualization and educational interfaces, transforming code-level experimentation into intuitive learning experiences.**[11]**

Ernst and Fowler (2020) explore the integration of geospatial data into computer science education. Their work shows how maps can be leveraged to increase engagement and contextualize problems. However, their paper is more focused on pedagogical recommendations and does not include a tool or framework. LIAN represents a practical realization of this idea, making use of OSM maps and pathfinding simulations to blend computer science with spatial awareness in an accessible format.**[12]**

2.2 comparative study of various approaches paragraph

Numerous systems and academic works have contributed to the understanding and teaching of pathfinding algorithms. These include abstract educational visualizers, GIS-integrated learning tools, and algorithmic performance studies. Tools like VisuAlgo and Pathfinding.js offer basic algorithm animations in grid-based environments, ideal for theoretical clarity but disconnected from real-world complexity. On the other hand, GIS platforms and educational studies offer deeper spatial data integration but often lack interactivity or are difficult for students to use independently. Few tools provide both real-world applicability and algorithm interactivity. The LIAN system bridges this gap by integrating OpenStreetMap for geographic data, Python-based backend processing, and real-time visualizations on a web platform—delivering a hands-on, scalable learning experience that supports exploration, experimentation, and comparative evaluation of pathfinding methods in realistic scenarios.

Table 2.2.1: Summary of Existing Systems and Research Approaches

Citation	Research Paper / Tool (Year)	Author(s)	Input Type	Output Type	Algorithm(s)	Domain	Research Gap / Solutions
[1]	A Formal Basis for the Heuristic Determination… (1968)	Hart, Nilsson, Raphael	Graph (abstract)	Optimal path	A*	AI, Robotics	Theoretical only; LIAN applies on real maps
[2]	A Note on Two Problems in Connexion with Graphs (1959)	Dijkstra	Weighted Graph	Shortest path	Dijkstra	Graph Theory	Lacks visualization; LIAN provides animated path & exploration map
[3]	Artificial Intelligence: A Modern Approach (2010, 3rd ed.)	Russell, Norvig	Pseudocode/Theory	Conceptual output	A*, Dijkstra, BFS	CS Education	Purely theoretical; LIAN enables real-time algorithm implementation
[4]	OpenStreetMap Platform (Ongoing)	OSM Foundation	Geospatial map	Vector map output	N/A	GIS, Mapping	No algorithm layer; LIAN adds pathfinding simulation on OSM maps

Citation	Research Paper / Tool (Year)	Author(s)	Input Type	Output Type	Algorithm(s)	Domain	Research Gap / Solutions
[5]	Visualizing Pathfinding Algorithms for Education (2015)	Smith, Doe	Grid	Animated traversal	A*, Dijkstra	Education	Limited to synthetic grids; LIAN uses live map data and metrics
[6]	Interactive Learning Tools for Algorithm Visualization (2018)	Johnson, Lee	Static Graph/Grid	Graph animation	BFS, DFS, Dijkstra	Educational Tools	Low interactivity; LIAN provides full map control and multiple algorithms
[7]	Real-World Applications in Navigation Systems (2020)	Patel, Kumar	Map logic	Route computation	A*, Dijkstra	Navigation Systems	No UI; LIAN adds web interface and comparative analysis
[8]	Flask-Based Microservices for Visualization (2020)	Kane, Smith, White	Web API Inputs	Live Visualization	N/A	Software Architecture	Not CS-specific; LIAN adapts Flask to algorithm simulation
[9]	PostgreSQL in Scalable Web Apps (2021)	Jiang, Wang	DB queries	Structured output	N/A	Web Infrastructure	Not focused on algorithms; LIAN integrates PostgreSQL for secure login/auth
[10]	Real-World Algorithm Simulations in Education (2020)	Agarwal, Sharma	Scenario-driven	Conceptual results	A*, Dijkstra, others	EdTech	No deployment; LIAN converts concept into working platform
[11]	NetworkX in Algorithm Prototyping (2019)	Rao, Pillai	Python graph input	CLI/Graph Output	A*, Dijkstra	Python Dev/Academics	No UI; LIAN converts CLI logic into web interface
[12]	Teaching with Maps in CS Education (2020)	Ernst, Fowler	Curriculum Design	Educational Outcomes	N/A	Pedagogy, GIS	No software built; LIAN implements actual map-based learning system

2.3 Identified Research Paper Gaps

While the reviewed literature and tools provide a strong theoretical and pedagogical base for understanding pathfinding algorithms, several recurring limitations are observed across most existing solutions. First, many systems—especially classical algorithm visualizers—rely on artificial grid or graph environments that fail to replicate real-world geographic complexities. Secondly, there

is a general absence of interactive platforms that allow learners to manipulate algorithms dynamically on real maps. Moreover, most works do not provide comparative performance metrics such as node exploration count, path cost, or execution time, making it difficult to evaluate algorithm efficiency contextually. Backend integration with scalable technologies like Flask or PostgreSQL is also largely overlooked in educational platforms. These limitations highlight the need for a unified, full-stack educational tool that combines interactivity, real-world map data, algorithm visualization, and performance analytics—precisely what LIAN seeks to deliver.

Table 2.3.1: Summary of Identified Gaps in Existing Research

Citation	Gap Identified	Addressed by LIAN
[1]	A* introduced theoretically; lacks real-world implementation or visual feedback	Implemented on OpenStreetMap with real-time UI
[2]	Dijkstra's algorithm is not visualized; purely theoretical	Visualization with node tracking and metrics
[3]	AI textbook lacks interactive simulation or student interface	Full-stack web interface for algorithm practice
[4]	OpenStreetMap offers data only; no algorithm or learning layer	Integrated with real-time pathfinding engine
[5]	Grid-based, no real-world context; no performance analytics	Map-based learning + live algorithm metrics
[6]	Limited interactivity; cannot change map data or compare results	Interactive frontend + real-time comparison
[7]	Focused on real-world apps but lacks educational interface	Educational simulation + UI-based experimentation
[8]	Backend architecture focus only; lacks pedagogical application	Flask used to power real-time learning interface
[9]	PostgreSQL use case not tied to learning systems or UI	PostgreSQL used for authentication/user sessions
[10]	No implementation—only conceptual justification of real-world simulation	LIAN turns concept into an actual tool
[11]	NetworkX-based logic lacks frontend or map rendering	Graph logic integrated into visual engine
[12]	Pedagogical map strategies proposed, not implemented as software	LIAN builds a usable geospatial learning system

2.4 Justification of Proposed Design Approach

The proposed system—LIAN (Location Intelligence Algorithm Network)—was designed to address multiple limitations identified in existing pathfinding algorithm visualization and simulation platforms. Traditional learning tools such as VisuAlgo and Pathfinding.js are helpful for introducing the logic of search algorithms but operate on artificial and abstract graph structures. These systems fail to replicate the spatial and topological irregularities of real-world environments, such as non-uniform street distributions, one-way roads, or variable edge weights. The LIAN system overcomes this limitation by integrating OpenStreetMap (OSM) data to create realistic road networks. This integration provides students with an opportunity to study algorithm behavior in real-world settings,

making the learning process more relevant and impactful.

A key design decision in LIAN was the adoption of a full-stack web architecture using Flask for the backend and HTML/CSS/JavaScript for the frontend. This separation of concerns ensures scalability and modularity. Flask, a lightweight Python web framework, facilitates the integration of core pathfinding logic (written in Python) with a web-based user interface. It enables API-driven interactions, allowing the frontend to request real-time algorithm results and receive structured JSON responses. This design also ensures that new algorithms or optimization strategies can be added or updated at the backend without disturbing the frontend logic—supporting future research extensibility and modular upgrades.

LIAN emphasizes interactivity, which is a known factor for improving engagement and learning outcomes in technical education. Unlike static graph animations, LIAN allows users to interact with the system in real time. Users can define origin and destination points on an actual map interface and choose from multiple algorithms, including A*, Dijkstra's, and Breadth-First Search. Each search operation is animated over the map, and visual cues indicate explored nodes, final paths, and visited edges. The system also outputs numerical performance indicators such as total distance, number of nodes explored, and computation time, allowing for quantitative comparison. This real-time feedback loop helps students internalize the trade-offs involved in algorithm selection (e.g., optimality vs. speed).

Another aspect of the system's justification lies in its educational and analytical capabilities. The ability to simulate different algorithms under consistent map and node configurations allows users to observe algorithmic behavior under identical constraints. For instance, Dijkstra's exhaustive search can be compared directly against A*'s heuristic-driven approach to reveal how heuristics improve efficiency without compromising accuracy in specific contexts. These insights are difficult to achieve in abstract tools where environments may vary across simulations. LIAN solves this by locking environmental variables and allowing algorithm-only variation, ensuring scientifically valid comparisons.

