Research Proposal:

Multi-Robot Coverage of Modular Environments

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CSE Track

POLITECNICO MILANO 1863

HONOURS PROGRAMME HP-SR in Information Technology

Outline

- What is Coverage?
- Why?
- Multi-Robot Coverage
- Preliminaries
- Our setting: Modular Environments
- State of the Art
- Research Plan

What is Coverage?

- An environment of which we know the map
- A set of points of interest in the map
- A mobile agent, equipped with a ‘covering tool’ of finite size

The goal is to find a path:

- optimal
- such that each point of interest fall under the covering tool at least once

Why?

- To physically pass over a specified set of points

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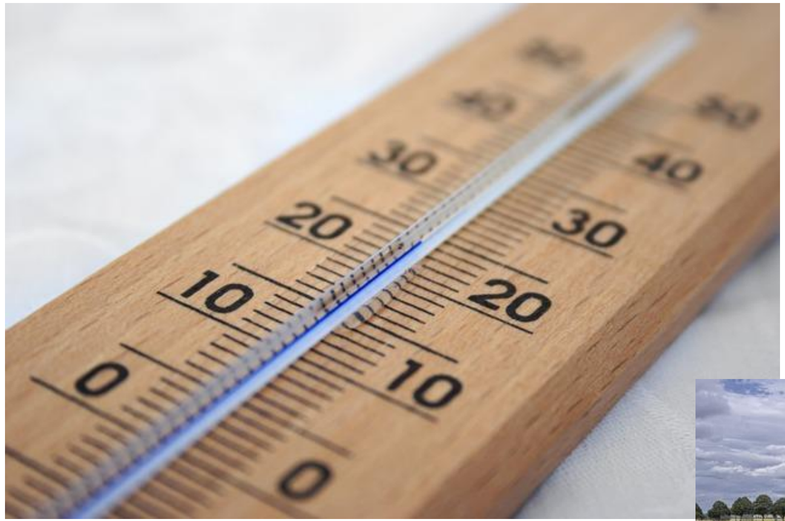
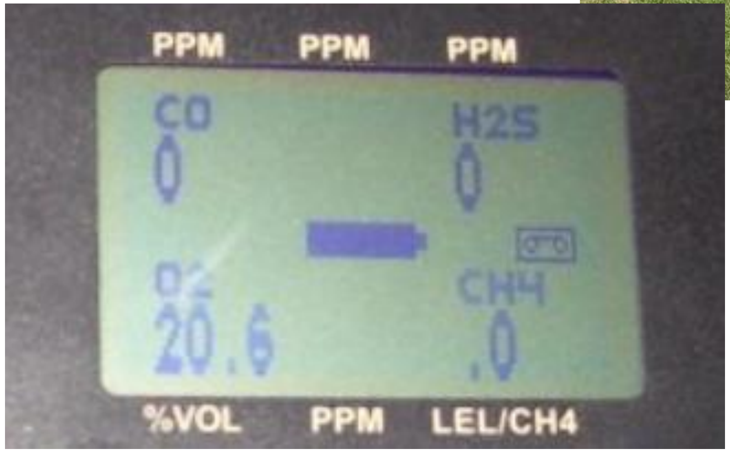
- To gather data about the environment





Why?

- To physically pass over a specified set of points
- To gather data about the environment
- For search and rescue applications

Multi-Robot Coverage

An approach that comes from the Multi-Robot Systems area

Advantages:

- it provides robustness (i.e., supporting the loss of a robot)
- it increases efficiency

Drawbacks:

- it needs to address coordination
- Increased algorithmic complexity

Multi-Robot Coverage

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The problem of Multi-Robot Coverage is defined as the planning of a number of paths, one for each robot, over a known environment

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the constraints of the environment are considered and the solution is optimal w.r.t. a certain metric

[Kong, C.S. et al., 2006]

