Verification of visibility-based properties on multiple moving robots in an environment with obstacles

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Motivation

1. Connectivity maintenance of mobile robots
2. Strength of network topology
3. Guarding an environment using mobile robots

Proposing a method to guarantee visibility-related properties without providing mathematical proof, using verification techniques

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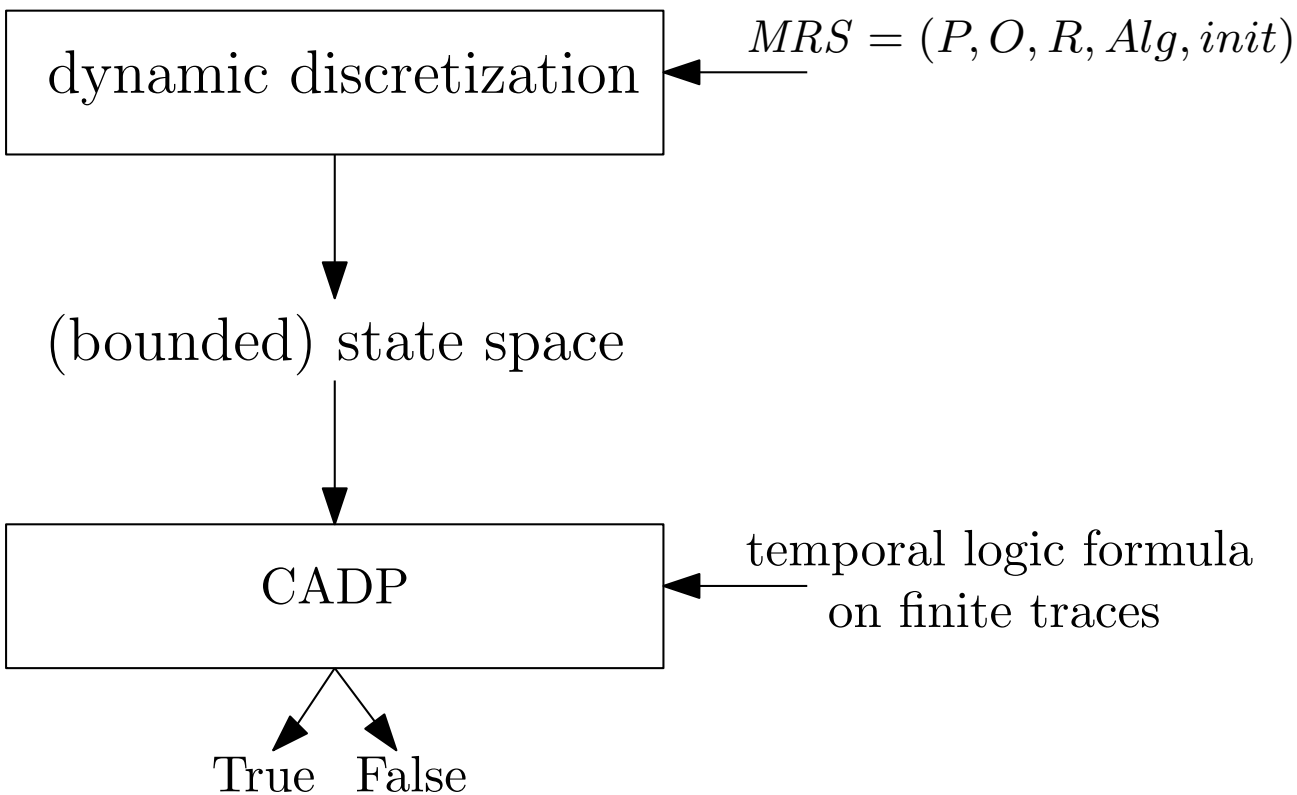
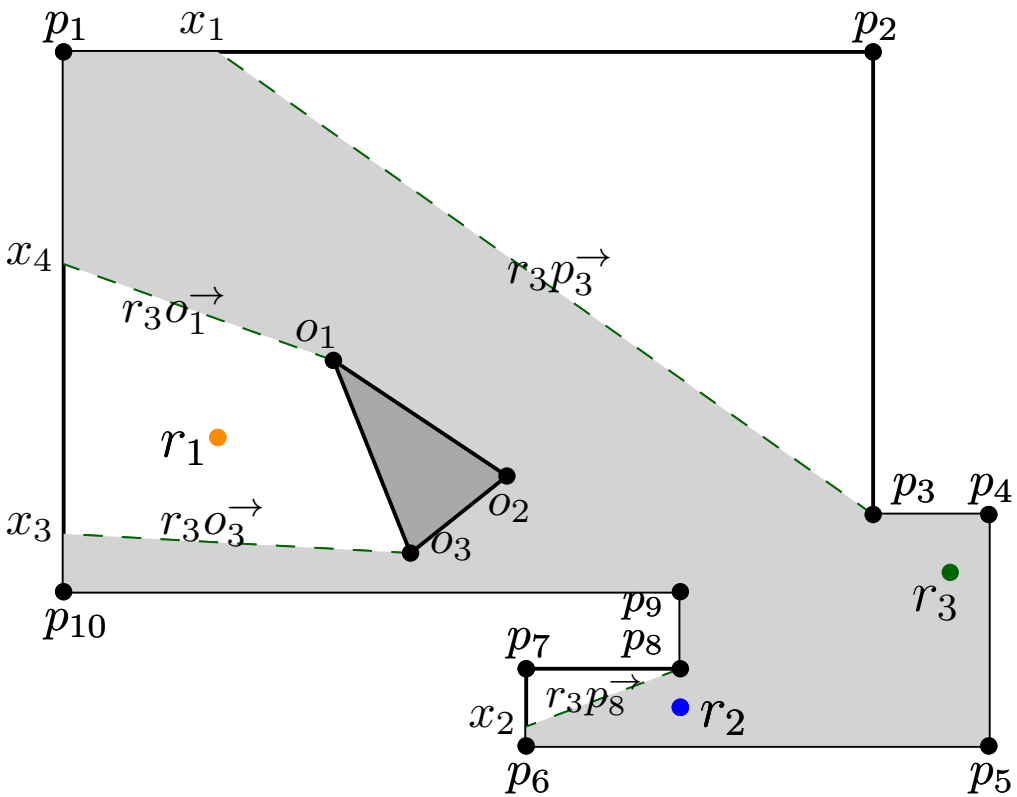
How to verify a multi-robot system?



