MATE: Benchmarking Multi-Agent Reinforcement Learning in Distributed Target Coverage Control

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Outline

1. MATE: the Multi-Agent Tracking Environment
   - Problem Settings
   - Scalable
   - Communicative Agents
   - Heterogeneous & Asymmetric
2. Results
   - Learning Cameras in Fully-Cooperative Game
   - Learning Targets in Fully-Cooperative Game
   - Zero-Sum Fully-Competitive Game

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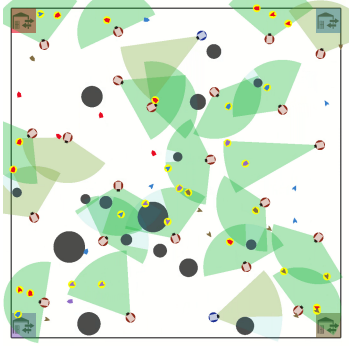
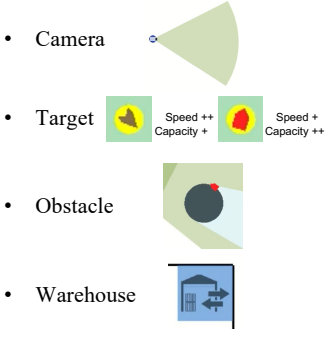
MATE: the Multi-Agent Tracking Environment

An asymmetric heterogeneous competitive-cooperative multi-agent environment under partial observations.

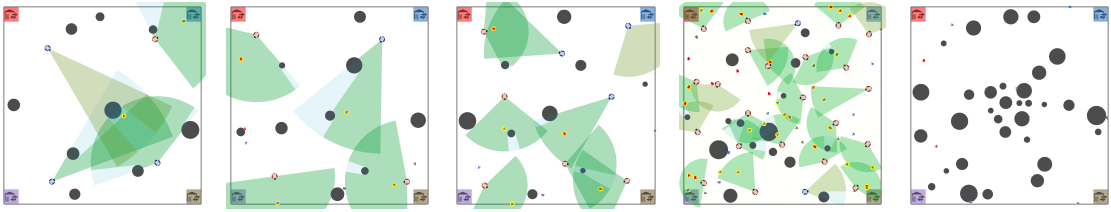
- **Cameras**: collaboratively maximize coverage on "targets" while minimizing repeated detection of the same "target".
- **Targets** (Vehicles): transport cargoes between warehouses while minimizing "cameras" surveillance.



(a) 100C vs. 20T (b) 24C vs. 48T



MATE: the Multi-Agent Tracking Environment



(a) 4C vs. 2T (b) 4C vs. 8T (c) 8C vs. 8T (d) 24C vs. 48T (e) Navigation

Five snapshots of The Multi-Agent Tracking Environment at different scales. Note that here we abbreviate "camera" as "C", "target" as "T".

Problem Settings

The two sides of the opposing team constitute a **zero-sum** game.

- **Target Team** (vehicles):
  - There are several vehicles in charge of transporting cargo, with two types, one with low speed and large capacity, and the other with high speed and small capacity.
  - The vehicle will receive a reward and new cargoes when it transports its payload to the destination.
- **Camera Team** (sensor network):
  - The surveillance sensor network contains several proactive cameras distributed in the scene.
  - Each camera can independently adjust its orientation and perception range (the viewing angle and radius of the sector area).
- **Warehouses**: distributed in the environment, and each warehouse has several (random number) cargoes to be transferred to the others.
- **Obstacles**: randomly distributed in the scene. The camera cannot observe the targets behind the obstacle, and the target (vehicle) cannot enter the obstacle.

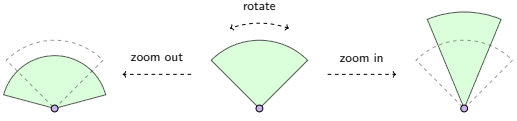
"Camera" Agent

Camera: in-place zoomable directional sensor (the purple colored entity at center)
Observation:

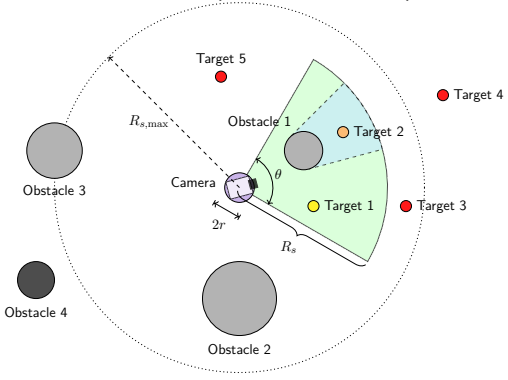
- the location of the vehicles (targets) and whether they are carrying cargo in the perception zone (the green colored area / blind spot (the cyan colored area))
- the location and size of obstacles within its maximum sensing radius (the dotted circle).

