

# Reinforcement learning project

Elie KADOCHE

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This is a reinforcement learning project on policy gradient methods. In this document you will find the instructions. More explanations will be given in the board during the practical sessions. Do not hesitate to ask for help if you need to. The overall project will be noted on 20. The notation is given for information and may slightly change. Your solutions will be gathered in a document and in the code.

- In the document, you will write your answers, thoughts and approaches for each section. Even if you do some mistakes, you can describe them and explain how you corrected them. It will be taken into account in the notation.
- In the code, each time there is a comment "`→ TODO`", there is some code missing that you need to write. Be mindful of the code quality. Each line of code should be associated to a comment where you describe what you do.

## 1 Setting up

You need to install Python 3.8+ on your machine. Open a terminal, go into this directory and install required packages.

```
pip install -r ./documents/requirements.txt
```

## 2 Cartpole environment (/2)

Your objective is to understand how the cartpole environment works and what is the problem we want to solve. The environment is in the "`./src/envs/cartpole.py`" file.

You can read the section 5 of the "`./documents/cartpole.pdf`" document for help. You can use script 0 to test a random policy on the environment.

You do not need to write any code for this section. Determine the states, the rewards and the actions. Write the Markov Decision Process associated to the problem.

```
python ./0_test_env.py
```

### 3 Policy deep neural network (/2)

We want to build a policy  $\pi_\theta(a|s) = P(a|s, \theta)$  that gives the probability of choosing an action  $a$  in state  $s$ . The policy is a deep neural network parameterized by some weights  $\theta$ . The policy is also referred to as "actor" and is defined the `"./src/models/actor.py"` file.

Depending on what you understood from the cartpole environment, you need to change in the actor code the `input_size` and `nb_actions` variables. In script 1, you need to find how to select an action from the output of the policy. Then, you can use the script 1 to test the policy. How does the policy performs on cartpole? Why?

Check the `"./documents/neural_network.py"` file to see how to train a deep neural network with PyTorch and how it can be trained with the gradient descent method. Execute it with `python ./documents/neural_network.py`.

```
python ./1_test_model.py
```

### 4 REINFORCE algorithm (/6)

We want to find the parameters  $\theta$  that maximize the performance measure  $J(\theta) = \mathbb{E}_{\pi_\theta}[G_0]$  with  $G_t = \sum_{k=0}^{\infty} \beta^k r_{t+k+1}$  and  $\beta \in [0, 1]$  being a discount factor. To do so, we use the gradient ascent method:  $\theta_{k+1} = \theta_k + \alpha \nabla_{\theta_k} J(\theta_k)$  with  $\alpha$  being the learning rate.

The performance measure depends on both the action selections and the distribution of states. Both are affected by the policy parameters, which make the computation of the gradient challenging.

The policy gradient theorem gives an expression for  $\nabla_{\theta} J(\theta)$  that does not involve the derivative of the state distribution:  $\nabla_{\theta} J(\theta) = \mathbb{E}_{\pi_\theta}[\sum_{t=0}^{\infty} G_t \nabla_{\theta} \ln \pi_\theta(a_t|s_t)]$ . The expectation is over all possible state-action trajectories over the policy  $\pi_\theta$ .

In the REINFORCE algorithm, we use a Monte-Carlo estimate over one episode, i.e., trajectory:  $\nabla_{\theta} J(\theta) = \sum_{t=0}^{\infty} G_t \nabla_{\theta} \ln \pi_\theta(a_t|s_t)$ .

Your objective is to complete script 2 to train the policy according to the REINFORCE method. After each training, you can use script 3 to test your policy.

1. Write the code to compute the discounted sum of rewards (/1).
2. Write the REINFORCE loss for the policy (/3).
3. Change the  $\alpha$  and the  $\beta$  parameters to solve the problem (/1).
4. Find a good metric to know when to stop the training of the policy (/1).

```
python ./2_reinforce.py
python ./3_test_model.py
```

## 5 Markov property (/5)

In the `./src/envs/cartpole.py` file, remove the accelerations from the states. Update the `./src/models/actor.py` network accordingly. Test and train back a model with scripts 1 and 2. Does it converge? Why?

Find a way to modify the states in `./src/envs/cartpole.py` file, without the accelerations, so that the environment becomes Markovian again. Update the `./src/models/actor.py` network accordingly and train the model back again. Does it converge? Why?

```
python ./1_test_model.py
python ./2_reinforce.py
python ./3_test_model.py
```

## 6 Open questions (/5)

You can choose to work on one or several of the following subjects. You are also encouraged to work on other subjects, if you have any ideas.

### 6.1 Different environments (moderately easy)

You can find other reinforcement learning problems with their corresponding environments on Internet and adapt your REINFORCE training script to solve it. You could also create your own simple reinforcement learning problem, determine the states, the actions, the rewards and code your own environment to solve it.

### 6.2 REINFORCE with baseline (moderately difficult)

To reduce the variance of the REINFORCE method, we can subtract to  $G_t$  a baseline  $v(s_t)$ . With  $v(s)$  being the estimate of the state value given by another neural-network, called critic. Based on the actor network, build the network for the critic in the `./src/models/critic.py` file. And based on the REINFORCE script 2, build the `./4_baseline.py` training script. Use script 5 to test your model.

```
python ./4_actor_critic.py
python ./5_test_model.py
```

### 6.3 Continuous actions (difficult)

In this project, we considered a discrete action space. How could we use policy gradient methods for continuous action spaces? You can give your ideas, you can code them, and ultimately, you can even find an environment with a continuous action space and try to solve it.