MAZE SOLVER (PATHFINDING) APPLICATION

A PROJECT REPORT

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BONAFIDE CERTIFICATE

Certified that this project report **"Maze Solver (Path finding) Application"** is the Bonafide work of "**Mayan Roy, Shashank Sharma"** who carried out the project work under my/our supervision.

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ABSTRACT

The *Maze Solver* project is an interactive pathfinding visualization system designed to demonstrate and compare the performance of three fundamental graph traversal algorithms — **Breadth-First Search (BFS)**, **Dijkstra's Algorithm**, and **A-Star (A*) Algorithm**.

The primary objective of this project is to provide a practical understanding of how different algorithms explore, traverse, and compute the shortest path in maze-like environments. Implemented using **Java (Swing GUI)** and **Web Technologies (HTML5, CSS, JavaScript)**, the system enables users to create custom mazes, visualize algorithm execution in real time, and analyze performance metrics such as execution time, visited nodes, and path length.

The project follows the **Model-View-Controller (MVC)** architecture for modularity and scalability. Experimental results confirm that while all three algorithms produce optimal paths, **A*** consistently achieves the best efficiency by utilizing heuristic guidance.

The *Maze Solver* serves as both an **educational tool** and an **analytical platform**, bridging the gap between theoretical algorithm design and practical visualization. It enhances comprehension of search strategies, computational efficiency, and algorithmic optimization — key aspects of Design and Analysis of Algorithms.

CHAPTER 1
INTRODUCTION

1.1 Identification of Client / Need / Relevant Contemporary Issue

In the current era of intelligent systems and automation, pathfinding plays a critical role in various real-world applications—ranging from GPS navigation, autonomous robots, and gaming AI to network routing and logistics optimization. Efficient route discovery in complex environments requires algorithms capable of computing optimal or near-optimal paths while minimizing computational resources.

The *Maze Solver* project has been designed as an educational and experimental platform to study, visualize, and compare three classical pathfinding algorithms: **Breadth-First Search (BFS)**, **Dijkstra's Algorithm**, and *A-Star (A) Algorithm**. The need for such a tool arises from the growing demand for algorithmic visualization and understanding of how different search strategies perform under varying conditions. This system provides learners, researchers, and developers with a clear, interactive way to observe how algorithms behave in real time, thereby bridging the gap between theory and practice.

1.2 Identification of Problem

In many domains, finding a path from a source to a destination in the presence of obstacles is a fundamental computational challenge. Manually analyzing algorithmic efficiency is often abstract and difficult to visualize. Students and developers frequently understand the mathematical model but struggle to connect it with practical behavior during execution.

Hence, the problem identified is twofold:

1. **Algorithmic Challenge:** To determine the shortest path in a grid-based environment while minimizing time and space complexity.
2. **Visualization Challenge:** To design a system that allows dynamic, real-time visualization of how each algorithm explores, backtracks, and converges toward the goal.

The *Maze Solver* aims to provide a dual solution—functional accuracy through algorithmic correctness and conceptual clarity through visualization.

1.3 Identification of Tasks

To meet the project objectives, the following key tasks were undertaken:

1. **Algorithmic Study:** Detailed study and analysis of BFS, Dijkstra, and A* algorithms, focusing on their working principles, time complexity, and optimality.
2. **System Design:** Designing a modular architecture using the **Model-View-Controller (MVC)** pattern for clarity and scalability.
3. **Implementation:** Developing both a **Java-based desktop version** using Swing and a **Web-based version** using HTML5 Canvas and JavaScript.
4. **Visualization:** Implementing real-time animation of algorithm traversal, node visitation, and path reconstruction.
5. **Performance Evaluation:** Measuring algorithm performance in terms of execution time, path length, and number of visited cells.
6. **Testing and Validation:** Verifying correctness through multiple test cases and analyzing algorithmic efficiency under different maze complexities.
7. **Documentation:** Preparing detailed technical documentation and comparative analysis of algorithm behaviors.

1.4 Timeline

Phase	Description	Duration (Weeks)
Phase 1	Problem identification, requirement analysis, and research on algorithms	1–2
Phase 2	System design and architectural planning	3
Phase 3	Implementation of BFS, Dijkstra, and A* algorithms	4–5
Phase 4	Integration of visualization module and GUI development	6
Phase 5	Testing, debugging, and performance analysis	7

Phase 6	Documentation, report compilation, and final review	8

This systematic approach ensured a balanced progression from theoretical understanding to practical execution.

