GraphVizFX

Project Report

---

1. Project Overview

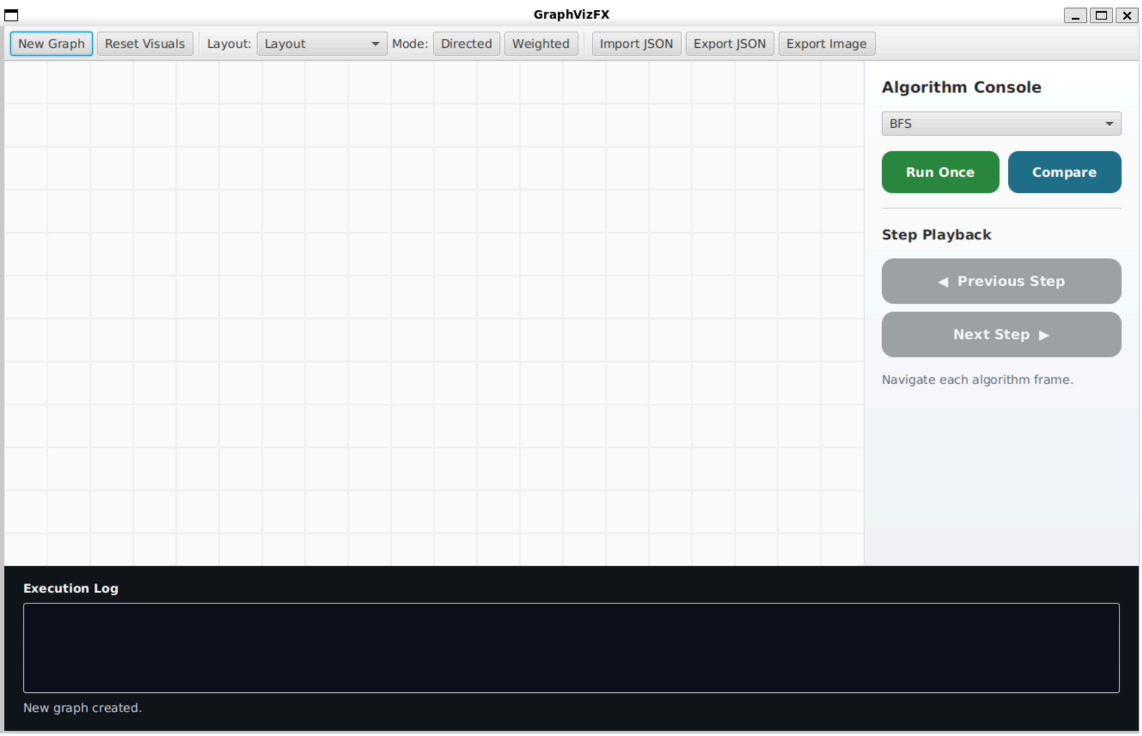
GraphVizFX is a desktop-based graph visualization and algorithm exploration platform developed in **Java** using **JavaFX**. The project is conceived as a **complete, polished, and extensible educational tool**, designed to go beyond basic algorithm demonstrations and offer a genuinely insightful exploration of graph theory.

At its core, GraphVizFX transforms abstract algorithmic concepts into **clear, interactive, and visually traceable processes**. Instead of treating algorithms as black boxes that output results, the application exposes their internal behavior, step by step, on user-defined graphs.

This makes GraphVizFX particularly compelling as a project because it combines:

- algorithmic correctness,
- thoughtful software architecture,
- interactive visualization,
- and quality-oriented development practices.

From an academic standpoint, it demonstrates not only knowledge of graph algorithms, but also the ability to **design a system that explains them**.



---

2. Objectives and Educational Value

The main objectives of GraphVizFX are:

- To provide a **visual and interactive representation** of graph structures and algorithms.
- To bridge the gap between **theoretical algorithm descriptions** and their **practical execution**.
- To offer a **safe experimentation environment** where users can modify graphs and instantly observe algorithmic behavior.
- To serve as a **foundation project** that can be extended with additional algorithms, layouts, or data sources.

From an academic and practical perspective, the project is valuable because it:

- reinforces algorithmic intuition,
- encourages modular software design,
- demonstrates real-world usage of JavaFX for non-trivial applications,
- integrates testing and quality considerations into an algorithm-heavy project.

---

3. Feature Set

GraphVizFX includes a comprehensive set of features that cover graph creation, manipulation, visualization, and analysis.

