Multi-UAV conflict risk analysis

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Overview

- Introduction to UAVs
- Reinforcement Learning
- My research topic
- ATC Challenge
- Your Homework

Introduction to UAVs

Why UAVs?

- High mobility in three-dimensional space
- Easy deployment
- Line-of-Sight communication
- Relatively low cost
- Vertical takeoff/landing
- Hovering

UAVs Applications

Link

- G. Silano, T. Baca, R. Penicka, D. Liuzza and M. Saska, "Power Line Inspection Tasks With Multi-Aerial Robot Systems Via Signal Temporal Logic Specifications," in IEEE Robotics and Automation Letters, vol. 6, no. 2, pp. 4169-4176, April 2021, doi: 10.1109/LRA.2021.3068114.

UAVs Applications

[Link]

- P. Petráček, V. Krátký and M. Saska, "Dronument: System for Reliable Deployment of Micro Aerial Vehicles in Dark Areas of Large Historical Monuments," in IEEE Robotics and Automation Letters, vol. 5, no. 2, pp. 2078-2085, April 2020, doi: 10.1109/LRA.2020.2969935.

UAVs Applications

Link

- DOFEC: Discharging Of Fire Extinguishing Capsules. Work in progress but you can find additional information **here**

Some other UAVs Applications

- Aerial base stations to provide services after a natural disaster, for network access in remote areas and rescue support
- To collect data from sensors and deliver them in emergency applications
- Surveillance tasks in risky and dangerous areas
- Cargo and goods delivery to supply food and medical goods
- In agricultural field to monitor and facilitate farming activities

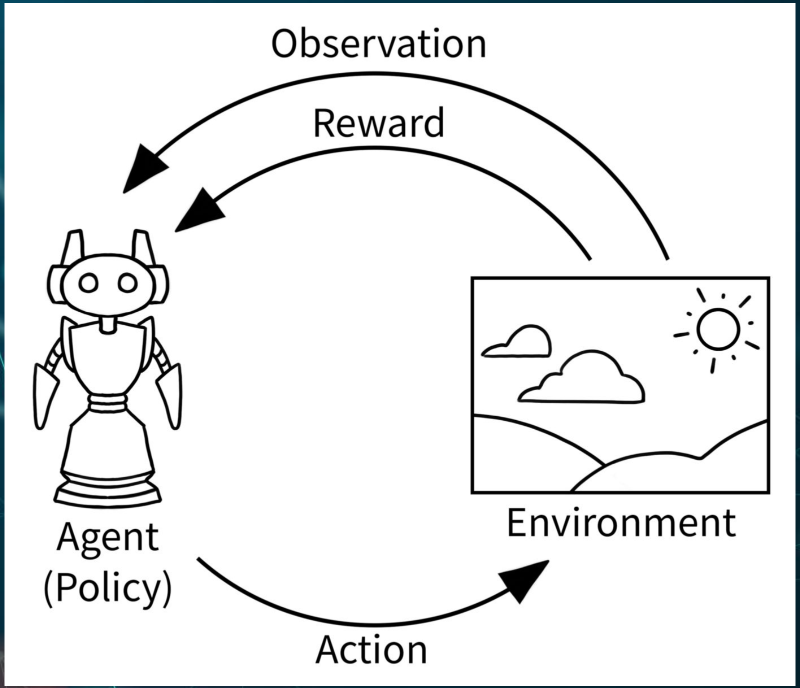
Increasing Interest in this Sector

- European Drone Outlook study [1] forecasts:
  - Increasing number of drones for government and commercial missions
  - More funds in R&D
- European Projects:
  - BUBBLES
  - RAPID
  - AERIAL-CORE
  - etc.

[1] Single European Sky ATM Research 3 Joint Undertaking, European drones outlook study : unlocking the value for Europe, Publications Office, 2017, https://data.europa.eu/doi/10.2829/085259

Reinforcement Learning

Reinforcement Learning



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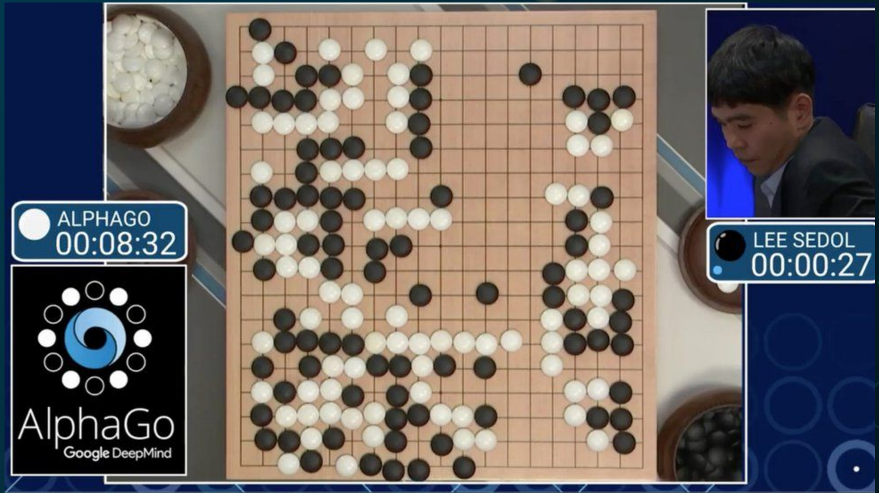
RL Advantages