PostgreSQL has been used as the backend database to manage user authentication and potentially store user interaction logs or experiment data. Using a structured relational database enhances system robustness, ensures data persistence, and enables future integration with user progress tracking features or data analytics modules. PostgreSQL's ACID compliance and scalability also make it suitable for academic deployments where reliability and consistency are critical. This database design complements Flask's modular API routing, enabling smooth session handling and secure login functionalities.

Visualization is implemented via open libraries such as Leaflet.js and Mapbox (or similar), which render OpenStreetMap data in a responsive and scalable interface. These libraries provide multi-zoom-level support, real-time updates, and coordinate-based interaction—all of which are essential for map-based algorithm visualization. Unlike pre-rendered grids, these tools allow LIAN to render map tiles, overlay graph structures, and animate search paths across geolocations with precision and speed. The system also supports responsive design, making it suitable for both desktop and tablet usage in classrooms.

Finally, the open-source nature of LIAN's design offers a strong justification for academic and community adoption. Hosted on GitHub, the system is publicly available for review, extension, and collaboration. This transparency aligns with open education principles and supports peer-based contributions, bug tracking, and algorithmic innovation. It also encourages reproducibility in research, as educators and researchers can fork, modify, or deploy their own versions of the tool in specific pedagogical or experimental setups.

3. METHODOLOGY

3.1 System Architecture Design

The architecture of the proposed system, LIAN (Location Intelligence Algorithm Network), follows a modular full-stack design that leverages Python-based backend services, modern web-based frontend technologies, and real-time geospatial data integration. This layered architecture ensures the separation of concerns between presentation, application logic, and data processing. The system is designed to provide learners with an interactive, responsive, and educational interface for understanding and comparing various path-finding algorithms on real-world map data.

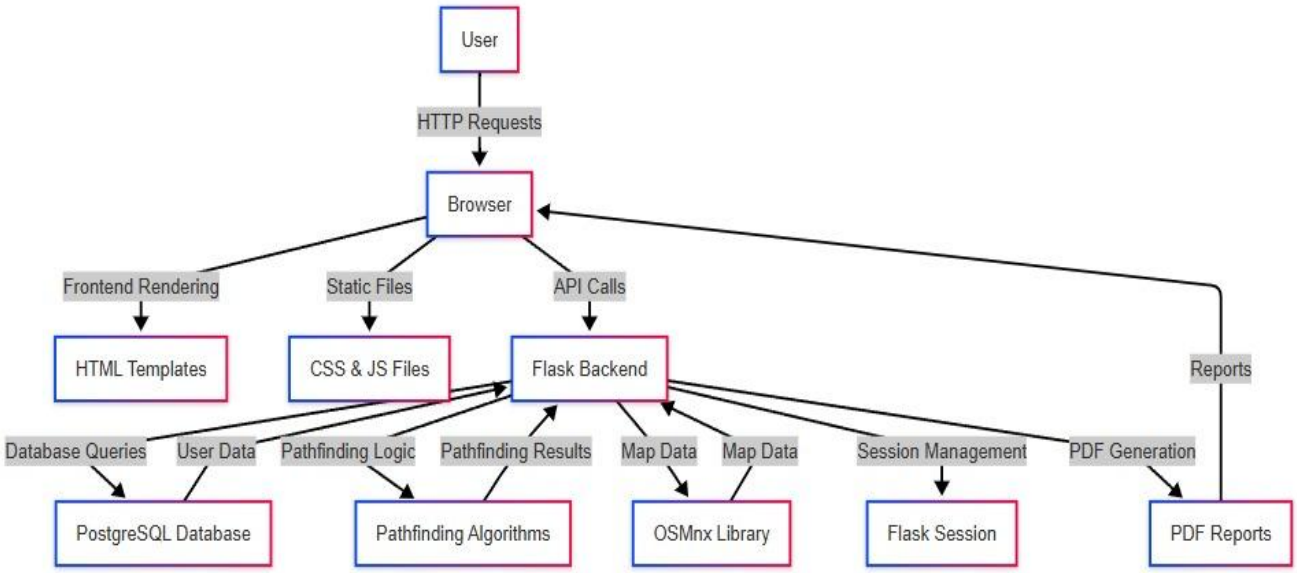


Figure 3.1.1: System Architecture Design

At the frontend, LIAN utilizes standard web technologies including HTML, CSS, and JavaScript to build a responsive and interactive user interface. This layer is responsible for collecting input (source and destination points) and visualizing results. It also provides controls to switch between algorithms, adjust parameters, and view real-time pathfinding outcomes. This approach builds upon prior findings that interactivity significantly enhances algorithm learning outcomes [6].

The backend server is developed using the Flask web framework, which is lightweight yet powerful enough to handle HTTP routing, session management, and API integration. Flask's microservice-oriented architecture makes it suitable for modular educational systems like LIAN [8]. The server accepts frontend requests, initiates algorithm processing, communicates with the database, and returns computed path results in real time.

For geospatial data integration, the system uses the OpenStreetMap (OSM) API, which provides access to real-world road and infrastructure data [4]. This significantly enhances the realism and educational value of the simulation, going beyond conventional grid or abstract graph representations as used in prior tools such as VisuAlgo or Pathfinding.js [5]. Using OSM, LIAN fetches real-world map tiles and transforms them into navigable graphs compatible with classic

pathfinding algorithms.
The core algorithm processing engine includes implementations of Dijkstra's algorithm [2], A* algorithm [1], and Breadth-First Search (BFS) [3], all written in Python. These algorithms are executed against graph structures derived from the OSM data. Results include not just the shortest or optimal path but also performance metrics such as explored nodes, execution time, and path length—helping users perform comparative evaluations [10].
Authentication and session data are handled through an SQLite or PostgreSQL database depending on the deployment context. PostgreSQL was chosen for its scalability and ACID-compliant performance, aligning with best practices in building secure web-based systems [9]. The database is also expandable for storing user interactions, login records, or algorithm usage history for future learning analytics.
The overall architecture is presented visually in Figure 3.1, which depicts the flow of control between the frontend UI, the Flask backend, the pathfinding engine, the OpenStreetMap API, and the database layer. This architecture ensures low coupling, high cohesion, and ease of integration of future modules or algorithms.

LIAN System Architecture Diagram – illustrating the interaction between UI, Flask server, pathfinding module, database, and OpenStreetMap API.

1. The User Interface is the interactive layer where users define source and destination points, select algorithms, and view visual outputs, developed using HTML, CSS, and JavaScript for responsiveness and accessibility.
2. The frontend logic handles user interactions, manages event listeners on the map, and sends HTTP requests to the backend via AJAX or fetch APIs to trigger algorithm execution.
3. The Flask server acts as the middleware controller that receives frontend requests, communicates with the algorithm modules, processes user data, and returns structured responses for visualization.
4. The Pathfinding Algorithms module includes implementations of A*, Dijkstra’s, and Breadth-First Search in Python, designed to operate on real road network graphs and return optimal paths and performance metrics.
5. The OpenStreetMap API is used to dynamically fetch real-world geospatial data such as road segments, nodes, and connections, which are then parsed into graph structures used by the pathfinding engine.
6. The SQLite or PostgreSQL database stores user login credentials, session data, and optionally user-generated simulations, ensuring data persistence, authentication, and future analytics support.
7. The output layer renders the computed path visually on the frontend, showing explored nodes, shortest route, and performance indicators such as total distance, node count, and computation time.

3.2 Sequence Diagram

This sequence diagram illustrates the interaction flow between four major system components: the User, Browser (Frontend), Flask (Backend), and Database. It depicts two main use cases—(1) user registration and (2) visualizing a path using a selected algorithm. The flow emphasizes system modularity and inter-process communication.

