Efficient Dynamic Replanning For Risk Aware Graph Search

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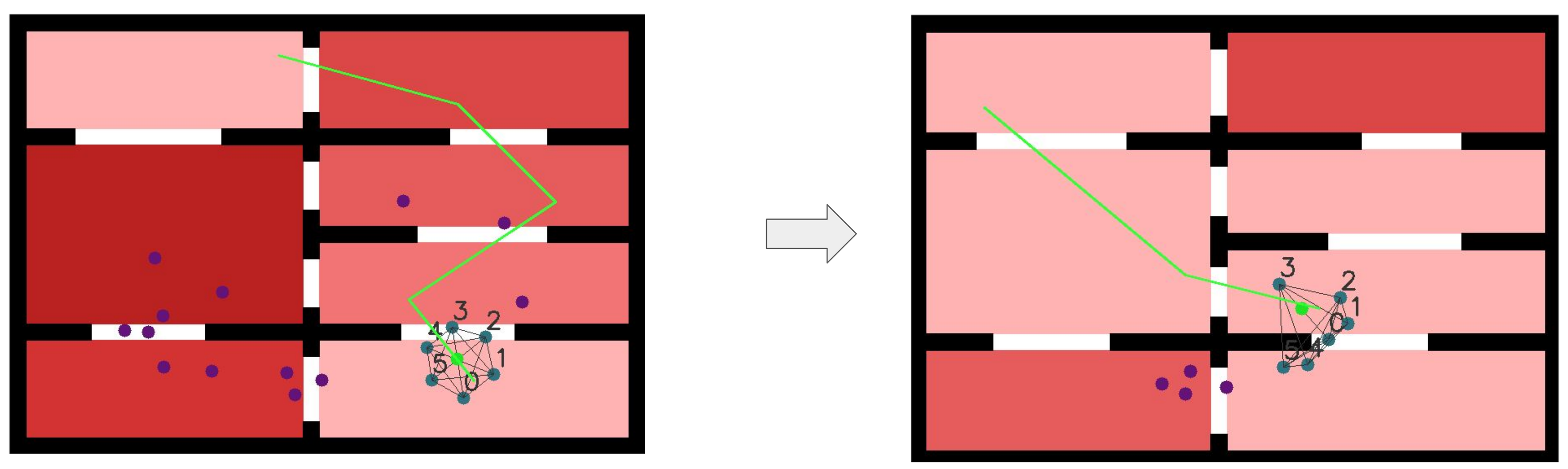
Motivation: Non Combatant Evacuation

- Robots are used for rescue missions which involve finding the safest path out of the environment.
- The environment here is **dynamic and uncertain.**
- The robots - numbered, escort the human along a path to the goal. Mobile adversaries are shown in purple. As adversaries are eliminated, the risk in the environment changes and the agents want to update the rescue path.



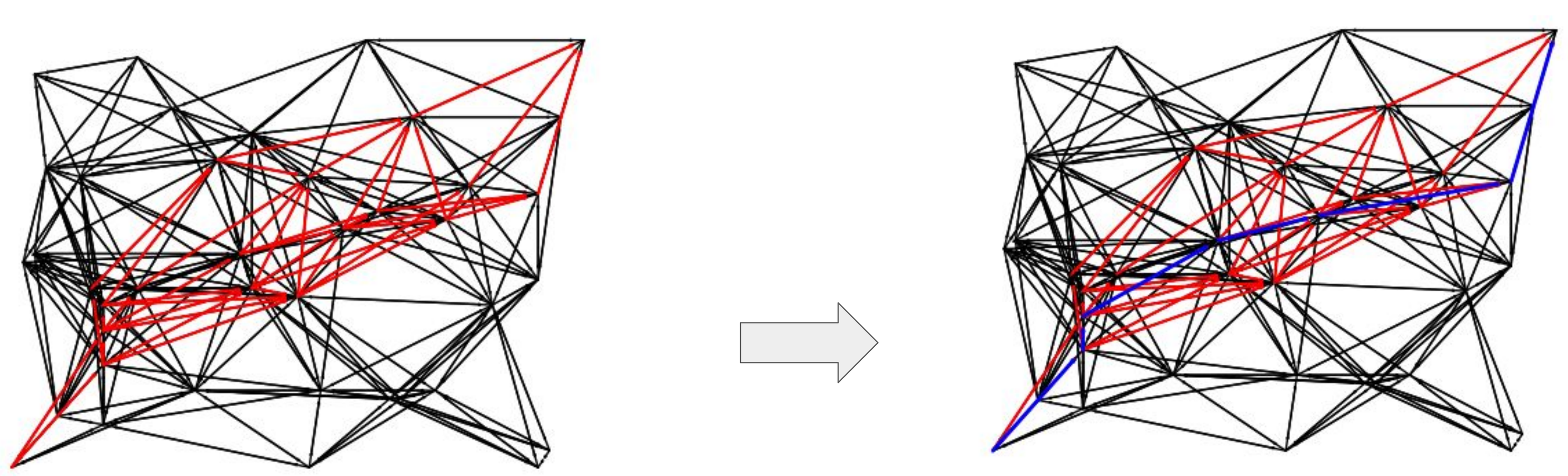
The **safest path** to the goal **changes** with changes in the environment