Action:

- rotate the orientation
- zoom in and out of the viewing angle.



Camera Action: rotation and zooming



Camera Observation (within the green sector)

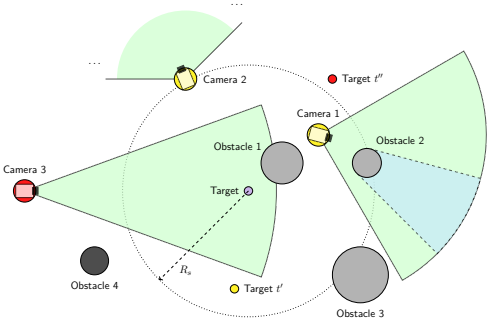
"Target" Agent

Target: movable vehicle equipped with omnidirectional sensors

Observation (in dotted circle):

- the camera location and pose (direction and opening angle)
- the location and size of obstacles
- the location of other vehicles (targets) and whether they are carrying cargo

Action: displacement relative to the current position $(\Delta x, \Delta y)$



Target Observation (within dotted circle)

Core Features

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- Sample Efficient and Easy to Use:
  - 300+ FPS
  - easy to setup and out-of-box usable
- Scalable
  - up to 100+ agents
- Communicative
  - explicit communication channels
  - peer-to-peer and broadcast
- Heterogeneous and Asymmetric
- Various Scenarios and Curricula Configurations
  - built-in agents
  - built-in wrappers

Scalable

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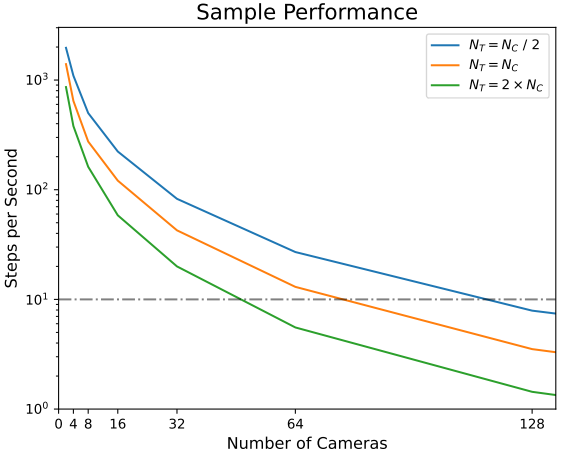
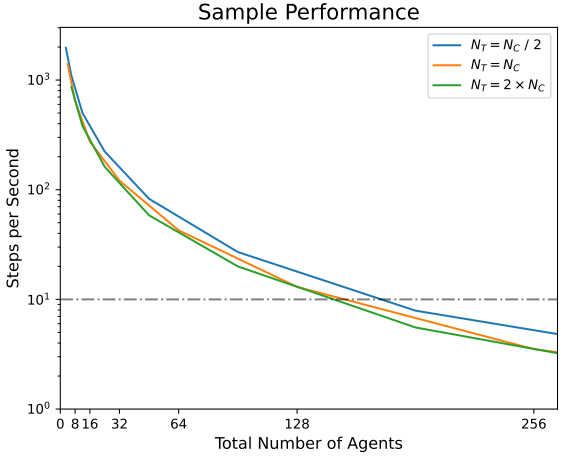
Up to hundreds of agents interact with the environment simultaneously.