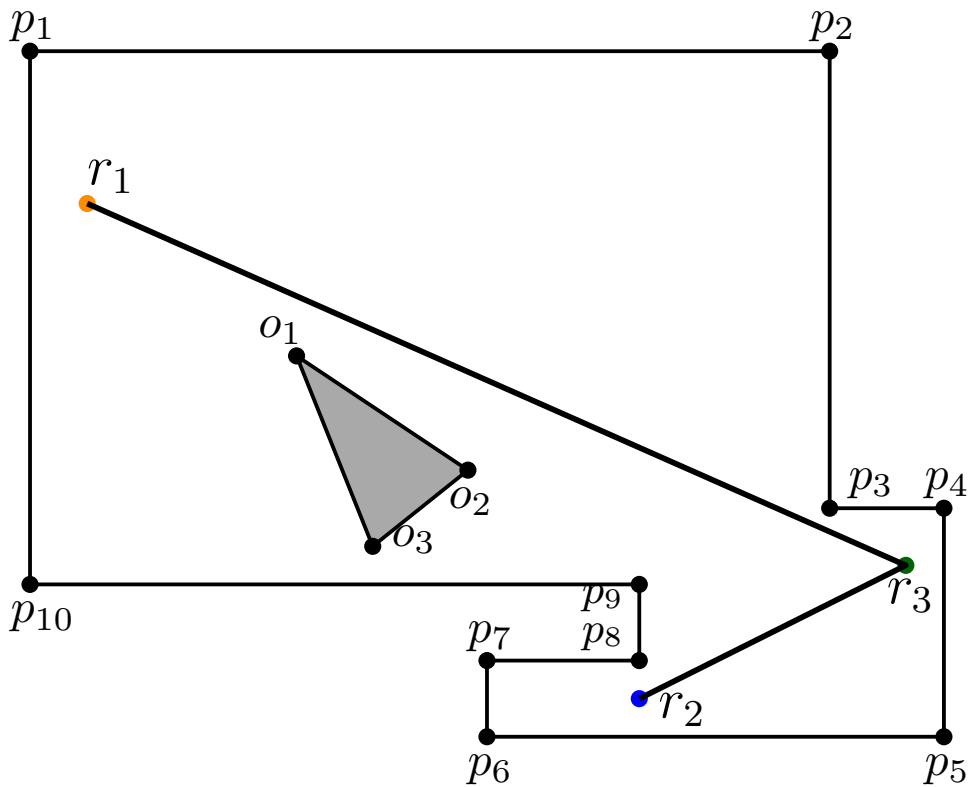
Visible area of a robot

The shaded area indicates the visible area of robot r_3, and the dashed line segments are called the *windows* of r_3.

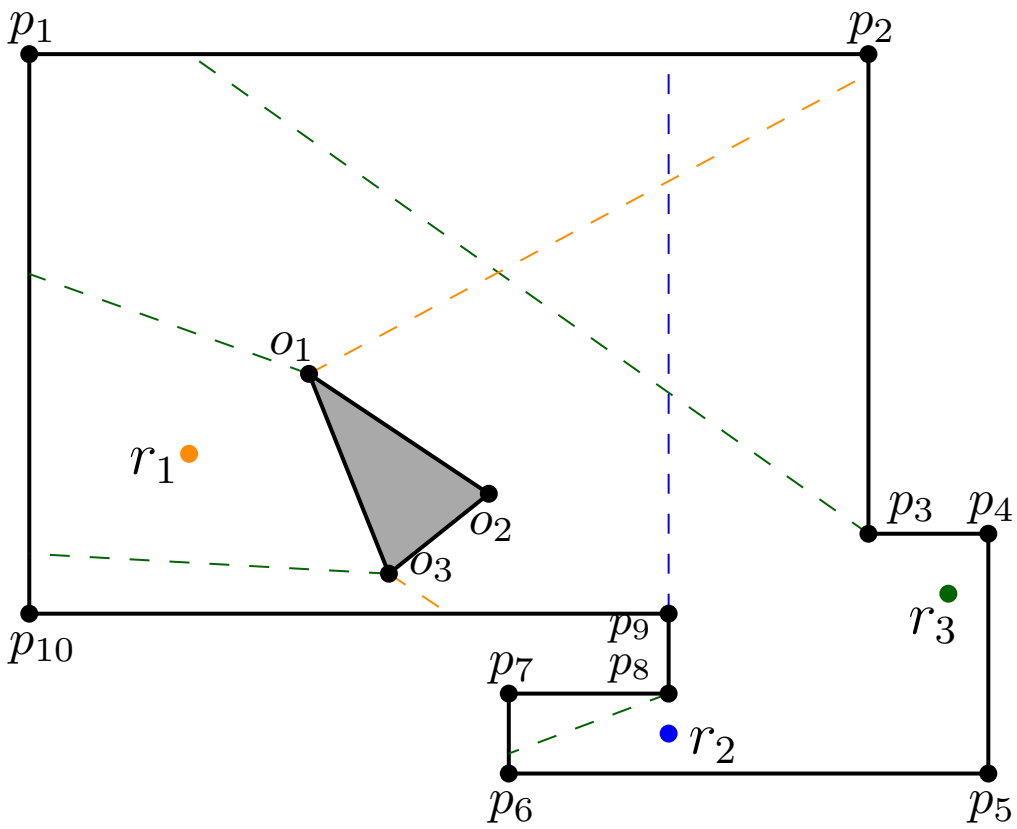


Connectivity property

The set of robots are connected if the graph induced by the visibility relation between pairs of robots is connected.



