Graph-based Nearest Neighbors with Dynamic Updates via Random Walks

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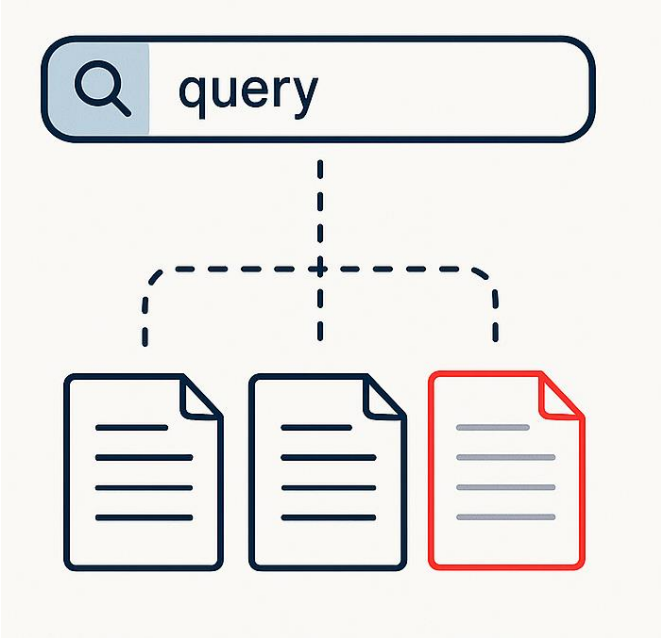
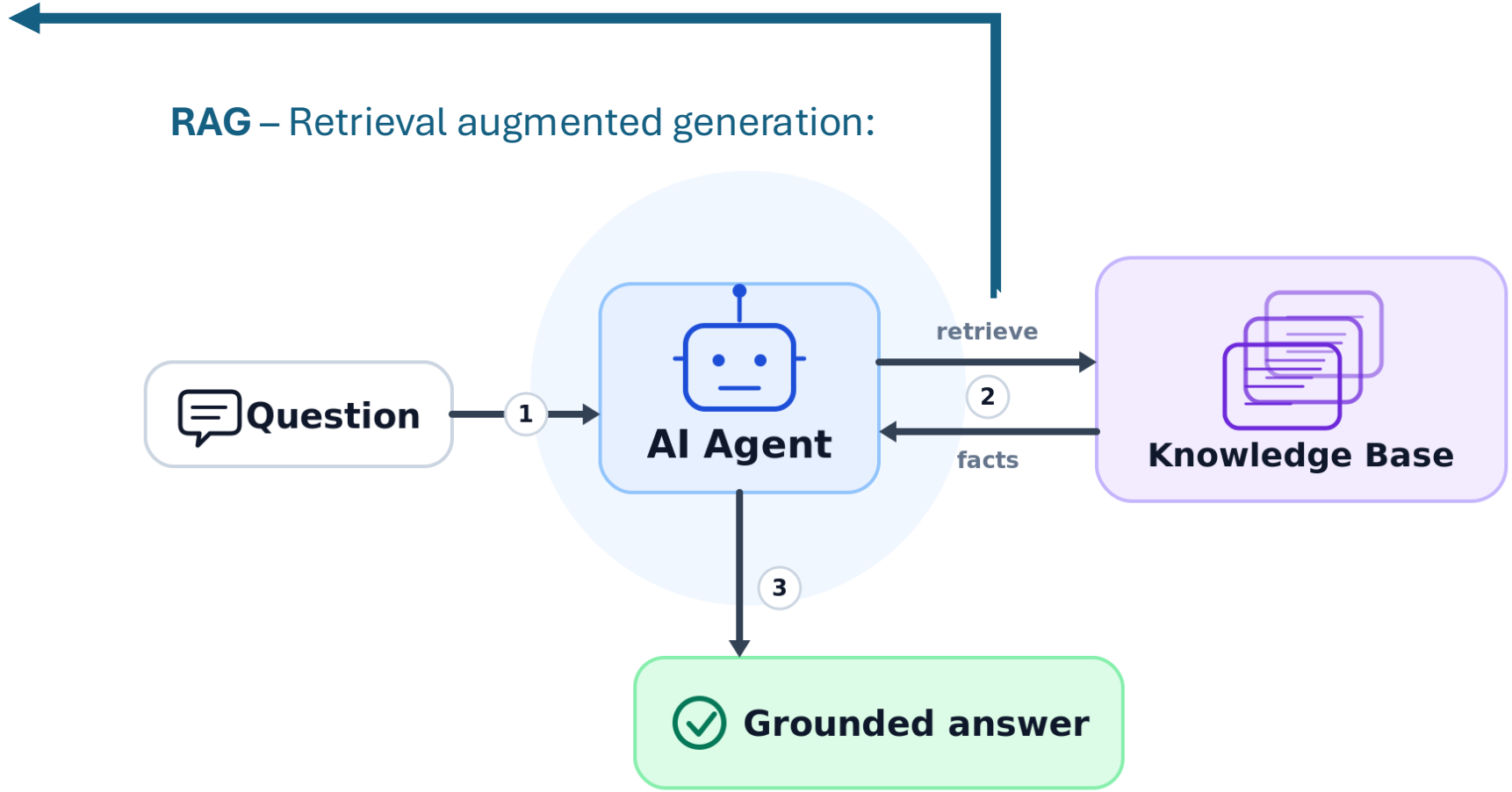
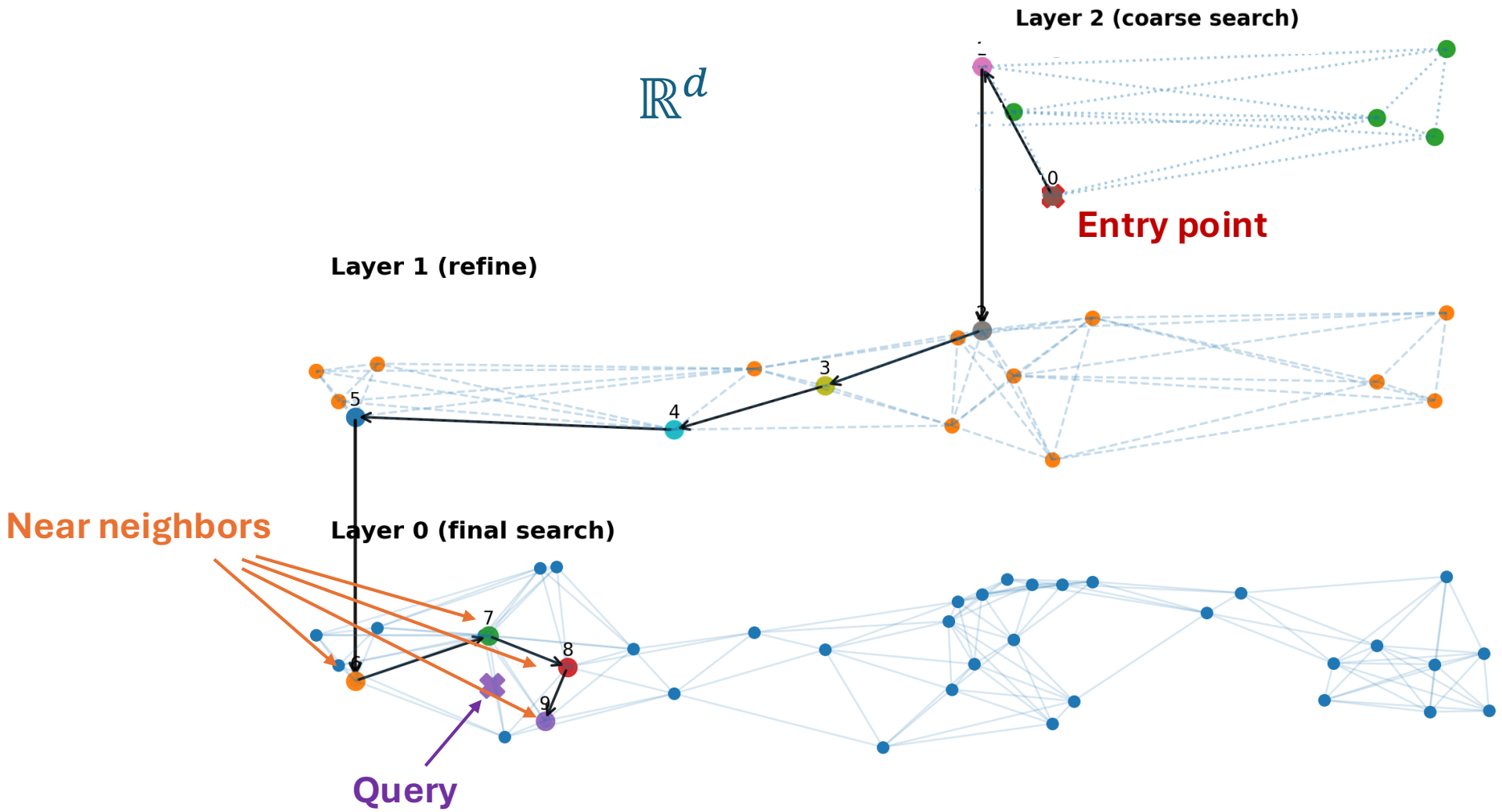
Approximate Nearest Neighbor Search (ANN)





