

Frontier Assignment for Multi-Agent Exploration Under Communication Constraints

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Multi-Robot Exploration

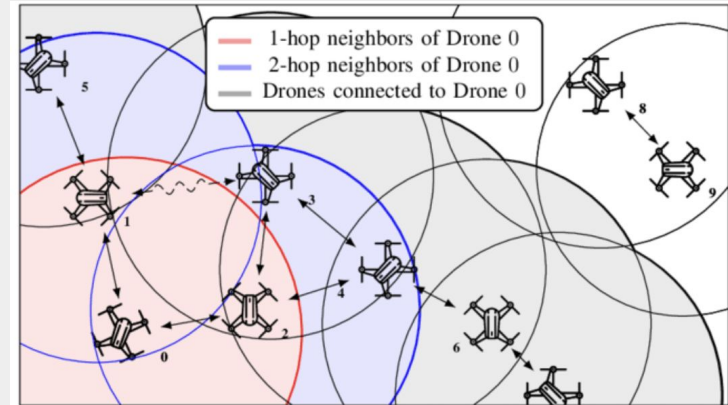
- Extension of the foundational problem of robotic exploration
- Applications to: Search & Rescue, Planetary Exploration, Military
- Many Significant Challenges
 - Collision avoidance, redundancy, communication

Coordination for Multi-Robot Exploration

- Efficient exploration requires coordinated efforts among multiple robots.
- Preventing redundancy and ensuring full coverage of the environment.
- Different levels of coordination—full planning, none, event-based

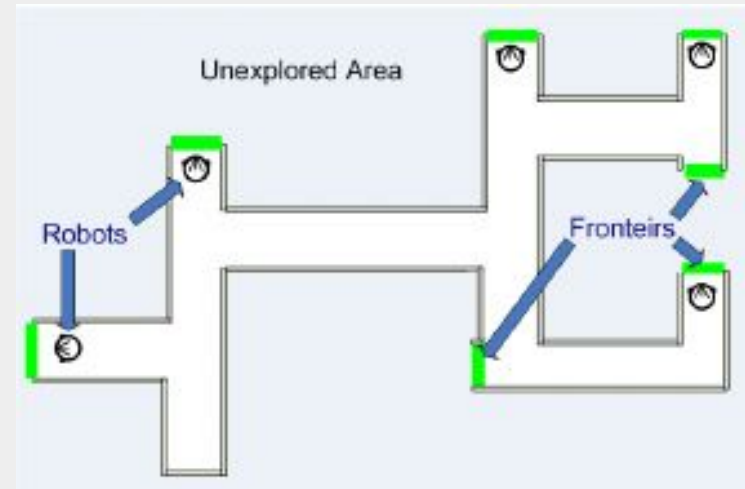
Connectivity Challenges

- Exploration often implies lack of centralized infrastructure e.g. cell network
- Need to design algorithms that intentionally maintain connectivity throughout exploration
- Challenges with planning, and maintaining links while robots act individually



Frontier-Based Exploration

- Designate “frontier” points between explored and unexplored areas
- Challenging to optimally assign robots to different frontiers
- Other approaches apply potential fields or other centralized constraints to drive robots apart



Problem Formulation - Assumptions

- Perfect sensing and localization.
- Circular communication model.
- No communication bandwidth constraints.

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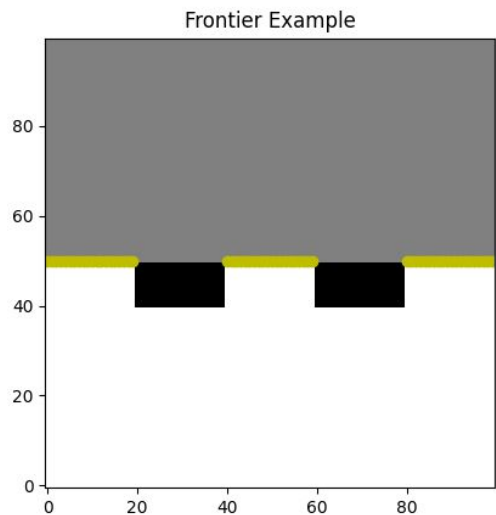
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How to Optimally Assign Frontiers?

