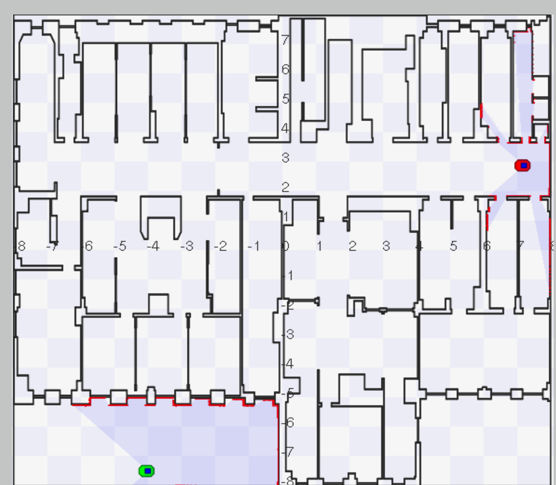
Combining Multi-Robot Exploration and Rendezvous

Malika Meghjani and Gregory Dudek
Centre for Intelligent Machines, McGill University, Montreal, Canada

Introduction

- **Motivation**: When two or more robots work together, they may need to meet or *rendezvous* first. We consider the case of robots that have been deployed in an unknown environment and are unable to communicate unless they are co-located.
- **Problem definition**: A pair of point robots must find one another to speed-up the exploration task in an unknown, GPS-denied, planar environment, where communication is only possible when robots are in the same place.
- **Challenges**: The robots need to meet while exploring and mapping, along with least dependency on communication.



A rendezvous simulation in Player/Stage [1]

Proposed Approach

- In order to combine exploration and rendezvous, we propose different ranking criteria and rendezvous strategies.
- Our ranking criteria is based on a *cost-reward* model which considers the distinctiveness and the accessibility of the potential rendezvous locations. This combination accounts for both the rendezvous and the exploration tasks which together reduces the total exploration time.
- The proposed ranking criteria includes:
  - area-based ranking:

$$\mathbf{rank}(\mathbf{p_i}) = \mathbf{area}(\mathbf{p_i}) \quad (1)$$

  - linear distance-based ranking:

$$\mathbf{rank}(\mathbf{p_i}) = \frac{\mathbf{area}(\mathbf{p_i})}{\mathbf{distance}(\mathbf{p_i})} \quad (2)$$

  - sigmoid distance-based ranking:

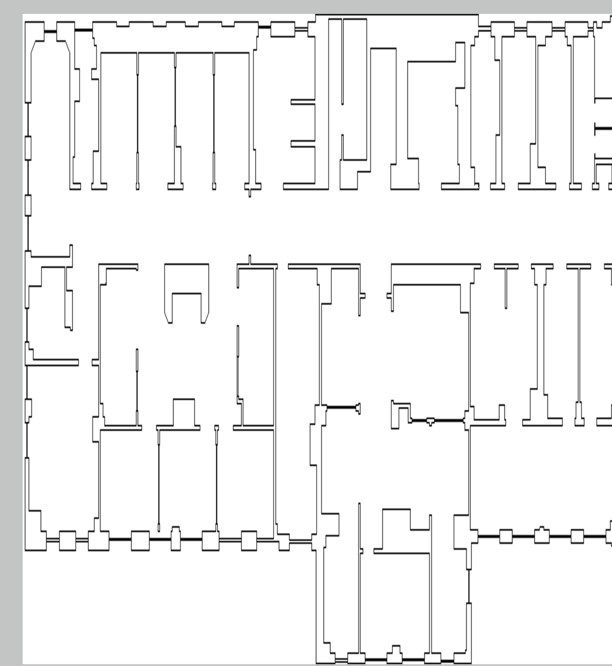
$$\mathbf{rank}(\mathbf{p_i}) = \frac{\mathbf{area}(\mathbf{p_i})}{\mathbf{sigmoid}(\mathbf{p_i})} \quad (3)$$

- The rendezvous strategies which we implemented are: asymmetric sequential, symmetric sequential [2] and exponential.
- The first two strategies are deterministic in nature and their names represent the pre-defined roles of the robots during the rendezvous period.The third strategy is probabilistic in nature and it assigns an exponential probability density function for visiting the ranked rendezvous locations.
- In order to discover the potential rendezvous locations, each robot is required to individually explore and map the environment.