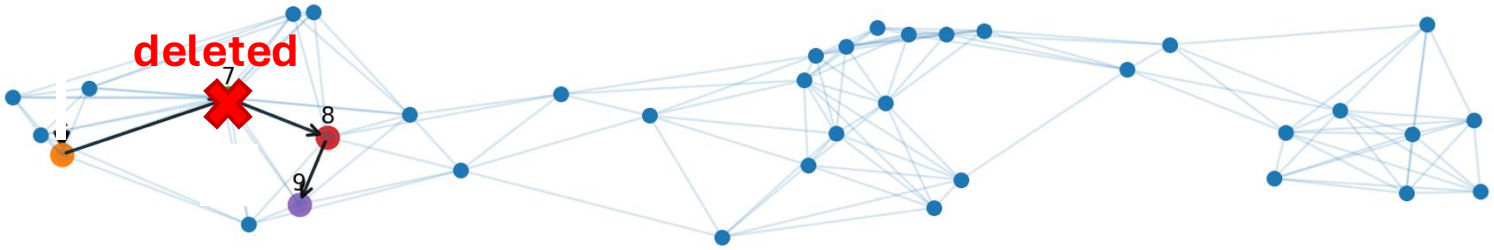
Graph Search Methods in ANN



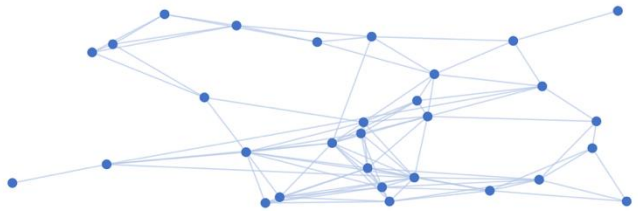
ANN with Dynamic Updates

- **Challenge:** Data is **dynamic**

- **How to update the navigation graph?**
  - Insertions are easier
  - **Deletions are harder**



Vanilla Solution 1: Periodic Rebuilds



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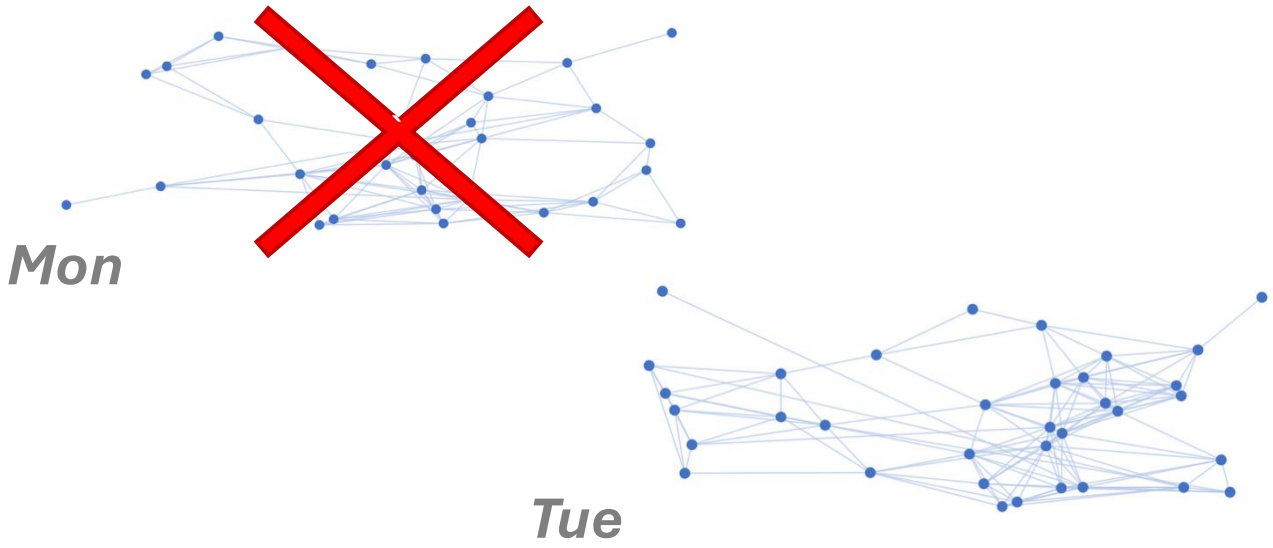