3.1 Graph Construction and Editing

- Creation of nodes and edges through an interactive interface
- Support for **directed and undirected graphs**
- Support for **weighted edges**
- Dynamic addition and removal of nodes and edges
- Automatic graph consistency maintenance after deletions

3.2 Graph Layouts and Visualization

- Multiple layout strategies (e.g., circular, grid-based, force-inspired layouts)
- Stable node positioning to preserve user mental models
- Clear visual distinction between nodes, edges, and weights
- Highlighting of active nodes and edges during algorithm execution
- Smooth animations for transitions and algorithm steps
- The ability to force directionality in undirected graphs for algorithm visualization purposes
- Resetting highlights and visual states after algorithm completion or manual reset

3.3 Algorithm Visualization

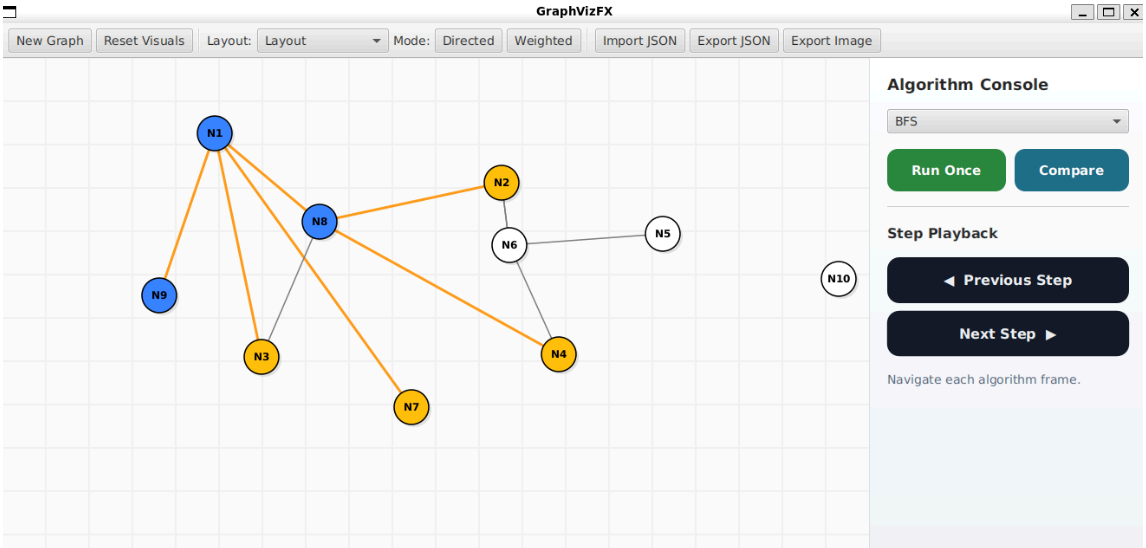
The application supports visualization of several classical graph algorithms, including:

- Breadth-First Search (BFS)
- Depth-First Search (DFS)
- Dijkstra’s shortest path algorithm
- A* search
- Minimum spanning tree algorithms (Prim, Kruskal)

For each algorithm:

- Execution is shown step by step
- Visited nodes and selected edges are visually highlighted
- Logs describe the internal decisions made by the algorithm
- Execution speed can be controlled by the user

A defining feature of GraphVizFX is that **algorithm visualization is deterministic and reproducible**. Given the same graph and starting conditions, the execution path remains consistent, making it suitable for rigorous comparison and learning.



