# Autonomous Multi-Robot Exploration & Coverage

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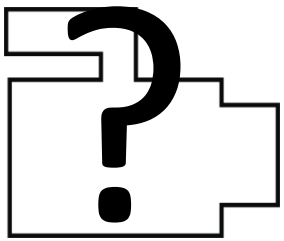
# Outline

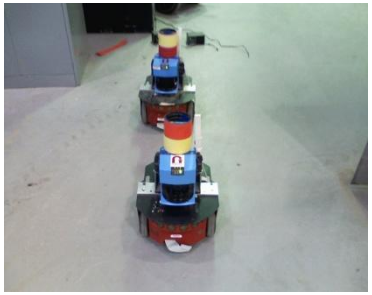
- Introduction
- Exploration
- Coverage
- Conclusion & Future Work

# The Treasure Hunt Domain

- Groups of robots cooperate to search for treasure in an unknown environment

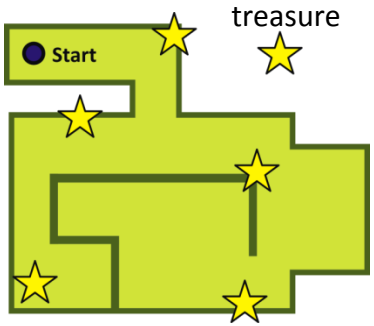


**Unknown environment**



**Robots explore and map the environment**

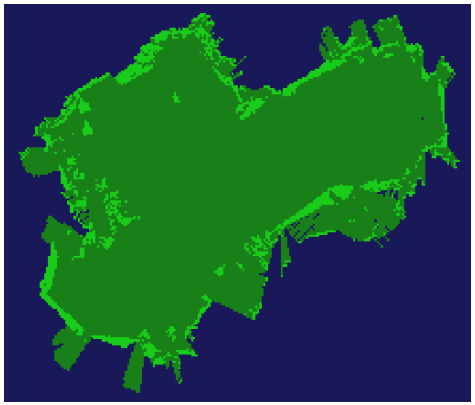
**Robot teams cover the environment in search for treasure**




**Environment is explored and treasures are retrieved**

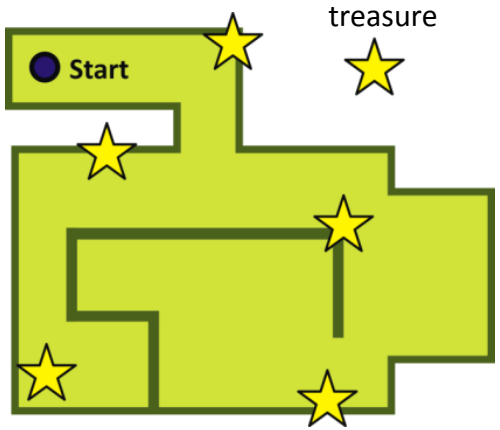
# What is exploration?

- How robots map an unknown territory in order to determine the conditions and characteristics of the environment.



# What is coverage?

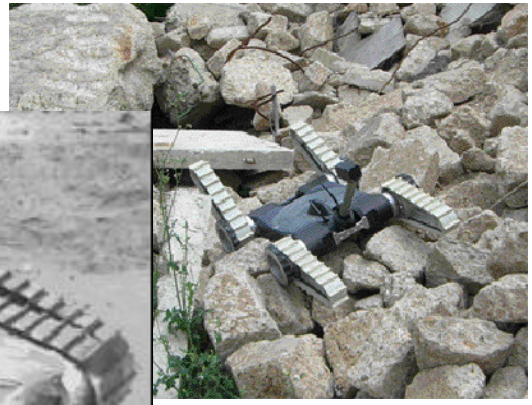
- Given a mapped environment, how robots traverse the environment in search of items of interest



# Applications

- Disaster recovery
- Battlefield surveillance and reconnaissance
- Industrial & residential maintenance
- Any environment not particularly suitable for humans