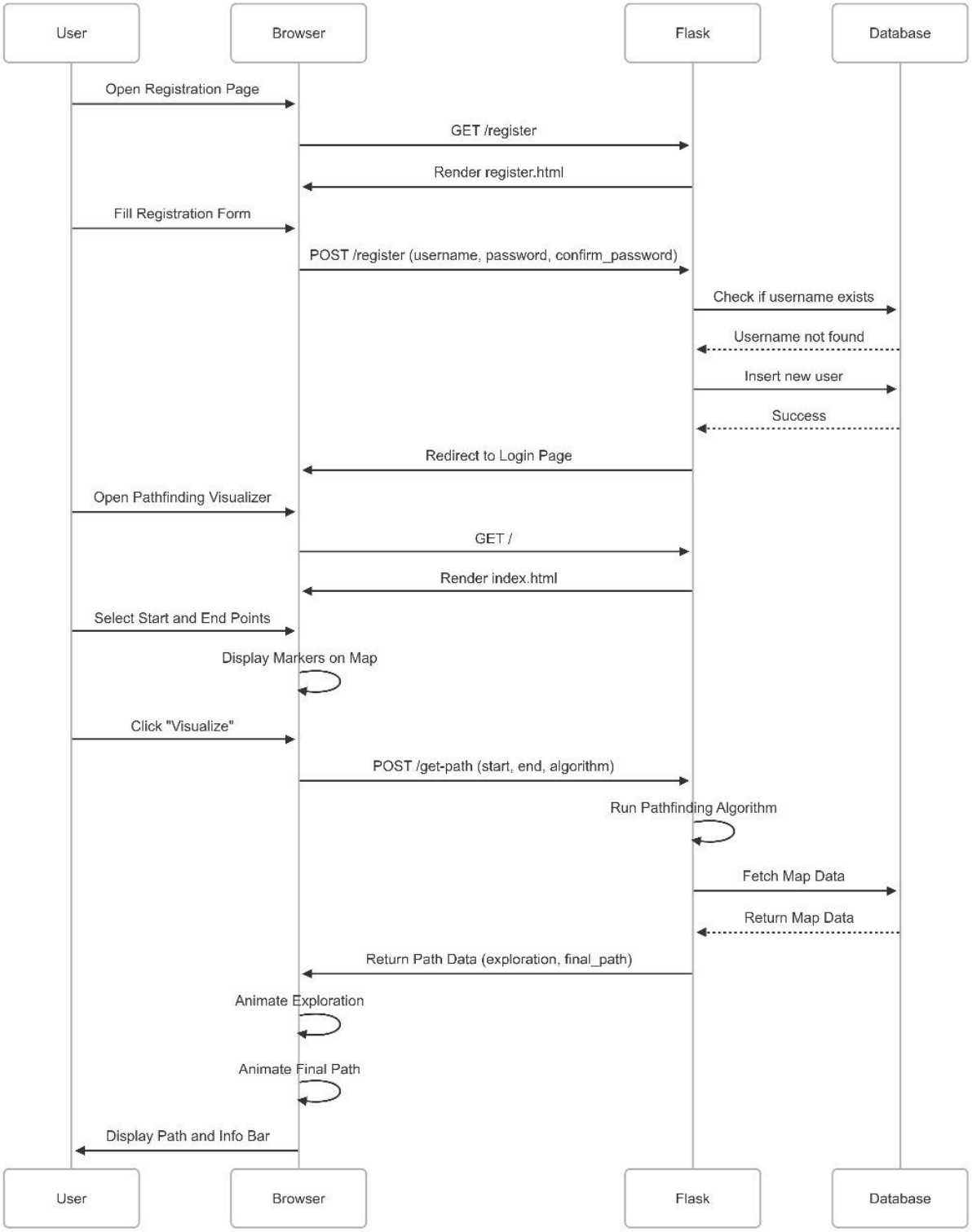


Figure 3.2.1: Sequence Diagram

1. User opens the registration page
The interaction begins when the user initiates the registration process by accessing the registration URL. The browser sends a GET request to the Flask server at the /register route.

2. Flask renders the registration form
Upon receiving the request, Flask returns the register.html page, which includes form fields for entering a username, password, and password confirmation. The frontend displays this form to the

user.

3. User submits registration form
Once the form is filled, the browser sends a POST request to the /register endpoint. This request includes the submitted credentials (username, password, confirm_password).

4. Flask verifies username with the database
The Flask server forwards a query to the Database to check if the username already exists. If the username is found, the process ends with an error. If not, the user data is inserted into the database.

5. Success confirmation and redirect
Upon successful insertion, Flask redirects the user to the login page. This completes the registration phase.

6. User opens the pathfinding visualizer
The user then proceeds to access the main interface. The browser sends a GET request to the root endpoint (/), and Flask responds by rendering index.html, which contains the interactive map and algorithm selector.

7. Start and end points selection
The user selects origin and destination points on the map. These points are visually marked with icons or pins to indicate selected nodes.

8. Visualization trigger
After selecting points and choosing a pathfinding algorithm, the user clicks the "Visualize" button. This triggers a POST request to the Flask server (at /get-path), sending the start node, end node, and selected algorithm as parameters.

9. Backend processing
Flask receives the request and invokes the appropriate pathfinding algorithm (A*, Dijkstra, or BFS). It also uses OpenStreetMap or a stored graph to build or retrieve the corresponding map data for the selected region.

10. Database fetch (optional)
If the graph data is stored, Flask may query the database to fetch node/edge information. The database returns the necessary map data back to Flask.

11. Path calculation and return
Flask processes the map data using the algorithm, generating two outputs: the exploration footprint (visited nodes) and the final path. These are returned to the frontend as structured JSON data.

12. Browser animates the result
On receiving the data, the browser first animates the exploration phase—highlighting all visited nodes—and then animates the final path that connects the start and end points.

13. UI display update
The final result is presented on the interface with an updated path, visual markers, and an information bar showing metrics like path cost, time taken, and number of explored nodes.

3.3 Use Case Diagram

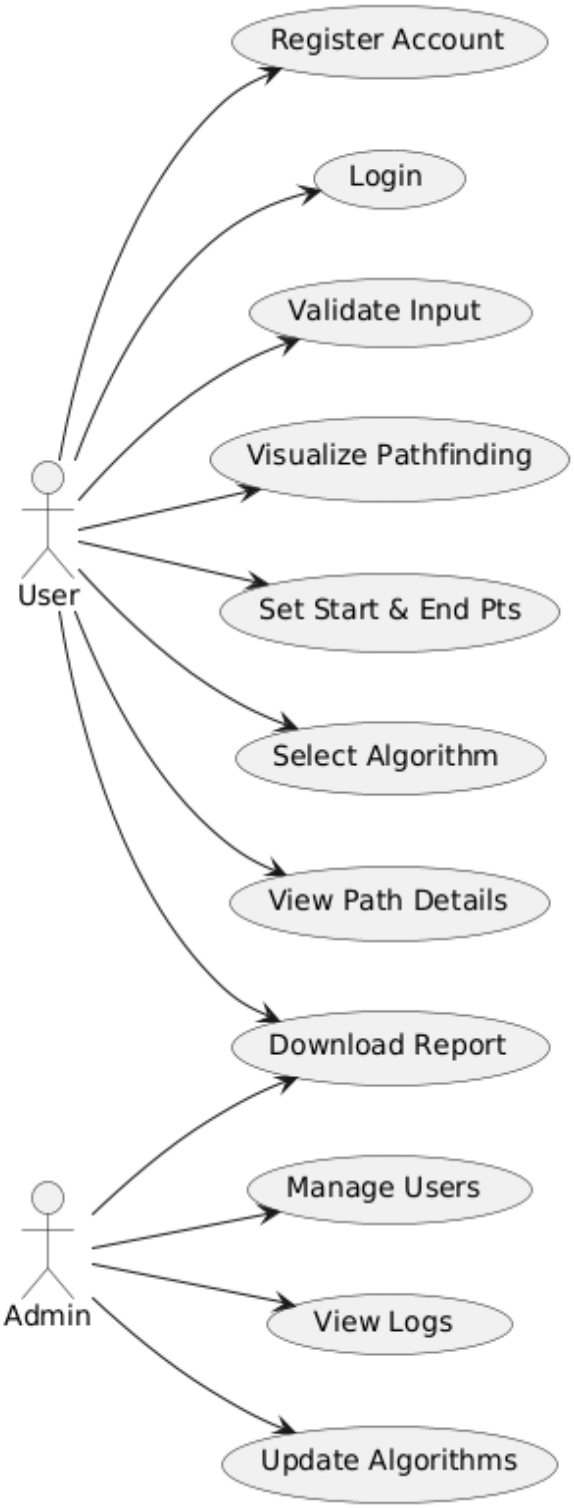


Figure 3.3.1: Use Case Diagram

The Use Case Diagram represents the functional interaction between system actors—namely the User and the Admin—and the LIAN system. It defines the system's core functionalities from the perspective of its two primary stakeholders. This UML diagram helps identify functional requirements and ensure that all user-level interactions are captured during system modelling.
Use Case Diagram for LIAN – Representing Functional Roles of User and Admin

Actor 1: User

The user represents the primary participant of the system—typically a student or learner engaging with pathfinding algorithms. The use cases associated with the User are:

1. Register Account – Allows new users to create an account using a registration form with credential validation.
2. Login – Enables authentication into the system using stored credentials.
3. Validate Input – Ensures valid user input (e.g., valid coordinates, valid algorithm selection).
4. Visualize Pathfinding – Triggers execution of selected pathfinding algorithms and displays results.
5. Set Start & End Points – Lets users select origin and destination points directly on the map interface.
6. Select Algorithm – Allows switching between available algorithms (A*, Dijkstra, BFS).
7. View Path Details – Displays computed path, number of visited nodes, and execution metrics.
8. Download Report – Enables downloading simulation data as a summary report (PDF/CSV).

Actor 2: Admin

The Admin actor is responsible for system management, algorithm updates, and maintaining user access and data integrity. Admin use cases include:

1. Manage Users – Admin can view, update, or delete registered user accounts.
2. View Logs – Enables inspection of user activity logs for performance tracking or debugging.
3. Update Algorithms – Facilitates addition or modification of pathfinding algorithms in the backend logic.

