Armando Ordorica
1005592164
Exercise 1
APS 1080
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APS 1080 REINFORCEMENT LEARNING - ASSIGNMENT 2

ARMANDO ORDORICA
STUDENT ID: 1005592164
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Exercise 3.7

Imagine that you're designing a robot to run a maze. You decide to give it a reward of +1 for escaping from the maze and a reward of zero for all other times.

The task seems to break down naturally into episodes — the successive runs through the maze — so you decide to treat it as an episodic task, where the goal is to maximize expected total reward. After running the learning agent for a while, you find that it is showing no improvement in escaping from the maze.
What is going wrong? Have you effectively communicated to the agent what you want it to achieve?

Escaping the Maze $\rightarrow R=+1$

All other times $\rightarrow R=\emptyset$

G_T = Expected Return = $R_{t+1} + R_{t+2} + \dots + R_T$

Discounted:

$$G_T = \sum_{k=0}^{\infty} \gamma^k R_{t+k+1}$$ where $0 \le \gamma \le 1$ and γ is called the discount rate

If the goal is to maximize the expected total reward (G_T), this number will always have a maximum value of 1, regardless of how long it takes for the agent to escape.

In order to ensure that the agent learns that speed is important, we can penalize (-1) every time step before the escape.

Exercise 3.8

Suppose that $\gamma = 0.5$ and the following sequence of rewards is received:

$R_1 = -1$
$R_2 = 2$
$R_3 = 6$
$R_4 = 3$
$R_5 = 2$

with $T = 5$

What are $G_0, G_1, \ldots G_5$

We define $G_T = 0$

In this case $T=5$, so $G_5 = 0$

$$G_4 = R_5 + \gamma G_5$$
$$= 2 + (0.5)(0) = 2$$

$$G_3 = R_4 + \gamma G_4 = 3 + (0.5)(2) = 3 + 1 = 4$$

$$G_2 = R_3 + \gamma G_3 = 6 + 0.5(4) = 8$$

$$G_1 = R_2 + \gamma G_2 = 2 + (0.5)(8) = 2 + 4 = 6$$

$$G_0 = R_1 + \gamma G_1 = -1 + (0.5)(6) = -1 + 3 = 2$$

Exercise 3.9

Suppose $\gamma = 0.9$ and the reward sequence is $R_1 = 2$ followed by an infinite sequence of 7s. What are G_1 and G_0?

$$G_t = R_{t+1} + \gamma G_{t+1}$$

$$G_0 = R_1 + \gamma G_1$$

$= 2 + 0.9\,(G_1) = 2 + 0.9\left(\frac{7}{1-0.9}\right) = 2 + \frac{6.3}{0.1} = 65$

$G_t = \sum_{k=0}^{\infty} \gamma^k R_{t+k+1}$ } Expected Discounted Return

$G_1 = \underbrace{\sum_{k=0}^{\infty} (0.9)^k}_{= \sum_{k=0}^{\infty} \gamma^k = \frac{1}{1-\gamma}} (7) = \frac{1}{1-\gamma}(7) = \frac{7}{1-0.9}$