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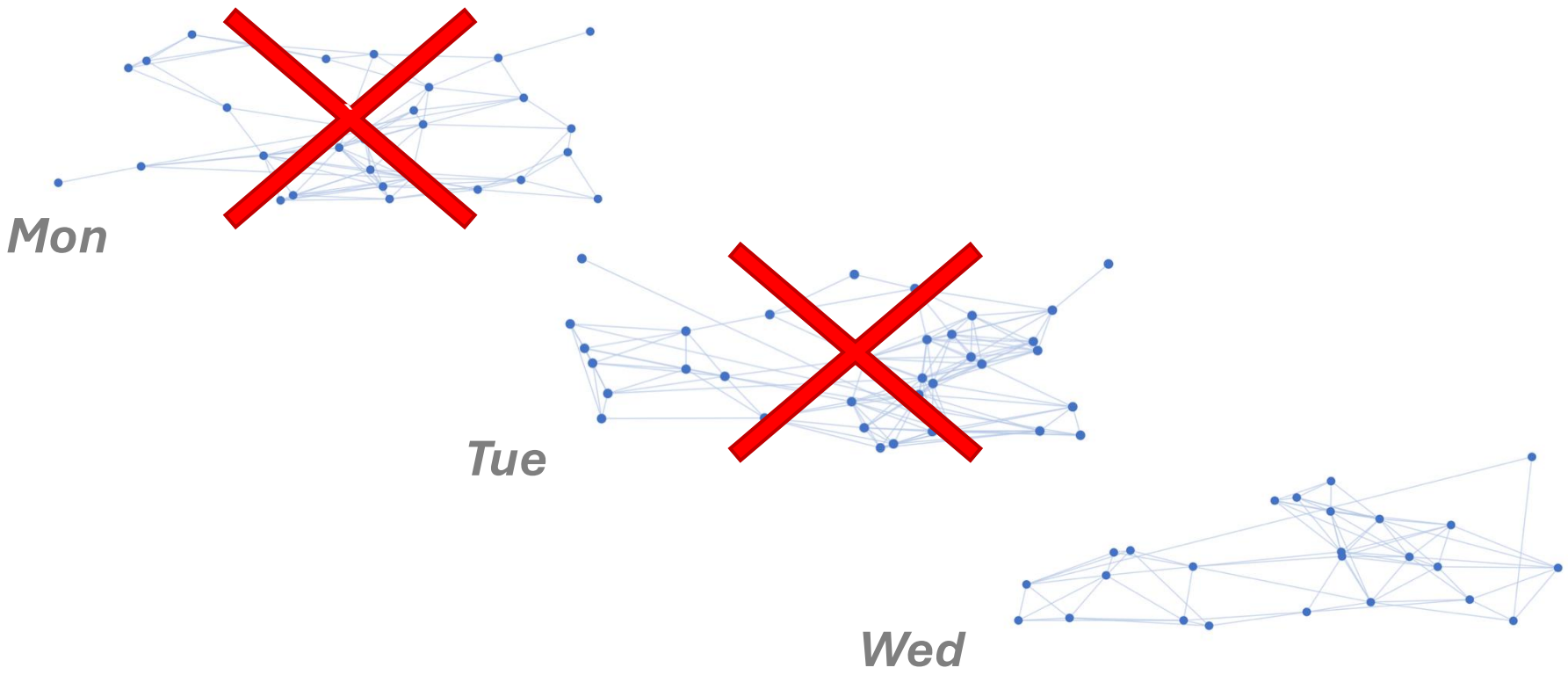