# Why Multi-Robot?

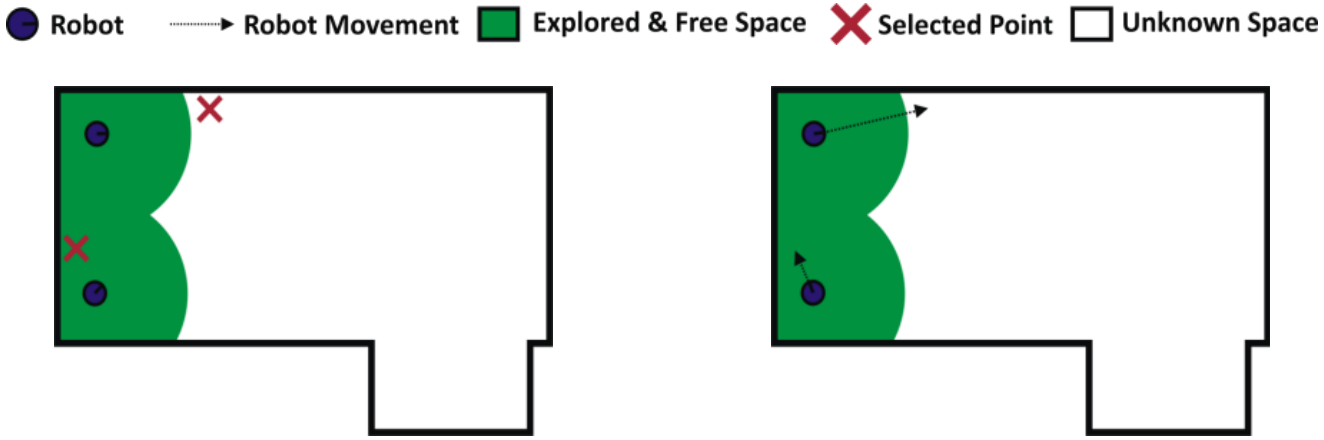
- Advantages
  - Potentially takes a shorter amount of time
  - Avoids having a single point of error
- Disadvantages
  - Requires more coordination between robots
  - Requires maintaining many robots

# Exploration: Methods of Exploration

- Random
- Frontier
- Human Directed

# Random

- Explore random points that are within 10*m* of each robot.
- Base metric for the performance of any exploration algorithm.
- Smarter version of the algorithm only picks points in unexplored area.

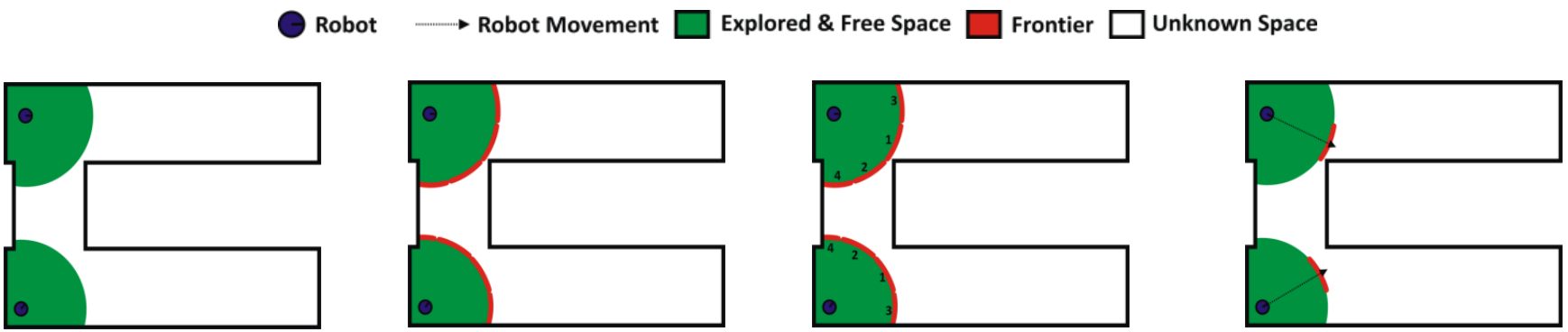



Robots each choose a random point

Robots go explore their selected point

# Frontier

- Explore the areas where known space ends and unknown space begins.
- Prioritize the different frontiers depending on their size, distance from robots, proximity to obstacles, and distance from other frontiers