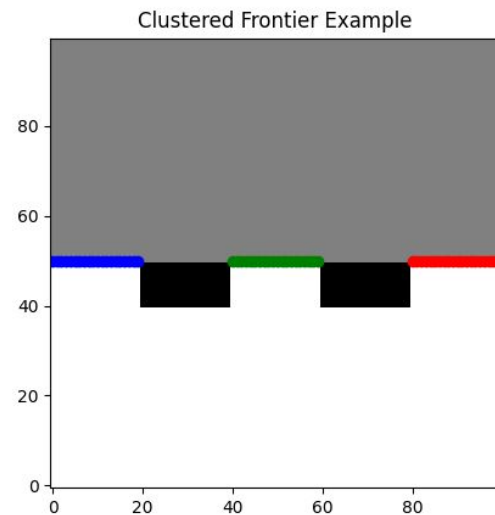
- Greedy approach – doesn't consider connectivity
- Need some kind of centralized controller to ensure global connectivity is maintained
- Could even apply local connectivity constraints, which when maintained would ensure global connectivity
- Many approaches enforce a fixed graph structure

Frontier Clustering

- Group frontier points together by proximity
- Will be used to simplify the optimization problem
- I used DBSCAN



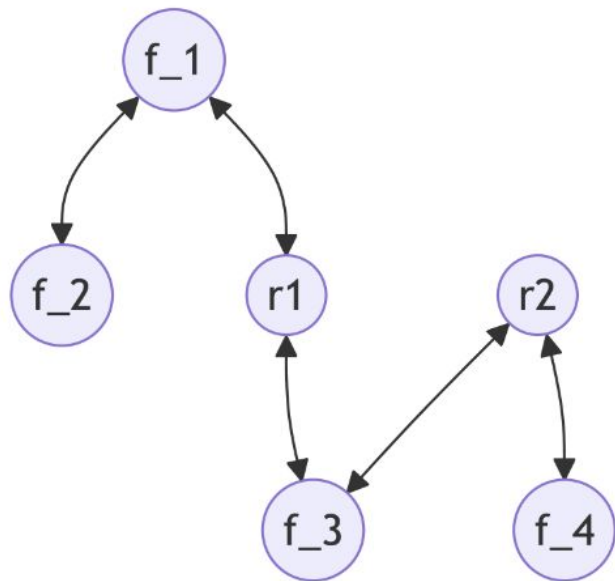
Example of Frontier Cells



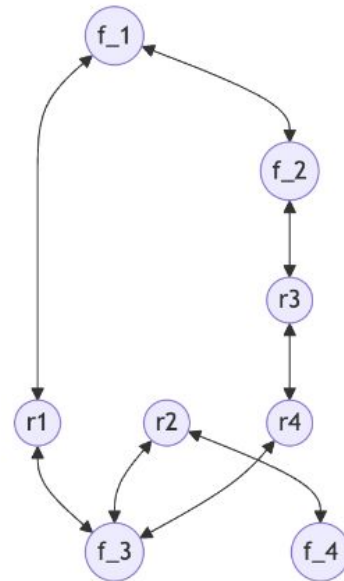
Frontier Cells Clustered
using DBSCAN

Graphical Frontier Assignment

- Introduce graph-based construction to find an optimal assignment that maintains connectivity
- Concept of “frontier” nodes and “route” nodes
- Construct based on communication radius and euclidean distance between frontier nodes



Example Graphical
Construction



2-Hop Graphical
Construction

Algorithmic Design

- For each agent, compute the cost of traversing to every node of the graph (Dijkstra)
- Now perform search of configuration space using branch-bound approach

Branch-Bound Approach

- Upper Limit – Maximum Information Gain w/No-Cost Assignment
- Explore all possible assignments, pruning branches which do not beat current optimal solution
- Seed algorithm with assignment of every agent to every frontier – maximize utility (cost of assignment - potential gain)

Simulation Results

- Algorithm proved too computationally intensive
- Need to do further work to improve upper bound
 - Current mode was far too generous, and led to the algorithm attempting to search almost the entire state space
- Unfortunately, due to the time it took me to develop this algorithm (see paper for many, many side adventures) I did not have time to reimplement

Conclusions

- Challenges with branch-bound algorithm
 - Further work required to improve minimum upper bound
- Graph based algorithm significantly reduces the dimensionality of the state space
 - I believe a tractable algorithm is possible but still need to do more work