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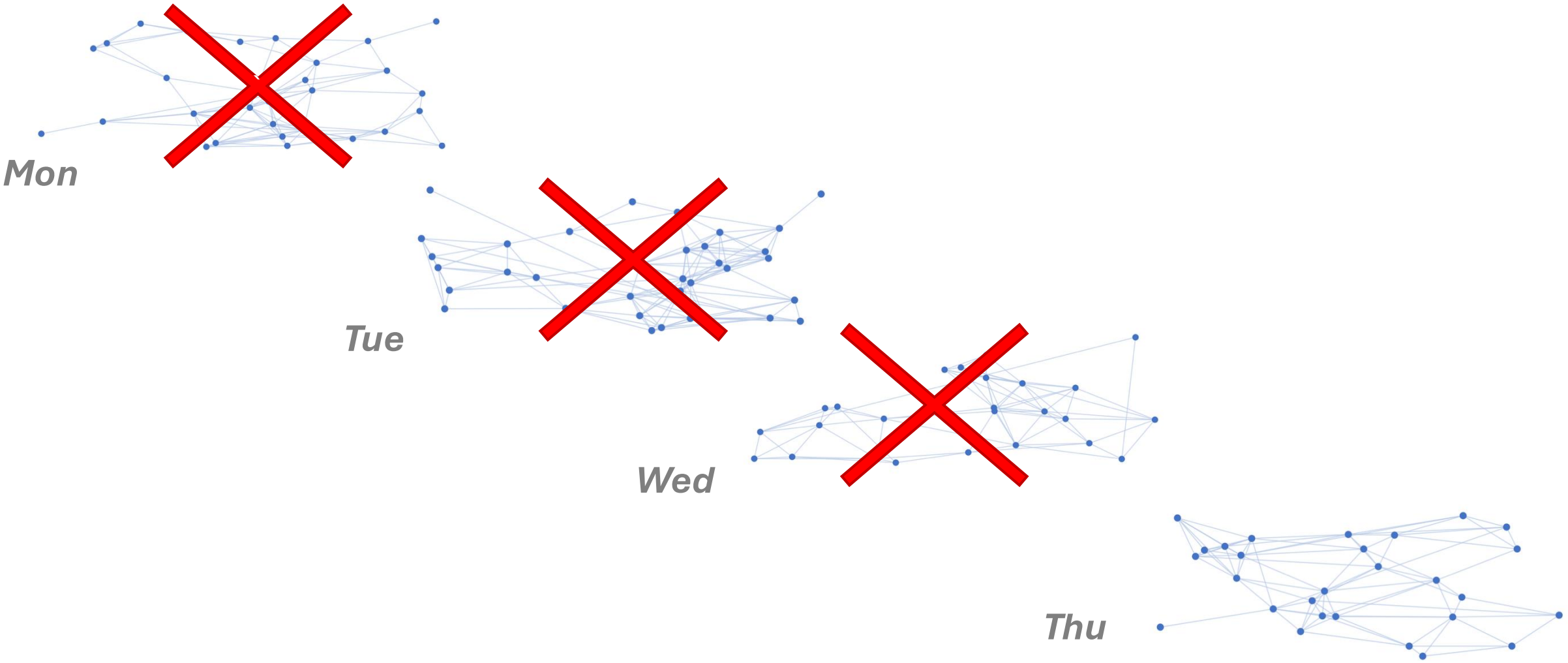
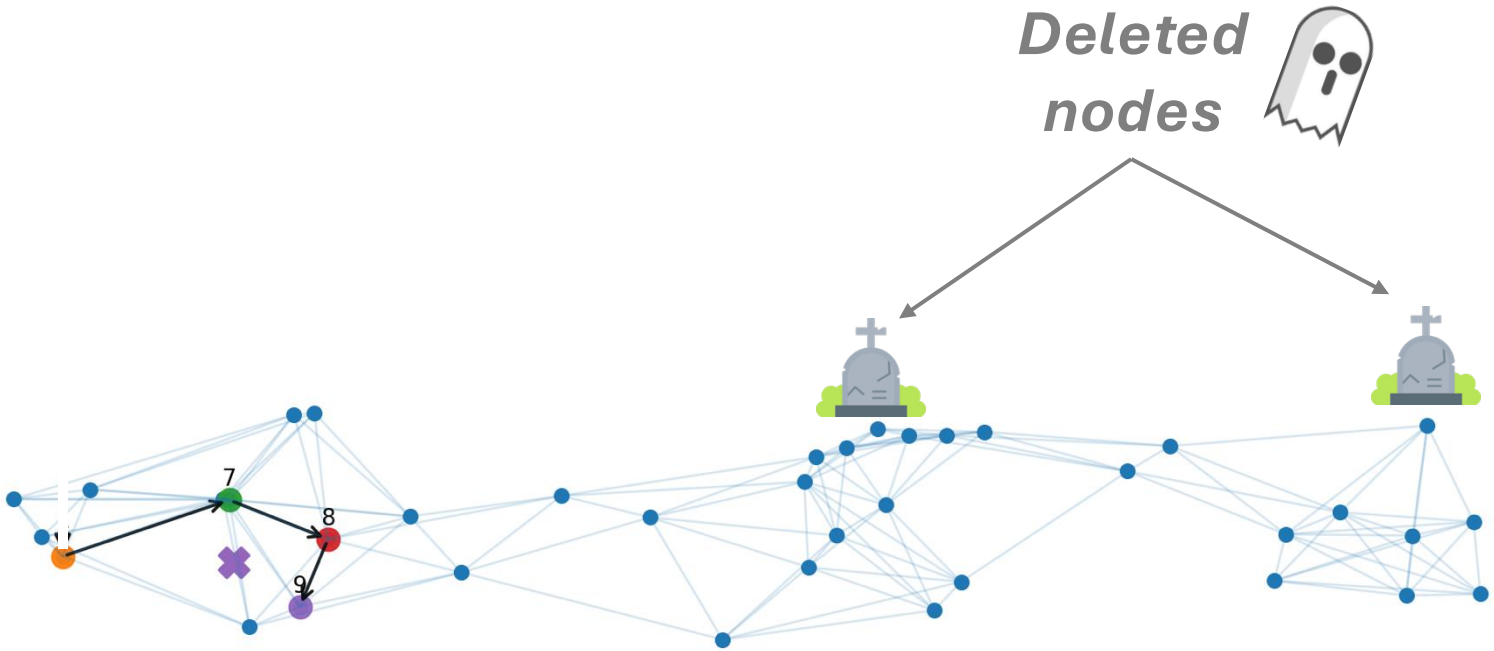


Vanilla Solution 2: Tombstones



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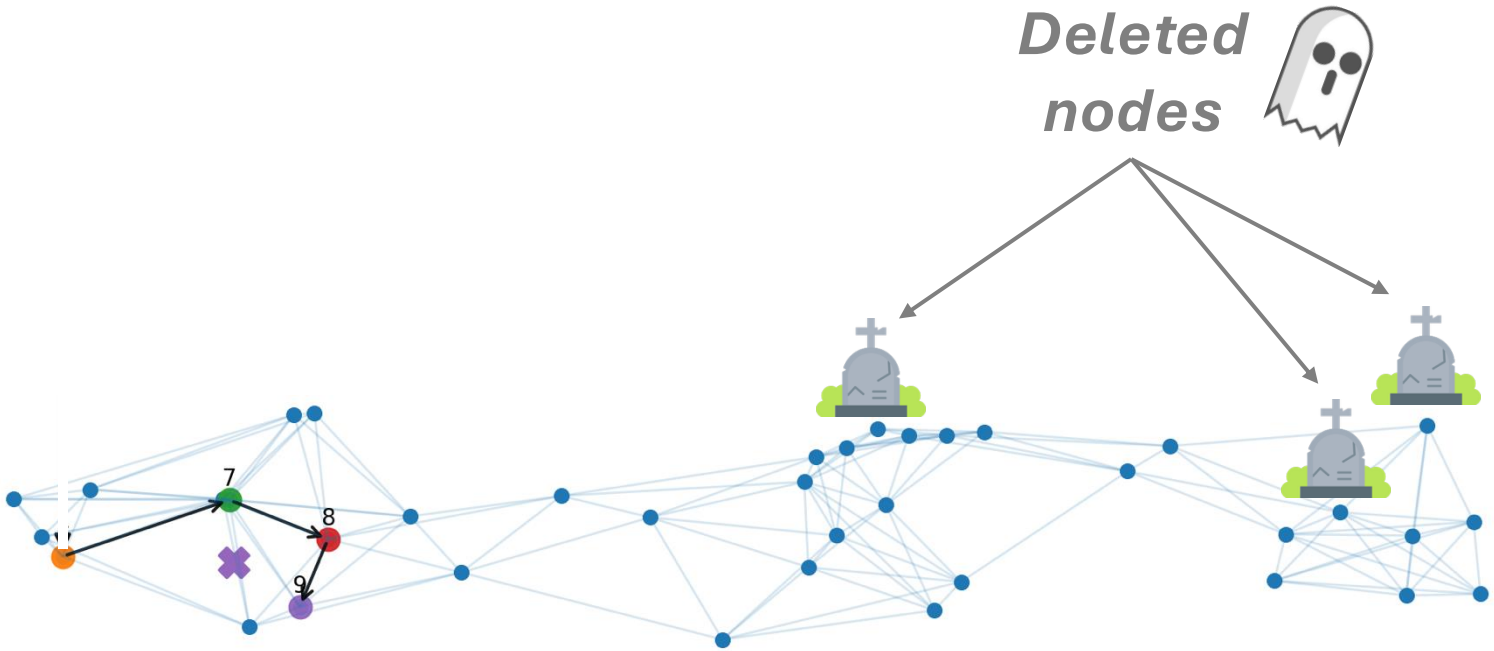