1.5 Organization of the Report

The remainder of this report is organized into five chapters:

- **Chapter 1: Introduction** – Provides an overview of the problem, motivation, objectives, and overall project structure.
- **Chapter 2: Literature Review / Background Study** – Discusses prior research, existing systems, and algorithmic foundations relevant to pathfinding.
- **Chapter 3: Design Flow / Process** – Explains the architectural design, constraints, and methodology adopted for system implementation.
- **Chapter 4: Results Analysis and Validation** – Presents experimental results, performance comparisons, and validation of algorithms.
- **Chapter 5: Conclusion and Future Work** – Summarizes the findings, highlights key achievements, and suggests possible improvements or extensions.

CHAPTER 2
LITERATURE REVIEW / BACKGROUND STUDY

2.1 Timeline of the Reported Problem

Pathfinding and shortest path determination have been central topics in computer science since the mid-20th century. Early research on graph traversal and search algorithms began in the 1950s, focusing on solving routing and network optimization problems.

- **1956:** *Breadth-First Search (BFS)* was formally introduced as a fundamental graph traversal technique, primarily used for unweighted shortest path problems.
- **1959:** *Dijkstra's Algorithm* was developed by Edsger W. Dijkstra as a solution for finding the shortest path in weighted graphs.
- **1968:** *A-Star (A*) Algorithm* was proposed by Peter Hart, Nils Nilsson, and Bertram Raphael, combining heuristic guidance with Dijkstra's strategy to achieve greater efficiency.

Over the decades, these algorithms have been widely adopted in artificial intelligence, robotics, and network systems, serving as the foundation for modern pathfinding techniques used in GPS systems, game engines, and automated navigation.

2.2 Existing Solutions

Numerous pathfinding implementations exist, ranging from theoretical models to practical software applications.

1. **Textbook Implementations:**
   Traditional algorithmic study materials often provide static or command-line implementations that lack visual feedback, making it difficult for learners to grasp algorithmic dynamics.
2. **Game Development Engines (e.g., Unity, Unreal):**
   Modern game engines include optimized pathfinding systems using A* and navigation meshes, but these implementations are complex and integrated into large-scale environments, not suited for educational visualization.
3. **Online Visualizers:**
   Web-based tools such as *Pathfinding Visualizer* (Clement Mihailescu) and

RedBlobGames Pathfinding Guide offer simplified A* demonstrations, but they often lack detailed performance metrics, dual algorithm comparison, or offline Java-based versions.

4. **Research Simulators:**
   Advanced research simulators exist for robotics and motion planning, but they tend to emphasize algorithmic performance under continuous space constraints rather than pedagogical clarity.

The gap identified here is the absence of a **lightweight, educational, and dual-implementation tool** that allows learners to both observe and analyze the working and efficiency of BFS, Dijkstra, and A* in a controlled maze environment.

2.3 Bibliometric Analysis

A review of existing literature and digital resources shows that these three algorithms dominate pathfinding research due to their balance of simplicity, optimality, and adaptability.

- **BFS** is cited in over 10,000 academic references as the foundational approach for unweighted graph traversal.
- **Dijkstra's Algorithm** has been cited extensively in works concerning **network routing**, **traffic optimization**, and **geographical mapping systems**.
- **A-Star Algorithm** remains the most referenced in **AI pathfinding research**, with applications in autonomous robotics and 2D/3D game navigation.

These works collectively form the theoretical backbone for the Maze Solver project.

2.4 Review Summary

From the literature studied, the following observations were made:

- Existing implementations often focus on either **performance** or **visualization**, but rarely combine both.
- Most educational tools provide algorithmic steps but not **quantitative performance metrics** like execution time or cell visits.
- Few implementations offer **multi-platform support** (desktop + web), which limits accessibility and reusability.

- Algorithmic understanding significantly improves when learners can *see* the process rather than just read about it.

This analysis justifies the development of the Maze Solver project as a practical, educational, and comparative tool.

2.5 Problem Definition

Despite the vast literature on pathfinding algorithms, there remains a need for a system that allows users to **interactively visualize**, **compare**, and **analyze** the working of BFS, Dijkstra, and A* in a structured maze environment.

Thus, the problem statement for this project is defined as follows:

"To design and implement a maze-solving system that demonstrates and compares the efficiency of BFS, Dijkstra, and A* algorithms through real-time visualization and performance metrics."