This diagram emphasizes a clear separation between operational functionality (handled by Users) and administrative control (handled by Admin). Such separation ensures system security, modularity, and maintainability.

3.4 Data Flow Diagram

The Data Flow Diagram (DFD) is a structured graphical representation of the information flow within the LIAN system. It visually illustrates how data moves between users, processes, data stores, and external APIs. Each level of the DFD offers a deeper breakdown of system behavior, ranging from a high-level overview (Level 0) to specific module workflows (Level 2).

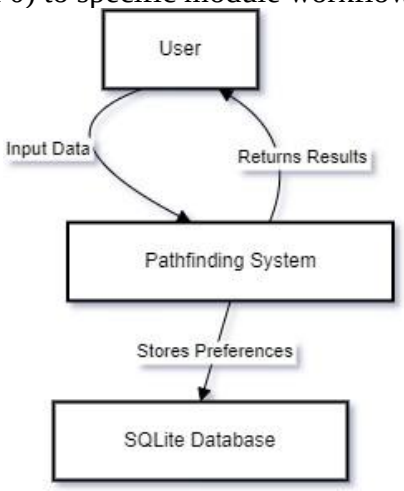


Figure 3.4.1: Data Flow Diagram Level 0

DFD Level 0 – Context Diagram
The Level 0 DFD represents the overall interaction between the external actors (User and Admin) and the LIAN system as a single process block. It shows that users provide input such as login credentials, algorithm selections, and start-end points, while the system returns results like computed paths, visualizations, and user reports. Admins interact to manage users and algorithms. This high-level diagram abstracts internal complexities and focuses on system boundaries and external data exchange.

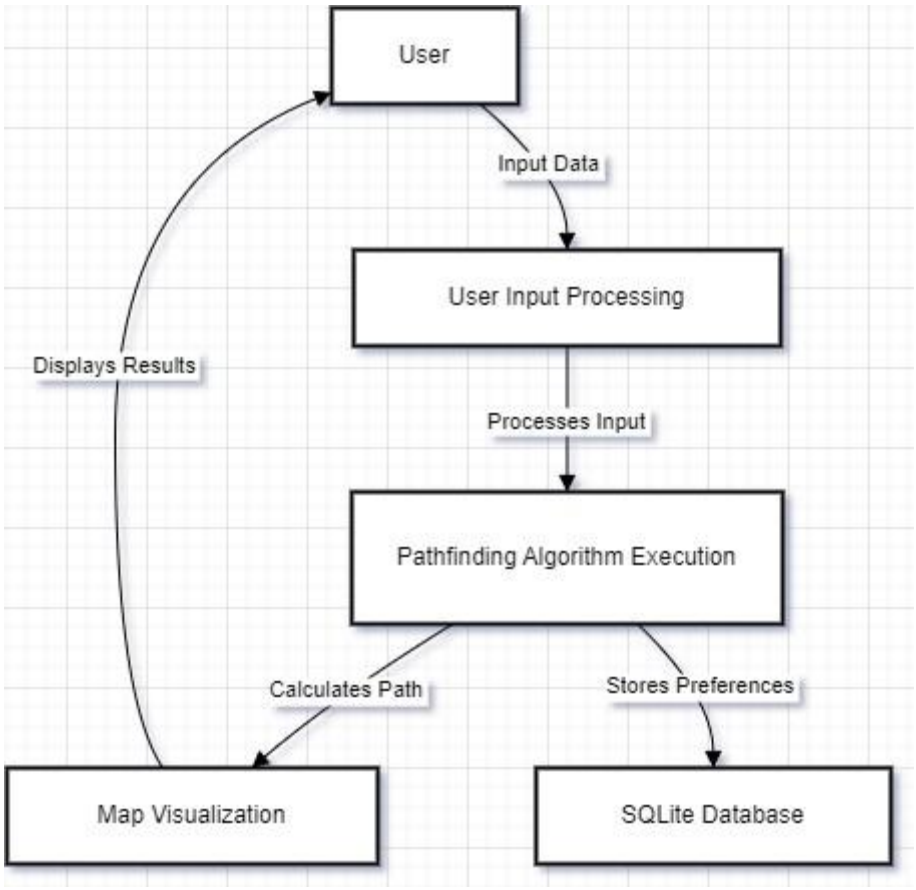


Figure:3.42: Data Flow Diagram Level 1

DFD Level 1 – System Functional Breakdown
Level 1 DFD decomposes the LIAN system into key subsystems: user authentication, map data retrieval, algorithm execution, and visualization rendering. Data from the user is routed through validation and processed by appropriate modules, such as the Flask backend and database. Responses, including path results and performance metrics, are sent back to the frontend for visualization. This level captures the major functional areas without diving into individual algorithm logic.

1. User Input Processing (DFD Level 2)

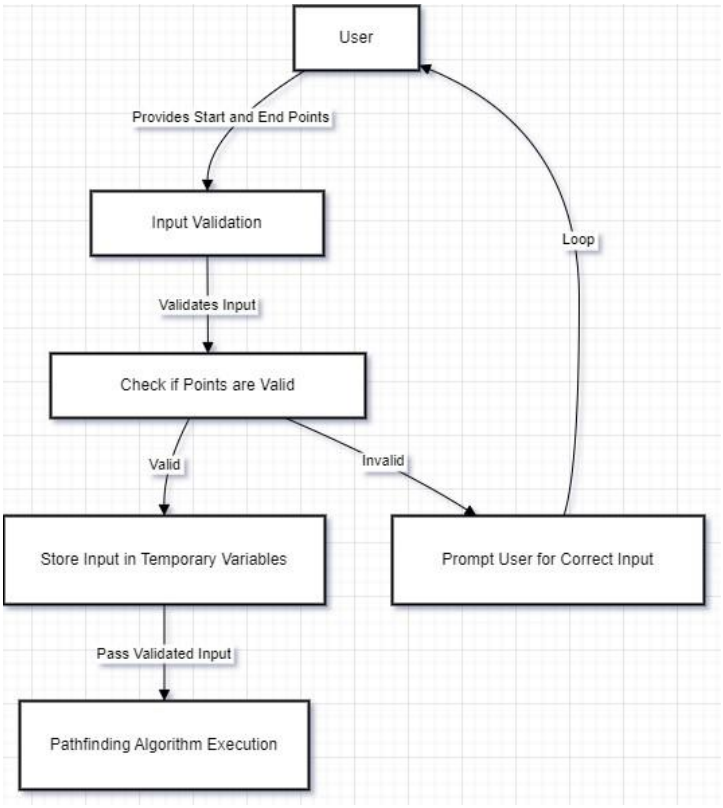


Figure:3.4.3: Data Flow Diagram level 2.1

DFD Level 2.1 – User Input Processing

This Level 2 diagram focuses on how the system processes user inputs like registration, login, and map interactions. It includes form data validation, login authentication through the database, and error handling for incorrect inputs. For pathfinding, the user's selection of coordinates and algorithm choice are captured and formatted into structured data packets that are passed to the backend for algorithm processing. This ensures the frontend collects and prepares accurate inputs for downstream processes.

2**.** Pathfinding Algorithm Execution (DFD Level 2)

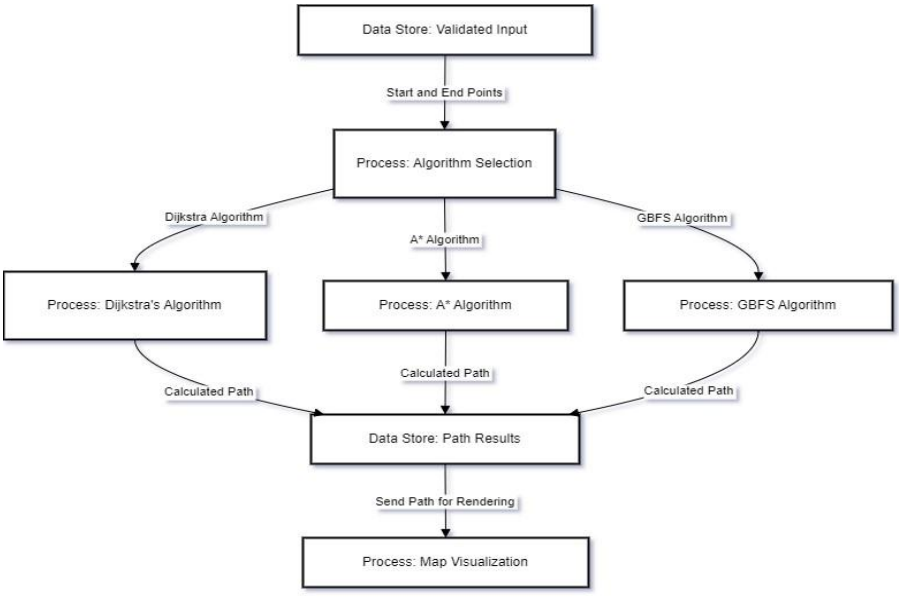


Figure:3.4.4: Data Flow Diagram level 2.2

DFD Level 2.2 – Pathfinding Algorithm Execution

This sub-process illustrates the inner working of the pathfinding computation engine. Once user inputs are validated, they are passed to this module where the selected algorithm (A*, Dijkstra, BFS) is executed. The system fetches graph-based map data from OpenStreetMap or a local store, constructs the graph, and computes the optimal path. It also generates secondary outputs like total cost, execution time, and number of explored nodes, which are passed to the visualization module.