Communicative Agents

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- Obtain extra information (partial observation)
- Sharing information and knowledge
- Reduce unnecessary exploration

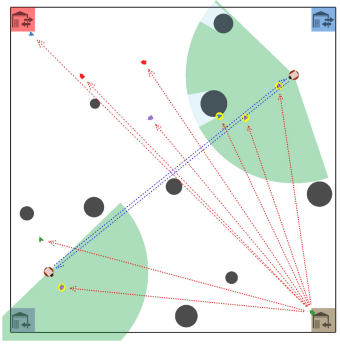
More Effective Cooperation

Two types:
- peer-to-peer
- broadcast

Multi-rounds:
- request
- response

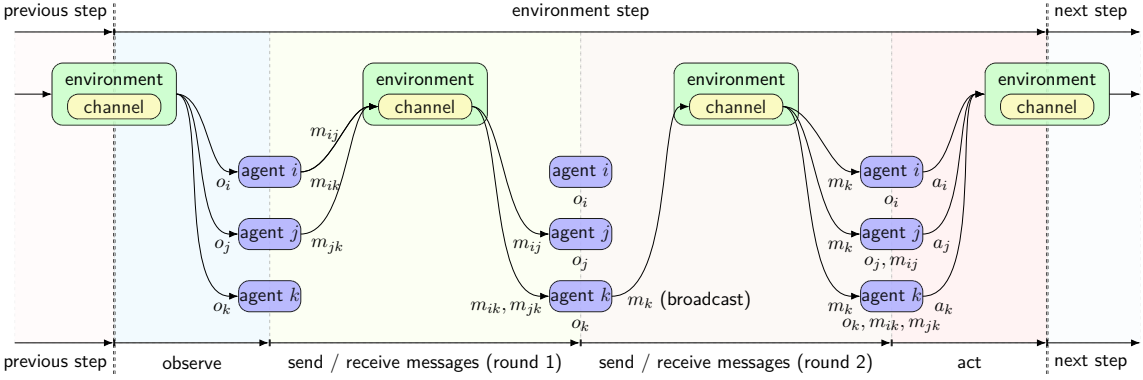
$\Rightarrow$ negotiate

Realistic:
- noise
- delay
- range restriction
- ...



- Cameras' intra-team ----------→
- Targets' intra-team ----------→

Communicative Agents



Multi-round Communication Mechanism

Communicative Agents

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- Camera 
- Target 

- Obstacle 
- Warehouse 

Rule-based Greedy Cameras vs. Rule-based Greedy Targets

Heterogeneous & Asymmetric

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Heterogeneous:

- **Inter-team**: the two types of agents have completely different dynamics and tasks.
- **Intra-team**: the "target" agents can use two different vehicles...
  - high speed and small capacity
  - low speed and large capacity

Asymmetric:

- The two sides' agents are heterogeneous.
- The game balance is affected by the capabilities of both agents.
- The size of both teams in the game is variable.

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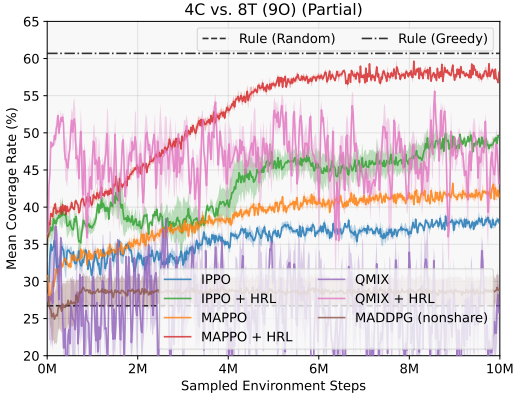
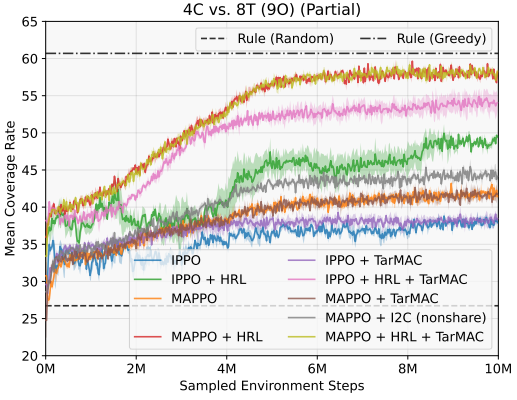
Learning Cameras in Fully-Cooperative Game