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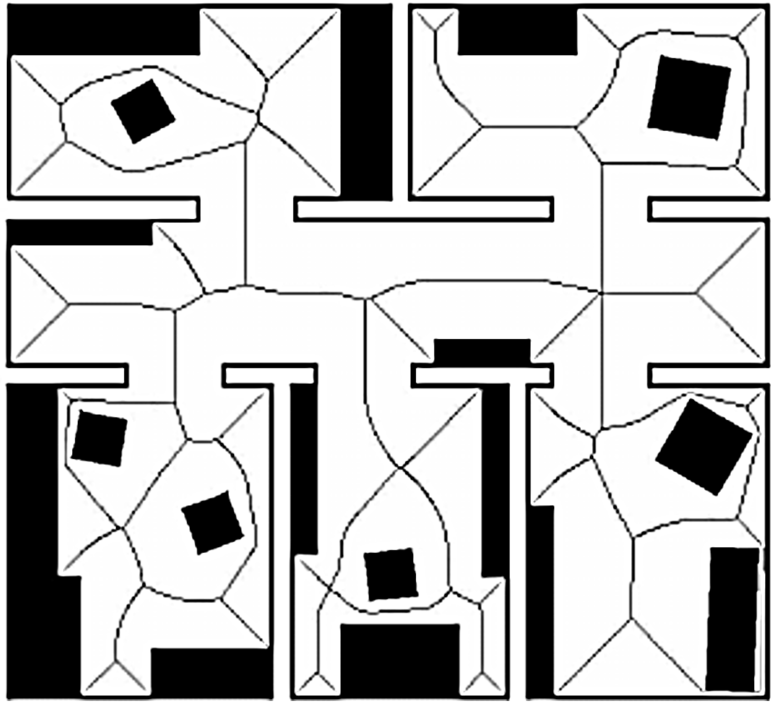
Common metrics: MINSUM, MINMAX

Preliminaries

From environment to graph

- Points of interest of the environment → nodes
- Connections between points → edges

Example: Voronoi tessellation



[Moratz, R., Wallgrün, J.O., (2003). Fig 8a]

Preliminaries

Traveling Salesman Problem (TSP):

“Given a set of cities and the distances between each pair of them, what is the shortest possible route that visits each city and returns to the origin city?”

Cities → nodes

Distances between cities → edges with associated cost

Origin city → depot

Preliminaries

Multiple Traveling Salesmen Problem (mTSP):

"Given a set of nodes and a cost metric defined in terms of distance or time, let there be *m* agents located at a single initial node, called depot. The remaining nodes are called 'intermediate nodes'. The mTSP consists of finding tours for all the *m* agents, which all start and end at the depot, such that each intermediate node is visited exactly once and the total cost of visiting all the nodes is minimized"

[Bektas, T., 2006]

NP-Hard

Preliminaries – mTSP approximations

- Frederickson et al. (1976): tour-splitting heuristic
  - Approximation factor: $\frac{5}{2} - \frac{1}{m}$
- Malik et al. (2007): for GMTSP (Generalized Multiple depot mTSP) with symmetric costs and triangle inequality satisfied
  - Approximation factor: 2