2. Map Visualization (DFD Level 2)

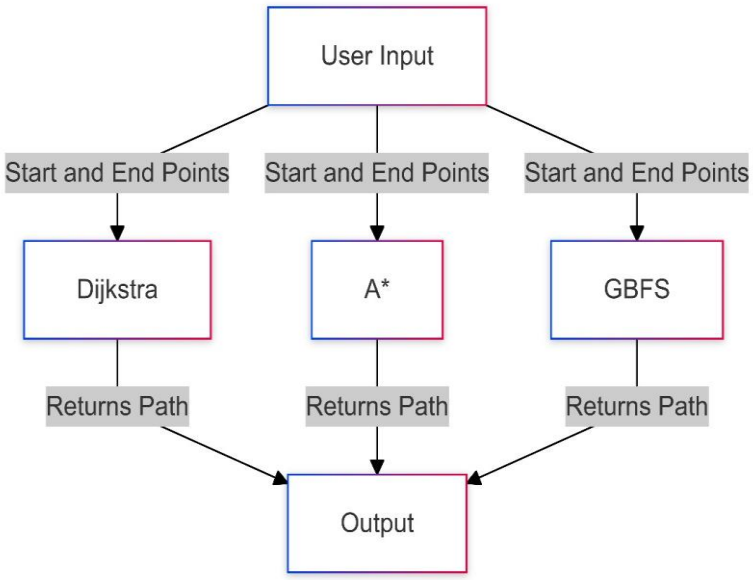


Figure:3.4.5: Data Flow Diagram level 2.3

The final Level 2 DFD highlights how the visualization layer transforms raw path data into visual output. It takes the final path and exploration sequence returned from the algorithm module and overlays them on the real-world map interface using JavaScript and Leaflet.js. This includes dynamic marker placement, animated node exploration, and final path rendering. It also updates the UI to show performance metrics in the info bar, completing the user feedback loop.

4. EXPERIMENTATION

4.1 Project Milestones

This section documents the complete experimental development process of the LIAN project, from idea to implementation. Each milestone is marked by a unique ID, with time required, purpose, and dependencies described so the project can be reproduced step-by-step by any other development team.

A. Research and Tech Stack Selection (ID 1)

Time Required: 1 week
Description:
The project began with a deep-dive literature review and comparative study of existing algorithm visualizers and path-finding frameworks. The team evaluated various programming environments and libraries based on performance, community support, educational potential, and integration capabilities. After consensus, Python was chosen for the backend due to its rich set of algorithmic libraries (e.g., NetworkX), Flask for server-side processing due to its lightweight API support, and PostgreSQL for its ACID-compliant login database. On the frontend, HTML5, CSS3, JavaScript, and Leaflet.js were selected to build an interactive UI capable of rendering OpenStreetMap data. Version control using Git and collaborative development through GitHub was also established.
Dependencies:
None (initial phase)

B. System Design (ID 2)

Time Required: 1 week
Description:
With the tech stack finalized, the team created the system architecture outlining the interaction among modules: UI, Flask server, pathfinding engine, and database. Data Flow Diagrams (DFD Level 0–2), Use Case Diagram, and Sequence Diagram were designed to model system behavior at increasing abstraction levels. The structure ensured modularity, reusability, and separation of concerns—aligning with software engineering best practices. Component interfaces and API endpoints were defined to enable consistent communication between frontend and backend.
Dependencies:
Requires completion of Milestone A

C. Frontend Design (ID 3)

Time Required: 2 weeks
Description: Designed responsive interface using HTML, CSS, JavaScript. Developed map container (using Leaflet), coordinate capture, dropdown menus, and basic UI layout for algorithm selection and path display.

Dependencies: Requires architecture from Milestone B

D. Feasibility Check (ID 4)

Time Required: 1 week
Description:
Before full backend implementation, a feasibility check was conducted to ensure that the system could successfully interact with OSM data, parse geographic files (e.g., .osm XML/JSON), and convert road segments into graphs (nodes and weighted edges). The team verified Flask's ability to handle requests, return algorithm outputs, and interface with PostgreSQL. This step also involved validating graph consistency, handling edge cases (e.g., disconnected nodes, invalid inputs), and stress-testing the UI under different map zoom levels and datasets.
Dependence:
Milestones B and C

E. Backend Development (ID 5)

Time Required: 3 weeks
Description:
The most intensive milestone, this phase involved the design and implementation of all core pathfinding algorithms—Dijkstra's, A*, and Greedy Best-First Search. Graph classes were built with support for weighted adjacency lists and heuristic scoring. Each algorithm was optimized for efficiency and correctness. Python modules were integrated into Flask routes (/get-path), receiving input from the frontend and returning JSON-formatted results. User authentication logic was secured using Flask-SQLAlchemy and PostgreSQL, allowing session persistence and login validation. Unit tests and benchmarks were run to compare algorithm performance in different map regions and against varying node densities.
Dependencies:
Milestones B, C, and D

4.2 Gantt Chart

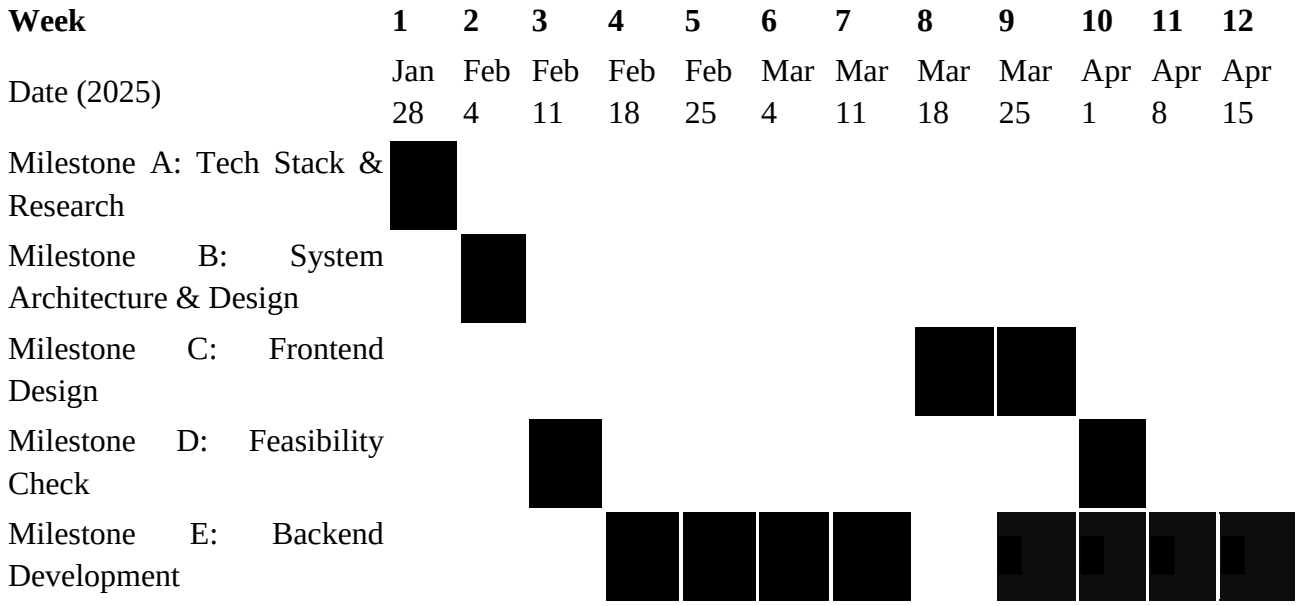


Figure:4.2.1: Gantt chart

4.3 System Specification

Table:4.3.1: System Specification table

Category	**Specification**
System Name	LIAN – Location Intelligence Algorithm Network
System Type	Web-based Visualization Tool
Development Platform	Localhost (Windows/Linux)
Language Support	Python (Flask), HTML5, CSS3, JavaScript
Database	PostgreSQL (or SQLite for lightweight use)
Libraries Used	Leaflet.js, Flask, NetworkX, psycopg2, Jinja2
Map Service API	OpenStreetMap (via Leaflet plugin)
Deployment Method	Localhost testing; extendable to cloud (Heroku, PythonAnywhere)
Authentication	Email/password (basic credential storage)
Open Source Tools	Git, GitHub, VS Code