- Learning through trial-and-error
- Ability to generalize to unseen scenario
- Model (dynamics) of the environment is not always needed
- Strong research base

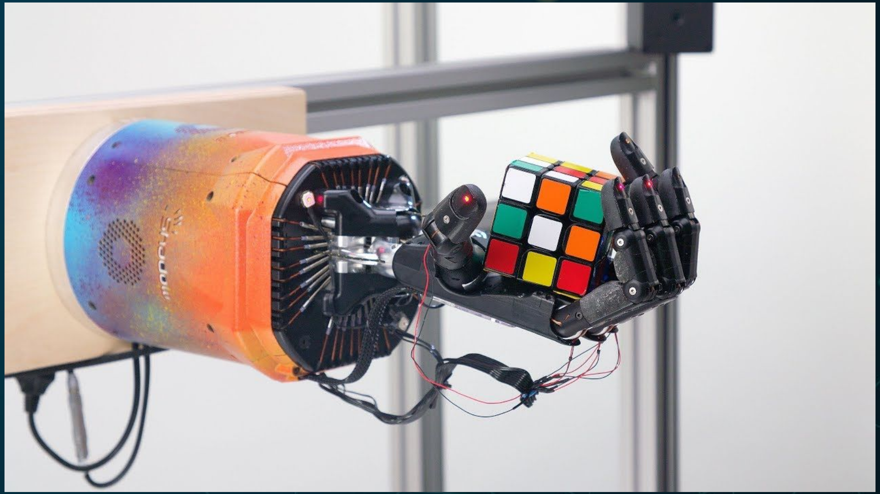
Reinforcement Learning Achievements



Mnih, V., Kavukcuoglu, K., Silver, D. et al. Human-level control through deep reinforcement learning. Nature 518, 529–533 (2015). https://doi.org/10.1038/nature14236

Silver, D., Huang, A., Maddison, C. et al. Mastering the game of Go with deep neural networks and tree search. Nature 529, 484–489 (2016). https://doi.org/10.1038/nature16961

Reinforcement Learning Achievements



Berner, C., Brockman, G., Chan, B., Cheung, V., Dębiak, P., Dennison, C., ... & Zhang, S. (2019). Dota 2 with large scale deep reinforcement learning. arXiv preprint arXiv:1912.06680.

Akkaya, I., Andrychowicz, M., Chociej, M., Litwin, M., McGrew, B., Petron, A., ... & Zhang, L. (2019). Solving rubik's cube with a robot hand. arXiv preprint arXiv:1910.07113.