Robots explore the immediate area

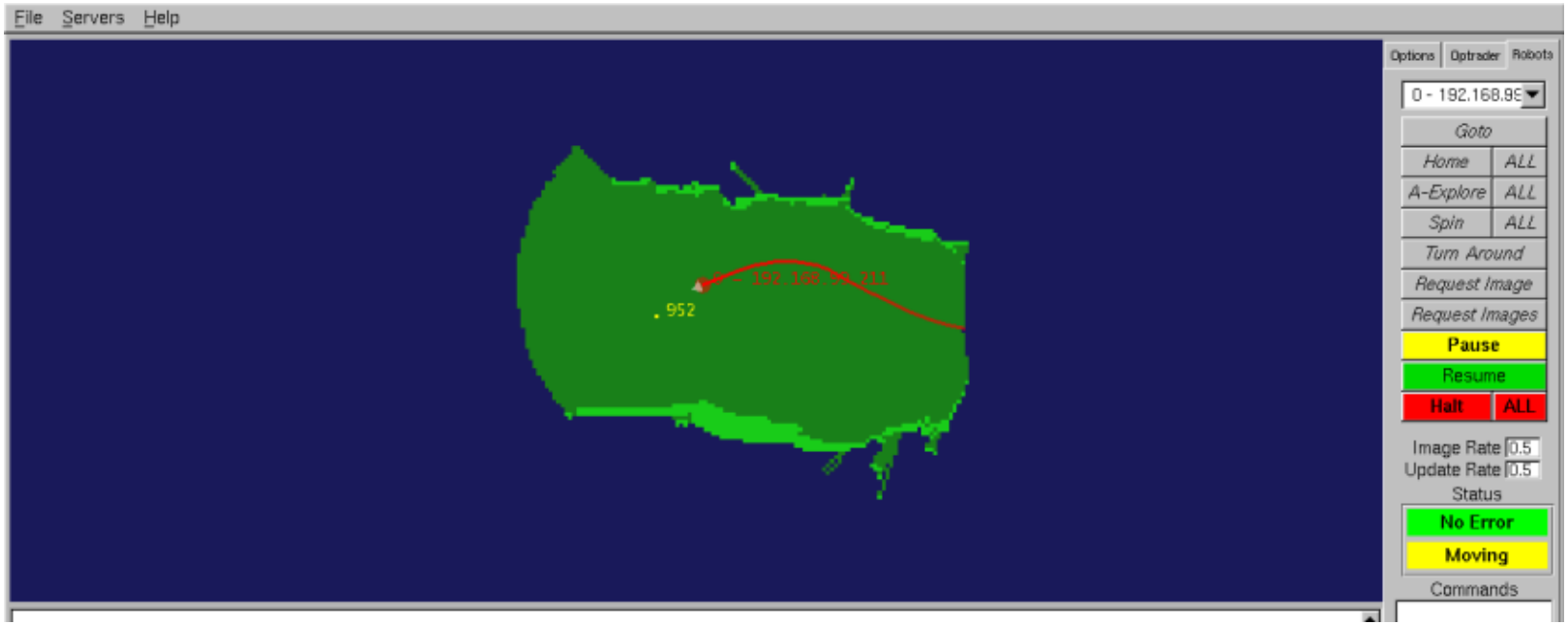
Frontiers are created and grouped

Frontiers are sorted according to their weights

Robots pick desired frontiers and explore them

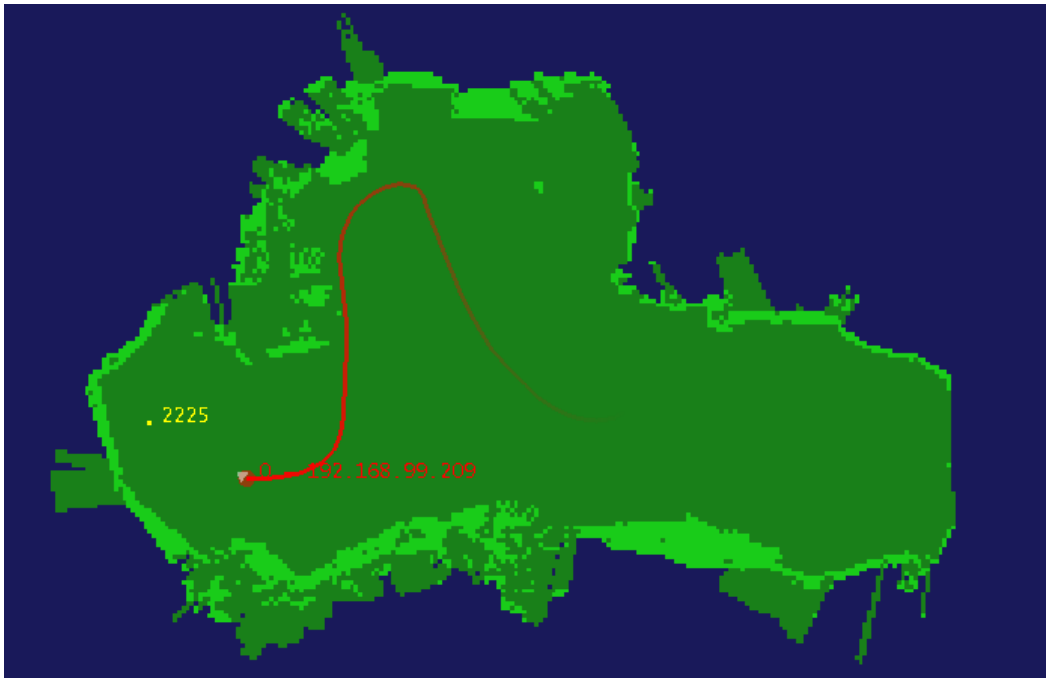
# Human Directed

- A graphical user interface enables humans to direct robots to explore the unknown environment
- An incrementally built map of the explored space was displayed to the users.



# Experiments

- A series of experiments were conducted using 1, 2, and 3 robots.
- Each method was used twice times for each of the number of robots, results were averaged.
- Explored the Robotics Institute High Bay