Risk Aware Search in an Uncertain Environment: RAGS

- **Uncertain environment:** The algorithm **RAGS** [1] (Risk aware graph search) finds low cost paths through a graph.
- **Edge costs are normal distributions**. The cost of traversing an edge is only revealed when the edge is reached.
- The RAGS algorithm works by computing a set of **Non Dominated paths:** candidate paths likeliest to yield the lowest travel cost. Path A dominates B if

$$A > B \Leftrightarrow \mu_A < \mu_B + \sqrt{2(\sigma_B^2 + \sigma_A^2)}\ \mathrm{erf}^{-1}(1 - 2d_{\mathrm{thresh}})$$

- It selects the final path by including the dynamically revealed edge costs.



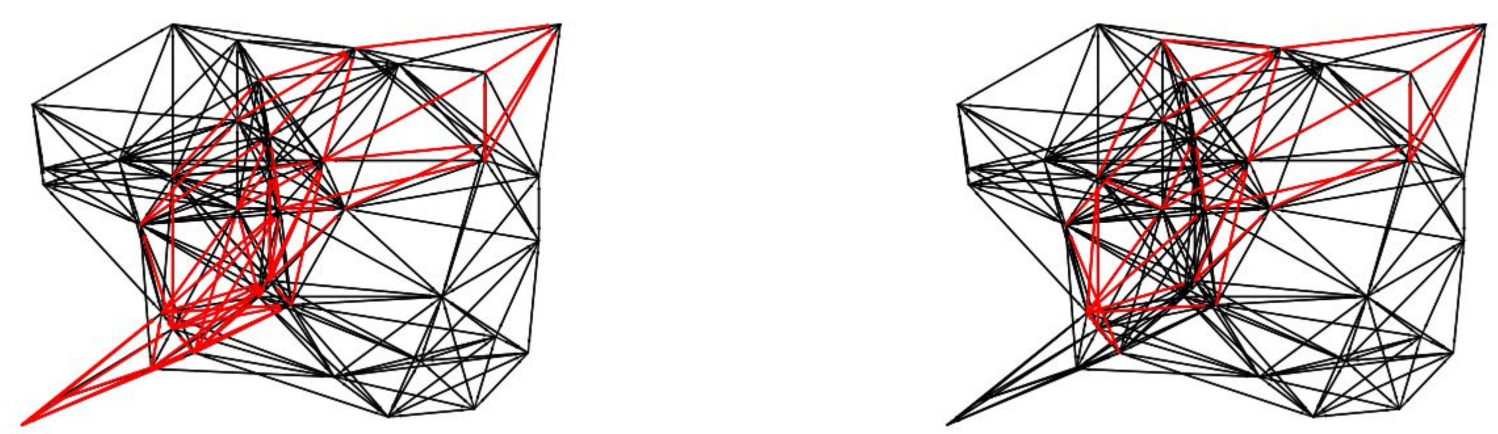
The best candidate paths **i.e non dominated paths** are shown in **red** and the path taken is shown in **blue.**

- If the expected cost of an edge is updated, **recomputing** this candidate path set during replanning would be **too expensive.**

Dynamic Replanning in a Dynamic Environment: d-RAGS

Due to similarities with A*[2], replanning with RAGS can be improved following memoization techniques **similar to D*-lite**[3].

