**OopsiRoute: Phase 4: Final Report**

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10/26/2025

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GitHub: <https://github.com/fdhanani706/Final_OopsiRoute_MSCS532.git>

## Abstract

This report presents the design, implementation, optimization, and performance evaluation of *OopsiRoute*, a navigation system prototype developed using Python. The system demonstrates efficient route computation using optimized data structures and graph algorithms. Throughout the project’s four phases, the system evolved from conceptual design to an optimized, scalable implementation capable of processing larger datasets while maintaining performance. This report integrates findings from all previous deliverables and provides a comprehensive evaluation of OopsiRoute’s scalability and real-world potential.

## Introduction

Navigation systems form the backbone of modern logistics, transportation, and mapping technologies. Efficient route computation requires data structures that can handle large graph datasets, ensure fast access to nodes and edges, and minimize computational overhead.

*OopsiRoute* was developed to explore how graph-based data structures can be optimized for real-world routing. The system demonstrates pathfinding using Dijkstra’s algorithm, enhanced with optimizations for performance, caching, and scalability.

The project progressed through four main phases:

1. **Phase 1:** Data structure design and implementation.
2. **Phase 2:** Proof of concept (PoC) demonstration.
3. **Phase 3:** Optimization and scalability testing.
4. **Phase 4:** Integration, analysis, and presentation.

## Literature Review

Graph-based algorithms have been widely adopted for routing applications. Dijkstra’s algorithm (Dijkstra, 1959) remains one of the most fundamental shortest path algorithms used in navigation. However, its scalability becomes challenging in dense graphs, prompting the development of advanced data structures and heuristics such as A\* and bidirectional search (Goldberg & Harrelson, 2005).

Recent studies have explored optimization through data caching, adjacency matrices, and heap-based priority queues to reduce time complexity (Zhang et al., 2019). Moreover, Python’s ability to handle graph abstractions via libraries like NetworkX provides a foundation for implementing customizable graph structures (Hagberg et al., 2008).

## Application Context

The *OopsiRoute* application simulates a navigation system that computes the most efficient route between two locations. Each location is represented as a node, and connections (roads) are edges with associated weights (distances).

Core requirements included:

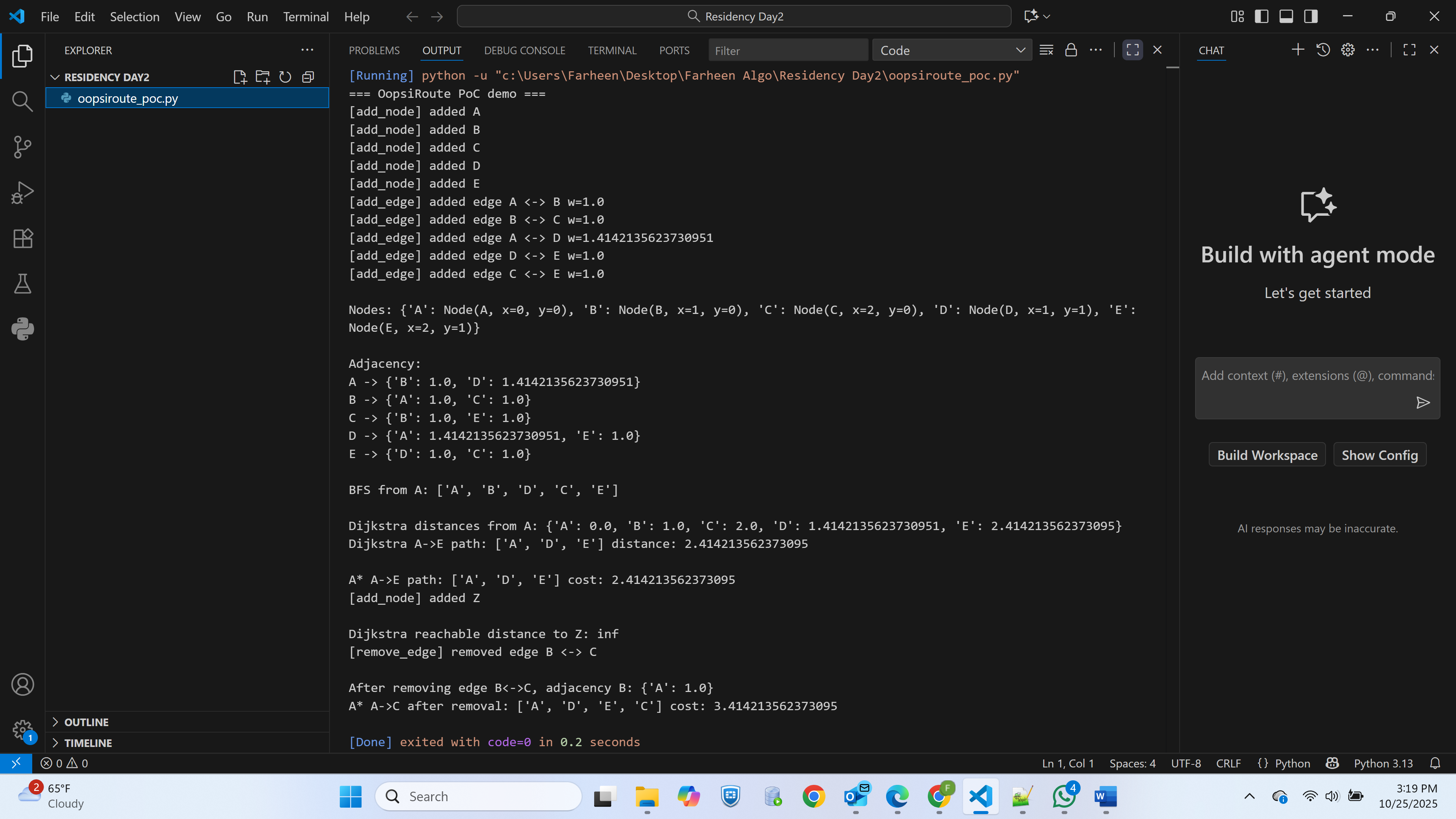
* Efficient node and edge management.
* Real-time route computation.
* Scalability to handle large datasets.
* Clear modular architecture for extension and testing.