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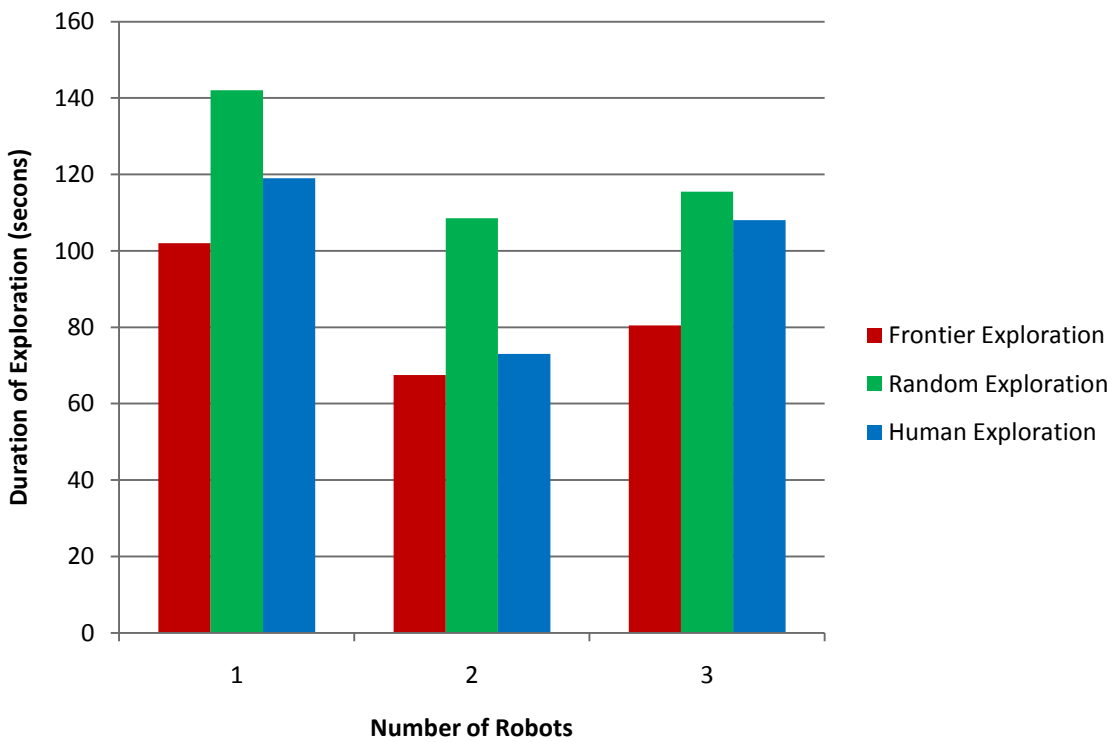
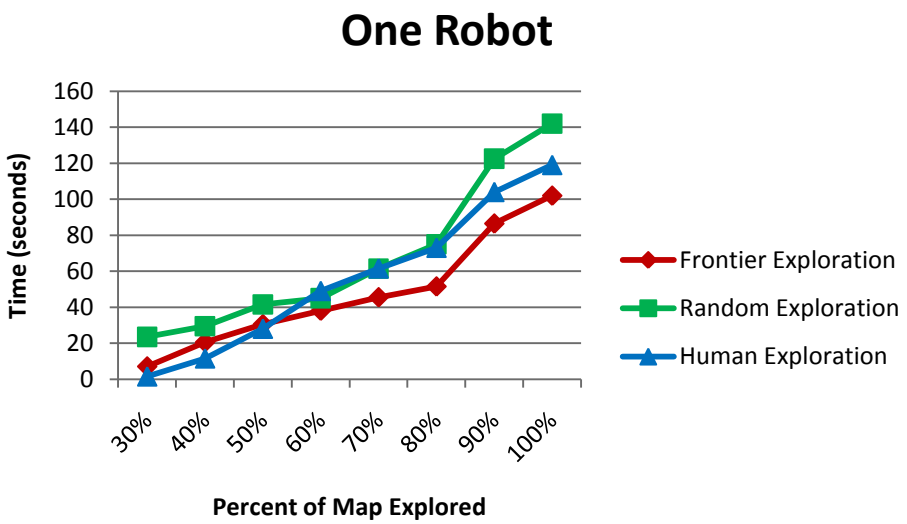
# Results

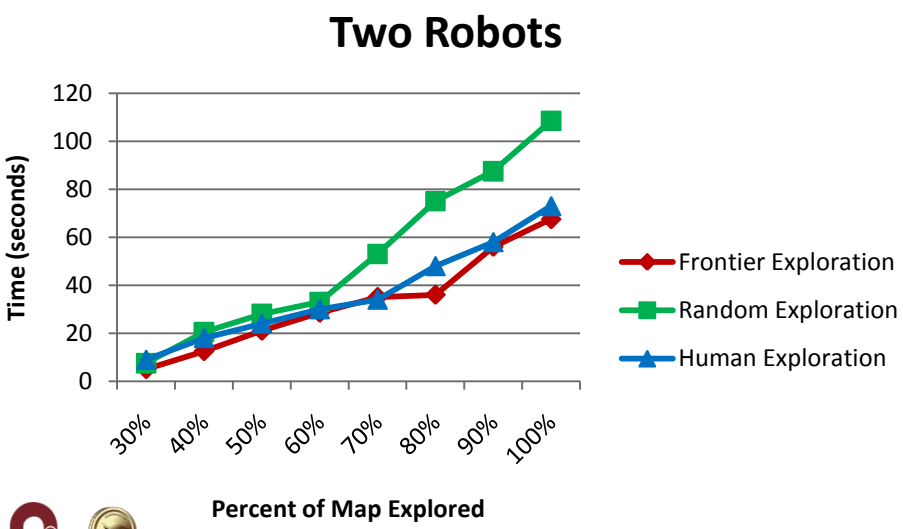
- Random performed worse out of all the methods while frontier performed the best.
- Using two robots led to the fastest exploration.