2.6 Goals / Objectives

The main objectives of the *Maze Solver* project are:

1. **To implement and compare** three core pathfinding algorithms—BFS, Dijkstra, and A*—in terms of performance and optimality.
2. **To develop an interactive visualization tool** that represents the exploration and solution path in real time.
3. **To analyze and record metrics** such as execution time, number of visited nodes, and path length for each algorithm.
4. **To provide dual platform support** with a desktop (Java) and web-based (HTML5, JS) version for accessibility.
5. **To aid in learning and research** by providing a transparent and reproducible implementation of fundamental DAA concepts.

These objectives align with the educational intent of Design and Analysis of Algorithms coursework, promoting both theoretical understanding and practical application.

CHAPTER 3
DESIGN FLOW / PROCESS

3.1 Evaluation & Selection of Specifications / Features

Before initiating the implementation, the design requirements and feature specifications were carefully evaluated to ensure that the final system was both **educationally useful** and **technically sound**. The following specifications were finalized after multiple iterations:

- Implementation of **three core algorithms**: Breadth-First Search (BFS), Dijkstra's Algorithm, and A* (A-Star) Algorithm.
- **Interactive visualization system** that dynamically demonstrates algorithm traversal and path discovery.
- **Configurable parameters** such as maze size, wall density, and animation speed.
- Support for both **4-directional** and **8-directional** movement with heuristic selection.
- Real-time tracking of **performance metrics** (execution time, nodes visited, and path length).
- Dual deployment:
    - **Java (Swing GUI)** for offline desktop use.
    - **Web version (HTML5 Canvas + JavaScript)** for browser-based interactivity.

These features were chosen to meet both **academic learning needs** and **practical experimentation** objectives.

3.2 Design Constraints

While designing the Maze Solver, several constraints were identified and managed carefully:

1. **Computational Limitations:**
   Since visualization runs in real time, excessive maze sizes or high animation speeds could affect performance. Grid dimensions were therefore limited to manageable sizes (typically up to 100×100).
2. **Memory Constraints:**
   Each cell in the grid maintains multiple state variables (visited, wall, parent, etc.),

leading to increased memory consumption in large grids. Efficient data structures were adopted to mitigate this.

3. **Algorithmic Complexity:**
    - BFS: O(V + E) time, O(V) space
    - Dijkstra & A*: O((V + E) log V) time, O(V) space
      For educational purposes, simplicity was prioritized over optimization (e.g., using arrays instead of binary heaps).
4. **User Interface Constraints:**
   The UI was designed to be minimalistic for clarity, avoiding heavy libraries or complex rendering systems.
5. **Platform Independence:**
   Both implementations were developed using **pure Java and JavaScript**, avoiding external dependencies to maintain cross-platform compatibility and easy execution.

3.3 Analysis of Features and Finalization Subject to Constraints

After analyzing available features and the identified constraints, the following design decisions were finalized:

Feature	Decision Taken	Reasoning
Pathfinding Algorithms	BFS, Dijkstra, A*	Provide a range from basic to advanced algorithms
Visualization Framework	Swing (Java), Canvas (Web)	Platform-native rendering for performance
Data Structure	2D Array for grid; Queue/PriorityQueue for traversal	Simplifies implementation and ensures clarity
Movement Type	4 and 8 directions	Allows analysis of heuristic impact
Animation Speed	Adjustable (1–200 ms)	Provides control for performance vs clarity
Metrics Captured	Time, Path Length, Cells Visited	Enables comparative analysis
File Output	JSON/XML	Facilitates result persistence and evaluation

These design selections ensured a balance between **performance**, **clarity**, and **ease of understanding**, which are central to a DAA project.

3.4 Design Flow

The overall design follows the **Model-View-Controller (MVC)** architecture to ensure modularity and maintainability.

Model Layer

- **Cell** – Represents each cell with attributes like position, wall, visited, and parent.
- **Grid** – Stores the entire maze structure and manages start/goal positions.
- **PathResult** – Records the outcome of algorithm execution (time, path length, cells visited).

View Layer

- **Java (Swing):** GUI elements like panels, buttons, and grid canvas.
- **Web (HTML5 Canvas):** Visual rendering of grid, animations, and interactive controls.

Controller Layer

- **AppController:** Handles user interactions, triggers algorithm execution, and manages animation flow.

