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Informatics & Telematics

Development and Evaluation of Reinforcement Learning models for the FOSSBot Open-Source educational robot

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Introduction

- Machine learning for real-world challenges.
- Robotics + simulations = refined algorithms & risk minimization.
- Tasks: Obstacle avoidance and navigation.
- Agent: FOSSBot
- RL Algorithms:
  - Proximal Policy Optimization (PPO)
  - Deep Q Network (DQN)

DIKW pyramid (source)

Related Work (1)
Educational Robotics

- Great potential for tertiary education.
- RL’s adaptability + educational robots = innovative teaching methods.
- Robots’ domain & roles classification – Mubin et al. 2013 [1]
- Technical creativity, Applied knowledge, Interest boost – Ospennikova et al. 2015 [2]
- Open-source education robot – FOSSBot – Chronis and Varlamis 2022 [3]

Related Work (2)
RL, Path Planning and Obstacle Avoidance

- Traditional Path Planning methods: BFS, DFS, Dijkstra’s algorithm.
  - Need for a model of the world-map (Obstacles’ positions)
- RL methods: Through trial-and-error, maximizing cumulative rewards.
  - Dynamic-Complex environments, no model needed, only experience – Sutton and Burto 2018 [4]
- DRL for obstacle avoidance [Kinect RGBD cam] – Tai and Liu 2016 [5]
- Path planner training [Demonstration learning] – Pfeiffer et al. 2017 [6]
- UAV navigation using A2C algorithm – Chronis et al. 2023 [7]

Our Approach: FOSSBot’s terrestrial self-navigation (sensors) + RL power

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Technologies used

- Environments:
  - OpenAI Gym
  - CoppeliaSim

CoppeliaSim

- Algorithms:
  - stable-baselines3

- Data Logging:
  - Weights and Biases

Weights & Biases

- Data Visualization:
  - Python’s matplotlib

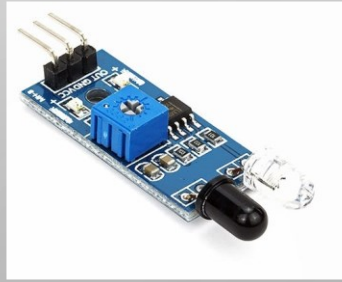
FOSSBot

- Open-source education robot
- 3D printed
- Flexible software stack
- Block-based (Blockly) or Text-based (Coding) programming

- Ultrasonic Distance Sensor (0.02 - 4m)
  - Distance, not bearing
- 3 x Infrared Obstacle Sensors (2-30cm)
  - 1: obstacle - 0: clear
- Inertial Measurement Unit (IMU)
  - Robot’s orientation & position

Software stack (source)

Ultrasonic Distance Sensor (source)



Infrared Obstacle Sensor (source)

RL Algorithms
Preliminaries

DQN – Roderick et al. 2017 [8]

Input: Observation space

Q-Value Estimation

Action Selection (ε-greedy)

Interaction & Reward

Experience Storage (replay buffer)

Weight Updates

Until Convergence

PPO – Schulman et al. 2017 [9]

Policy Initialization

Input: Observation space

Advantage Calculation

Objective Clipping

Gradient Computation

Policy Update

Epoch Iteration

Until Convergence

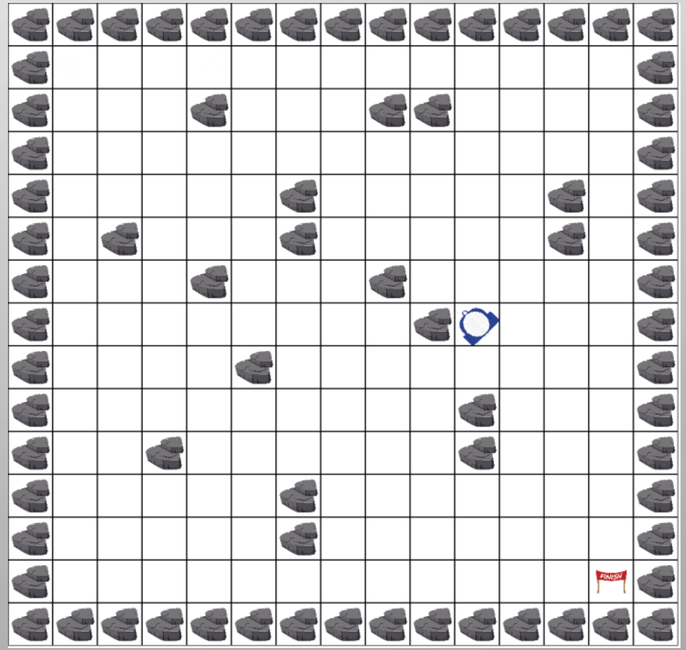
Epoch

Convergence

Experimental Setup (1)
Grid Environment

- Custom environment (OpenAI Gym).
- Action space: 3 discrete actions [Move forward, 45-degree left turn, 45-degree right turn]
- Observation space: i) Agent's angle diff from the target $\Delta\theta$ (in degrees), ii) Euclidean distance d_{eucl}, iii) Total steps (max: 200), iv) 3 IR sensors (implemented) values as a List (size: 3 / 0 or 1)
- Reward Function: $\boxed{\boldsymbol{reward = -d_{eucl}}}$
- Map: List of lists – 0: open path, 1: obstacles
- Default rewards: obstacle collision: -10,