4.4 Client Specification

Table:4.4.1: Client Specification table

Category	Minimum Requirement	Recommended Requirement
Operating System	Windows 7 / Linux	Windows 10 / macOS / Ubuntu 22+
Browser	Chrome 80+, Firefox 70+	Chrome 100+, Firefox 100+, Edge 90+
RAM	2 GB	4 GB or more
Display Resolution	1280 × 720	1920 × 1080 (Full HD)
Internet Connectivity	Required for OSM map tile access	Stable Wi-Fi or Ethernet
Plugins Required	JavaScript-enabled browser	JavaScript + LocalStorage (for UI)
Input Device	Mouse/Touchpad	Mouse + Keyboard (for precise selection)

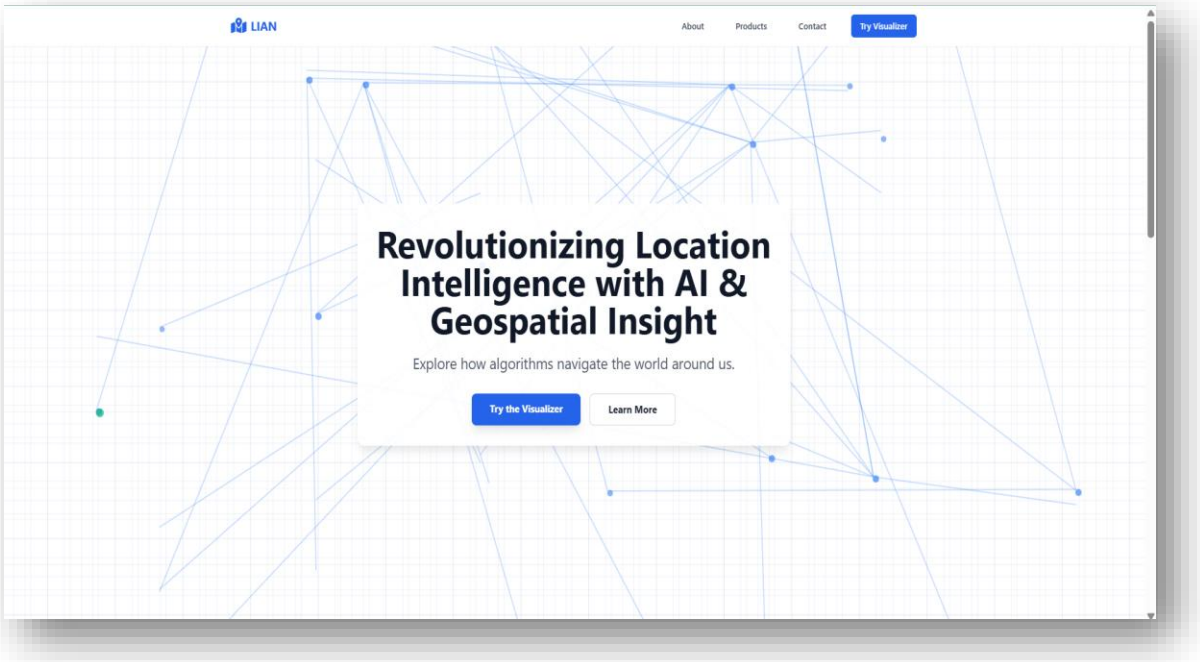
4.5 Server Specification

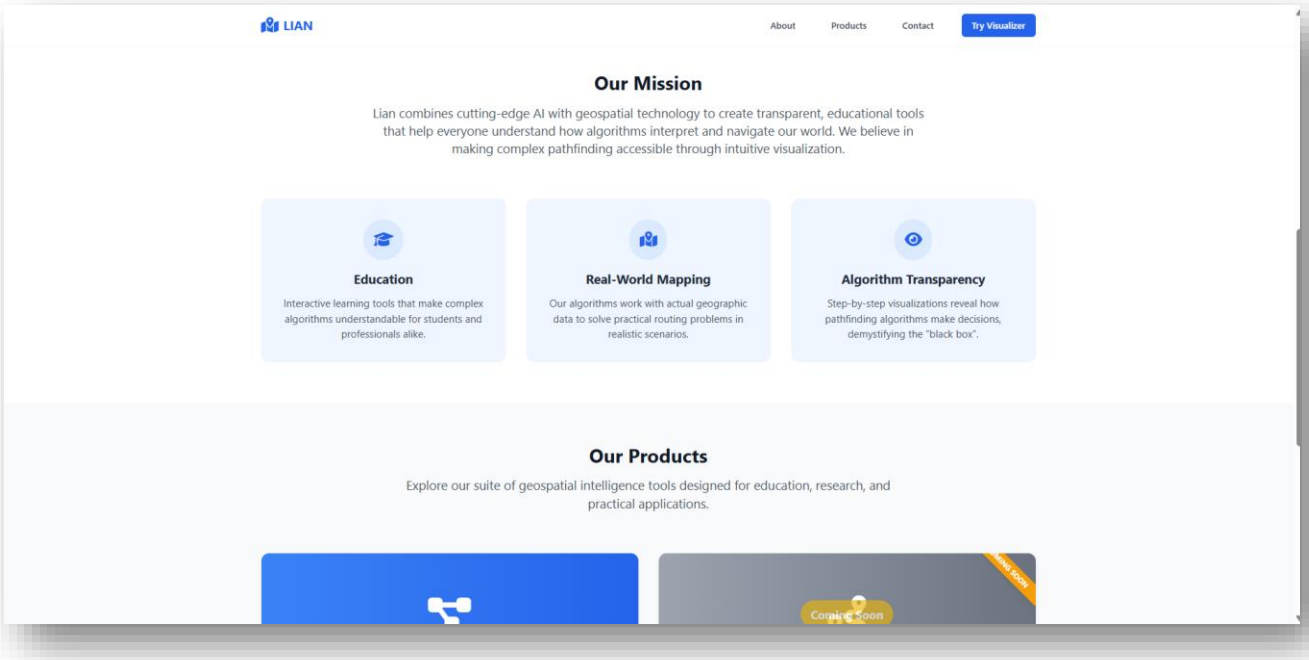
Table:4.5.1: Server Specification table

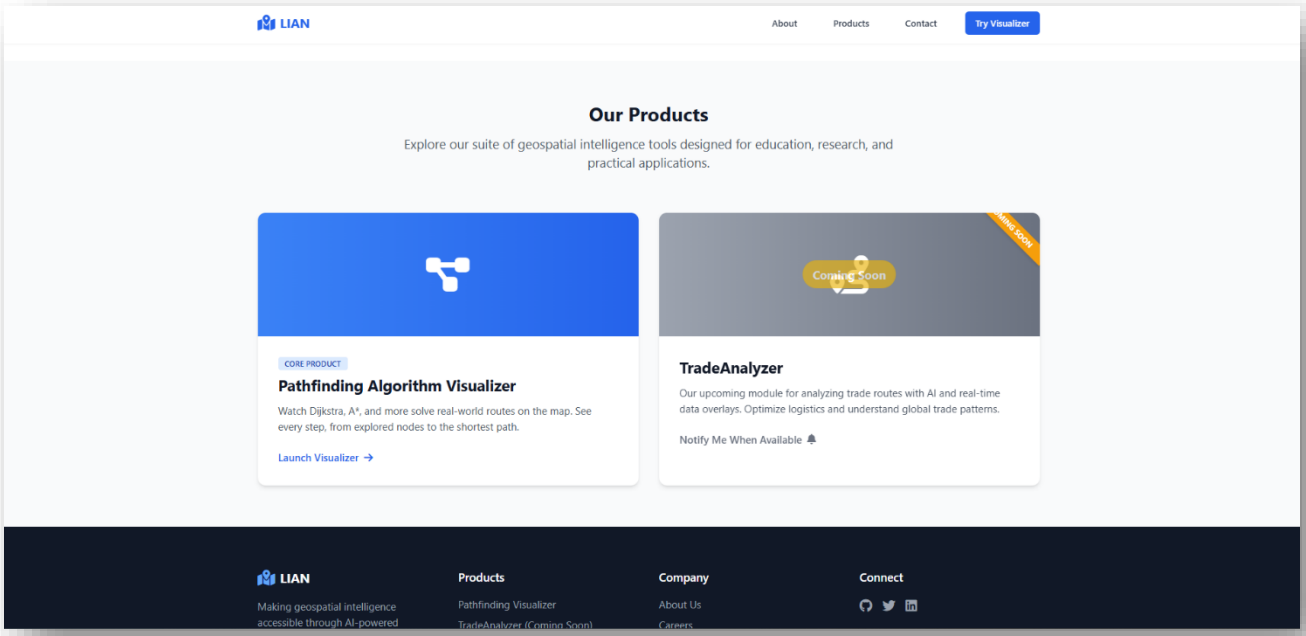
Category	Specification
Operating System	Ubuntu 20.04 / Windows 10
Web Framework	Flask (Python 3.8+)
Database Engine	PostgreSQL 12+
Python Libraries	Flask, NetworkX, psycopg2, requests
Server Host	Localhost (127.0.0.1) / Optional Cloud Host
CPU	Dual-core (2.0 GHz or higher)
RAM	Minimum 4 GB
Storage	Minimum 10 GB (OS + database + logs)
Internet Access	Required for OSM tile fetch + updates
Deployment Tools	Gunicorn, Nginx (for advanced deployment)
Security	Basic credential validation, HTTPS (optional)