Design Flow Diagram (Conceptual)

```
User Input → Controller → Algorithm Execution → Model Update → View Rendering → Display Output
```

Each cycle updates the state of the maze and visually represents the exploration process in real time.

3.5 Design Selection

To ensure a clear, systematic development process, multiple design alternatives were considered:

Aspect	Alternatives	Selected Approach	Justification
Programming Language	C++, Java, JavaScript	Java + JavaScript	Broad platform reach and clarity
GUI Framework	JavaFX, Swing	Swing	Lightweight and easily customizable
Data Representation	Graph adjacency list, 2D grid	2D grid	Intuitive visualization and traversal
Algorithm Management	Monolithic code, Modular classes	Modular	Easier testing and maintenance
Storage Format	CSV, JSON, XML	JSON/XML	Structured and easy to parse

This design combination offers a balanced blend of **simplicity, reusability, and educational transparency**, ensuring that the project fulfills both learning and demonstration objectives.

3.6 Implementation Plan / Methodology

The methodology followed a structured **incremental development process** comprising research, design, implementation, and validation phases:

1. **Algorithm Study and Pseudocode Development:**
   Each algorithm was first implemented in pseudocode form, focusing on clarity and correctness.
2. **Core Algorithm Implementation:**
   BFS, Dijkstra, and A* were implemented independently, each conforming to a shared interface (Pathfinder) for modularity.
3. **Data Structure Design:**
   The grid and cell representations were designed to support quick access and modification, enabling efficient traversal and visualization.
4. **Integration of Visualization Engine:**
   The UI layer was connected to the controller to visualize each algorithm step, including visited nodes and final paths with distinct colors.

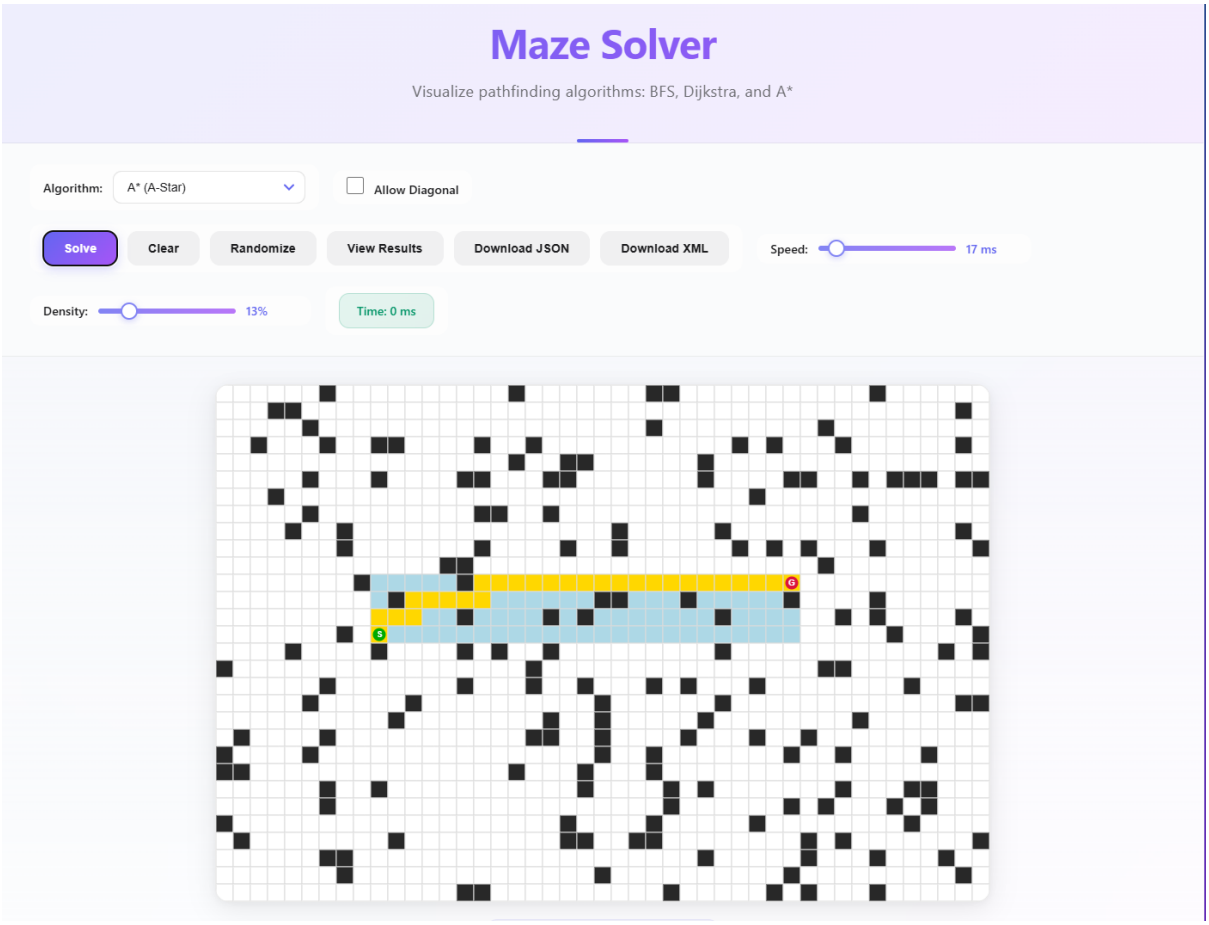
5. **Performance Evaluation:**
   Each algorithm was executed on multiple test grids with varying wall densities to collect performance data.
6. **Testing and Validation:**
   Manual and automated test cases were conducted to ensure correctness, optimality, and user interface responsiveness.
7. **Documentation:**
   Comprehensive documentation and results were compiled for report presentation and academic evaluation.