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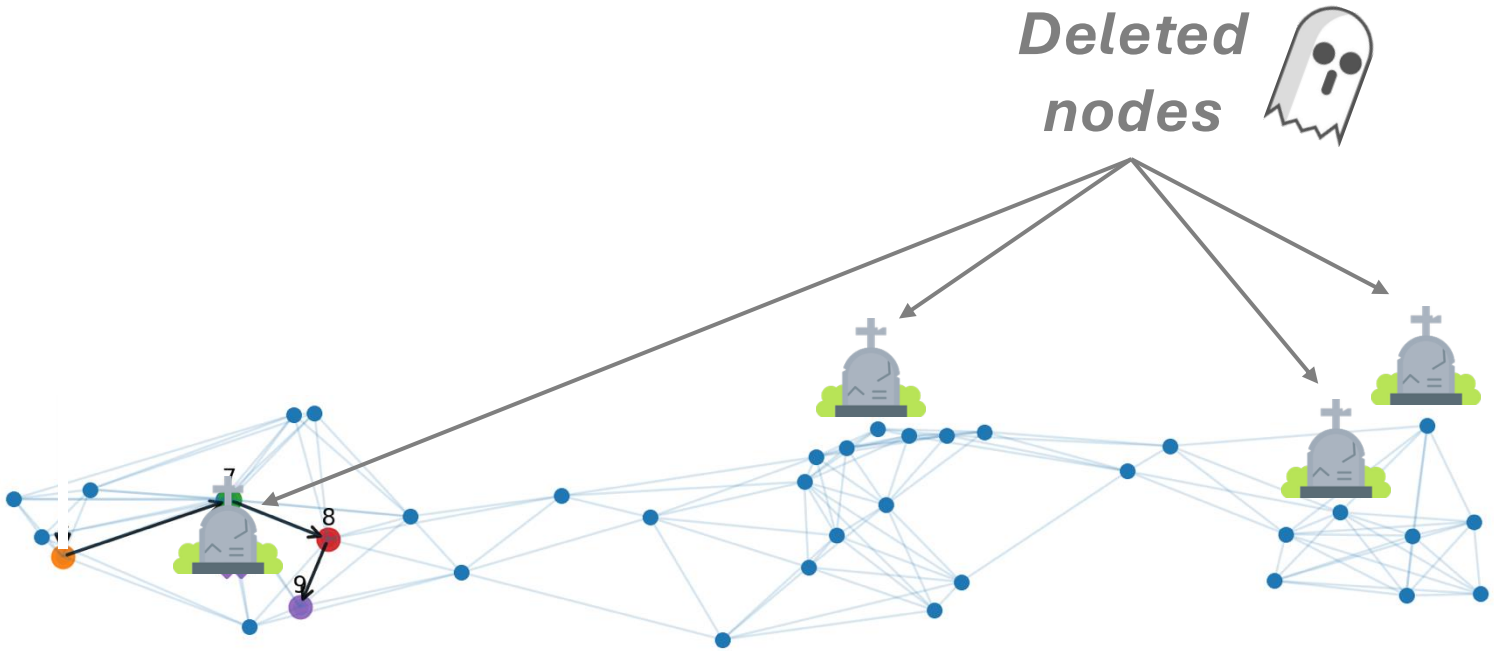

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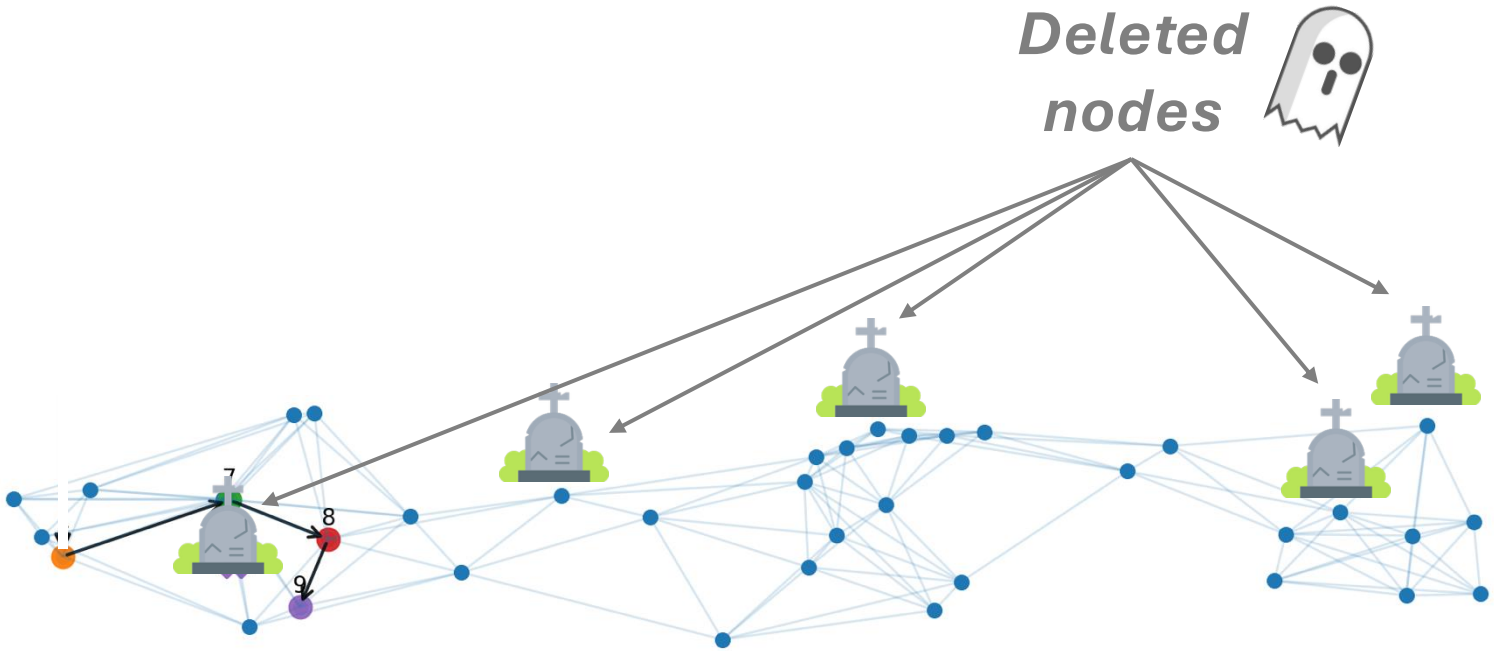