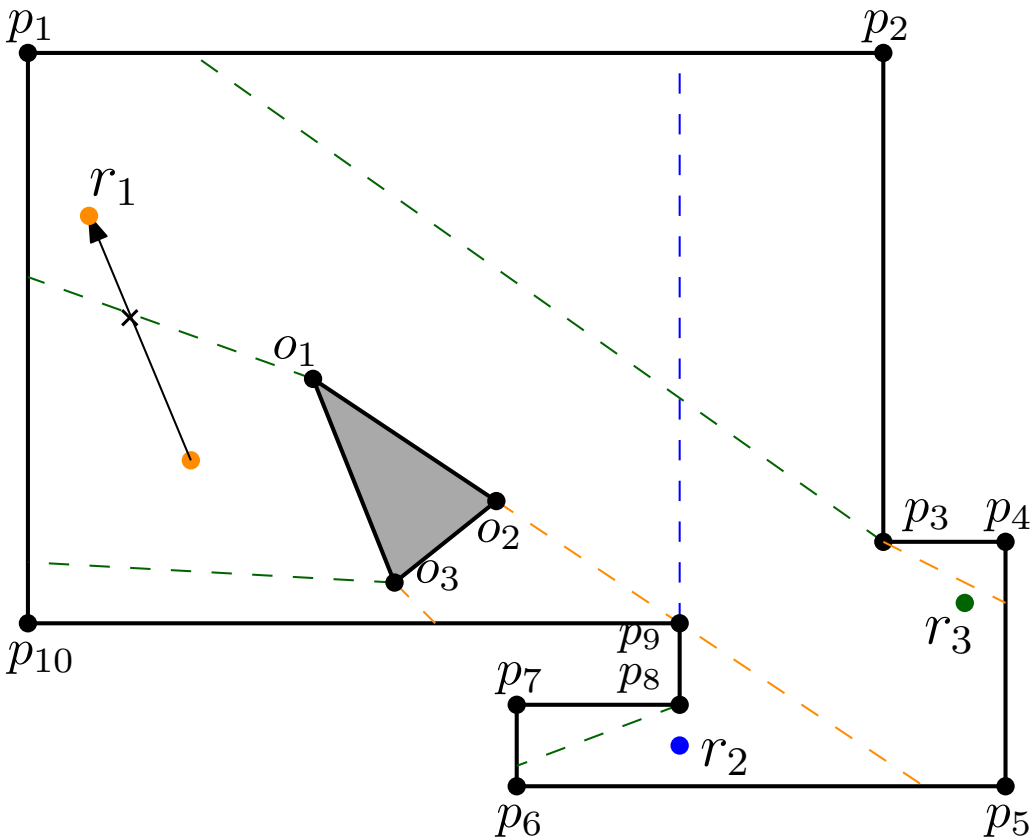
An example: Is the *Connectivity* property satisfied?



Robot r_1 is visible from none of the robots

An example: Is the *Connectivity* property satisfied?