3.12 Give an equation for V_π in terms of q_π and π.

V_π is a state value function,

$$V_\pi(s) = \mathbb{E}\left[G_t \mid S_t = s\right] \quad \forall s$$

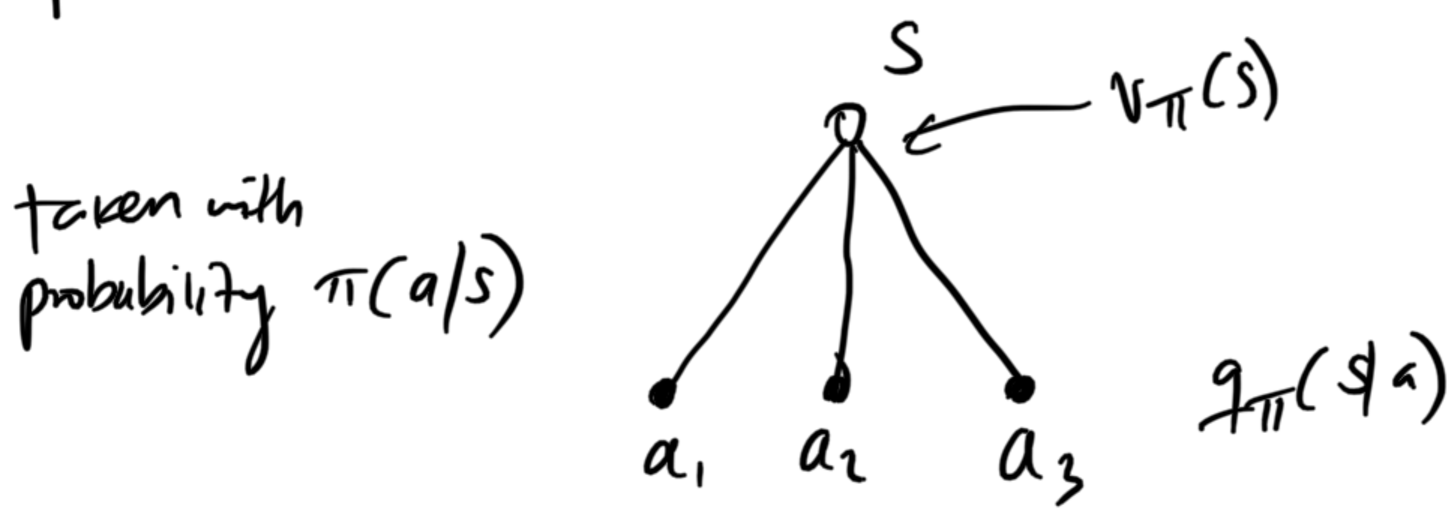
$$q_\pi(s,a) = \mathbb{E}\left[G_t \mid S_t = s,\ A_t = a\right]$$

$\downarrow$

Helps to solve the action selection problem because the maximum value of the expectation can be computed directly.

$$V_\pi(s) \doteq \sum_a \pi(a|s)\, q_\pi(s,a)$$

3.18 The value of a state depends on the values of the actions possible in that state and how likely each action is to be taken under the current policy. We can think of this in terms of a small backup diagram rooted at the state and considering each possible action:



Give the equation corresponding to this intuition and diagram for the value at the root node $v_\pi(s)$, in terms of the value at the expected leaf node $q_\pi(s,a)$ given $S_t = s$. This equation should include an expectation condition on following the policy, π. Then, a second equation in which the expected value is written out explicitly in terms of $\pi(a|s)$ such that no expected value notation appears in the equation.

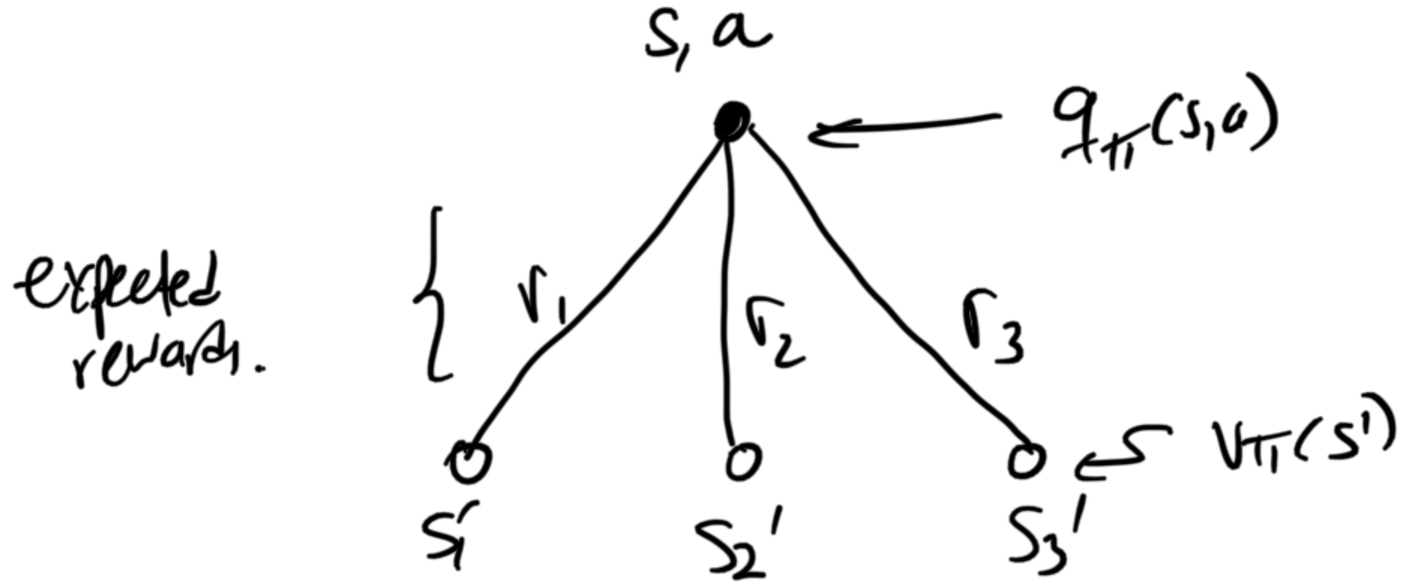
$V_\pi \propto$ Actions possible in that state
$\times$
prob of each action given policy.