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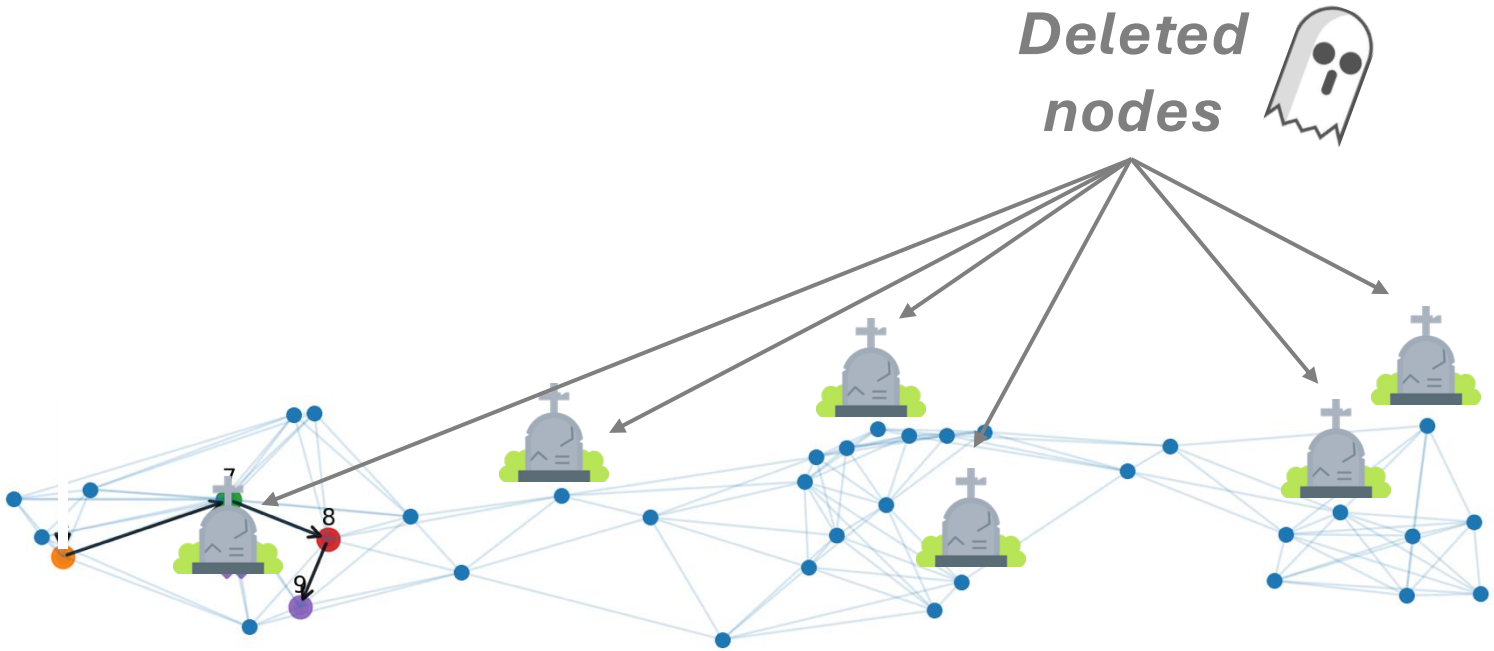
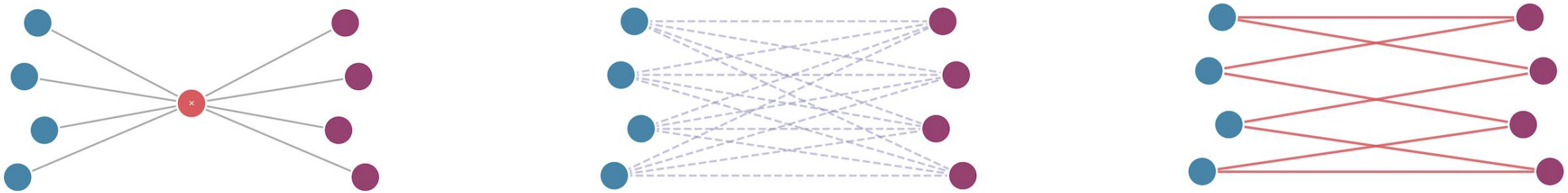


Our Approach: Local Patching

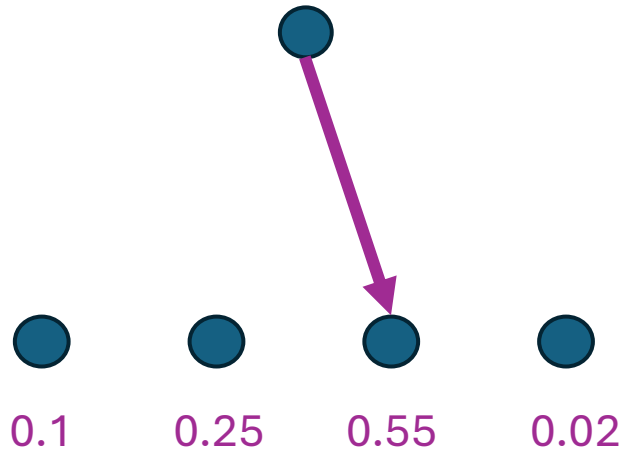
- **But how?**

- Our method: ***SPatch* – Sparsified Patching**

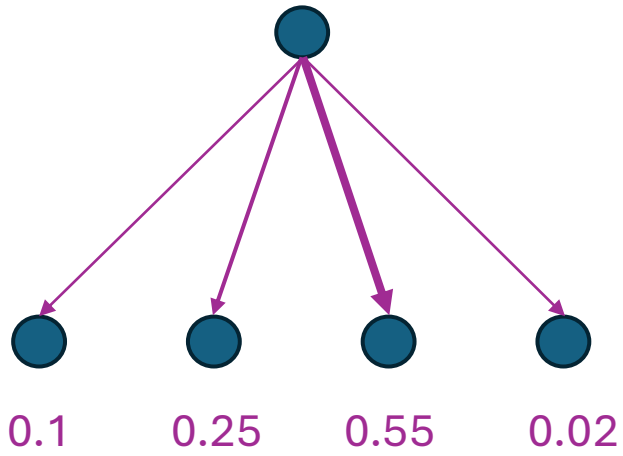


Our formulation: “Softmax Walk”