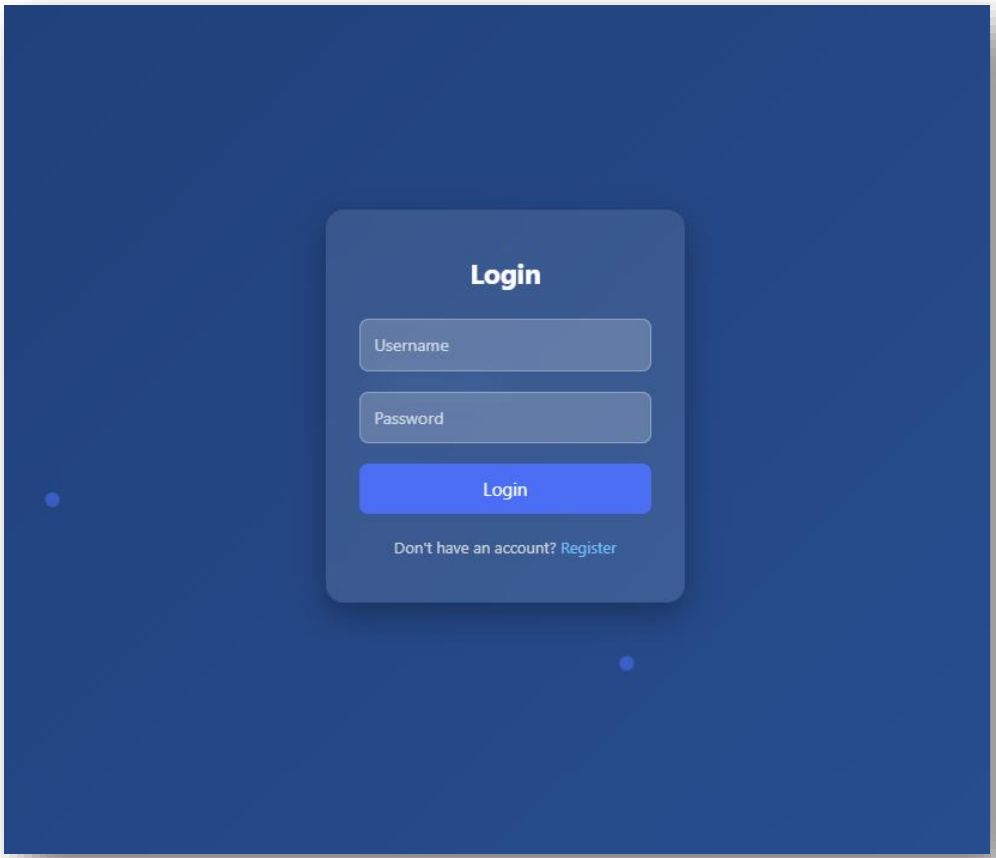
5. RESULT AND DISCUSSION

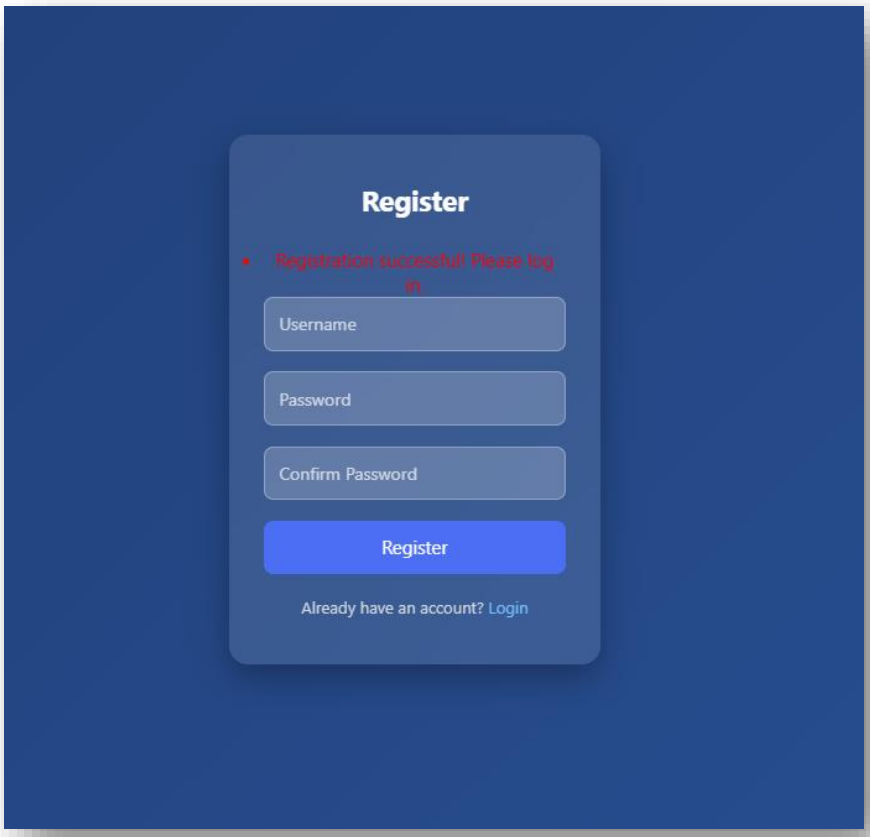
5.1 Result from web applications

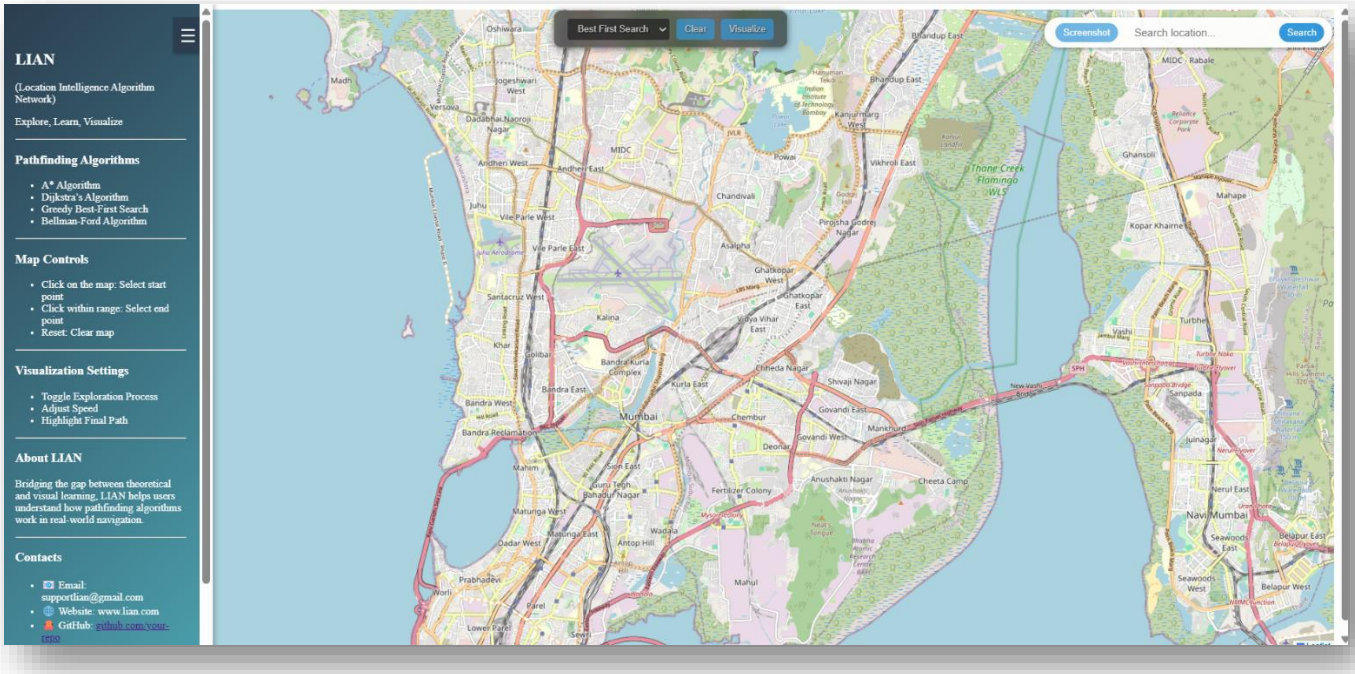


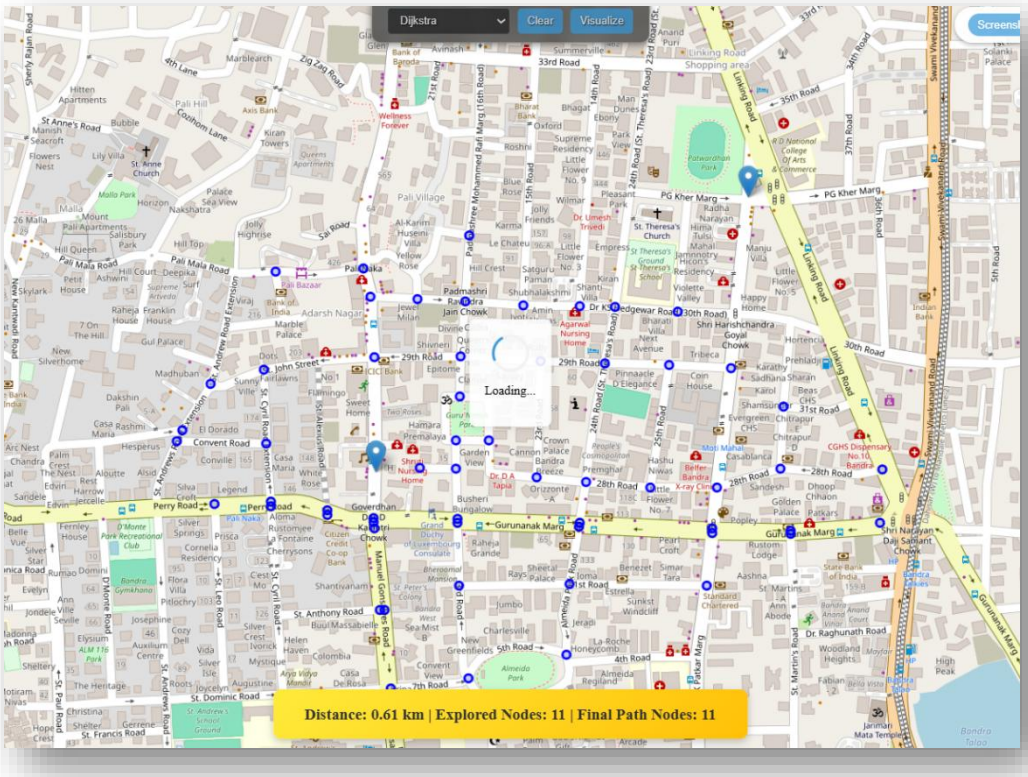



LIAN
About
Products
Contact
Try Visualizer
Our Products
Explore our suite of geospatial intelligence tools designed for education, research, and practical applications.
Coming Soon
COMING SOON
CORE PRODUCT
Pathfinding Algorithm Visualizer
Watch Dijkstra, A*, and more solve real-world routes on the map. See every step, from explored nodes to the shortest path.
Launch Visualizer
TradeAnalyzer
Our upcoming module for analyzing trade routes with AI and real-time data overlays. Optimize logistics and understand global trade patterns.
Notify Me When Available
LIAN
Making geospatial intelligence accessible through AI-powered
Products
Pathfinding Visualizer
TradeAnalyzer (Coming Soon)
Company
About Us
Careers
Connect


Login
Username
Password
Login
Don't have an account? Register


Register
Registration successful! Please log in.
Username
Password
Confirm Password
Register
Already have an account? Login


LIAN
(Location Intelligence Algorithm Network)
Explore, Learn, Visualize
Pathfinding Algorithms
A* Algorithm
Dijkstra's Algorithm
Greedy Best-First Search
Bellman-Ford Algorithm
Map Controls
Click on the map: Select start point
Click within range: Select end point
Reset: Clear map
Visualization Settings
Toggle Exploration Process
Adjust Speed
Highlight Final Path
About LIAN
Bridging the gap between theoretical and visual learning, LIAN helps users understand how pathfinding algorithms work in real-world navigation.
Contacts
Email: supportlian@gmail.com
Website: www.lian.com
GitHub: github.com/your-repo
Best First Search
Clear
Visualize
Screenshot
Search location...
Search
Mumbai
Navi Mumbai


Dijkstra
Clear
Visualize
Loading...
Distance: 0.61 km | Explored Nodes: 11 | Final Path Nodes: 11


Distance: 0.61 km | Explored Nodes: 93 | Final Path Nodes: 9

6. CONCLUSION

The LIAN (Location Intelligence Algorithm Network) system successfully bridges the gap between theoretical pathfinding algorithms and their real-world application by integrating classic search techniques such as A*, Dijkstra's, and Greedy Best-First Search with real-time map-based visualizations. Through the use of OpenStreetMap data and an intuitive frontend interface, the system enables users—particularly students and educators—to gain an in-depth, visual understanding of how search algorithms operate within real geographical networks. The comparative analytics provided by the platform (e.g., execution time, explored nodes, and path length) further allow learners to analyze trade-offs between optimality and performance under various constraints.
Technically, the project demonstrated the effective use of a modular full-stack architecture. Python's Flask framework provided a scalable and lightweight backend solution that seamlessly integrated with the algorithm processing modules and the PostgreSQL database. On the frontend, JavaScript and Leaflet.js enabled dynamic interaction and map rendering, while asynchronous communication ensured smooth user experience. Each component—from graph construction to visual rendering—was designed to work independently but cohesively, ensuring maintainability and extensibility for future improvements.
The implementation of LIAN has proven not only its feasibility but also its educational value. By visualizing the step-by-step progress of each algorithm on real city maps, students can better understand the logic behind path expansion, heuristic application, and optimal route selection. Additionally, the inclusion of metrics like total path cost, execution time, and nodes explored supports deeper algorithmic analysis and benchmarking.