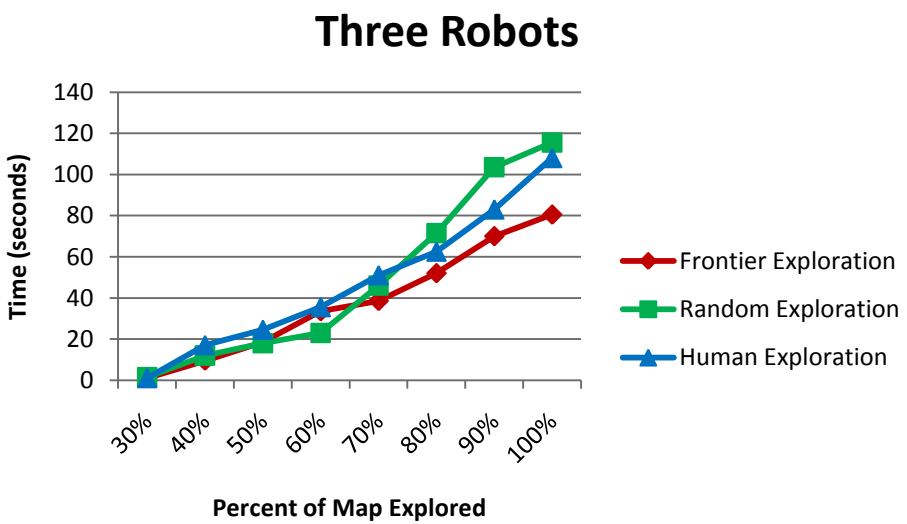


# Results

- Random exploration performs well when less than 50% of the environment is explored.