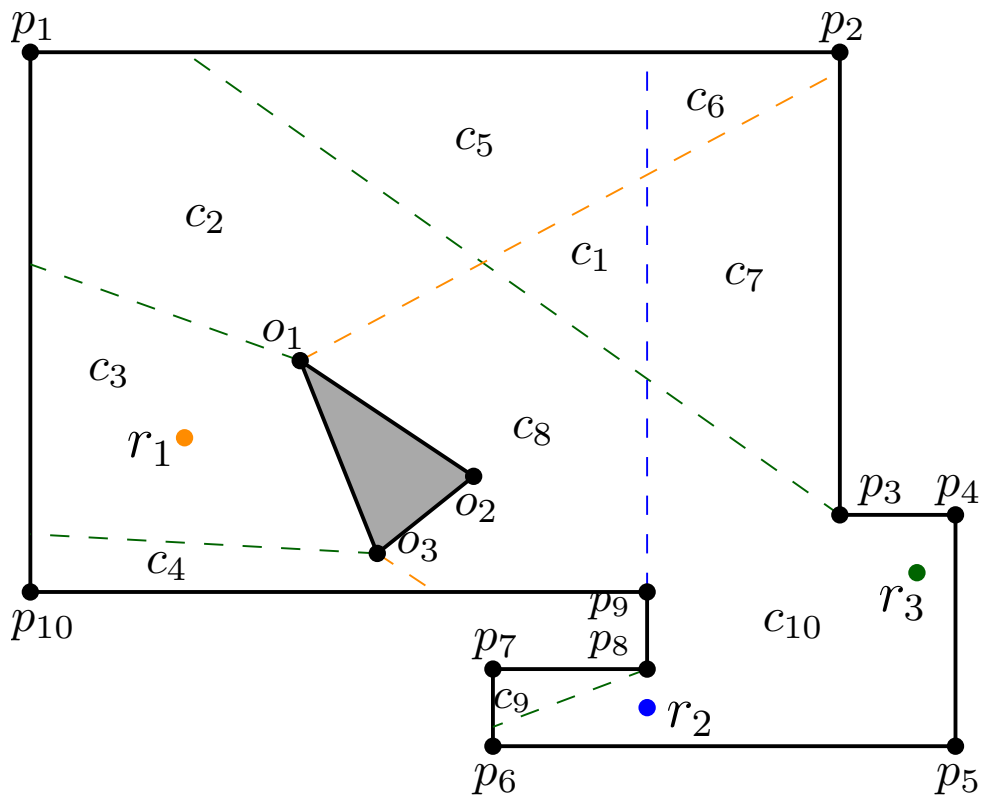
Robot r_1 navigate to a new position:



Connectivity property gets satisfied

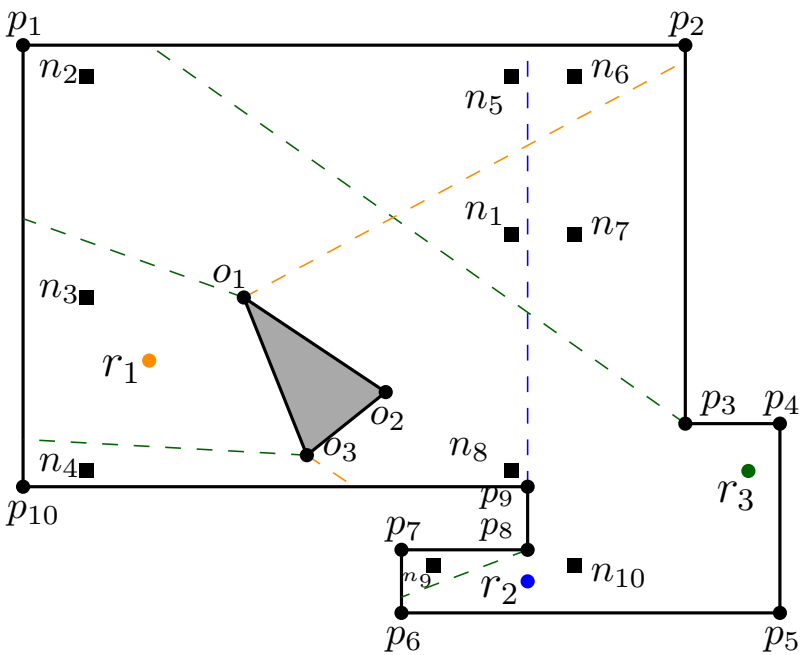
To define a state: Using visibility-related characteristics

- The intersection of robots' windows lead to a subdivision.
- The number of visible robots for each neighboring cells differs in one.