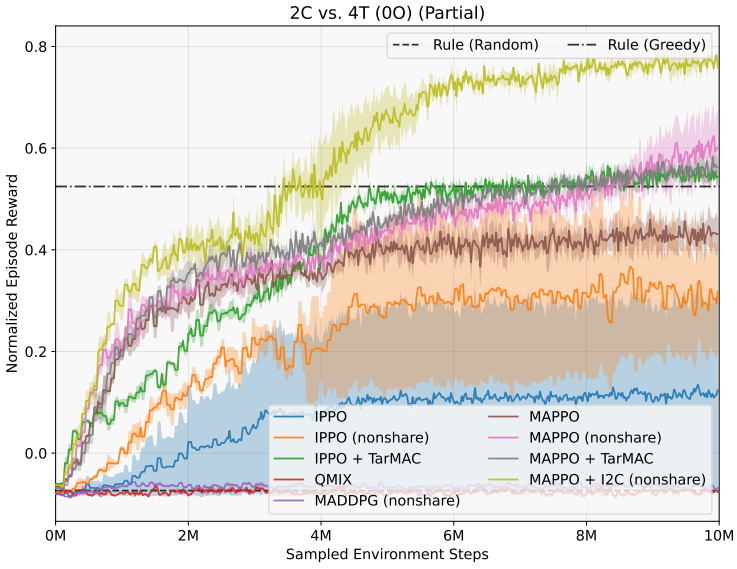


(a) MARL baselines



(b) MARL with multi-agent communication

Learning Targets in Fully-Cooperative Game



Learning Targets in Fully-Cooperative Game

Emergence of Roles via Multi-Agent Communication

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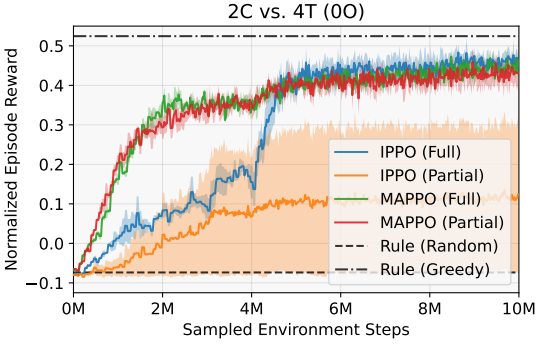
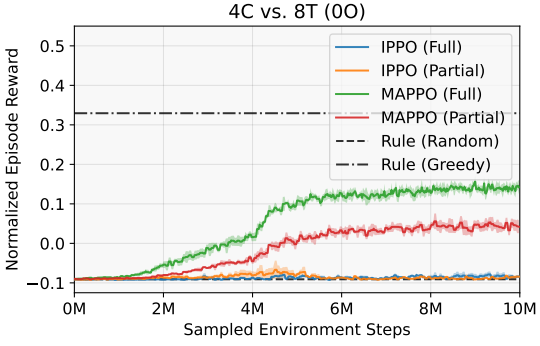
Learning Targets in Fully-Cooperative Game

Progressive Difficulty in Configurable Environments





Zero-Sum Fully-Competitive Game

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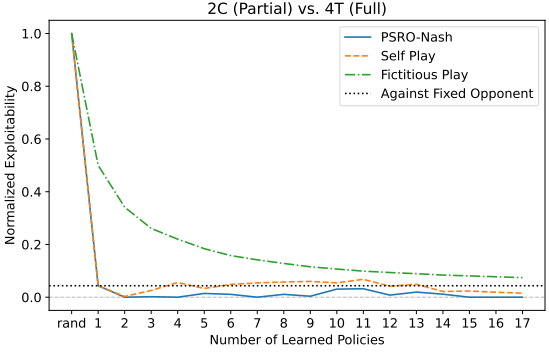
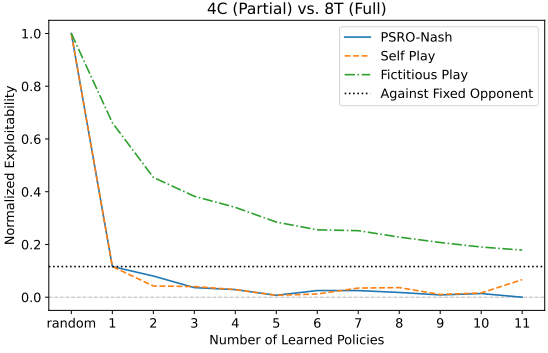
$$\text{exploitablility}(\Pi^R, \Pi^C) = \frac{1}{2} \sum_{i \in \{R,C\}} \left[U^i\left(\mathbf{BR}(\Pi^{-i}), \Pi^{-i}\right) - U^i\left(\Pi^i, \Pi^{-i}\right) \right],$$





Zero-Sum Fully-Competitive Game