  max steps: -10, target reached: $+1000$
- Visualization: PyGame



Grid Environment – Gym/PyGame

Experimental Setup (2)

Simulation Environment (1)

- Custom environment (CoppeliaSim).
- Action space: 3 discrete actions [Move forward, Forward-left, Forward-right]
- Observation space: i) Agent's angle diff from the target $\Delta\theta$, ii) Euclidean distance d_{eucl},

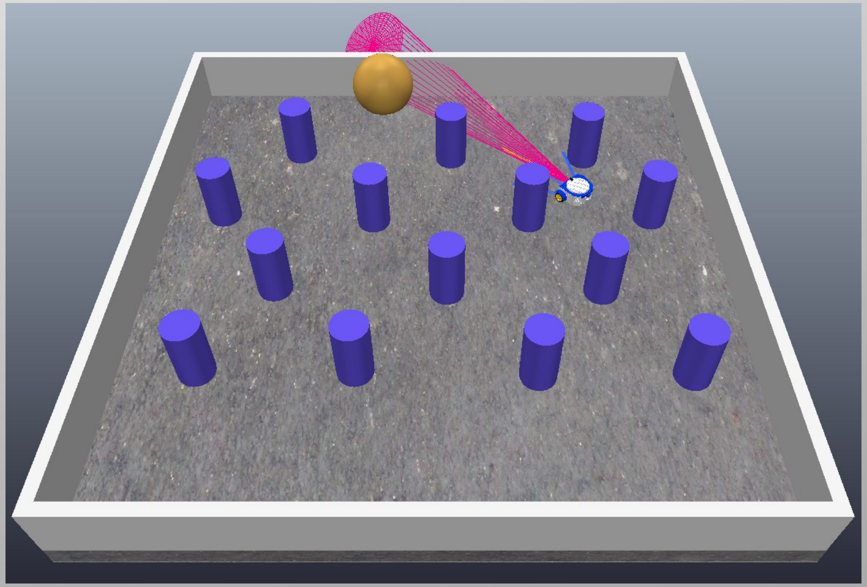
iii) Obstacle distance d_{obs} (by ultrasonic sensor), iv) 3 IR sensor binary values s_l, s_c, s_r

- Reward Function:

$$\boldsymbol{reward} = \boldsymbol{w_{obs}} \cdot \left[\boldsymbol{0.5} \cdot \left(\boldsymbol{1} - \frac{\boldsymbol{l_{arc}}}{\boldsymbol{180} \cdot \boldsymbol{d_{target}}} \right) + \boldsymbol{0.5} \cdot \left(\boldsymbol{1} - \frac{\boldsymbol{d_{target}}}{\boldsymbol{d_{max}}} \right) \right]$$