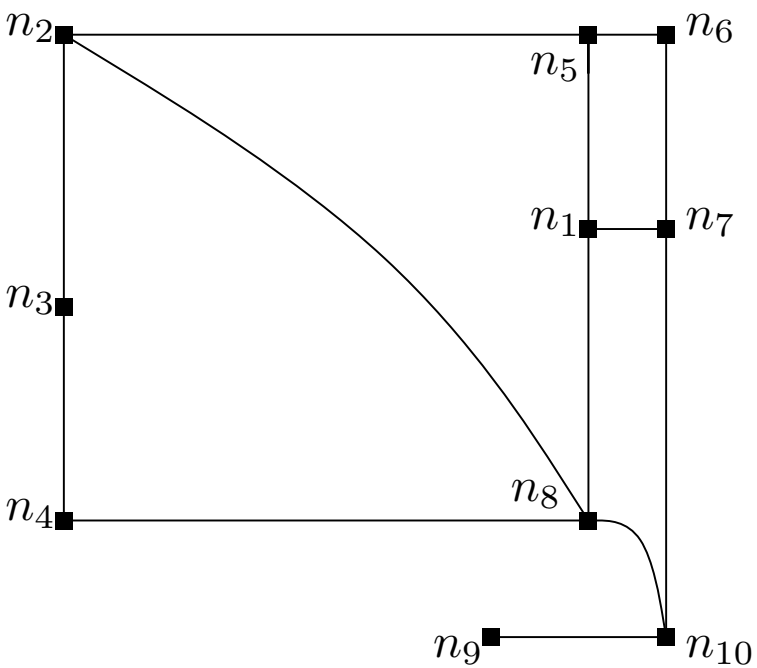


Continuous movement: dynamic state apace

- Dynamically discretize the environment based on the geometrical properties



Subdivision of the environment



Dual graph of the subdivision

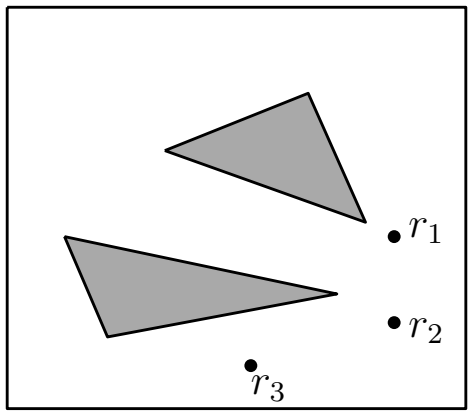
Constructing the state space

We define the LTS of *MRS* as the tuple $(S, Act, \hookrightarrow, s_0, AP, L)$ where

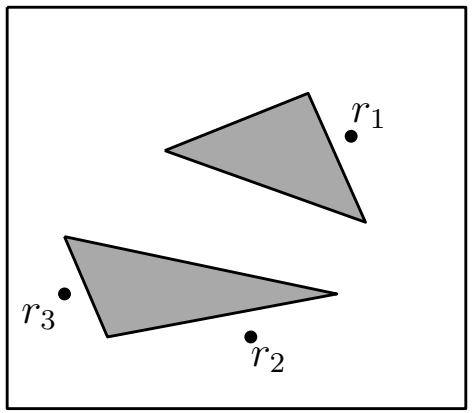
- S is the set of states,
- Act is the set of actions denoting the movements of the robots,
- $\hookrightarrow \subseteq S \times Act \times S$ is the transition relation, (we use the notation $s \overset{\alpha_j}{\hookrightarrow} s'$ whenever $(s, \alpha_j, s') \in \hookrightarrow$),
- $s_0 \in S$ is the initial state (determined based on *init*),
- $AP = \{Connectivity, Coverage\}$ is the set of atomic propositions,
- $L : S \to 2^{AP}$ is the labeling function.

Practical case study

Guaranteeing the connectivity maintenance of a swarm aggregation algorithm [Leccese et el.]



Polygon (IV)



Polygon (V)

LTL Formulas	Polygon (IV)	Polygon (V)
$\Box$ *Connectivity*	True	False
$\Diamond\Box$ *Connectivity*	True	True
$\Box\Diamond$ *Connectivity*	True	True
$\Diamond$(*Connectivity* $\wedge$ *Coverage*)	False	False

Reference

[1] Sheshkalani AN, Khosravi R. Verification of visibility-based properties on multiple moving robots in an environment with obstacles. *International Journal of Advanced Robotic Systems*. July 2018. doi:10.1177/1729881418786657

Thanks

Thanks for your time.