Our idea: exploit constraints on the environment to get tighter bounds

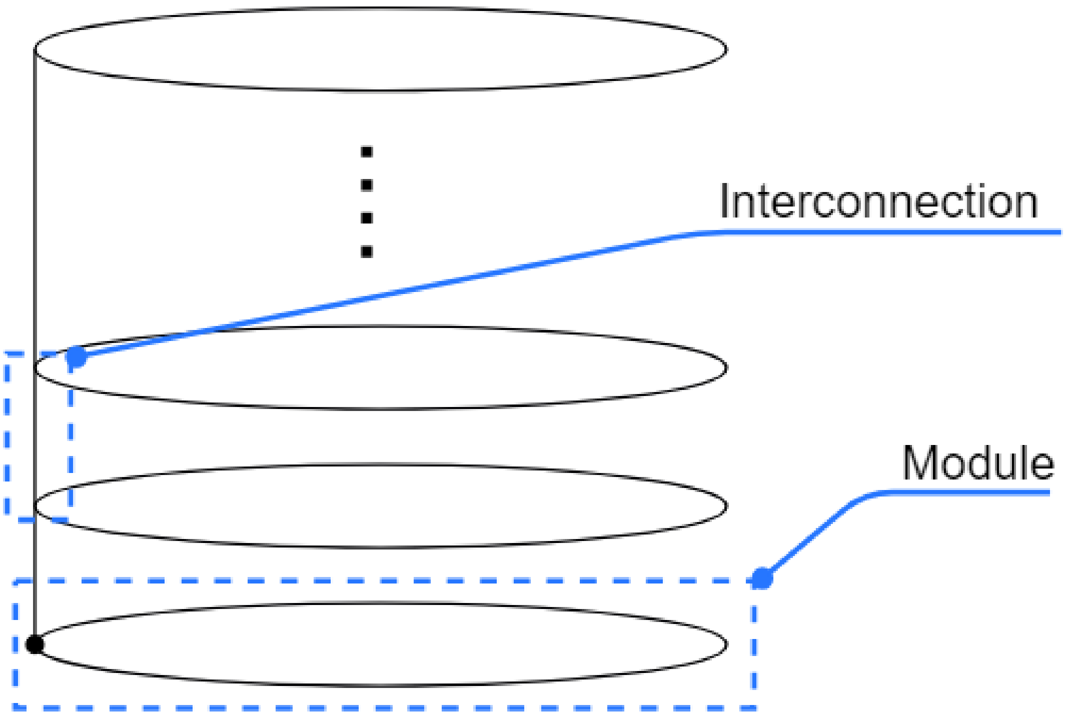
Our setting: Modular Environments

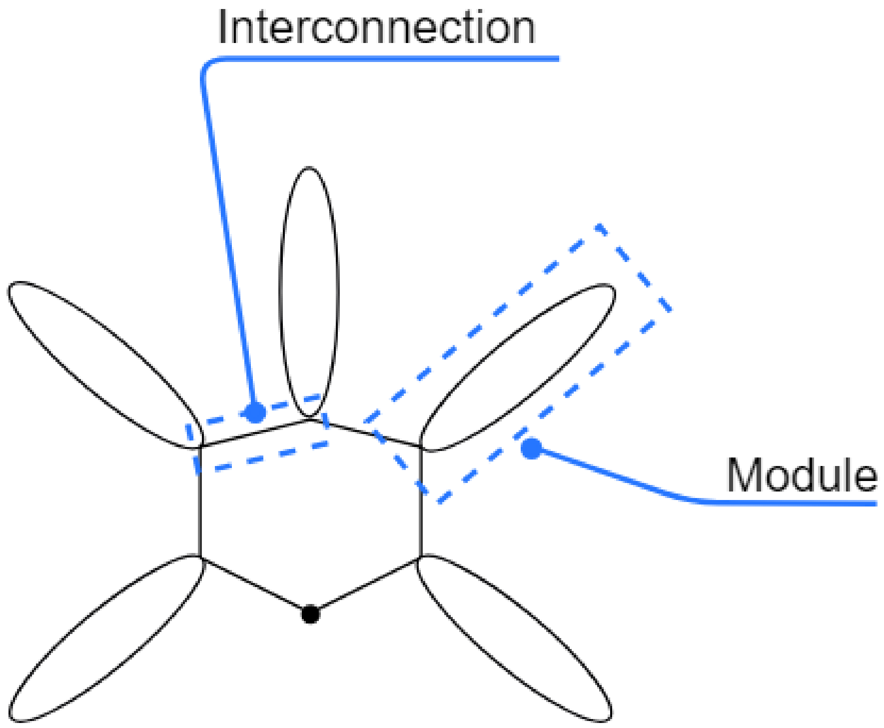
- Repeated identical subparts: the ‘modules’
- Environment is made up only by these modules, all identical to each other, and their interconnections

Our setting: Modular Environments

Exemplified by residential buildings

Our setting: Modular Environments





Our setting: Modular Environments

- All robots are considered equivalent
- Robots can move at constant speed through the whole environment
- Same starting location for all robots
- We are interested in minimizing the completion time (MINMAX)