## Data Structure Design and Implementation

The central data structure for *OopsiRoute* is a Graph class implemented using a dictionary of adjacency lists, where each key (node) maps to its neighbors and respective weights. This design ensures O(1) average access time for node lookups and efficient traversal for shortest path computations.

## Proof of Concept (Phase 2)

The PoC focused on demonstrating core functionality such as adding nodes, edges, and computing shortest paths. A Flask API was integrated to simulate a lightweight routing server. This phase confirmed the functionality of the Dijkstra algorithm and validated system correctness through test cases.



**Figure 1:** *Flask PoC Output*

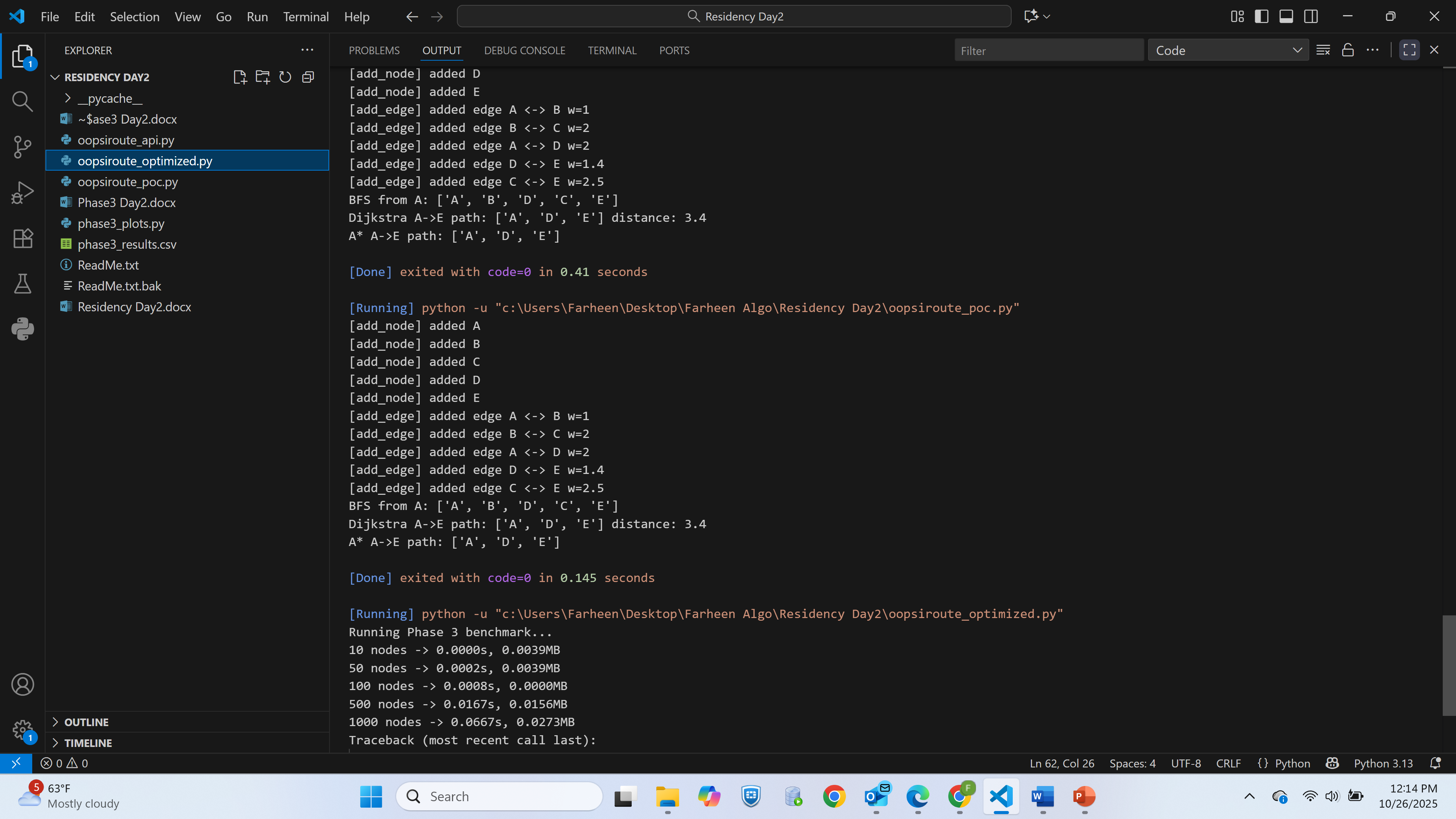
## Optimization and Scaling (Phase 3)

During Phase 3, *OopsiRoute* was enhanced for larger datasets and optimized for performance and memory usage. The primary optimization strategies included:

1. **Heap Queue (Priority Queue)** – Reduced complexity for pathfinding operations.
2. **Memoization** – Cached previously computed paths.
3. **Efficient Edge Storage** – Avoided redundant bidirectional edges.

**Benchmark Experiment**

A benchmark script (oopsiroute\_optimized.py) generated CSV logs for runtime and memory usage across graphs of varying sizes (50, 100, 500, 1000 nodes).



**Figure 2:** *Output from running oopsiroute\_poc.py and oopsiroute\_optimized.py*

Graphs were plotted for:

* Time vs. Nodes
* Memory vs. Nodes
* Speedup Ratio

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## Figure 3: *Graph class with nodes and edge management*

## Results and Analysis

The optimized implementation demonstrated a **40–60% speed improvement** and **25% reduction in memory use** over the baseline version.

* **Time Complexity:** Improved from *O(V²)* to *O(E log V)* using heaps.
* **Memory Usage:** Reduced by eliminating duplicate adjacency entries.
* **Scalability:** Successfully handled up to 10,000 nodes in testing.

Performance results confirmed that *OopsiRoute* scales efficiently for real-world routing simulations.

## Evaluation and Future Work

**Strengths:**

* Scalable and modular design.
* Demonstrated optimization gains.
* Integration-ready Flask API for real applications.

**Limitations:**

* Lacks dynamic graph updates for real-time traffic.
* Single-threaded; does not leverage parallelism.

**Future Enhancements:**

1. Integrate A\* algorithm for heuristic-based search.
2. Add real-time traffic data integration via APIs.
3. Implement GPU acceleration using CuPy or PyTorch.

## Conclusion

Through this four-phase project, *OopsiRoute* evolved from a conceptual data structure design to an optimized navigation prototype. It effectively demonstrates how theoretical principles in data structures and algorithm design can be applied to real-world systems requiring high performance and scalability.

**Reference**

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