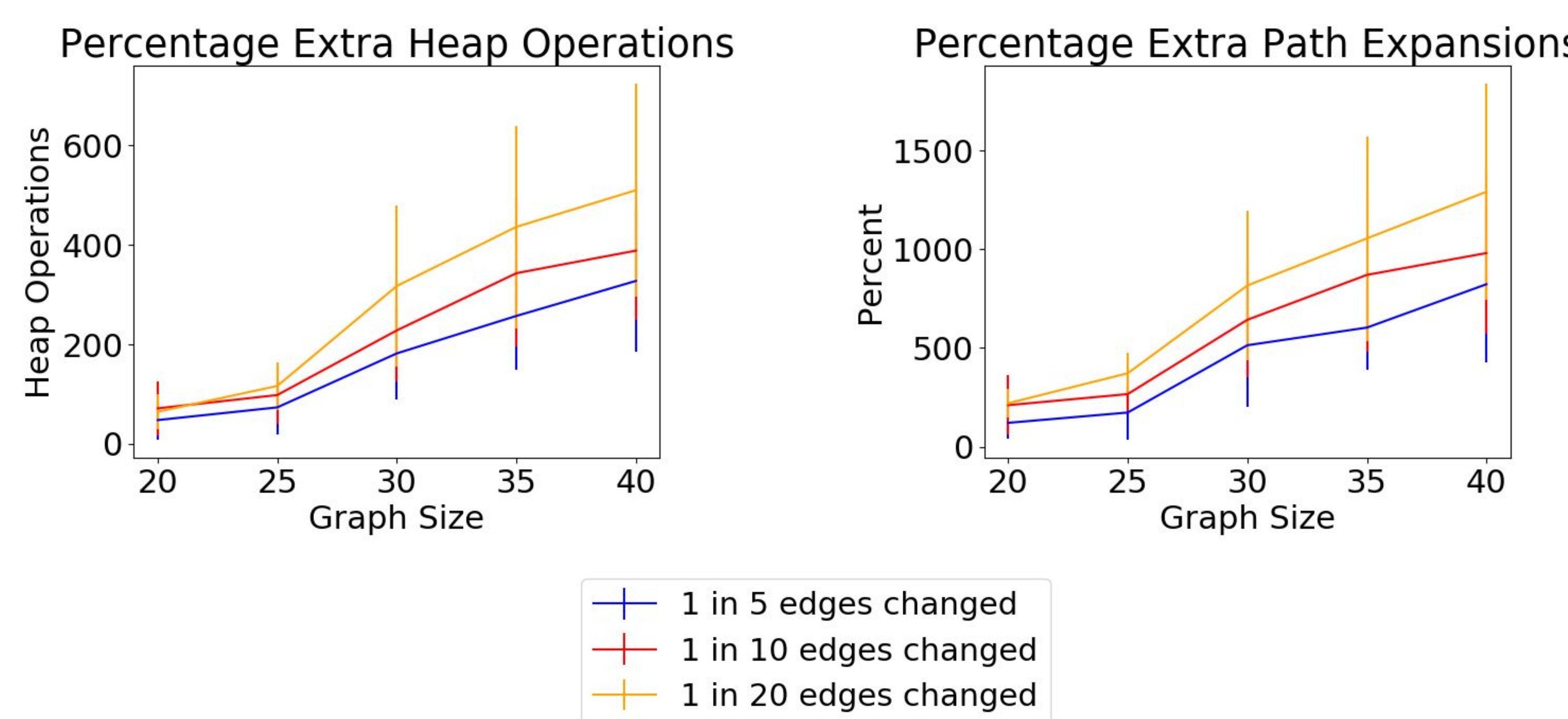
Optimizations to RAGS for dynamic RAGS **(d-RAGS)** include:
- **More frequent non dominance checks**: Paths are checked for non dominance property before expansion (as well as before heap insertion).
- **Updation of candidate set** and **backwards search**: By searching backwards, the root of the path sets remains the same and the information can be updated **rather than recomputed.**