- Default rewards: obstacle collision (-100),

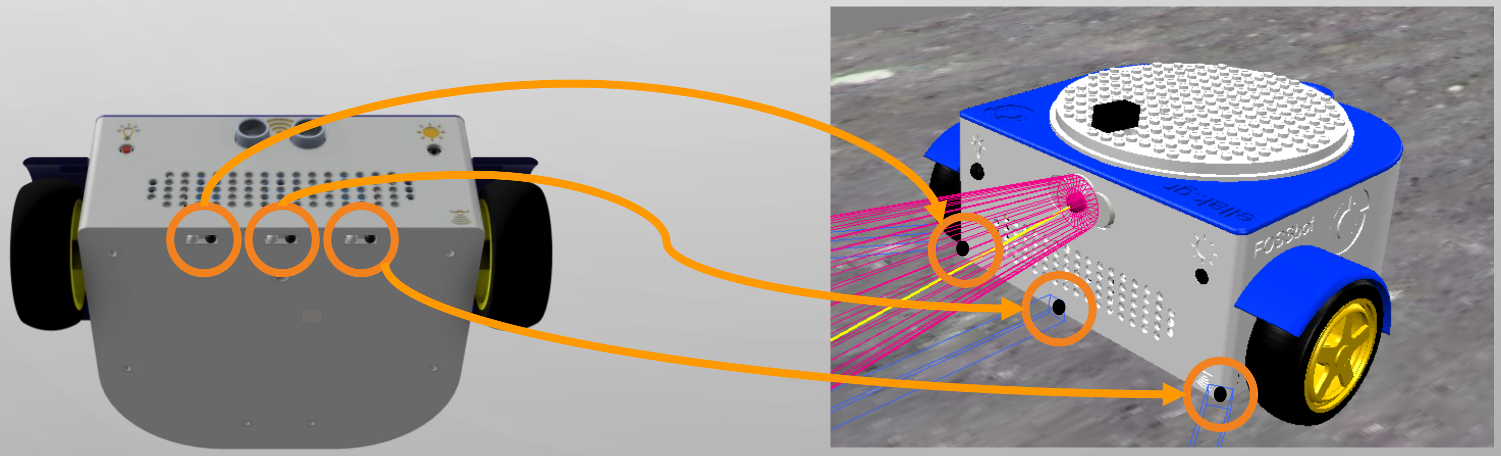
target reached $(+1000)$



Simulation Environment - CoppeliaSim

Experimental Setup (2)
Simulation Environment (2)

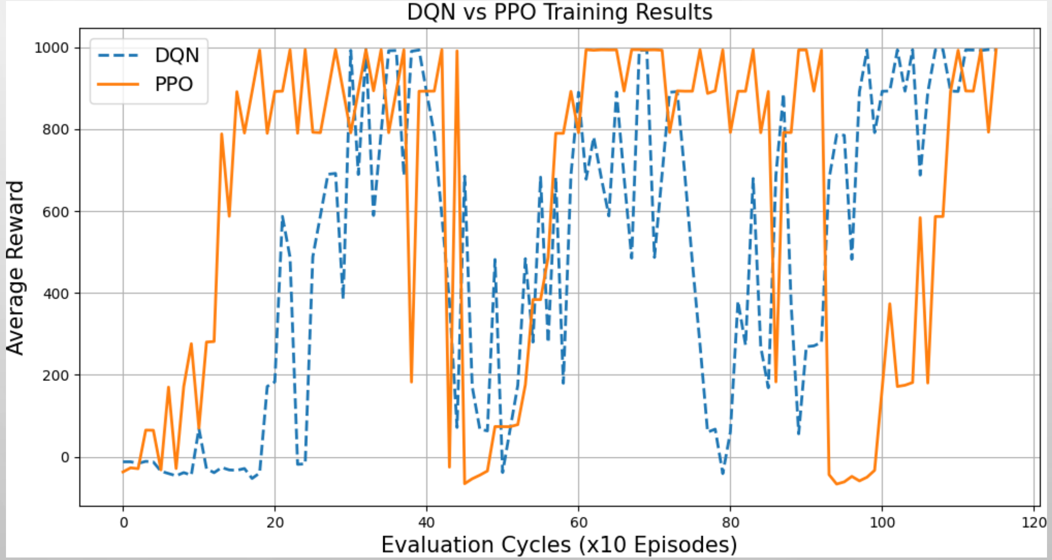
- Current FOSSBot structure – Difficulties
- Ultrasonic sensor gives distance, but not bearing.
- IR obstacle sensors come to rescue(!)
- If they detect something, we get some info about the target's bearing.