Greedy walk (vanilla graph-search):
Deterministic walk

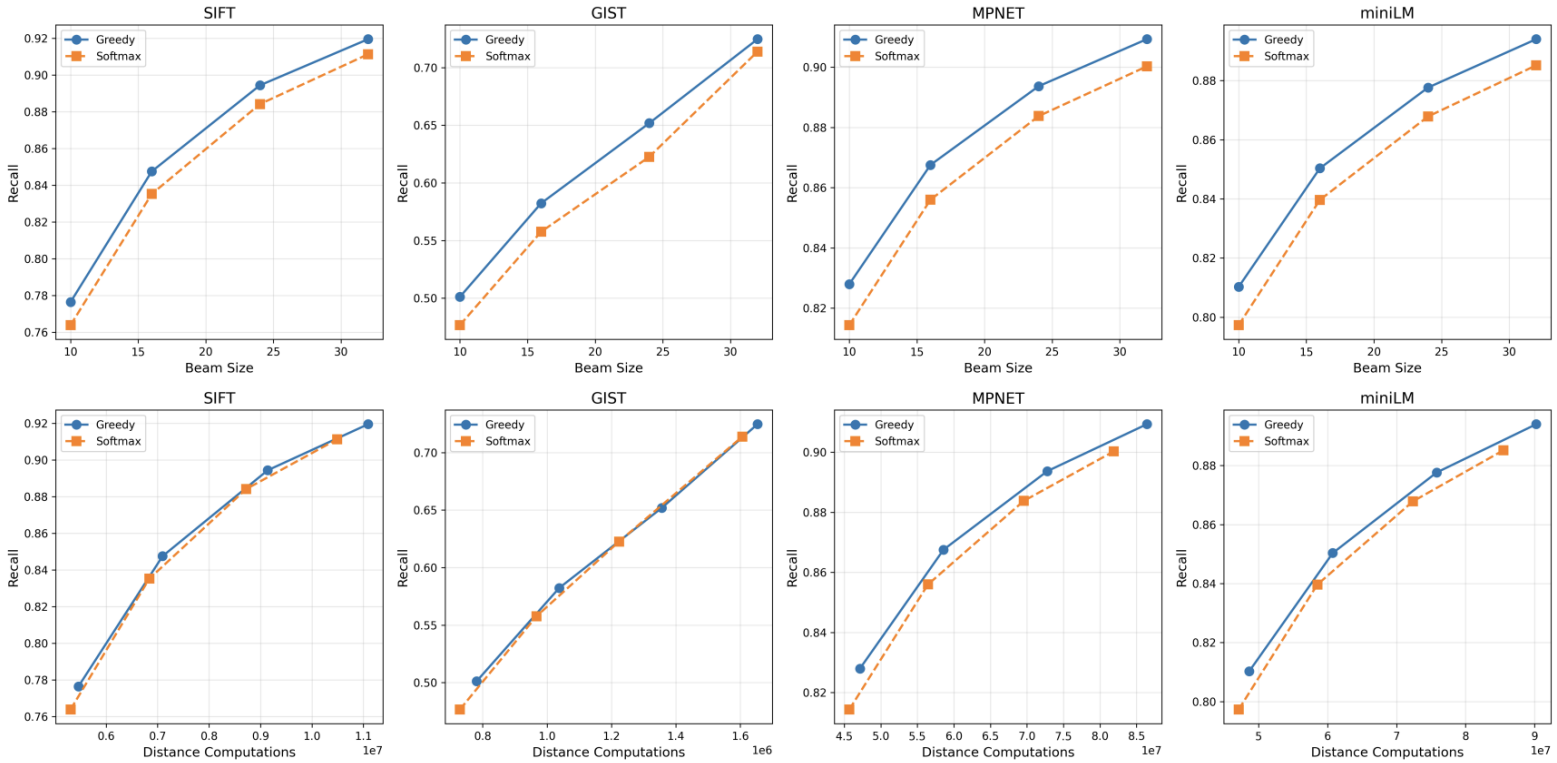


Softmax walk (our conceptual analog):
Random walk



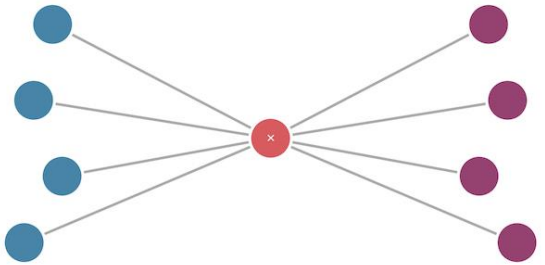
Softmax Walk: Why?

- Access to random walk theory on graphs
- Leads to theoretically motivated patching algorithm (SPatch)
- Maintains empirical performance:

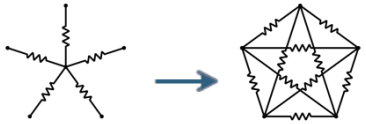


SPatch

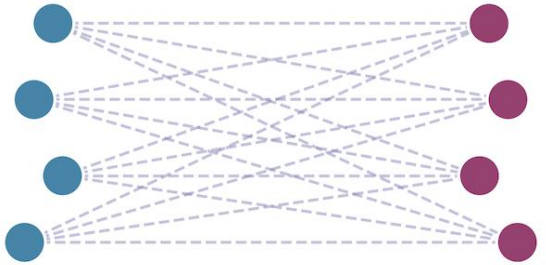
1. Delete node



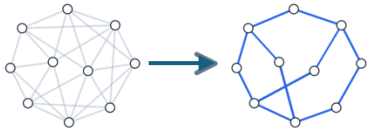
2. Star-mesh transform



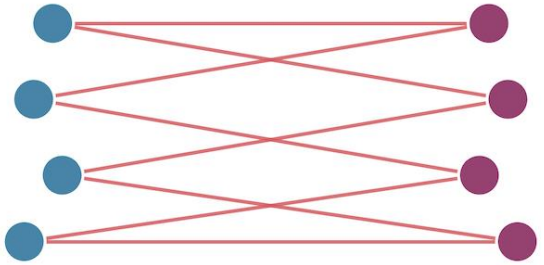
- ➢ Restores random walk connectivity
- ➢ Makes neighborhood too dense