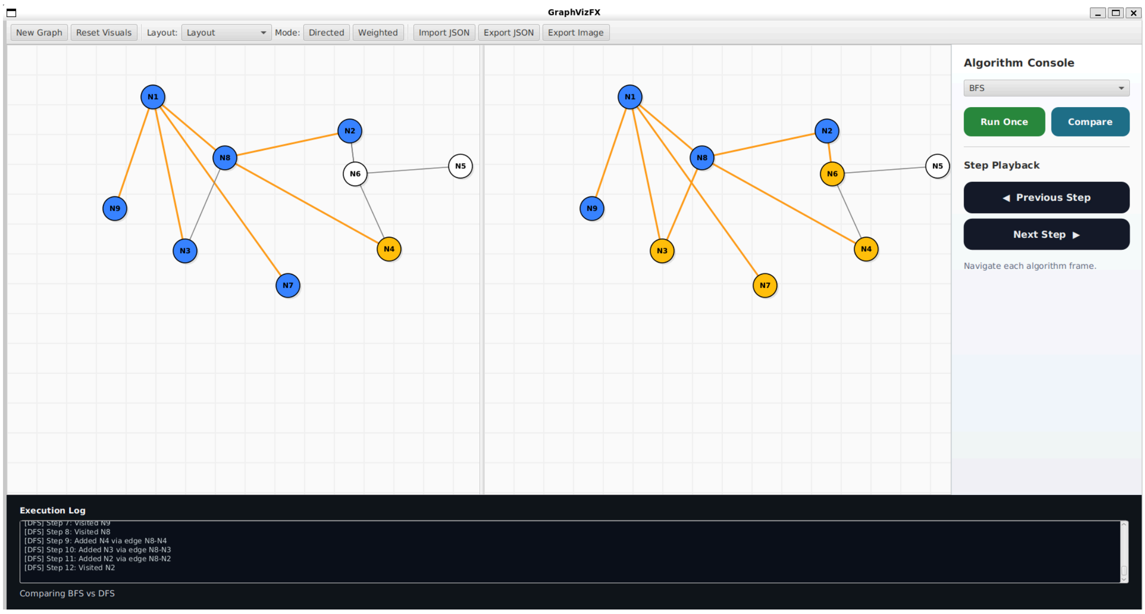
3.4 Algorithm Comparison Feature

GraphVizFX includes an **algorithm comparison mode**, allowing users to execute and compare two algorithms on the **same graph** under identical conditions.

This feature enables:

- Direct comparison of traversal strategies (e.g., BFS vs DFS)
- Comparison of shortest-path algorithms (e.g., Dijkstra vs A*)
- Visual and textual contrast of visited nodes, selected edges, and execution paths

By presenting algorithms side by side, the application highlights **differences in strategy, efficiency, and behavior**, reinforcing theoretical insights through direct observation.



3.5 Import, Export, and Persistence

- Graphs can be exported to **JSON** format
- Previously saved graphs can be re-imported
- Export of graph visualizations as image files (PNG)

3.5 Logging and Observability

- Real-time logs describing algorithm progress
- Clear textual feedback synchronized with visual updates
- Logs designed to complement, not replace, visualization

3.6 Little demonstration

Here is a little demonstration of the application in action:

Little Demonstration

4. Technical Architecture

4.1 Technology Stack

- **Java 21**
- **JavaFX 21** for UI and visualization
- **Maven** for build and dependency management
- **JUnit 5 (Jupiter)** for unit testing

4.2 Project Structure

The codebase follows a modular and readable structure:

- `model` – core graph data structures (nodes, edges, graphs)
- `algorithms` – algorithm implementations independent of UI

- `layout` – node positioning and layout strategies
- `io` – JSON import/export logic
- `controller` – interaction logic connecting UI and core logic
- `view` – JavaFX components and visualization layers

This separation ensures that algorithmic logic remains testable and reusable, while UI-specific code is isolated.

---

5. Implementation Details

5.1 Core Logic

The core graph model is designed to be deterministic and robust:

- Nodes are uniquely identifiable and safely comparable
- Edges encapsulate direction and weight information
- Graph operations enforce internal consistency

Algorithms operate exclusively on these data structures, without direct dependency on JavaFX components. This design decision was intentional to:

- simplify testing,
- reduce coupling,
- allow future reuse of algorithms outside the UI context.

5.2 Algorithm Execution Flow

Each algorithm follows a structured execution model:

1. Validation of input graph and source node
2. Initialization of algorithm-specific data structures
3. Step-by-step execution with explicit state updates
4. Emission of visual and textual events

This approach enables both visualization and logging without duplicating logic.

5.3 Unit Testing

Unit tests were added under `src/test/java` using **JUnit 5**.

The tests focus on:

- Graph data structures (node and edge creation, addition, removal)
- Algorithm correctness on small, deterministic graphs
- Handling of edge cases (disconnected graphs, invalid sources)
- JSON import/export consistency

UI rendering, JavaFX stages, and animation timing are intentionally excluded from unit testing to avoid brittle tests and unnecessary complexity.

The test suite is designed to run with:

```
mvn test
```

and integrates cleanly with Maven and CI pipelines.

---

6. Challenges Encountered and Solutions

6.1 Integration of OpenStreetMap Data

Problem: An early idea was to integrate OpenStreetMap (OSM) data to allow real-world map-based graph visualization. However, the available APIs produced incomplete and inconsistent data. Some streets were missing, others were poorly rendered, and the overall visualization lacked clarity.

Analysis: The integration introduced significant complexity while providing limited educational value. Moreover, the visual noise reduced readability, which contradicted the project's primary goal of clarity and algorithm understanding.

Solution: The OSM integration was deliberately postponed. The feature was dropped in favor of maintaining a clean and controlled visualization environment. The project remains open to future integration with a more suitable and reliable mapping API.

6.2 JavaFX and Maven Compatibility Issues

Problem: Initial builds failed due to a mismatch between the Java version installed on the system (Java 17) and the JavaFX and Maven configuration targeting Java 21.

Analysis: JavaFX is particularly sensitive to version mismatches, and the issue manifested as runtime and plugin resolution errors in `pom.xml`.

Solution: The issue was resolved by installing **Java 21** and explicitly configuring the correct SDK in the development environment. Maven and JavaFX dependencies were aligned with the target Java version, restoring build stability.

6.3 Logging Synchronization Issues

Problem: During early algorithm executions, logs were not displayed consistently with visual updates, leading to confusion about algorithm progress.