$$V_\pi(s) = \sum_{a \in A} \pi(a|s) \sum_{s' \in S} \sum_{r \in R} \left[p'(s', r | s, a) \left[r + \gamma V_\pi(s') \right] \right]$$

$$V_\pi(s) = \mathbb{E}_\pi \left[q_\pi(S_t, A_t) \mid S_t = s, A_t = a \right]$$

$$= \sum_a \pi(a|s) \, q_\pi(s,a)$$

3.19 The value of an action, $q_\pi(s,a)$, depends on the expected next reward and the expected sum of the remaining rewards. Again, we think of this in terms of a small backup diagram, this one rooted at an action (state-action pair) and branching to the possible next states:



Give the equation for this intuition and diagram for this action value, $q_\pi(s,a)$, in terms of the expected reward, R_{t+1}, and the expected next state value, $v_\pi(S_{t+1})$, given that $S_t = s$ and $A_t = a$. This equation should include an expectation but not one conditioned on following the policy. Then, give a second equation, writing out the expected value explicitly in terms of $p(s', r \mid s, a)$ defined by (3.2) such that no expected value notation appears in the equation.

$q_\pi(s,a) \rightarrow$ Action value function for policy π.

- $R_{t+1} \rightarrow$ Expected Reward
- $v_\pi(S_{t+1}) \rightarrow$ Expected Next State value.

(3.2)
$$\underbrace{p(s', r \mid s, a)}_{\text{Dynamics of the MDP}} \doteq \Pr\{S_t = s', R_t = r \mid S_{t-1} = s, A_{t-1} = a\}$$

$$G_t = R_{t+1} + \gamma G_{t+1}$$

$$q_\pi(s,a) = \mathbb{E}_\pi[G_t \mid S_t = s, A_t = a]$$

$$q_\pi(s,a) = \mathbb{E}_\pi \left[R_{t+1} + \gamma v_\pi(S_{t+1}) \mid S_t = s, A_t = a \right]$$

$$= \sum_{s',r} p(s', r \mid s, a) \left[r + \gamma v_\pi(s') \right]$$

Exercise 1 - Part 2 (Practical)

APS 1080 - Exercise 1

- Armando Ordorica
- Student ID: 1005592164
- Prof. Nebu Mathai
- Jan 2023

1. Anatomy

Read the code and observe how the concepts of the course thus far relate to it. Comment on these correspondences.

- The code defines a Tic-Tac-Toe game that can be played by two players. It defines a "State" class that represents the state of a game. In this case, the states are represented by possible configurations of the board, which are 3^9 = 19,683 possibilities.
- The code contains many boards in the `all_states` variable, which uses combinatons of 0,1, and -1. 1 is to represent '*', which is the human player, and -1 to represent 'x', which is the computer's symbol.
- The `Judger` class initializes two players, player1 and player2 and assigns the signs to each other. P1's symbol is 1 ('*') and P2's symbol is -1 ('x').

What does an RL agent solve?

The RL agent would learn to play the game optimally by repeatedly playing the game and receiving rewards or penalties based on its performance. The agent would learn to make decisions that maximize its chances of winning the gamge by adjusting its strategy based on the rewards and penalties it receives.

The agent is solving a decision-making problem where it needs to choose an action to take in each state (or position) of the game so as to maximize its rewards. The goal of the agent is to win the game, or draw if it can't win, by choosing moves that result in the best outcomes based on the current state of the game. The agent interacts with the environment, in this case the tic-tac-toe game, by taking actions, observing the results of the actions and receiving rewards, and updating its policy based on the observed outcomes. The policy is a mapping from states to actions that the agent takes, and the objective is to learn a good policy through trial-and-error and reinforcement from rewards.

What should a RL agent have inside of it? Do you observe these in the program?

The RL agent should have the following components:

1. **State Representation:** The agent needs to have a way of representing the current state of the game board. This could be done using a 2D array, where each element

represents the state of a particular cell on the board. This code has a `State` object, which contains a 3x3 numpy array that is stored in the `data` attribute. The variable `all_states` contains all the possible board configurations. As stated above, the `all_states` variables contains ~6k possible combinations of 1, -1, and 0 to represent the human player, the computer, and empty cells respectively.