My Research Topic

Multi-Agent Reinforcement Learning

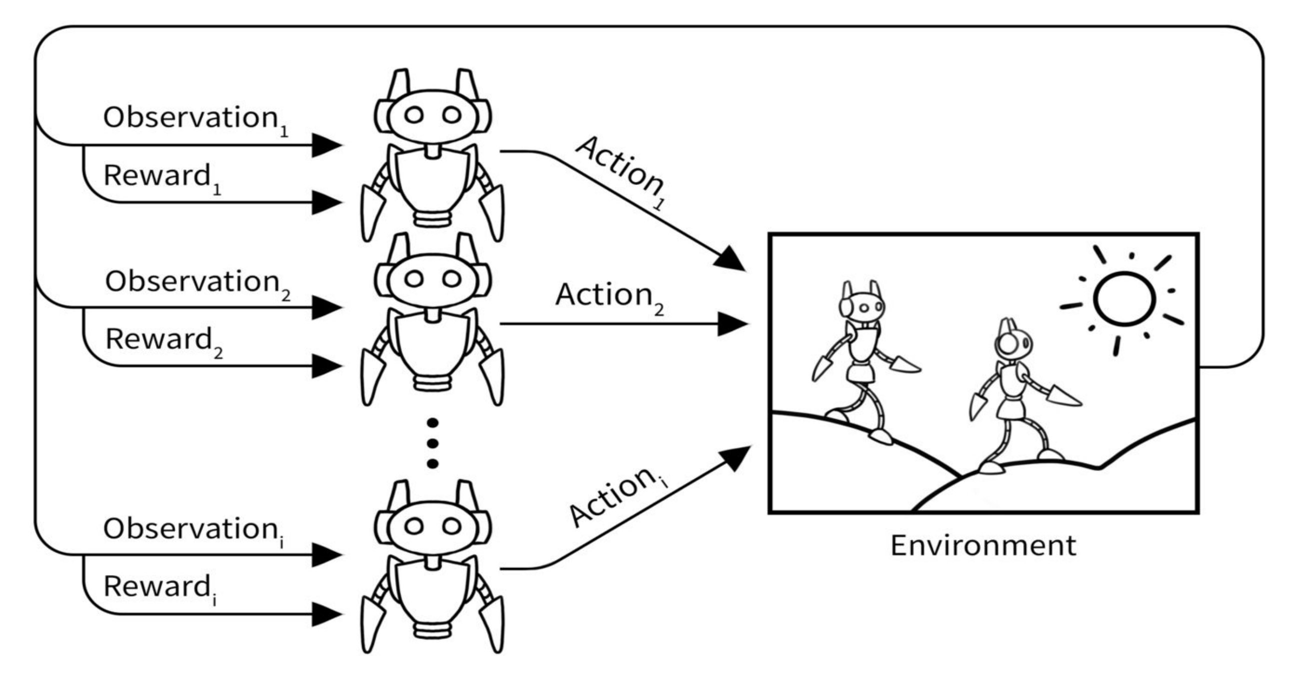


Image Source

My Goal

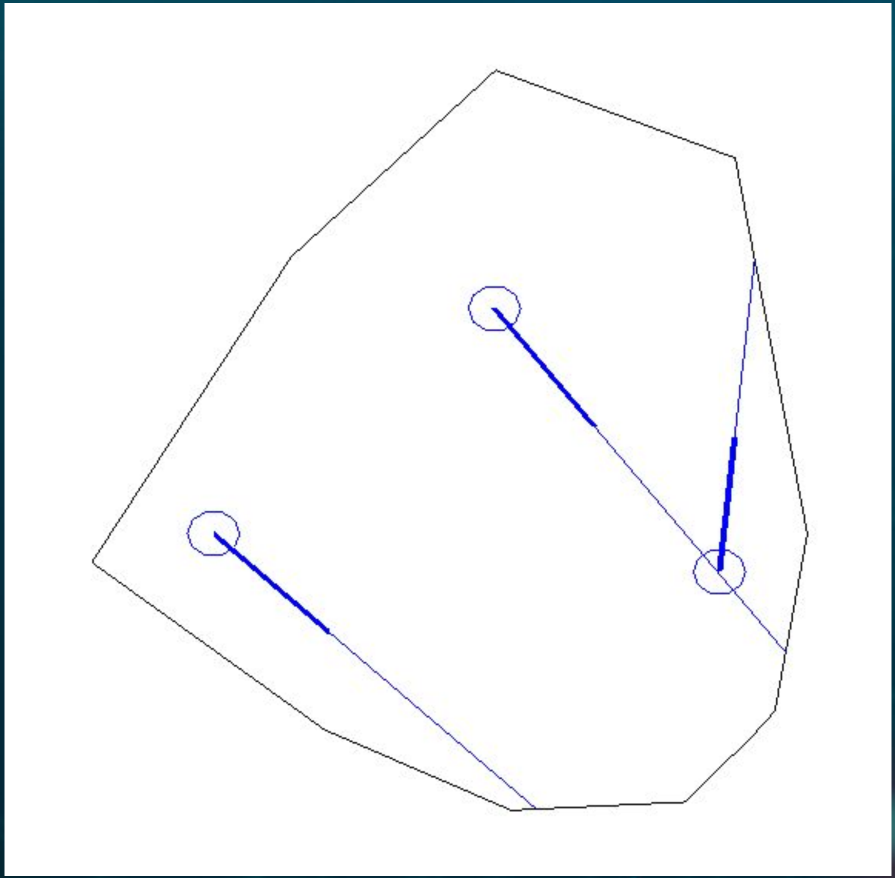
- Apply Reinforcement Learning to Heterogeneous Multi-Agent systems such as:
    - Mixed human-machine teams
- Develop Novel framework and algorithms
- Improve Sample efficiency (practical applicability)

ATC Challenge

The ATC Challenge

- Drone deconfliction with Reinforcement Learning
- They provide an Air Traffic Control (ATC) environment built on the Gym python framework and based on the shapely library.
- The Airspace, is a 2D convex polygon
  - UAVs randomly generated inside the polygon
  - Target points situated on the edges of the polygon

Example of configuration with 3 UAVs



The Task

- Define:
  - The observation function
  - The reward function
  - The action space (e.g., heading change, speed change)

- Train the optimal policy using a reinforcement learning algorithm of our choice

Bonus Points

- Implement uncertainty
- Implement weather (wind)
- Implement 3D

Evaluation

Based on:

- The performance of our model (number of conflicts, extra distance, number of required actions etc.)
- Scalability of the solution
- Originality
- Bonus tasks