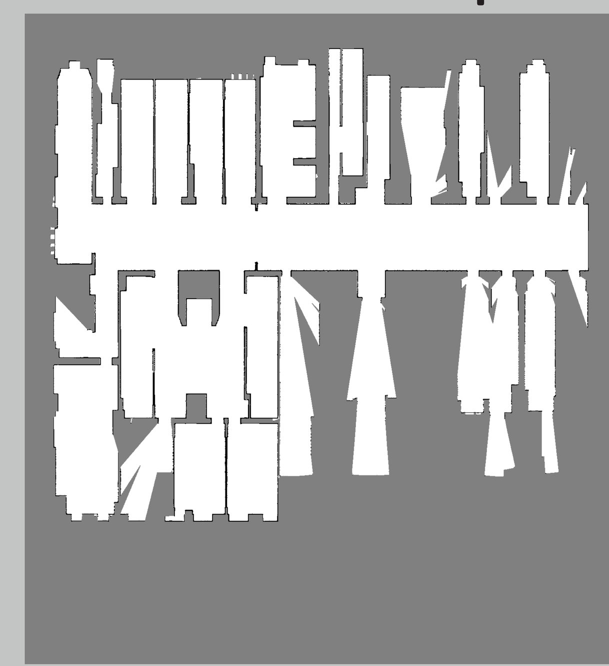
Mapping

- Individual maps of the environment are maintained by each robot using the grid-based approach as shown below.

Floor Plan

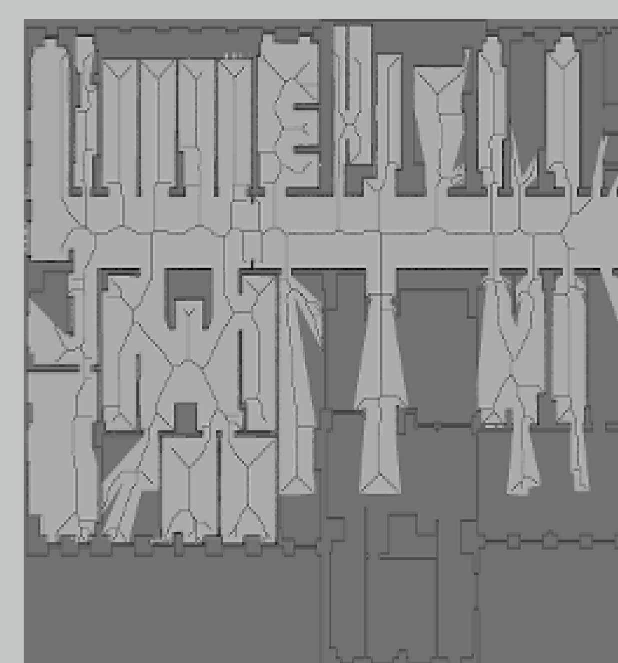


Generated Map



Exploration

- The grid-based map is transformed into a skeleton structure of the free-space.
- The skeleton structure is stored as an undirected graph for exploration.
- This graph is explored by traversing the nodes in depth-first order and using **A*** search algorithm for path-planning.