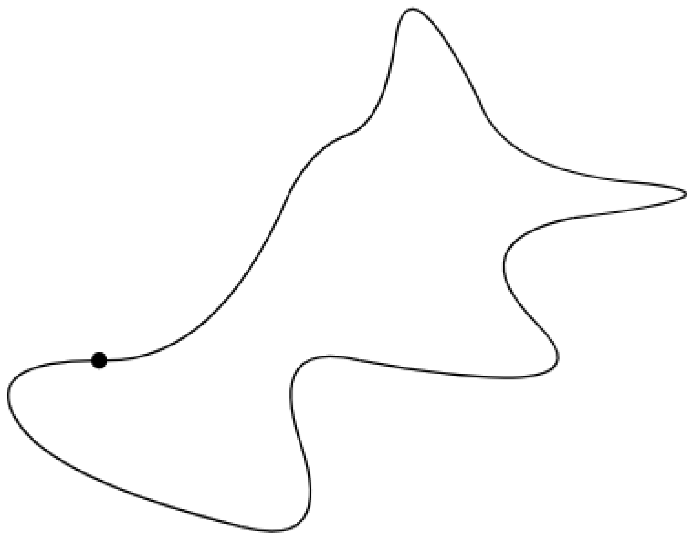
State of the Art

Common approaches:

- Split the TSP solution
- Use clustering

State of the Art

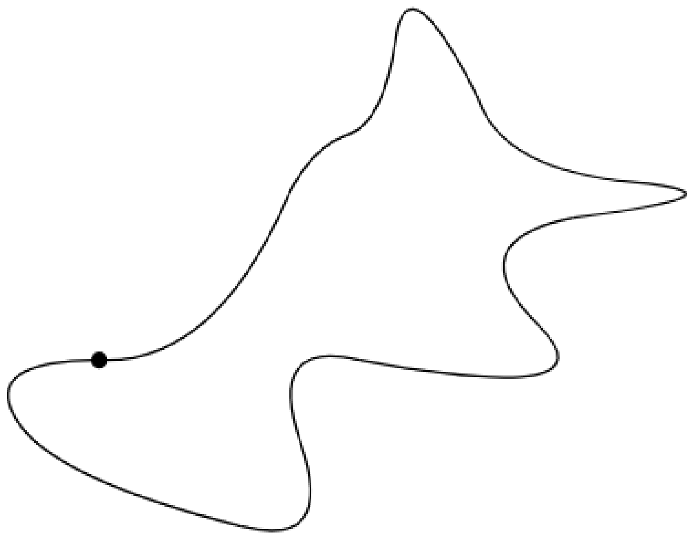
Split the TSP solution



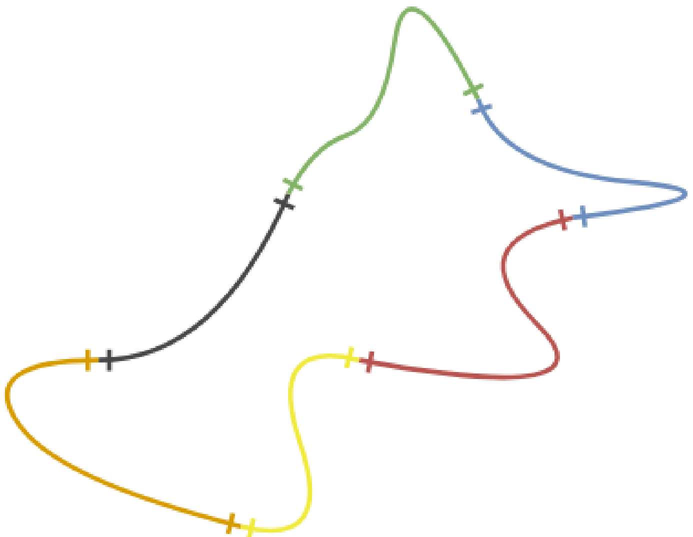
[Frederickson, G.N. et al., 1976]

State of the Art

Split the TSP solution



6 robots



[Frederickson, G.N. et al., 1976]