2. **Action**:The actions in this game are the placement of a chessman (represented by 1 or -1) in a given position on the board.
3. **Reward**:The reward in this game is the end result, either a win, a loss, or a draw. A win is represented by a 1, a loss by -1, and a draw by 0.
4. **Policy**: The Player object contains a dictionary called `estimations`, which gets updated using a backup function. The code ends up saving these learned estimations as a policy in a `.bin` file. Note that estimations are not available for the `HumanPlayer` object and only for the AI player with the `Player` class.
5. **Model**: the model in this code is implicit in the state and the transition from one state to the next through the actions.

2. Instrumentation and Play

Modify the code so it trains against you interactively. Instrument the code to print the value function as it learns, and also when it takes an exploit vs explore action.

The `self.estimations` attribute in the `Player` object contains a dictionary with the policy values. They get initialized to 0.5 values but get updated as the AI trains itself.

For example, in one realization, this was a value before in the `estimations` dictionary for state 9841 : `9841.0: 0.4999386591027`. However, the value of this state changed in the `estimations` dictionary after updating: `9841.0: 0.5000613408972999`.

The following code leverages exploration exploitation by using an ϵ greedy approach, the `act()` function selects the next positions at random. However, the *risk tolerance* or willing to choose a next position at random will only take place if a random number is below ϵ. In this case, if ϵ is set to 0.01, that means that less that a random position will be selected less than 1% of the time.

```
def act(self):
        state = self.states[-1]
        next_states = []
        next_positions = []
        for i in range(BOARD_ROWS):
            for j in range(BOARD_COLS):
                if state.data[i, j] == 0:
                    next_positions.append([i, j])
                    next_states.append(state.next_state(
                        i, j, self.symbol).hash())

        if np.random.rand() < self.epsilon:
            action =
```

```
next_positions[np.random.randint(len(next_positions))]
            action.append(self.symbol)
            self.greedy[-1] = False
            return action
```

Let the agent train against you for N games. Comment on how the agent's competence increases as N increases.

- As the number of epochs increases, the win rate for both players decreases. This could be because it is possible to force Tic-Tac-Toe to a draw in the worst case scenario.
- If you decrease the number of times it trains against itself, it becomes significantly dumber. I changed it to only train itself 10 times and winning against it was trivial.