3. Spectral sparsification



- ➢ Approximately preserves restored connectivity
- ➢ Keeps neighborhood sparse



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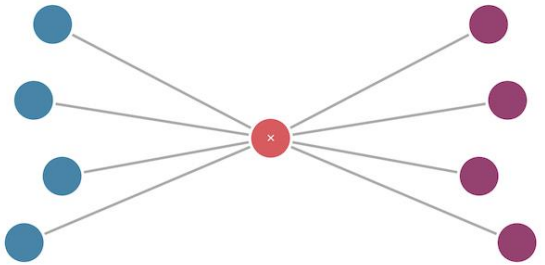
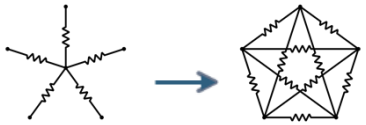


Spectral graph theory

2. Star-mesh transform



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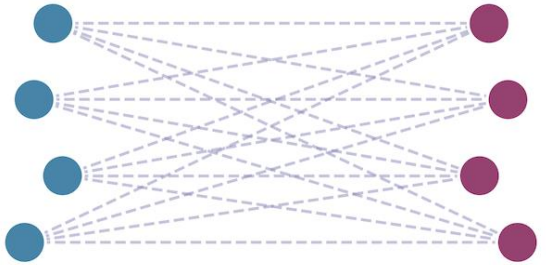

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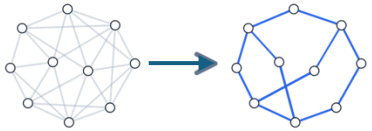

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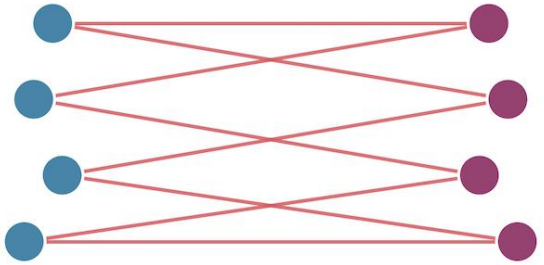
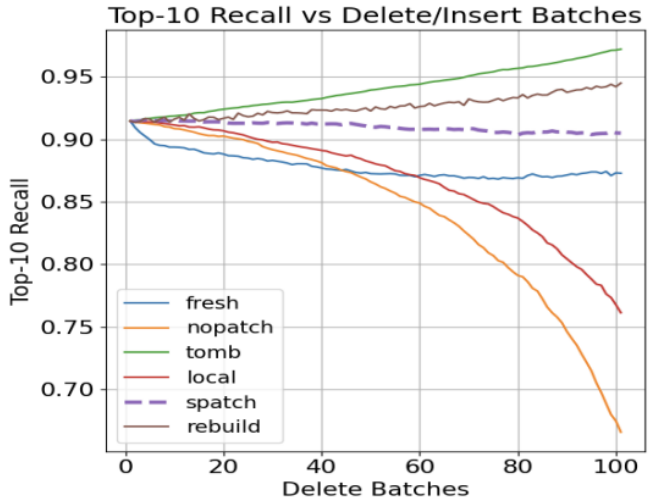
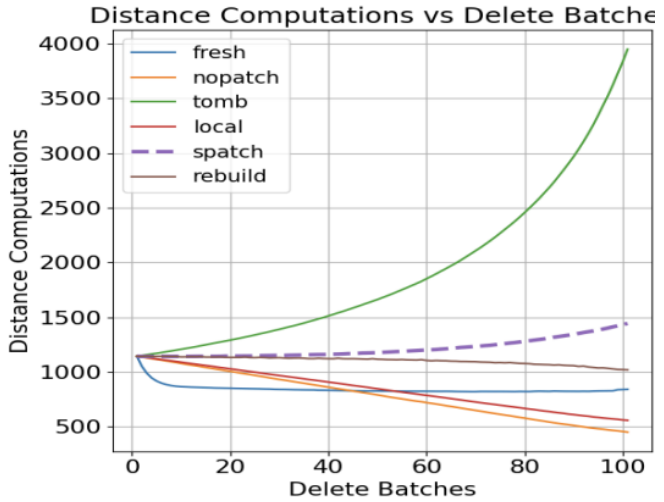


Experiments

Method	Recall	Speed	Del Time	Space
Tombstone	✓	×	✓	×
No patch	×	✓	✓	✓
Local	×	✓	✓	✓
FreshDiskANN	✓	✓	×	✓
Global	✓	✓	×	✓
SPatch (ours)	✓	✓	✓	✓

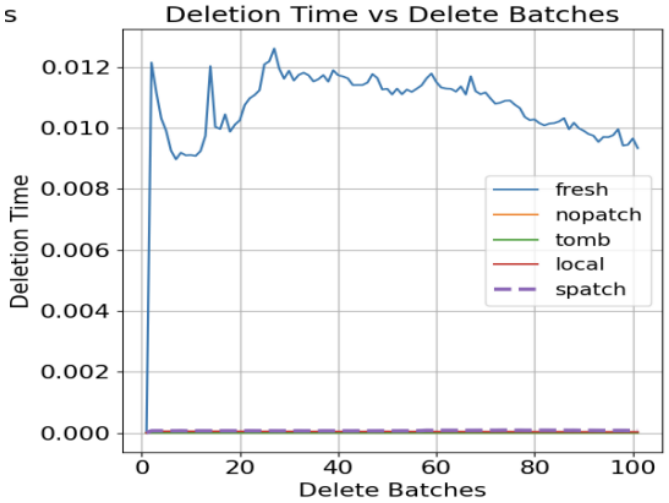
Accuracy

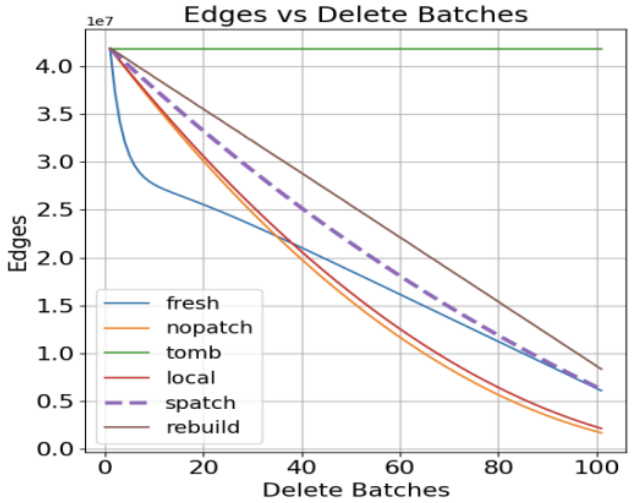




Query time

Deletion time





Memory usage

Conclusion

- **SPatch** is a new deletion algorithm for graph-based nearest neighbor search indices like HNSW
  - Mathematically grounded in spectral graph theory
  - Based on a “softmax walk” formulation
  - Efficient and accurate empirically

- **Thank you**