Going Beyond the Frontier in Autonomous Exploration

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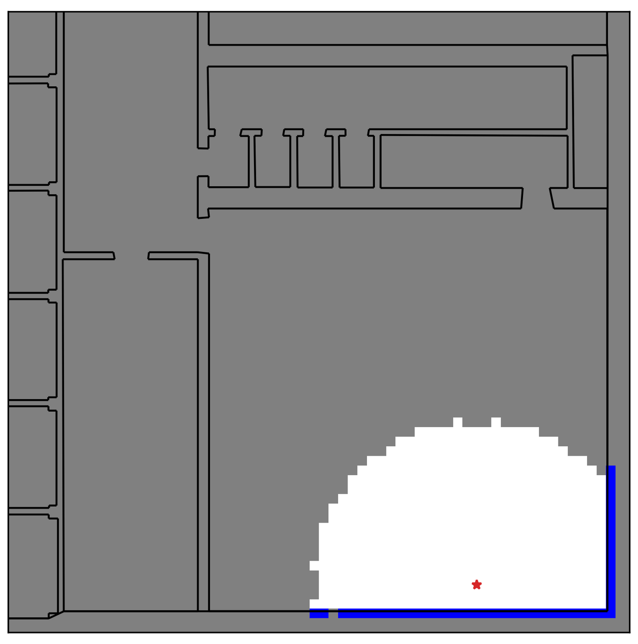
Problem Statement



There are many situations in robotics where a robot has to explore an unknown environment, e.g., in order to perform mapping, or in a search & rescue mission.

$$\min_{\text{path}} \quad \text{length}(\text{path})$$
$$\text{s.t.} \quad \text{see}(\text{whole environment})$$

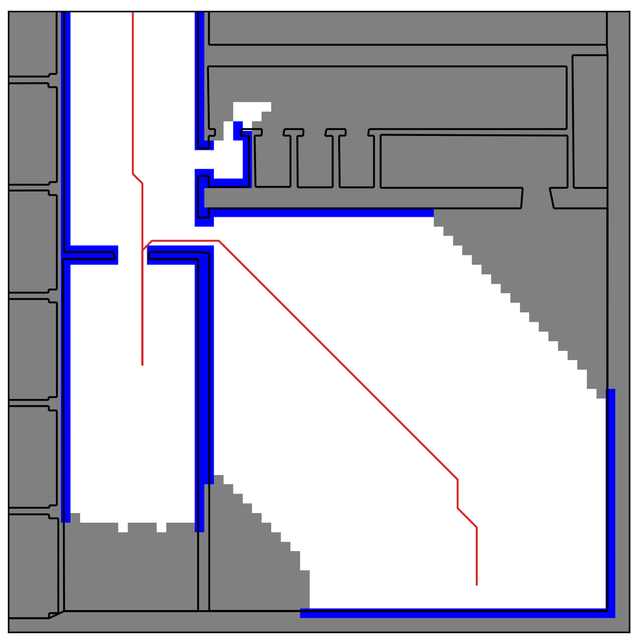
However, this is **computationally hard** and requires a **model**, since the environment is unknown.

Existing Methods & Limitations

Autonomous exploration methods are based on two fundamental ideas: **frontiers** and **information gain**.

$$\max_{f \in \text{frontiers}} \widehat{\text{novel}}(f) - \lambda \text{distance}(x_t, f)$$

However, this formulation leads to greedy behaviour, causing **back-tracking** and long paths. Furthermore, the methods get **worse with better predictive models**.

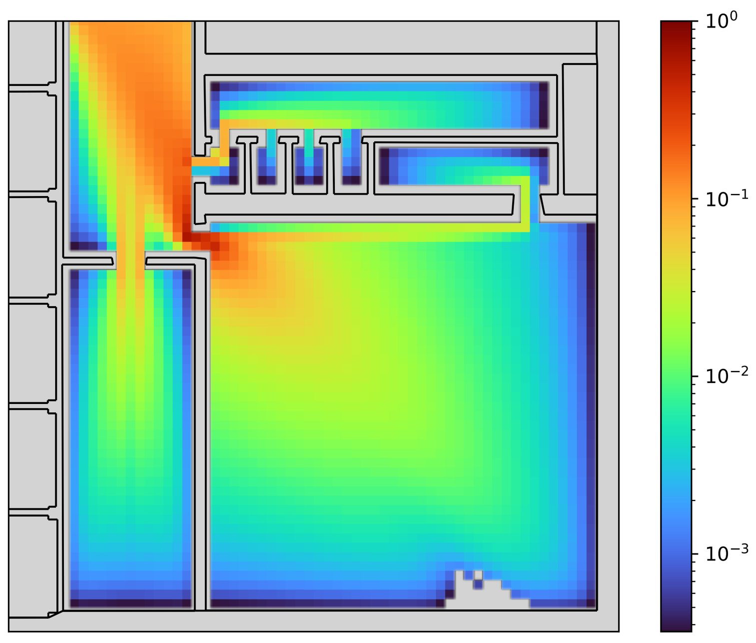


Approach

To minimize back-tracking, we want to determine what is **unlikely to be seen** and explicitly plan to see it.