What we did

- Distributed solution
- Developed a Curriculum learning
- Local observations

Your Homework

Tasks

- Classification Task
- Regression Task

Dataset

You will be provided with a dataset in a .tsv format
(tab-separated values)

Dataset Structure

For each UAV you will have:

UAV_1_track	UAV_1_x	UAV_1_y	UAV_1_vx	UAV_1_vy	UAV_1_target_x	UAV_1_target_y
0.02706824578082	-62300.5917212185	-59305.6820676595	6.70568356002059	247.671969782037	-59569.480481833	41566.9126943863
4.02310092358072	-17220.6125704085	47439.5869092574	-167.653031097199	-138.169552871066	-98139.2589880163	-19248.6985412498
1.84199432853569	-19900.3504378451	59030.8335952098	208.716696749697	-58.0333283538021	70435.2775605812	33913.1633593367

Features

FOR EACH UAV:

- **UAV_i_track**: clockwise angle from north between the ith UAV and its target $(0, 2\pi)$:
- **UAV_i_x, UAV_i_y**: position components of the ith UAV in meters
- **UAV_i_vx, UAV_i_vy** (dx, dy): speed components of the ith UAV in meters/seconds
- **UAV_i_target_x, UAV_i_target_y**: position components of the ith UAV target in meters

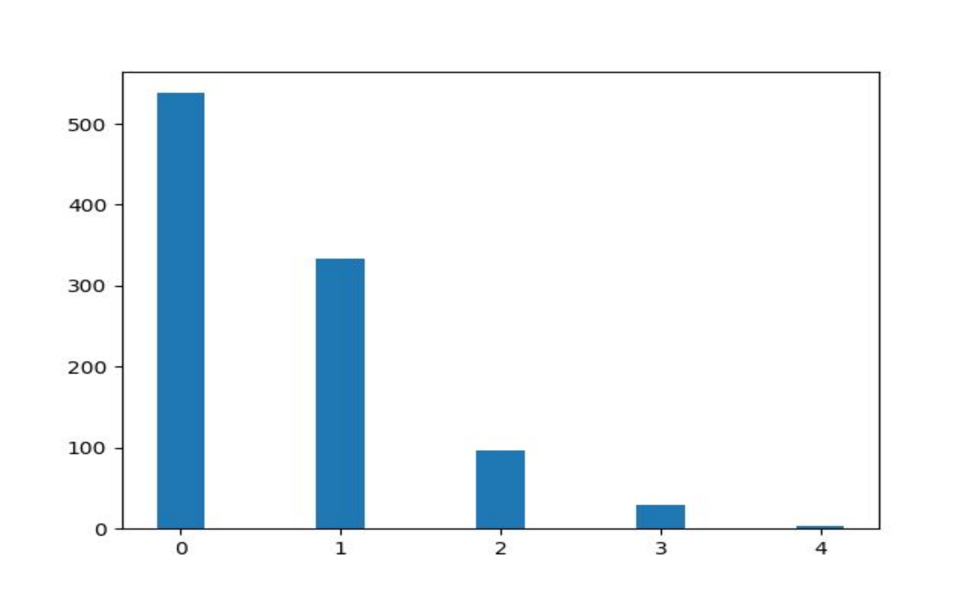
Your Homework

1. **Classification problem**: estimate the total number conflicts between UAVs given the provided features
2. **Regression problem**: predict the minimum Closest Point of Approach (CPA) [1] among all the possible pairs of UAVs

[1] **CPA**: An estimated point in which the distance between two objects, of which at least one is in motion, will reach its minimum value

Classification

Predict the number of collision between the UAVs given the previous features. You will have 4 classes and the dataset is unbalanced



What you have to do

- Use at least two methods for both the classification and the regression tasks.
- Compare the two methods
- Write a report
  - Describe what you tested
  - Include metrics (precision, confusion matrix, f1, recall, etc.)
- You can use the sklearn library and all the algorithms studied up until now during the ML course

What you can and can't do

- You can't use **Neural Networks**
- You need to use a **Machine Learning algorithm**

A Few Tips

- Remember to normalize the data (**All!**)
- Try different hyperparameters (**Grid Search**)
- Try ensemble models
- Pay attention to overfitting

Evaluation

- Clarity of the report
- Experiments
    - Don’t focus too much on the score
    - Try to explain why one method is working better than another

Pandas Snippet

To load the dataset

```
import pandas as pd
dataset = pd.read_csv("train_set.tsv", sep='\t', header=0)
```

To access the column by index

```
X = dataset.iloc[:,:-2]
y = dataset.iloc[:,-2]
```

To access the column by name

```
uav_1_x= X['UAV_1_x']
```

Sklearn functions accept pandas dataframe as input

For an introduction to pandas click here

Thanks!
Questions?