State of the Art

Split the TSP solution

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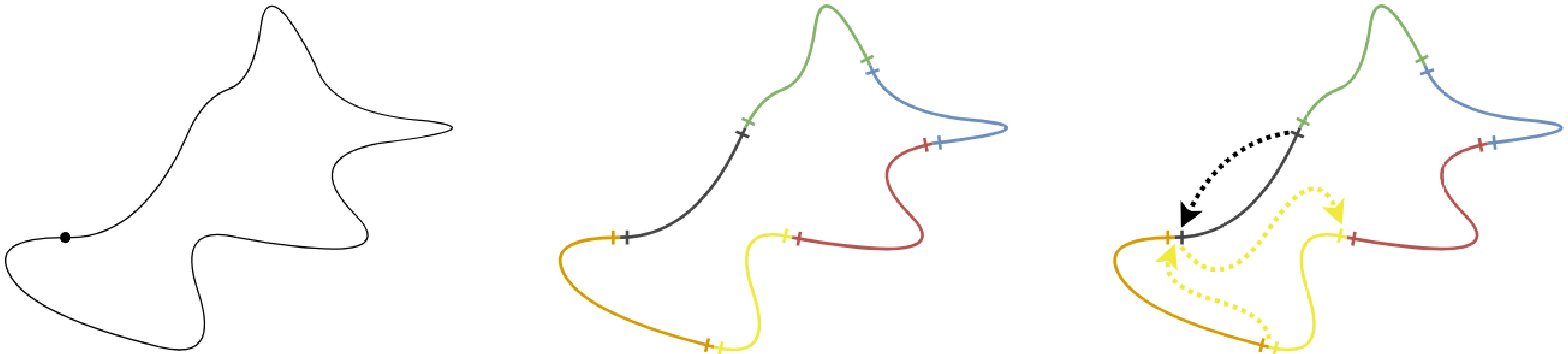

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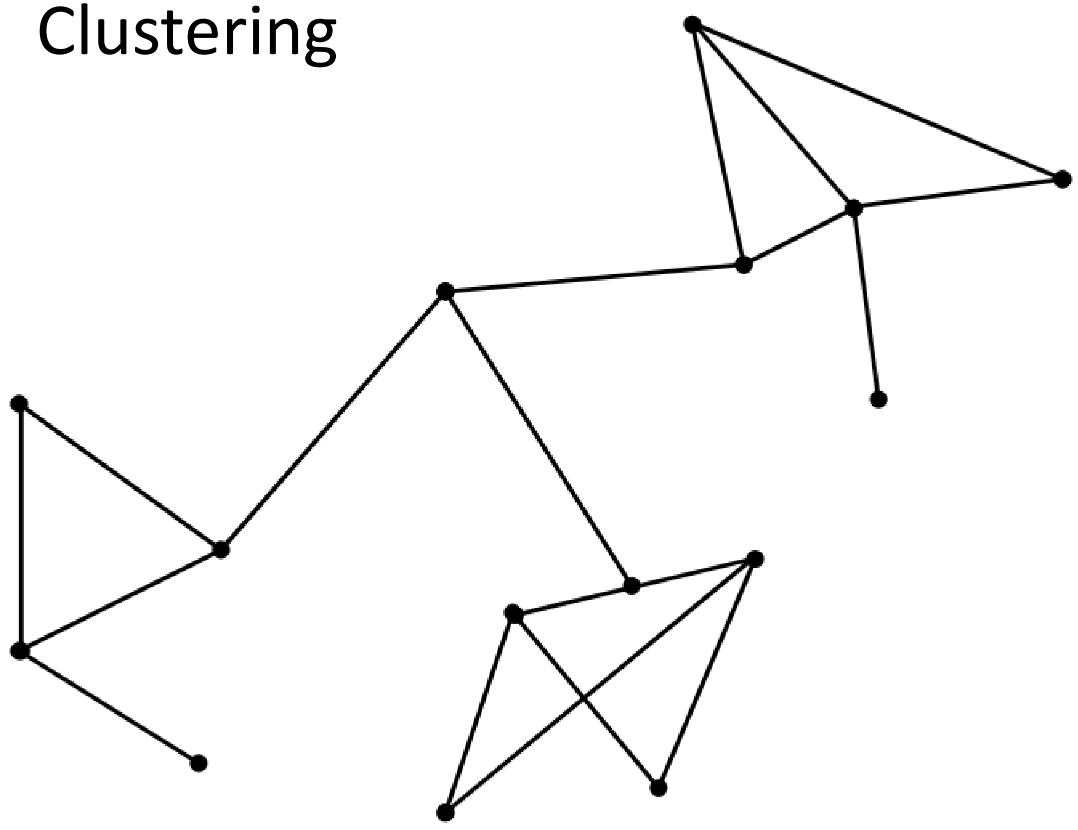
State of the Art

Clustering



[Chandran, N. et al., 2006]