The skeleton structure overlaid on the grid-based map

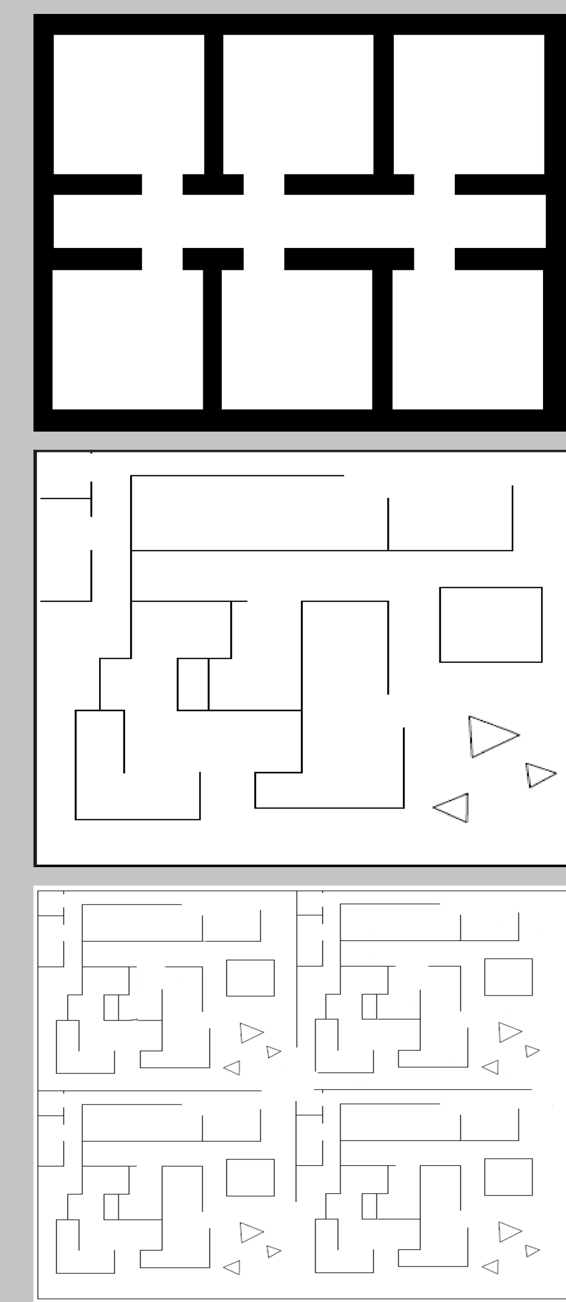
Rendezvous

- The rendezvous process is characterized by a sequence of attempts $\mathbf{r_i}$ of the robots $\mathbf{R} \in \{1, 2\}$ to meet with one another at specific times $\mathbf{t(r_i)}$.
- The rendezvous process for two robots is defined below which can easily be scaled for multiple robots.
  - At the *rendezvous time* $\mathbf{t(r_i)}$ the robots attempt to meet.
  - Each robot $\mathbf{R}$ selects a location $\mathbf{p^R}$ to visit on this attempt, thus defining a sequence of attempted rendezvous locations $\mathbf{p_i^R}$.
  - Each robot travels to its appointed location $\mathbf{p_i^R}$ and, if $\mathbf{p_i^1} = \mathbf{p_i^2}$ (they are in the same place) it finds the other robot there and the rendezvous process is completed.
  - In the event of a failed rendezvous, the robots continue their background activity until the next rendezvous time.

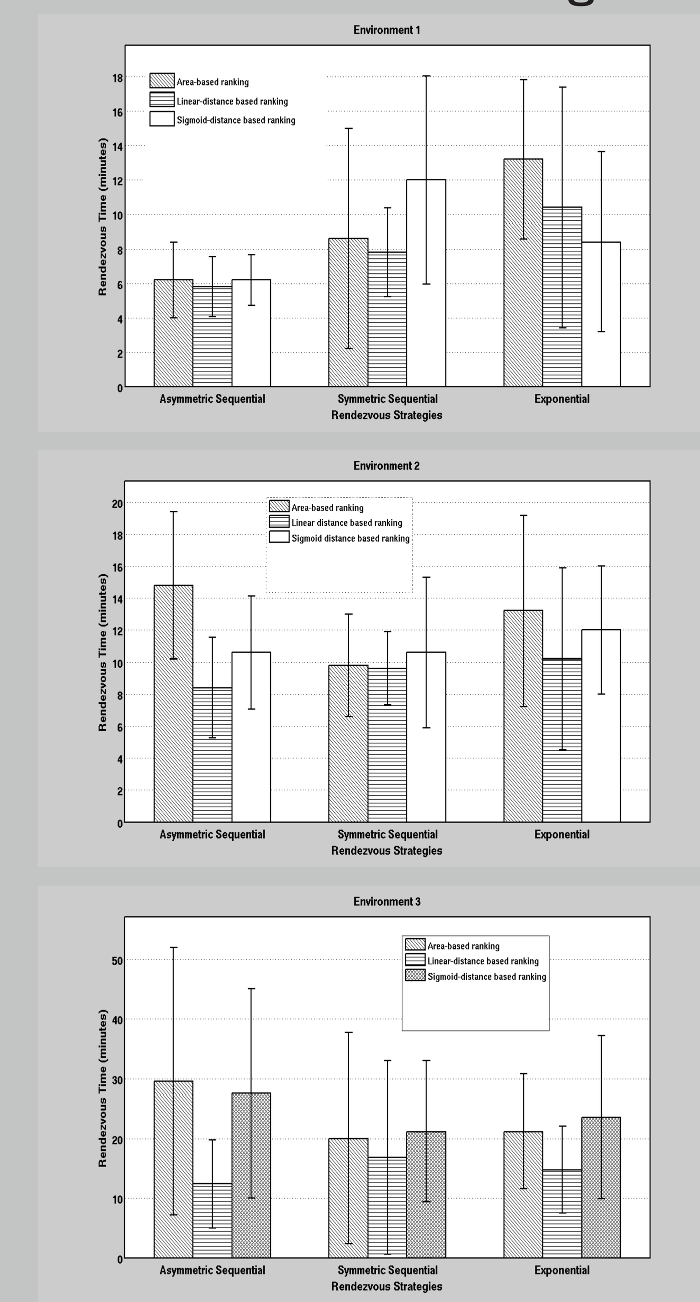
Experimental Results

- We validate our approach in three different simulated environments using nine algorithmic variations produced by pairwise combining each of the rendezvous strategies with the ranking criteria.
- The simulation results reported are based on an average of 10 trials in each environment for all the algorithmic variants.

Floor Plans



Rendezvous Timing



- The results suggest that the proposed linear distance-based ranking criteria consistently performed better than area and sigmoid distance-based ranking with respect to the total rendezvous time.
- The results for the rendezvous strategy reflect that the symmetric strategy was convenient for environment 2 and 3 whereas the asymmetric strategy did better in environment 1.

Conclusion

- The use of distance-based ranking criteria can be effective in selecting locations of potential rendezvous.
- The conclusion is to take into account the accessibility of a rendezvous point while selecting where to go such that attempts to rendezvous can be interleaved with other activities including exploration.

References

- B.P.Gerkey, R.T.Vaughan and A. Howard. The Player/Stage project: tools for multi-robot and distributed sensor systems. *11th International Conference on Advanced Robotics 2003.*
- N.Roy and G.Dudek. Collaborative exploration and rendezvous: algorithms, performance bounds and observations. *Autonomous Robots 2001.*

{malika,dudek}@cim.mcgill.ca