Suggested IR sensors position modification

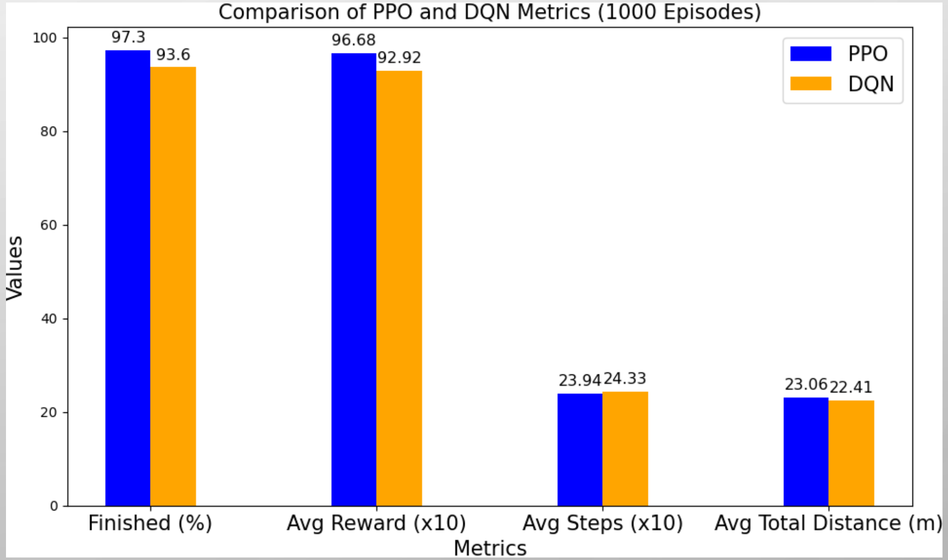
Results
Grid

Training



Evaluation Cycle: 10 evaluation episodes

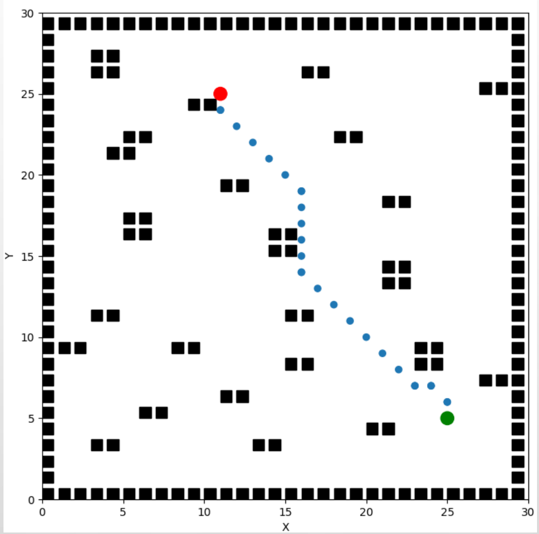
Evaluation

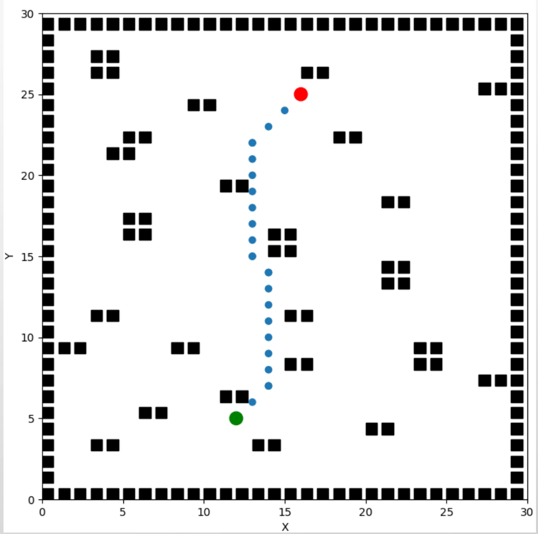


Final Evaluation: 1,000 evaluation episodes

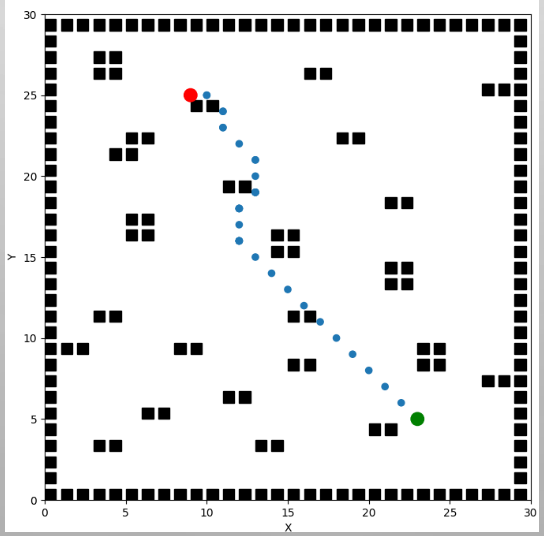
Trajectories
Grid