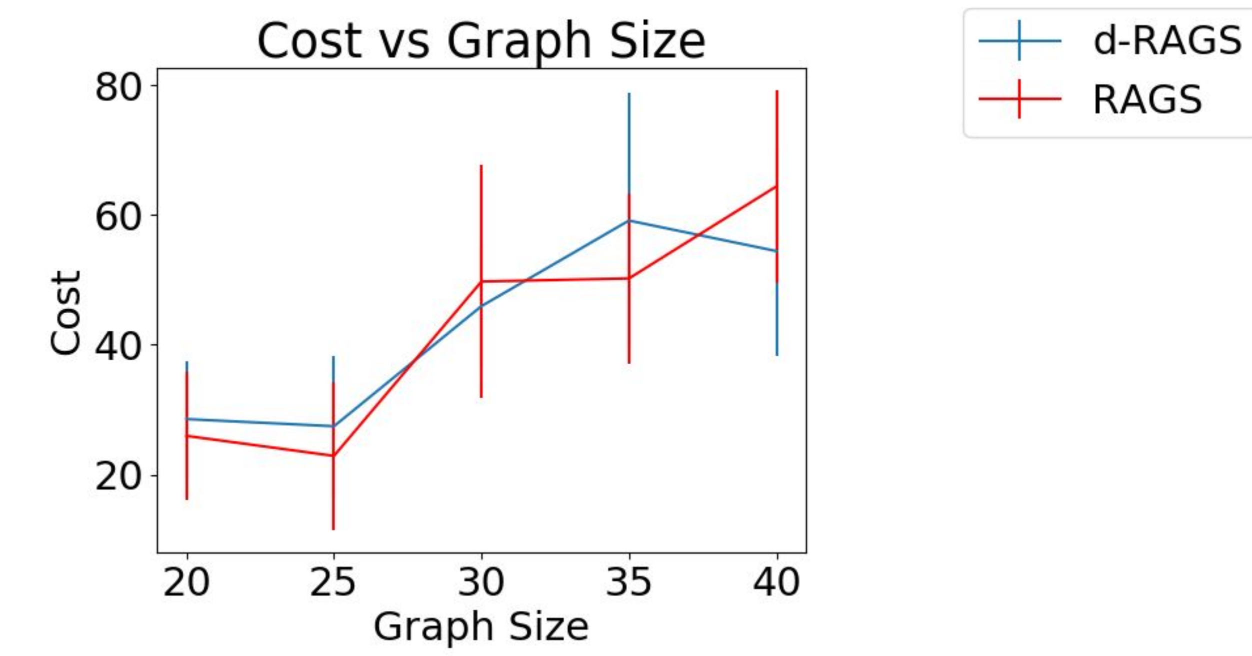
Much of the **candidate set remains similar between replans**. Planning backwards takes advantage of this for updates.

Performance: Comparing d-RAGS and RAGS

- Graphs were generated with a range of sizes (number of nodes) and varying number of edges that would change upon inspection (i.e a 2 step lookahead).
- For each edge variance = U(1, 10)
  edge mean = distance_between(nodes) + U(0,10)
- Performance is measured by **observing percentage of extra algorithm operations in RAGS over d-RAGS.**
- **Path expansion** - a subpath is evaluated as non dominated and paths one edge longer are added to the heap.
- **Heap operations** - subpaths are added or removed from the heap.



Both operations are drastically lower in d-RAGS.



The **costs** of paths produced by each algorithm are **similar.**

Conclusions

- d-RAGS is able to find a low cost path with fewer operations in this case of 2 step lookahead for edge updates.
- The benefit becomes more pronounced as the graph size increases.
- The majority of the speedup comes from the more frequent non dominance checks.

Future Work

- Formally prove the correctness of this approach.
- Further optimize so performance gains are seen in the **case of edge updates from anywhere in the graph** to include updates seen by all robots in a multi-agent scenario.
- Include information theoretic concepts in the edge weight and updation to adapt algorithm for planning paths for information gain.

Acknowledgements

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References

[1] - Chung, J. J., Smith, A. J., Skeele, R., & Hollinger, G. A. (2019). The International Journal of Robotics Research, 38(2–3), 182–195.
[2] - Nilsson,N.1971.Problem-Solving Methods in Artificial Intelligence. McGraw-Hill
[3] - Koenig, S., & Likhachev, M.2002a.D*Lite. In Proceed-ings of the National Conference on Artificial Intelli-genceAAAI