State of the Art

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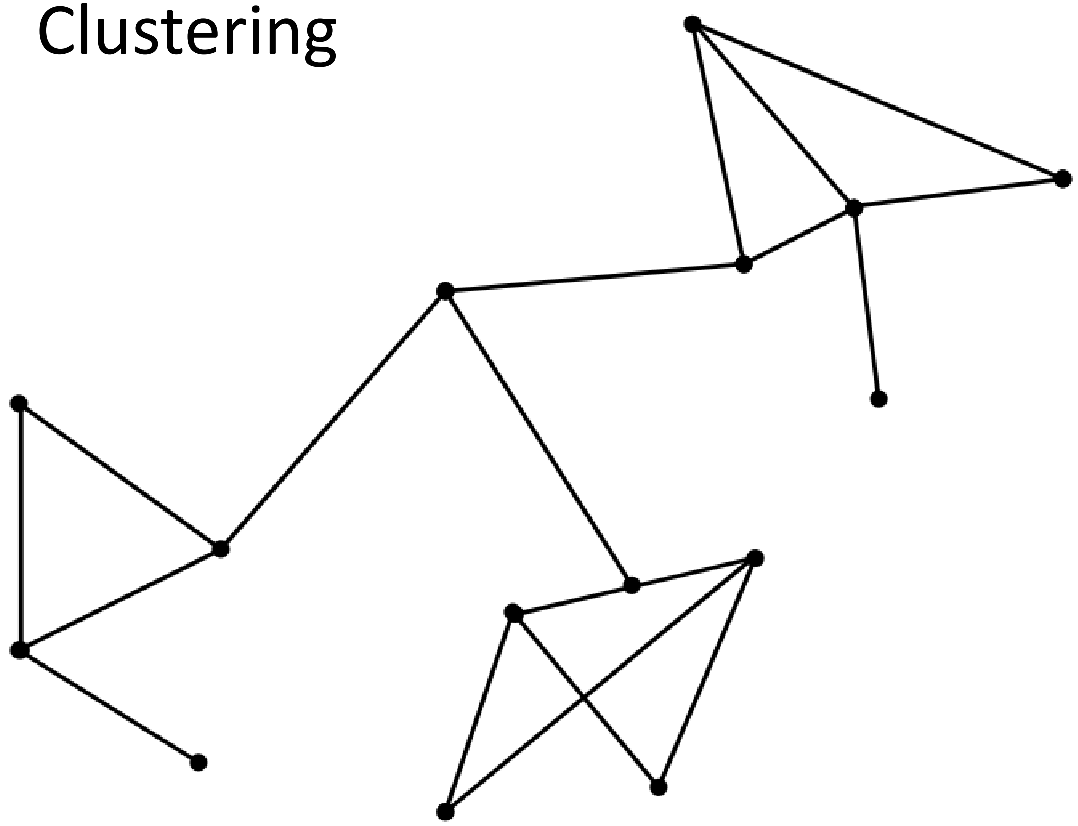
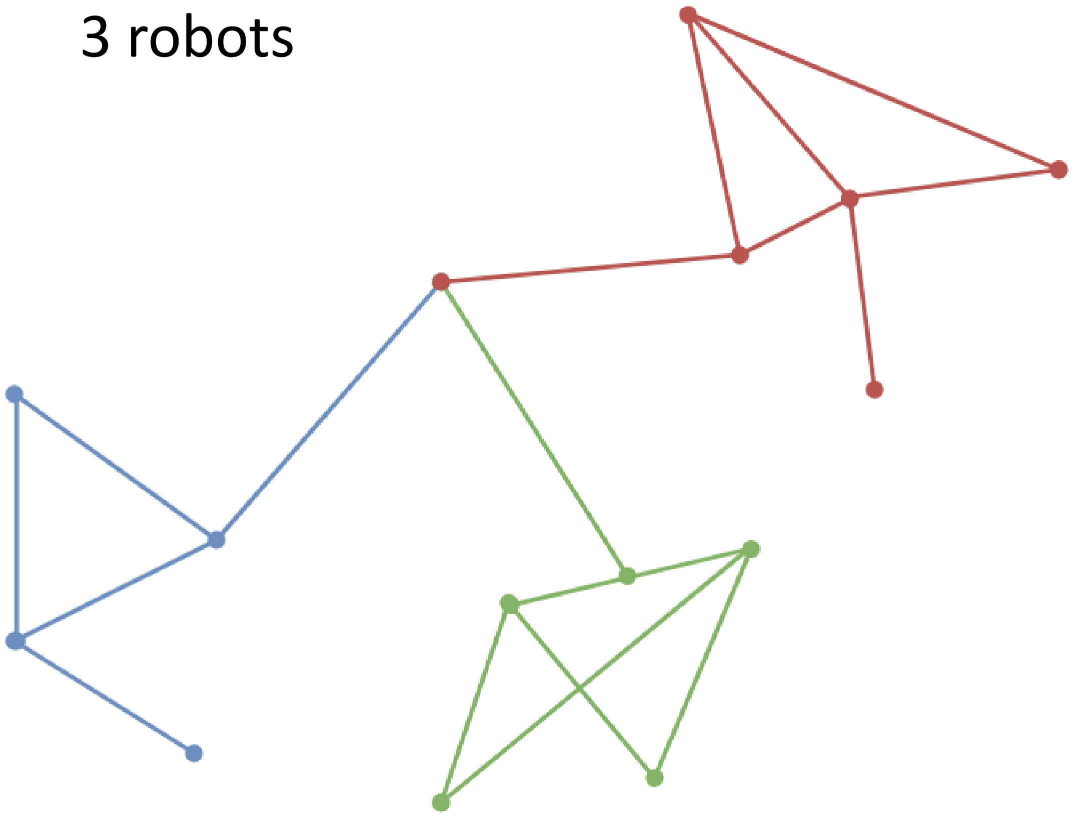