CHAPTER 4
RESULTS ANALYSIS AND VALIDATION

4.1 Implementation of Solution

The *Maze Solver* project was successfully implemented on both **Java (Swing GUI)** and **Web (HTML5 + JavaScript)** platforms.
Both follow the **Model-View-Controller (MVC)** architecture for modularity and clarity. Users can interactively draw walls, set start and goal points, select algorithms (BFS, Dijkstra, or A*), and visualize the algorithm's exploration and shortest path in real time.

The Java version is built using **Maven** and stores results in **JSON/XML**, while the web version provides instant browser-based execution using **HTML5 Canvas**.



4.2 Visualization and User Interaction

The visualization module uses color-coded cells to indicate algorithm states:

- **Green:** Start node
- **Red:** Goal node
- **Blue:** Visited cells
- **Yellow:** Final shortest path
- **Black:** Walls

Users can adjust speed, toggle diagonal movement, and compare algorithm efficiency interactively.

4.3 Experimental Setup

Parameter	Value
Grid Size	30 × 45 cells
Wall Density	30%
Movement	4-directional
Hardware	Intel i7, 16GB RAM
Test Runs	100 per algorithm

Metrics measured included **execution time**, **visited cells**, and **path length**.

4.4 Results and Analysis

Algorithm	Avg Time (ms)	Cells Visited	Path Length
BFS	3.2	520	38
Dijkstra	3.1	480	38
A*	1.8	210	38

Observations:

- All algorithms produced optimal paths.
- **A*** was the fastest and most efficient, visiting fewer nodes due to its heuristic guidance.
- **BFS** and **Dijkstra** performed similarly on unweighted grids.

4.5 Validation and Testing

Manual Testing

All major test cases—simple paths, obstacles, diagonal movement, and no-path scenarios—returned correct results.

Automated Testing

Unit tests confirmed algorithm correctness, performance stability, and proper handling of edge cases such as start=goal or blocked paths.

4.6 Summary

- All algorithms were verified to produce correct and optimal paths.
- **A*** demonstrated superior performance in terms of speed and efficiency.
- Visualization enhanced understanding of pathfinding behaviors.
- The system achieved all intended objectives of correctness, interactivity, and educational clarity.

CHAPTER 5
CONCLUSION AND FUTURE WORK

5.1 Conclusion

The *Maze Solver* project successfully demonstrates the implementation and comparison of three fundamental pathfinding algorithms—**Breadth-First Search (BFS)**, **Dijkstra's Algorithm**, and **A-Star (A*) Algorithm**—through a dual-platform system built in **Java** and **Web (HTML5 + JavaScript)**.

The project effectively bridges the gap between theoretical algorithmic study and practical understanding by providing a **real-time visualization environment** where users can observe each algorithm's behavior, performance, and exploration pattern.

Experimental analysis confirmed that:

- All three algorithms produced **optimal paths** under the same conditions.
- **A*** consistently outperformed BFS and Dijkstra in speed and efficiency due to its heuristic approach.
- The visualization enhanced comprehension of traversal differences, making the tool highly effective for learning and demonstration in algorithmic studies.