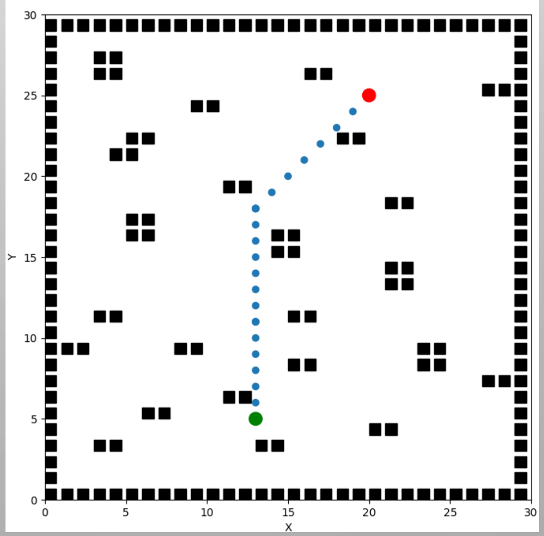
PPO-





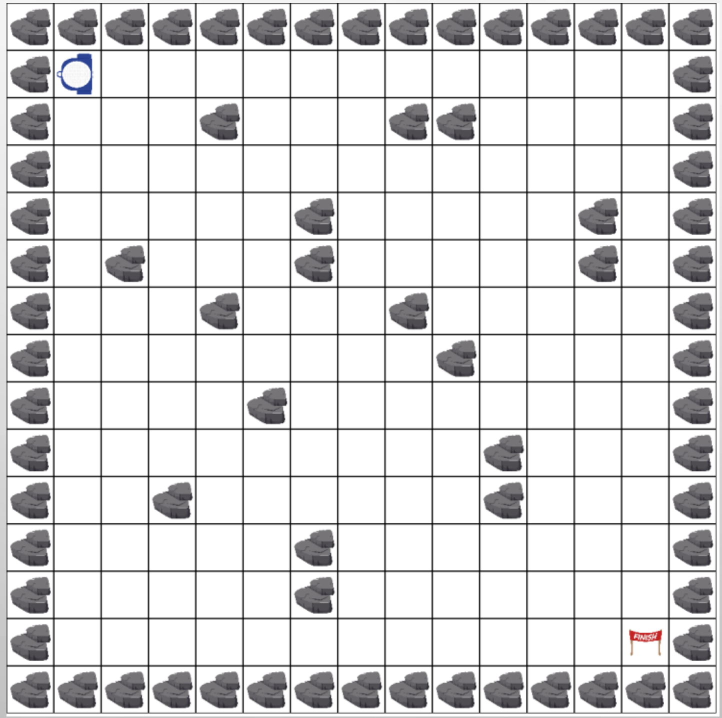
DQN-



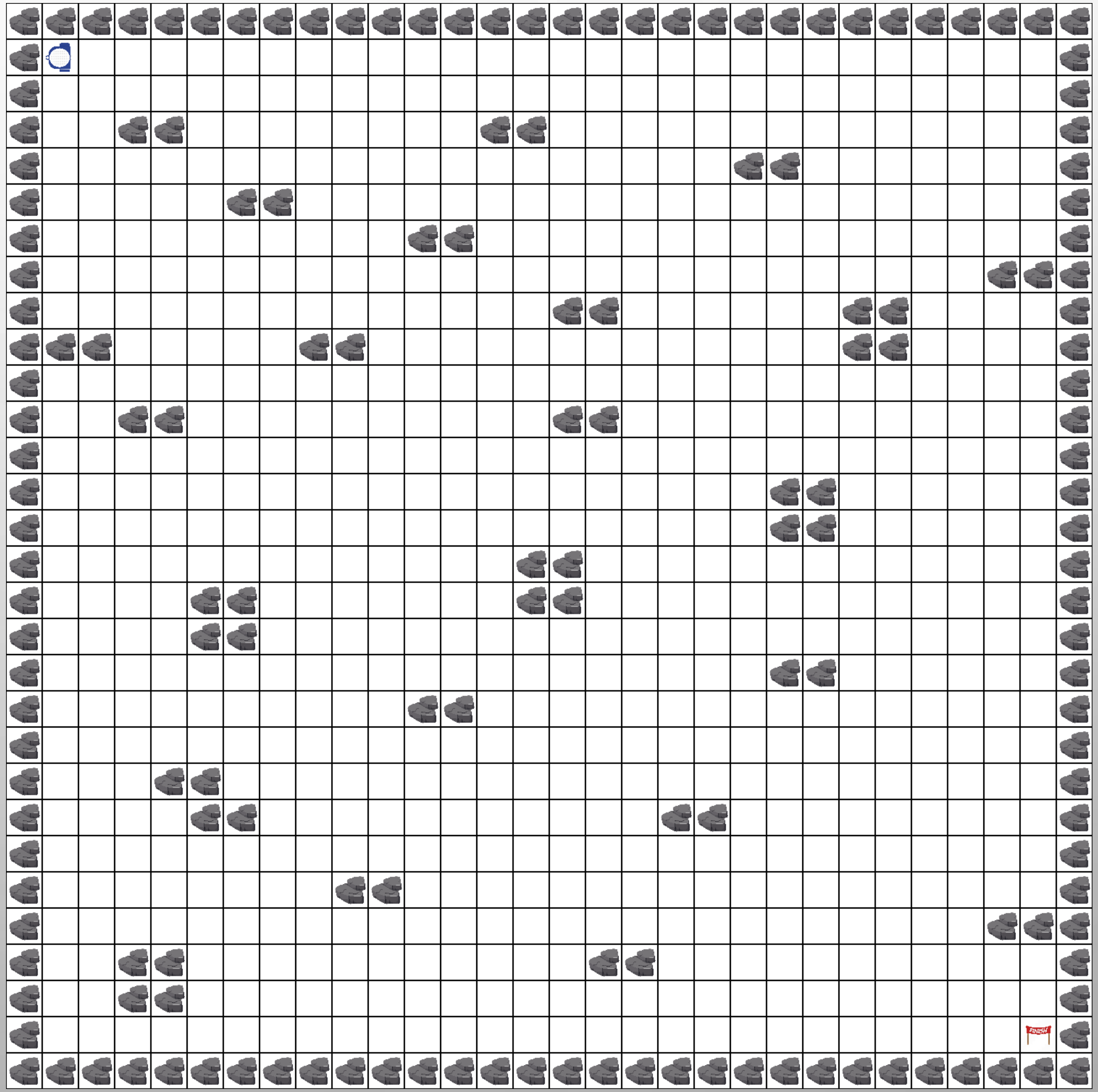


Solutions

Grid



15x15 - DQN

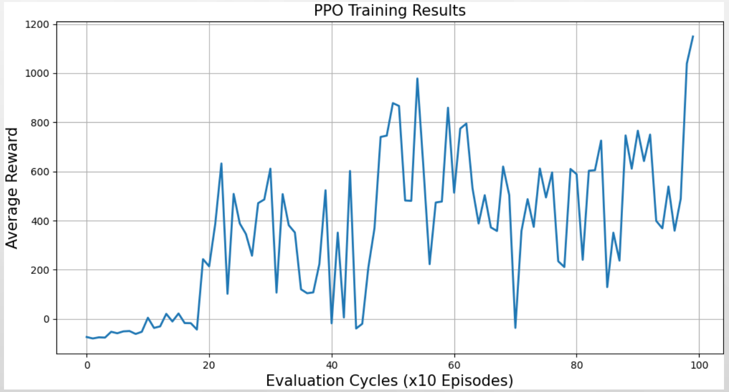


30x30 - PPO

Results

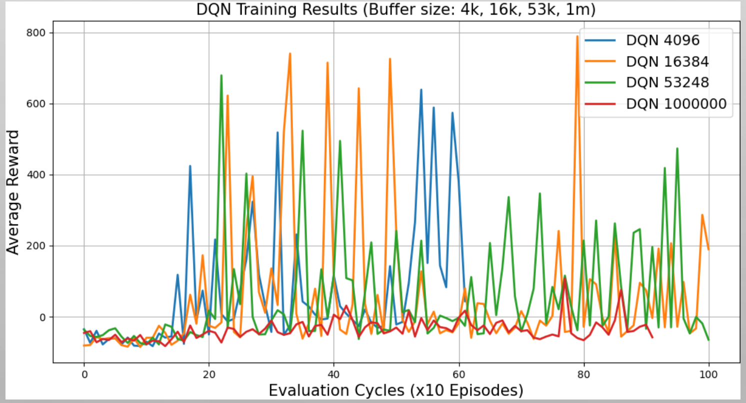
Simulation

Training



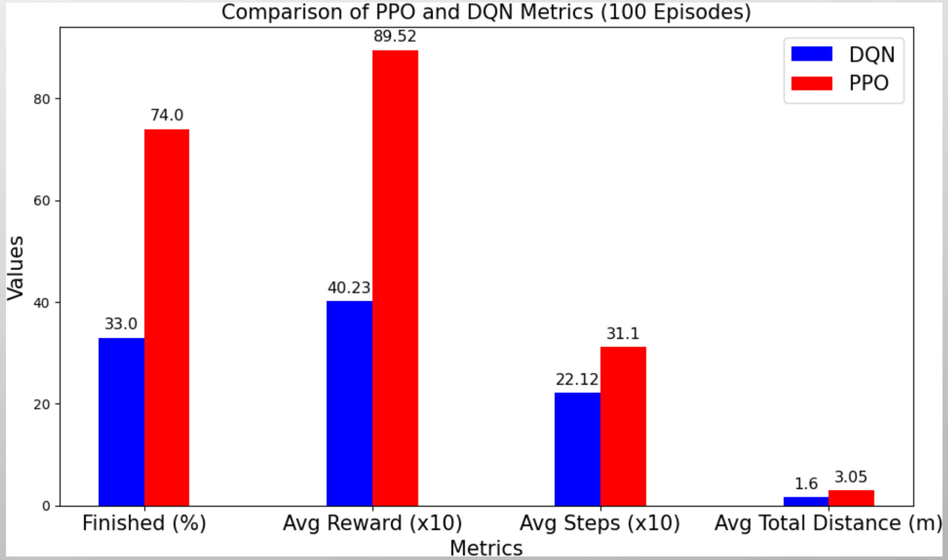
-PPO

DQN-