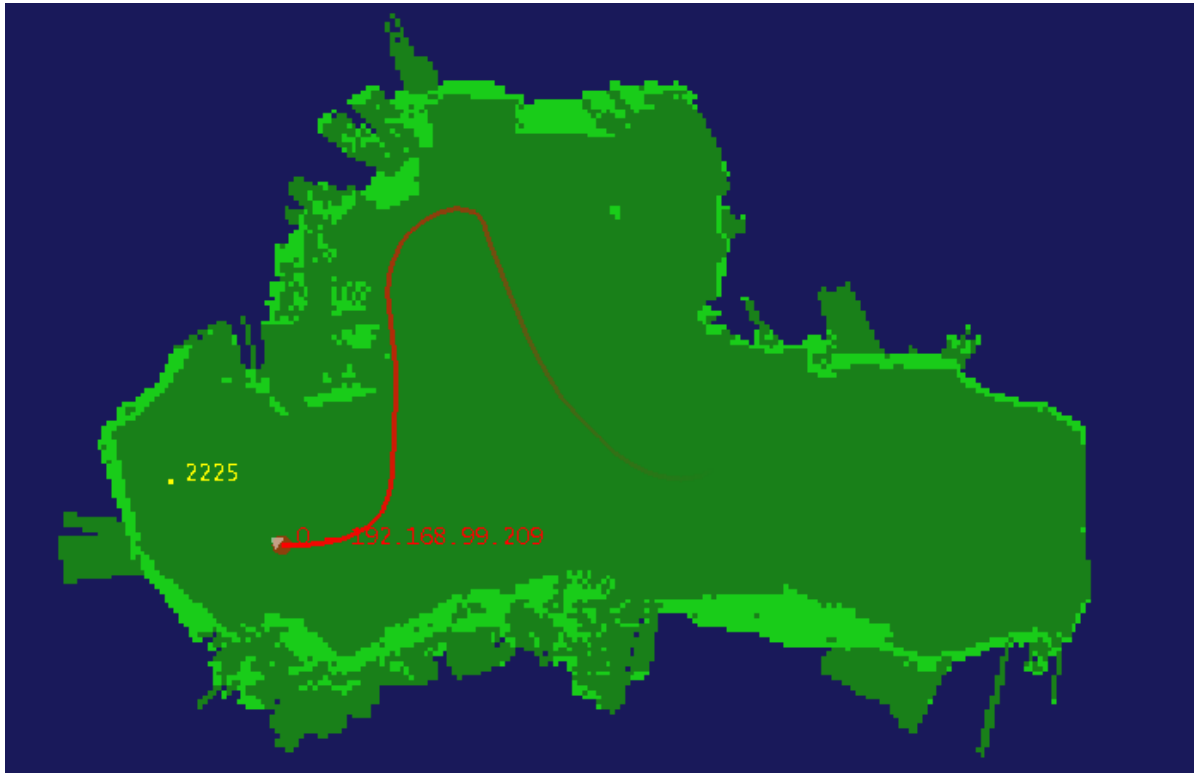


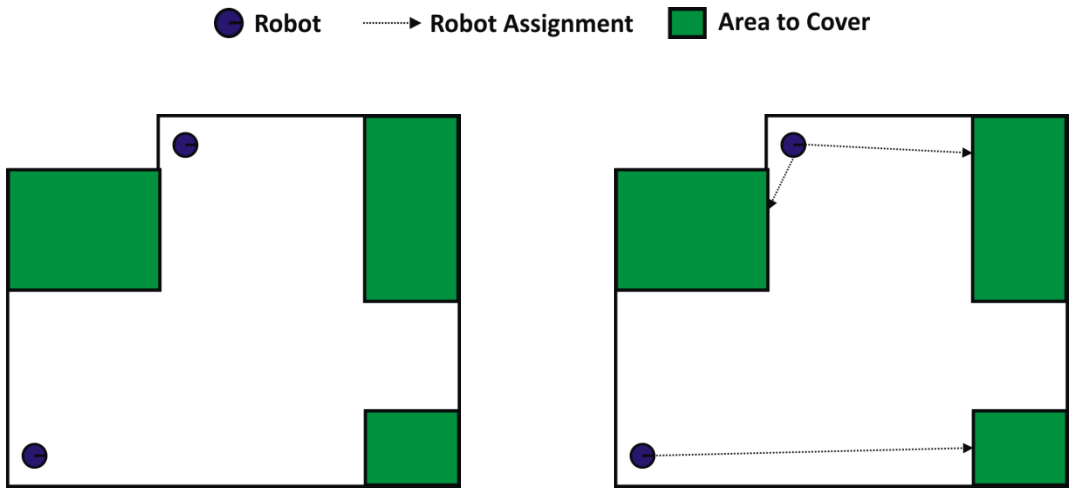
# Coverage: Methods of Coverage

- Greedy
- Pairing
- Exhaustive



# Greedy

- Robot select the closest area to its current position and covers it.
- Fast to compute but might produce bad results.