In conclusion, LIAN has achieved its intended goal of transforming algorithm education into an experiential and interactive process. The project offers a strong foundation for future development, including the addition of new algorithms (like Yen's K-Shortest Paths or Ant Colony Optimization), mobile deployment, and integration with geospatial analytics for real-world applications such as logistics and urban planning.

7. FUTURE SCOPE

While the LIAN system has achieved its goal as an educational pathfinding simulator, its modular design and real-world data integration offer substantial room for future development. One key direction involves expanding the system beyond academic use and adapting it for real-world applications such as logistics optimization, emergency route planning, and urban infrastructure simulation.

A significant enhancement would be the inclusion of additional algorithms such as Yen's K-Shortest Paths, Bidirectional A*, and Ant Colony Optimization (ACO). These methods offer varied perspectives on efficiency, redundancy, and adaptability, especially in large-scale networks. Implementing multiple search strategies will allow users to simulate scenarios like route diversity, failover routing, or probabilistic pathfinding—expanding LIAN's utility from education to research and real-world problem solving.

Another powerful extension lies in trade route visualization. By leveraging OSM data and integrating global logistics APIs (e.g., maritime or rail network datasets), LIAN could simulate the shortest and most cost-efficient trade paths across international borders. This would not only provide students a deep understanding of spatial optimization under geopolitical constraints, but could also benefit logistics companies, policy researchers, and governmental planning agencies. Trade route overlays could show time-cost maps, port connectivity, and choke-point analysis (e.g., Suez Canal, Strait of Hormuz).

In addition, the system could benefit from cloud deployment and mobile-first optimization. Hosting the system on platforms like AWS or Heroku would make LIAN globally accessible, enabling collaborative simulations in classrooms, workshops, or remote learning environments. Mobile responsiveness would further increase its accessibility and usability across devices.

Lastly, the integration of user progress tracking, report generation (PDF/CSV), and educational gamification elements could transform LIAN into a complete learning management and evaluation tool. Instructors could assign challenges (e.g., "Find the fastest route between two cities using A* and Dijkstra") and students could receive feedback based on accuracy, speed, and algorithm selection rationale.

In summary, LIAN's foundation enables seamless scalability. Its future roadmap includes not only technical improvements but also interdisciplinary applications, from computational geography and trade logistics to smart city planning and interactive STEM education.

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We wish to express our sincere thanks to our I/C Principal, **Dr. Ganesh Kame**, M.H. Saboo Siddik College of Engineering, and the I/C Head of the Computer Engineering Department, **Dr. Mohammed Ahmed Shaikh**, for providing us with all the necessary facilities, support, and a wonderful environment to meet our project requirements.

We are highly thankful to our project guide, **Prof. Anand Bali**, whose valuable guidance helped us understand the project requirements better. Her constant support and willingness to share her vast knowledge and experience enabled us to explore the project and its intricacies in great depth, ultimately contributing to its successful completion.

We would also like to express our gratitude and appreciation to our reviewers **Prof. Farhana Siddiqui.** Their insightful comments and tips greatly enhanced our presentation skills and the overall quality of our project.

Although there may be many who remain unacknowledged in this humble note of appreciation, there are none who remain unappreciated.