Analysis: The issue was traced back to improper synchronization between algorithm execution steps and log emission.

Solution: The logging mechanism was restructured so that logs are emitted at well-defined execution points. This ensured that textual feedback accurately reflects the current algorithmic state.

---

7. Limitations

While GraphVizFX is functional and robust, certain limitations remain:

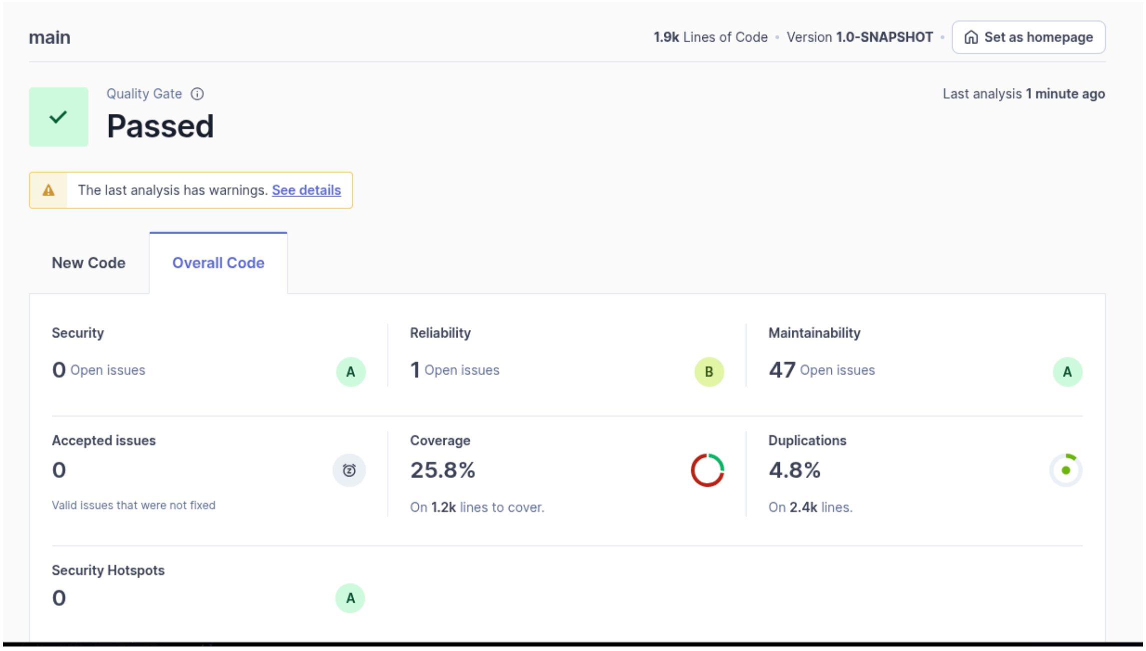
- No automated UI testing
- Limited number of layout algorithms
- No real-world map integration at this stage
- Performance optimizations for very large graphs are limited

These limitations are acknowledged and documented for future work.

---

8. Software Quality and SonarQube Analysis

2.1 Static Analysis (SonarQube)



Metric	Result	Detail
Quality Gate	Passed	Main branch, version 1.0-SNAPSHOT; ~1.9k LOC analyzed
Reliability	B	1 open issue (indicates at least one non-trivial bug)
Maintainability	A	47 open code smells
Coverage	25.8%	1.2k lines to cover; markedly below target and tied to previously noted Critical Weaknesses
Duplications	4.8%	2.4k lines analyzed, low duplication footprint

The static analysis confirms the project passes the Quality Gate with strong Security (A, 0 issues/hotspots) and Maintainability (A). However, the Reliability grade of B signals a remaining defect that should be addressed prior to release. Most notably, coverage at 25.8% leaves a significant portion of logic unverified; this gap directly aligns with the Critical Weaknesses highlighted in the Executive Summary and should be prioritized to mitigate undiscovered regressions. Duplications remain acceptable at 4.8%.

---

9. Conclusion

GraphVizFX positions itself as more than a simple academic exercise. It is a **coherent, well-architected, and feature-rich platform** that successfully merges algorithmic theory with practical visualization.

The project distinguishes itself through:

- its emphasis on explanation rather than mere execution,
- its clean separation between logic and visualization,
- its support for direct algorithm comparison,

- and its integration of testing and quality-oriented development practices.

These characteristics make GraphVizFX particularly well-suited for academic demonstration, learning environments, and future research-oriented extensions.

With continued refinement, quality analysis via SonarQube, and the addition of new algorithms and comparison metrics, GraphVizFX has the potential to evolve into a reference tool for graph algorithm visualization.

In short, GraphVizFX is not just functional — it is **convincing, extensible, and academically valuable**.