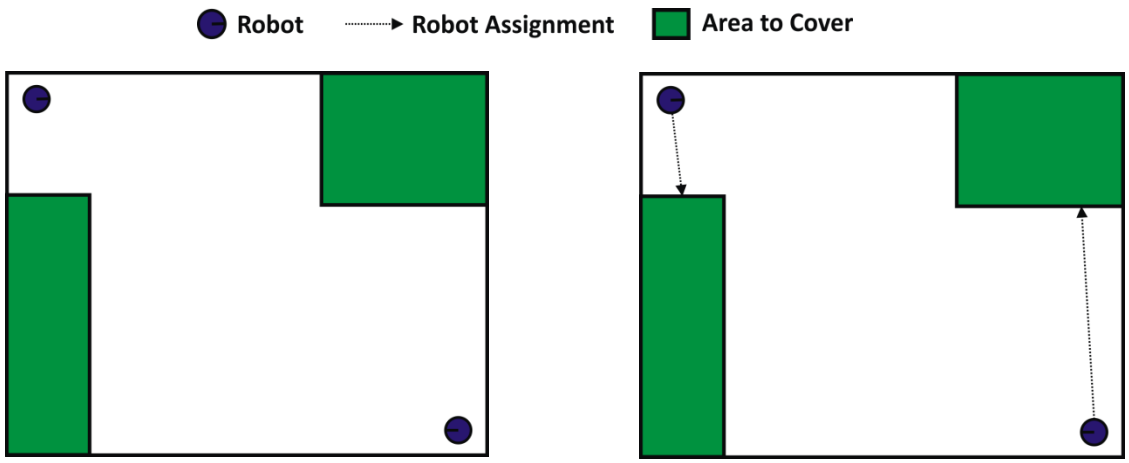



Areas to be covered are chosen

The closest areas to each robot are assigned to the robots

# Pairing

- Robots are paired one-to-one with an area using the *stable marriage* algorithm.
- Fast to compute and produces very good results but can only be used when the number of areas is equal to the number of robots.

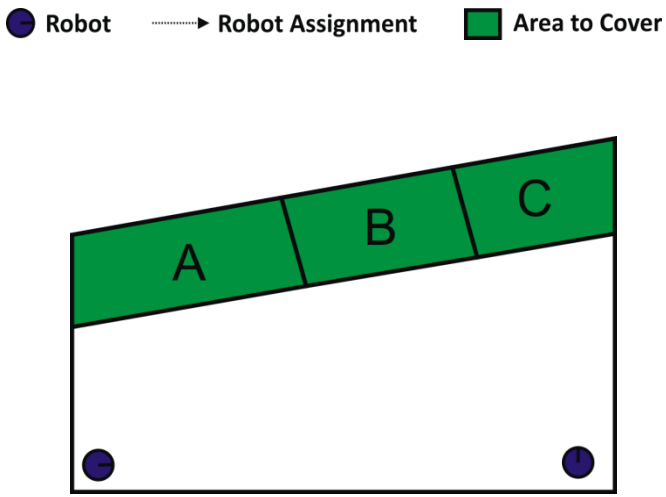



Areas to be covered are chosen

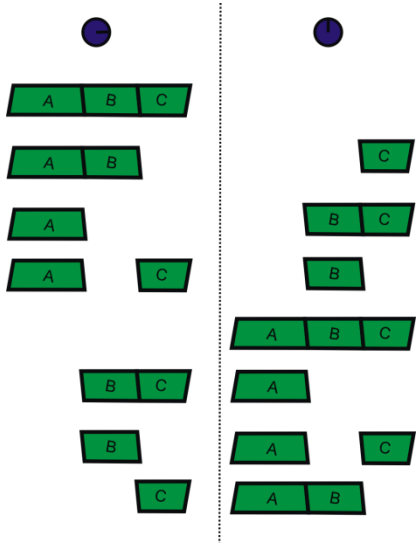
Areas are paired with robots

# Exhaustive

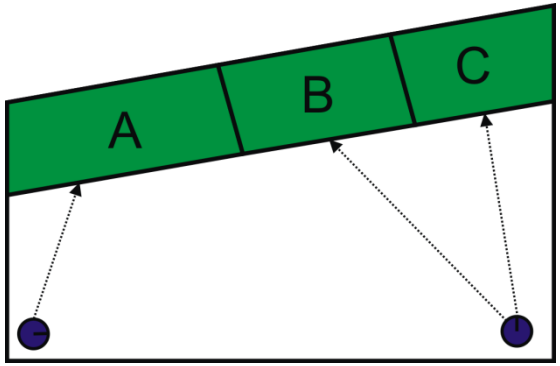
- All possible assignments are explored and the assignments that covers the area in the shortest amount of time is chosen.
- Long time to compute but produces the optimal results.




Areas to be covered are chosen




Possible combinations are examined




Combination that takes the least total time is chosen

# Conclusion

- The frontier algorithm proves to be the most efficient for up to three robots in the environment we tested.
- Random exploration exhibits the interesting ability of quickly exploring up to 50% of the environment.

# Future Work

- Analysis of implemented methods
- Integration into the treasure hunt framework
- Consider centralization versus distribution
- Study how size and complexity affects performance

# Questions?

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