3 robots



[Chandran, N. et al., 2006]

Research Plan

Purpose: investigate the potential improvements over the bounds of approximations given by path planning algorithms for multi-robot coverage problems enabled by considering environments characterized by repeated identical sub-structures

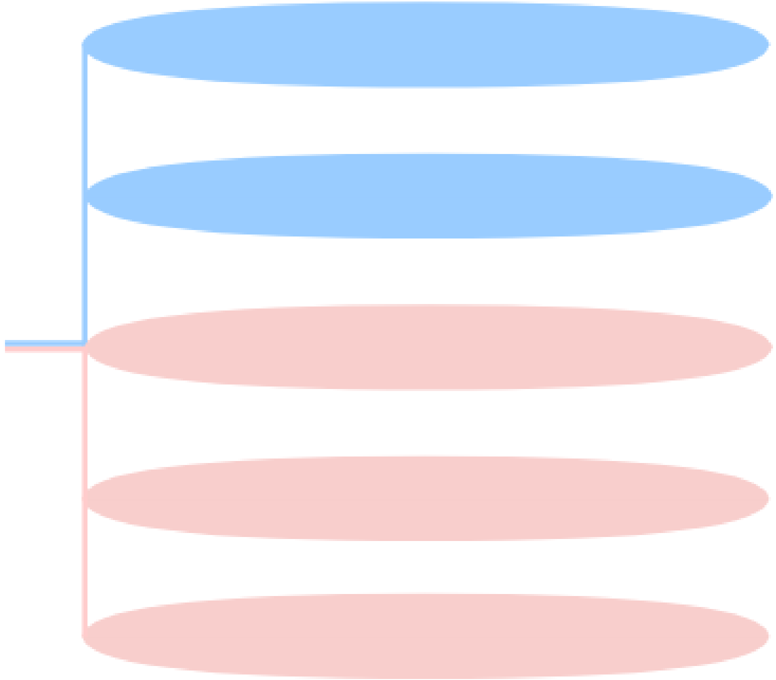
Three phases:

- Phase 1: integer algorithm
- Phase 2: algorithm with no integrity constraints
- Phase 3: splitting the TSP global solution

Research Plan: Phase 1

Integer algorithm:

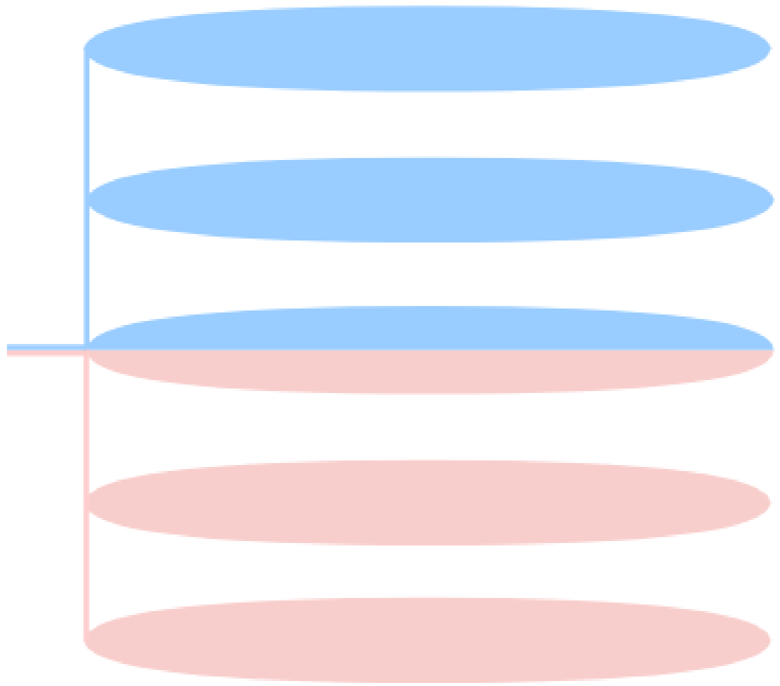
- Modules considered as indivisible parts
- Each module assigned to one and only one robot
- Look for an algorithm that provides an assignment that minimizes the completion time



Research Plan: Phase 2

Algorithm without integrity constraints:

- Relaxation of the integrity constraints
- Each module can be shared among multiple robots
- Expected to provide tighter approximation bounds

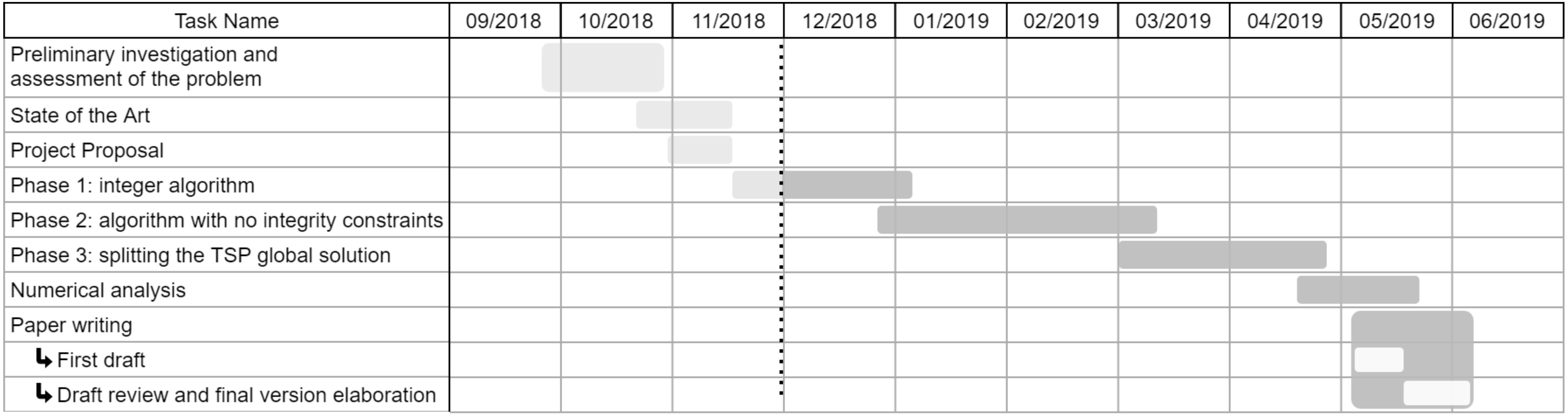


Research Plan: Phase 3

Splitting the global TSP solution:

- Compute the TSP solution over all the nodes
- Split it using a heuristic on the modules that considers:
  - Relative positions
  - Size of each module
  - Number of modules
  - Internal structure of modules

Research Plan



Thank you for the attention

Questions?