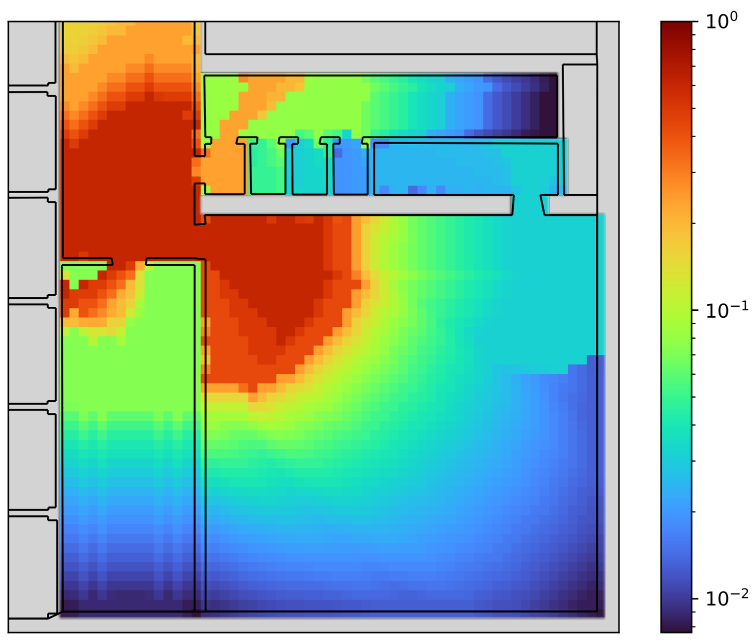
1. Estimate probability of visiting a cell using Brandes' algorithm for betweenness centrality.

$$\hat{p}(\text{visiting } v) \propto \sum_{\substack{\text{all shortest} \\ \text{paths}}} \hat{p}(\text{visiting } v | \text{take path})$$



2. Estimate probability of seeing a cell using sensor model and probability of visiting cells.

$$\hat{p}(\text{seeing } u) \approx \sum_{\substack{\text{cells } v \\ \text{that see } u}} 1 - \hat{p}(\text{visiting } v)$$



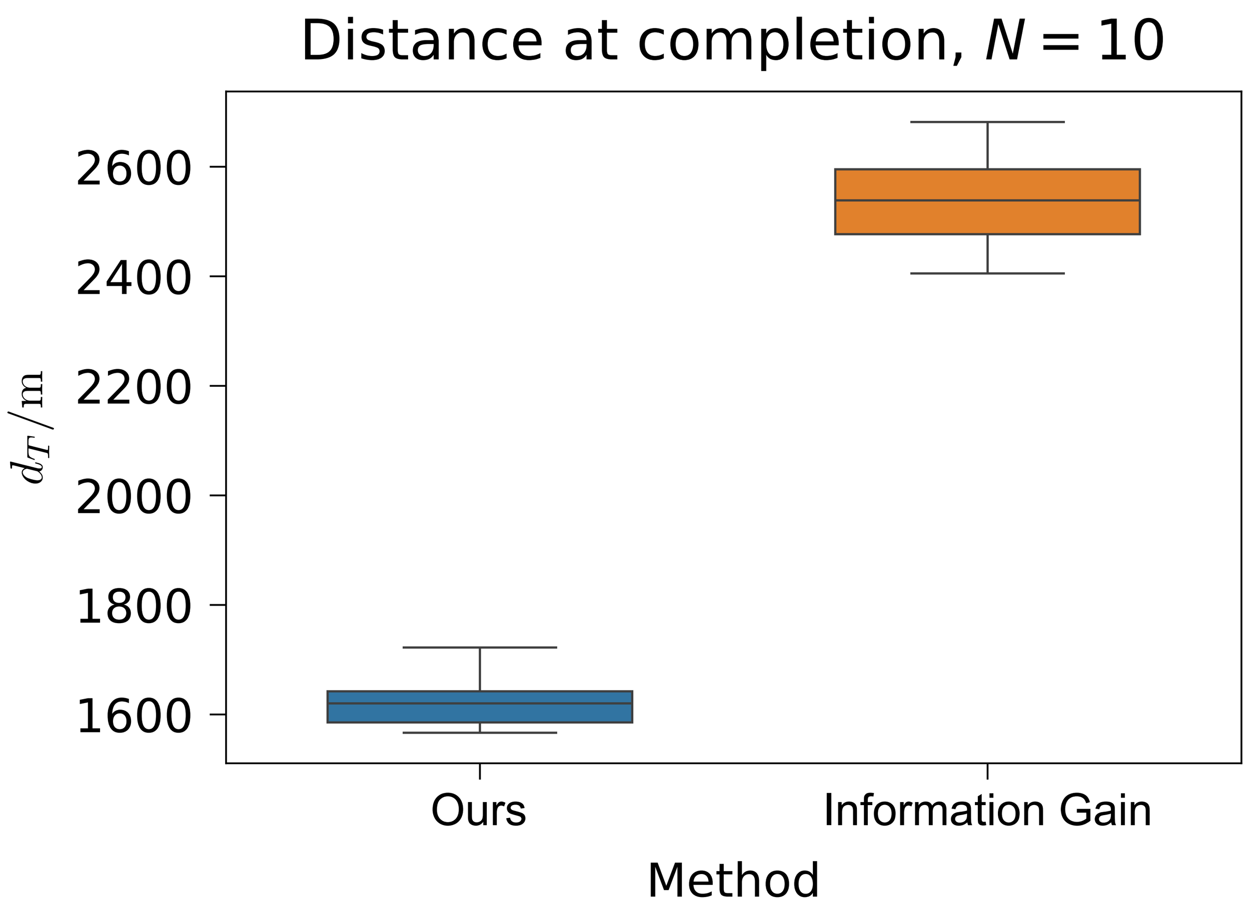
3. Plan to see hard to see cells.

$$\max_{f \in \text{frontiers}} \text{cost}(\hat{p}(\text{not seeing cell}), f) - \lambda \text{distance}(x_t, f)$$

Results

In a simulation environment, our approach leads to **~40% shorter paths**.

This improvement holds across starting locations.



References

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