Artificial Intelligence: Programming 3 (P3)
Reinforcement Learning

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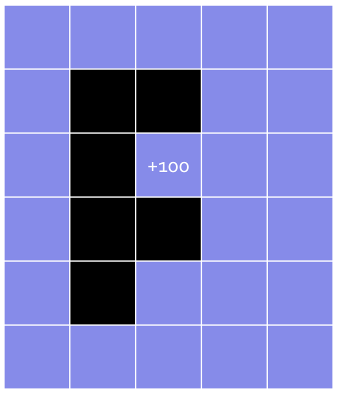
Due Time: 10PM, 12/3/2020

In this project, we aim to implement one of Reinforcement Learning algorithms: the `Q-Learning` algorithm.

1 Instructions

We extend the windy maze defined in P1 with probabilistic outcome after an action and one terminal state (top left) with a reward +100. It becomes a MDP problem. The maze map is shown in the following figure. However, we assume that the agent doesn't know either the reward function or the



transition model. The agent aims to run many trials in order to obtain Q-value for each (state, action) pair and the optimal action at each state.

Environment In your implementation, you need to simulate the windy maze environment: We assume that the wind comes from the north and the cost of one step for the agent is defined as follows: 1 for moving southward; 2 for moving westward or eastward; 3 for moving northward. The reward will be the negation of the reward. The agent can drift to the left or the right from the perspective of moving direction with probability 0.15. If the drifting direction is an obstacle, it will be bounced back to the original position. If the agent falls into any terminal state, it can't move out.

Reinforcement Learning In your implementation, you will generate many trials, each of which will result in a trajectory of (state, action, reward) tuple. The agent will use the ϵ-`Greedy` algorithm to choose an action at each state along each trajectory, where $\epsilon = 0.05$: the agent chooses a latest optimal action at each state with 95% and a random action with 5%. The initial state for each trial is chosen randomly and each trial will end at the goal state. Along each trajectory, the agent will use `Q-Learning` to update the Q-values. Since the reward function $R(s, a)$ here depends on both the state and the action taken at this state, the Q-value update equations should be revised accordingly.

$$N(s,a) \leftarrow N(s,a) + 1 \tag{1}$$

$$Q(s,a) \leftarrow Q(s,a) + \frac{1}{N_{s,a}} \Big(R(s,a) + \gamma \max_{a'} Q(s',a') - Q(s,a) \Big) \tag{2}$$

We choose $\gamma = 0.9$.

Testing and Outputs In your testing, generate 10,000 trials starting from a random open square. We initialize the Q-values at any state-action as 0 except for one terminal state with +100 respectively. If the number of steps of a trial is more than 100, you can abort this trial and continue with next trial to save time. After 10,000 trials (including the aborted trials), report the following three outcomes for each algorithm:

- the access frequency at each state-action $N_{s,a}$;
- the Q-value function at each state-action $Q(s,a)$;
- the optimal action at each state-action.

The expected outcome should look like as follows:

- **Table of $N(s,a)$:**

```
      28                 72                 689                85                 38

 36         2071    63         3596   128        8347    93          86    35          45

     285                406                175                6643               2711

     1584                                                      309                139

 150         53             ####               ####      335        328    1015        155

     1235                                                     26916              11212

      38                                                       428                167

 44          37             ####               +100      35796      474    13041       185

     2929                                                      484                503

      68                                                      25141              1836

 70          69             ####               ####      312        342    16690       256

     4526                                                      312                245

     107                                        83            10266              13045

 132        110             ####          70        5767    871        163    162         179

     7730                                      115             154                223

     260                149                172                8794               5131

 243        5352    157        9061   187       12647   128        147    88          78

    12459               1934               934                539                578
```

- **Table of $Q(s,a)$:**

```
    -1.1              6.4               8.2               22.5              20.3
-3.3     1.7      1.7     12.4      9.7     22.7      22.2    26.0      24.8    24.2
    -4.7              -2.3              8.8               33.7              30.4
    -4.5                                                  31.2              27.9
-6.0    -6.5          ####              ####          40.6    39.5      33.5    33.9
    -6.2                                                  51.7              41.7
    -7.8                                                  48.8              36.9
-6.9    -7.1          ####              +100          67.7    40.5      47.3    35.3
    -6.7                                                  54.4              39.8
    -8.4                                                  46.7              33.6
-7.5    -7.1          ####              ####          43.3    31.7      37.1    28.9
    -6.8                                                  30.0              28.2
    -8.5                                10.8              28.1              25.5
-7.4    -7.2          ####          5.5     13.4      15.2    19.7      22.3    18.6
    -6.3                                4.5               9.1               13.9
    -7.6              -4.3              4.9               13.9              14.1
-7.1    -4.9      -5.5    -0.5      -0.0     6.4      7.2      8.9      9.0      8.3
    -5.9              -5.4              -3.9              -2.1              -2.3
```

- **Table of the optimal policy:**

```
>>>>    >>>>    >>>>    vvvv    vvvv

^^^^    ####    ####    vvvv    vvvv

vvvv    ####    +100    <<<<    <<<<

vvvv    ####    ####    ^^^^    <<<<

vvvv    ####    >>>>    ^^^^    ^^^^

>>>>    >>>>    >>>>    ^^^^    ^^^^
```

  where `<<<<`: moving westward; `^^^^`: moving northward; `>>>>`: moving eastward; `vvvv`: moving southward; +100: the terminal reward.

For the first two tables, it is expected that the trend of your outputs should match the above while the exact values could be very different from the above due to the random operations. For the last table regarding the optimal policy, most actions of your output should match exactly with above.

2 Submission

Form a group on Canvas if you want to work with another student. You are going to report the following things:

(a) Describe in details how you implemented the following modules in the report: `environment simulation`, ϵ-`greedy`, and `Q-learning update`.

(b) Comment your code in details so that the grader can understand it well.

(c) Include the screenshots of all above testing outcomes. Each screenshot should include your username and the current time, which show that you did it by yourself.

(d) Specify the contribution made by each member if you work as a group.

The report should be written in a ".docx", ".doc", or ".pdf" format. Submit both the report and the source code to the assignment folder P3 on Canvas. Any compression file format such as `.zip` is not permitted.