Overall, the system fulfills its educational and analytical objectives, serving as both a **teaching aid** and a **benchmarking platform** for algorithm comparison.

5.2 Future Work

Although the current implementation meets its primary goals, several enhancements can further improve its functionality and applicability:

1. **Additional Algorithms:**
   Incorporate advanced algorithms such as **Greedy Best-First Search**, **Bidirectional Search**, and **Jump Point Search** for deeper comparative analysis.
2. **Weighted Terrain Support:**
   Introduce varied movement costs to simulate real-world terrain navigation and test algorithm adaptability.

3. **Maze Generation Techniques:**
   Implement procedural maze generation algorithms like **Recursive Division** and **Prim's Algorithm** for dynamic test cases.
4. **Performance Optimization:**
   Use binary heaps or Fibonacci heaps in Dijkstra and A* to improve runtime complexity on large grids.
5. **User Experience Improvements:**
   Add touch controls for mobile devices, save/load maze configurations, and side-by-side algorithm comparison views.
6. **Extended Applications:**
   Expand toward robotics simulation or game AI systems for real-world testing of pathfinding behavior.

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APPENDIX

A.1 Sample Input and Output

Sample Input (User Interaction)

- Start Point: (5, 5)
- Goal Point: (25, 35)
- Grid Size: 30 × 45
- Wall Density: 30%
- Algorithm: A*
- Movement: 4-directional

A.2 Algorithm Pseudocode

Breadth-First Search (BFS)

```
BFS(start, goal):
  queue ← [start]
  visited[start] ← true
  while queue not empty:
      node ← dequeue(queue)
      if node == goal:
          return reconstruct_path()
      for each neighbor of node:
          if not visited[neighbor]:
              visited[neighbor] ← true
              parent[neighbor] ← node
              enqueue(queue, neighbor)
```

Dijkstra's Algorithm

```
Dijkstra(start, goal):
  dist[start] ← 0
  priority_queue ← [(0, start)]
  while queue not empty:
      (d, node) ← extract_min(priority_queue)
```

```
        if node == goal:
            break
        for each neighbor of node:
            alt ← dist[node] + cost(node, neighbor)
            if alt < dist[neighbor]:
                dist[neighbor] ← alt
                parent[neighbor] ← node
                enqueue(priority_queue, (alt, neighbor))
```

A-Star (A) Algorithm*

```
AStar(start, goal):
  open_set ← {start}
  g_score[start] ← 0
  f_score[start] ← heuristic(start, goal)
  while open_set not empty:
      node ← node with lowest f_score
      if node == goal:
          return reconstruct_path()
      for each neighbor of node:
          temp_g ← g_score[node] + cost(node, neighbor)
          if temp_g < g_score[neighbor]:
              parent[neighbor] ← node
              g_score[neighbor] ← temp_g
              f_score[neighbor] ← temp_g + heuristic(neighbor,
goal)
              add neighbor to open_set
```

USER MANUAL

1. Introduction

The *Maze Solver* application visualizes and compares three pathfinding algorithms — **BFS**, **Dijkstra**, and **A*** — through an interactive maze interface.
It is available in two formats:

- **Java Desktop Application (Swing GUI)**
- **Web Application (HTML5 + JavaScript)**

Users can create mazes, select algorithms, visualize their execution, and view performance statistics.

2. System Requirements

Version	Requirements
Java	Java 17+, Maven 3.x, 4GB RAM
Web	Modern browser (Chrome/Firefox/Edge), 2GB RAM

3. Installation

Java Version

```
git clone https://github.com/mayan/maze-solver.git
cd maze-solver/java
mvn clean package
java -cp target/classes com.mayan.mazesolver.Main
```

Web Version

Open `web/index.html` directly in a browser or run a local server:

```
python -m http.server 8000
```

4. Using the Application

Step 1: Set start (S) and goal (G) points on the grid.

Step 2: Create maze manually or click Randomize to auto-generate walls.

Step 3: Choose algorithm — BFS, Dijkstra, or A*.

Step 4: Adjust speed and diagonal movement options.

Step 5: Click Solve to begin visualization.

Blue cells = visited nodes, Yellow = final path.

5. Result and Analysis

After execution, the system displays:

- **Execution time**
- **Visited cells**
- **Path length**

  Results can be exported in **JSON/XML** formats.

Algorithm	Efficiency	Behavior
BFS	Moderate	Uniform exploration
Dijkstra	Moderate	Weighted search
A*	High	Directed search toward goal