Evaluation Cycle: 10 evaluation episodes

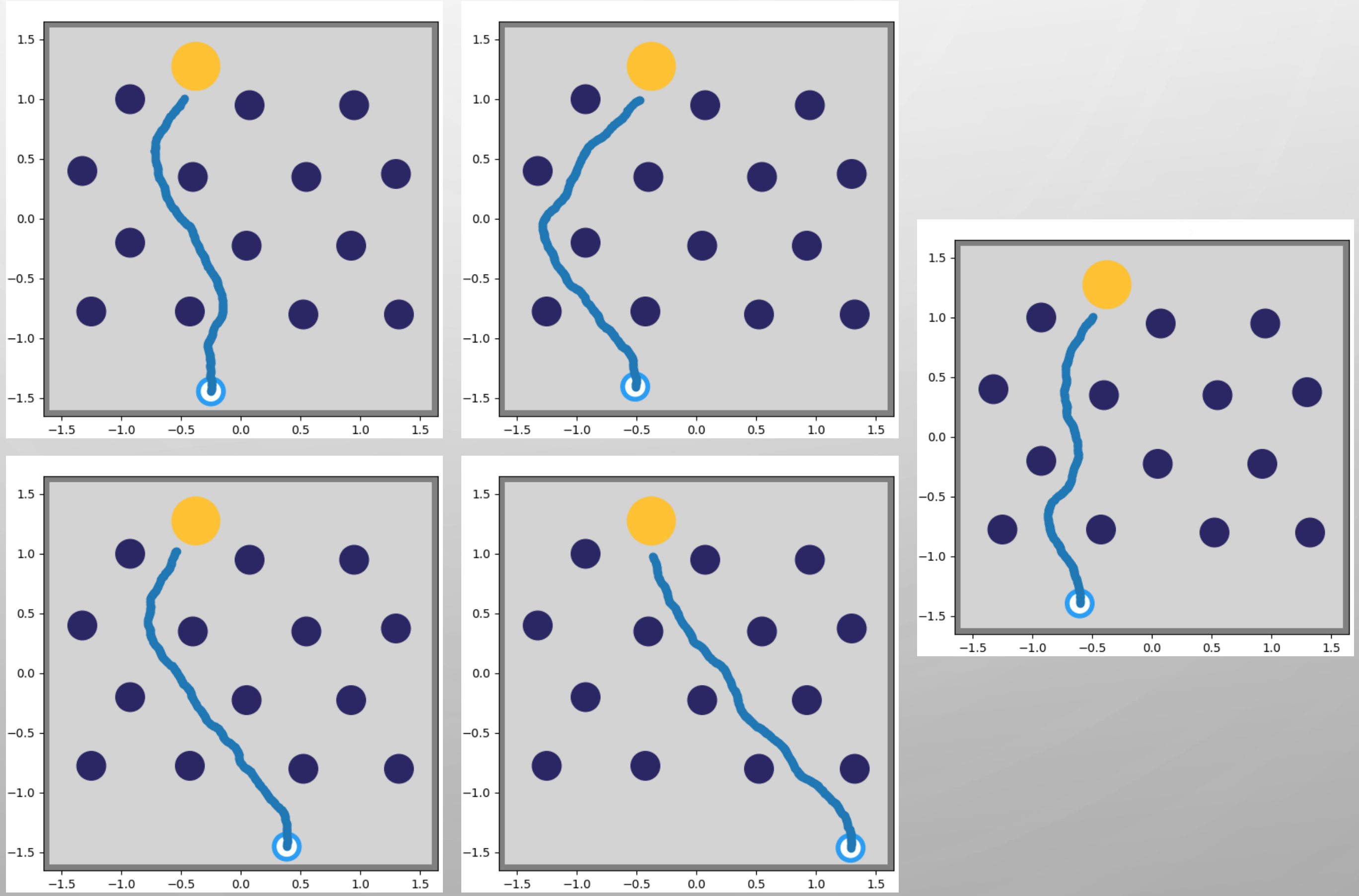
Evaluation



Final Evaluation: 100 evaluation episodes

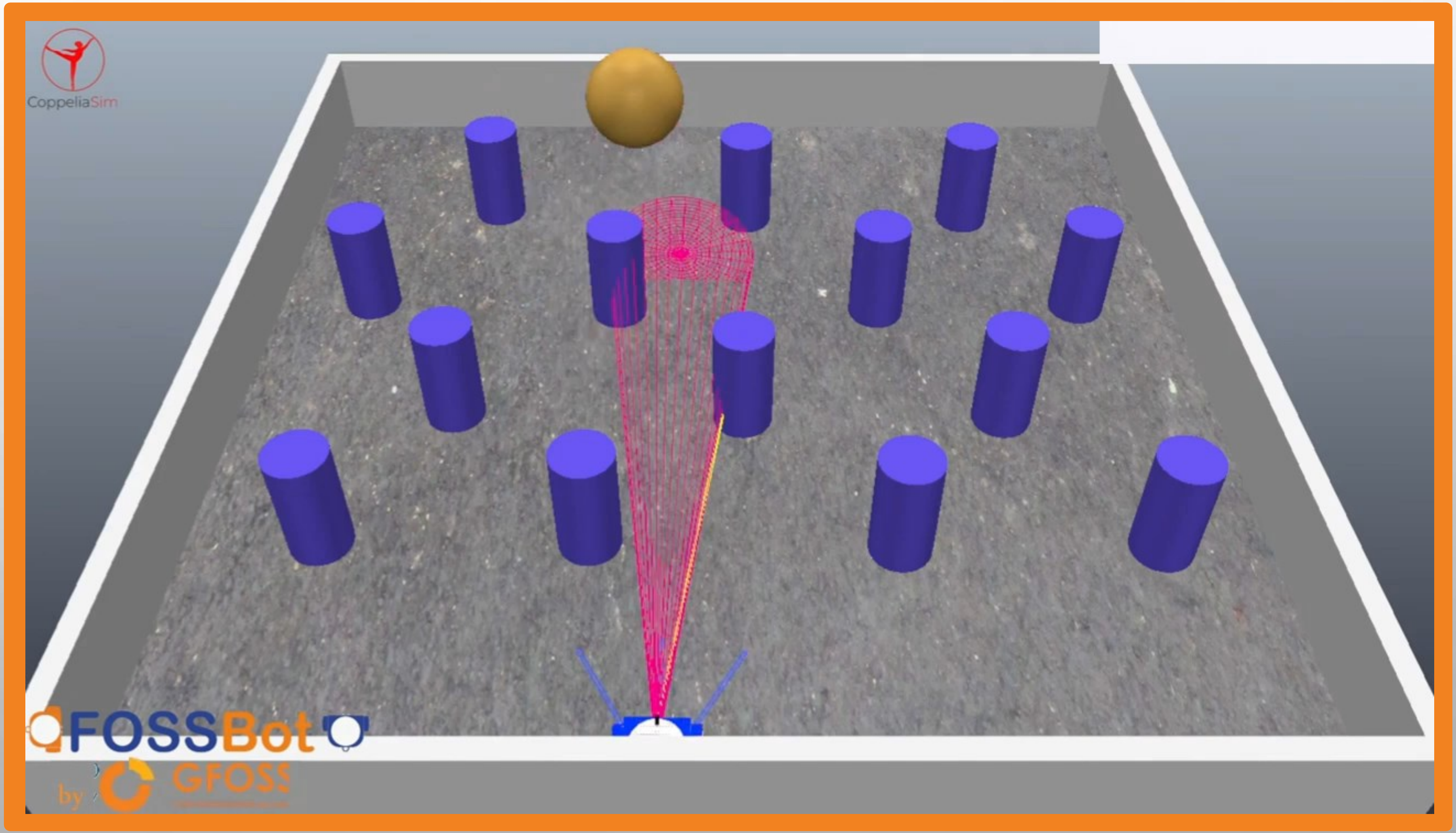
Trajectories
Simulation

PPO-



Solutions

Simulation



Conclusions

- PPO & DQN excel in simple grid environments.
- PPO outperforms DQN in complex simulations, and learns rapidly and effectively.
- FOSSBot is now autonomous in path planning.
- Future work:
  - Develop path-planning library.
  - Apply successful strategies to real FOSSBot.
  - Optimize RL algorithms.

Acknowledgments

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- FOSSBot evolution through the GSoC contest
- Buying & Assembling the first 100 robots + sending them to Greek schools
- FOSSBot in academic assignments ➡ Python programming in practice

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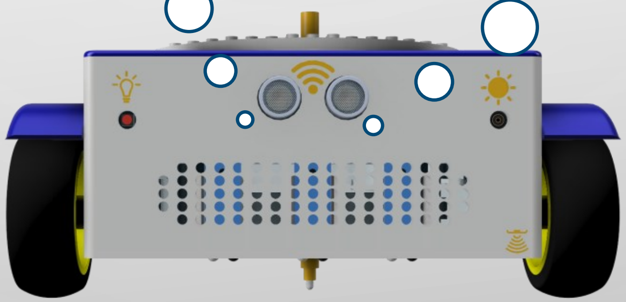
Thank you!

Finally! I know how to avoid obstacles!

Dear Lord T-800! Whatever!
Any questions?



Don't rest on your laurels buddy!
It's only the beginning!

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