In [1]:

```
#######################################################################
# Copyright (C)                                                       #
# 2016 - 2018 Shangtong Zhang(zhangshangtong.cpp@gmail.com)           #
# 2016 Jan Hakenberg(jan.hakenberg@gmail.com)                         #
# 2016 Tian Jun(tianjun.cpp@gmail.com)                                #
# 2016 Kenta Shimada(hyperkentakun@gmail.com)                         #
# Permission given to modify the code as long as you keep this        #
# declaration at the top                                              #
#######################################################################

import numpy as np
import pickle

BOARD_ROWS = 3
BOARD_COLS = 3
BOARD_SIZE = BOARD_ROWS * BOARD_COLS


class State:
    def __init__(self):
        # the board is represented by an n * n array,
        # 1 represents a chessman of the player who moves first,
        # -1 represents a chessman of another player
        # 0 represents an empty position
        self.data = np.zeros((BOARD_ROWS, BOARD_COLS))
        self.winner = None
        self.hash_val = None
        self.end = None

    # compute the hash value for one state, it's unique
    def hash(self):
        if self.hash_val is None:
            self.hash_val = 0
            for i in np.nditer(self.data):
                self.hash_val = self.hash_val * 3 + i + 1
        return self.hash_val

    # check whether a player has won the game, or it's a tie
    def is_end(self):
        if self.end is not None:
            return self.end
        results = []
        # check row
        for i in range(BOARD_ROWS):
```

```
            results.append(np.sum(self.data[i, :]))
        # check columns
        for i in range(BOARD_COLS):
            results.append(np.sum(self.data[:, i]))

        # check diagonals
        trace = 0
        reverse_trace = 0
        for i in range(BOARD_ROWS):
            trace += self.data[i, i]
            reverse_trace += self.data[i, BOARD_ROWS - 1 - i]
        results.append(trace)
        results.append(reverse_trace)

        for result in results:
            if result == 3:
                self.winner = 1
                self.end = True
                return self.end
            if result == -3:
                self.winner = -1
                self.end = True
                return self.end

        # whether it's a tie
        sum_values = np.sum(np.abs(self.data))
        if sum_values == BOARD_SIZE:
            self.winner = 0
            self.end = True
            return self.end

        # game is still going on
        self.end = False
        return self.end

    # @symbol: 1 or -1
    # put chessman symbol in position (i, j)
    def next_state(self, i, j, symbol):
        new_state = State()
        new_state.data = np.copy(self.data)
        new_state.data[i, j] = symbol
        return new_state

    # print the board
    def print_state(self):
        for i in range(BOARD_ROWS):
            print('-------------')
            out = '| '
            for j in range(BOARD_COLS):
                if self.data[i, j] == 1:
                    token = '*'
                elif self.data[i, j] == -1:
                    token = 'x'
                else:
                    token = '0'
                out += token + ' | '
            print(out)
        print('-------------')
```

```python
def get_all_states_impl(current_state, current_symbol, all_states):
    for i in range(BOARD_ROWS):
        for j in range(BOARD_COLS):
            if current_state.data[i][j] == 0:
                new_state = current_state.next_state(i, j, current_symbol)
                new_hash = new_state.hash()
                if new_hash not in all_states:
                    is_end = new_state.is_end()
                    all_states[new_hash] = (new_state, is_end)
                    if not is_end:
                        get_all_states_impl(new_state, -current_symbol, all_sta


def get_all_states():
    current_symbol = 1
    current_state = State()
    all_states = dict()
    all_states[current_state.hash()] = (current_state, current_state.is_end())
    get_all_states_impl(current_state, current_symbol, all_states)
    return all_states


# all possible board configurations
all_states = get_all_states()


class Judger:
    # @player1: the player who will move first, its chessman will be 1
    # @player2: another player with a chessman -1
    def __init__(self, player1, player2):
        self.p1 = player1
        self.p2 = player2
        self.current_player = None
        self.p1_symbol = 1
        self.p2_symbol = -1
        self.p1.set_symbol(self.p1_symbol)
        self.p2.set_symbol(self.p2_symbol)
        self.current_state = State()

    def reset(self):
        self.p1.reset()
        self.p2.reset()

    def alternate(self):
        while True:
            yield self.p1
            yield self.p2

    # @print_state: if True, print each board during the game
    def play(self, print_state=False):
        alternator = self.alternate()
        self.reset()
        current_state = State()
        self.p1.set_state(current_state)
        self.p2.set_state(current_state)
        if print_state:
            current_state.print_state()
        while True:
            player = next(alternator)
            i, j, symbol = player.act()
```

```python
            next_state_hash = current_state.next_state(i, j, symbol).hash()
            current_state, is_end = all_states[next_state_hash]
            self.p1.set_state(current_state)
            self.p2.set_state(current_state)
            if print_state:
                current_state.print_state()
            if is_end:
                return current_state.winner


# AI player
class Player:
    # @step_size: the step size to update estimations
    # @epsilon: the probability to explore
    def __init__(self, step_size=0.1, epsilon=0.1):
        self.estimations = dict()
        self.step_size = step_size
        self.epsilon = epsilon
        self.states = []
        self.greedy = []
        self.symbol = 0

    def reset(self):
        self.states = []
        self.greedy = []

    def set_state(self, state):
        self.states.append(state)
        self.greedy.append(True)

    def set_symbol(self, symbol):
        self.symbol = symbol
        for hash_val in all_states:
            state, is_end = all_states[hash_val]
            if is_end:
                if state.winner == self.symbol:
                    self.estimations[hash_val] = 1.0
                elif state.winner == 0:
                    # we need to distinguish between a tie and a lose
                    self.estimations[hash_val] = 0.5
                else:
                    self.estimations[hash_val] = 0
            else:
                self.estimations[hash_val] = 0.5

    # update value estimation
    def backup(self):
        states = [state.hash() for state in self.states]

        print("Printing Estimations from Value Function BEFORE Updating...")
        print(self.estimations)

        print("Printing Greedy from backup function BEFORE Updating...")
        print(self.greedy)

        for i in reversed(range(len(states) - 1)):
            state = states[i]
            td_error = self.greedy[i] * (
                self.estimations[states[i + 1]] - self.estimations[state]
            )
```

```python
            self.estimations[state] += self.step_size * td_error
        print("Printing Estimations from Value Function AFTER Updating...")
        print(self.estimations)

        print("Printing Greedy from backup function BEFORE Updating...")
        print(self.greedy)

    # choose an action based on the state
    def act(self):
        state = self.states[-1]
        next_states = []
        next_positions = []
        for i in range(BOARD_ROWS):
            for j in range(BOARD_COLS):
                if state.data[i, j] == 0:
                    next_positions.append([i, j])
                    next_states.append(state.next_state(
                        i, j, self.symbol).hash())

        if np.random.rand() < self.epsilon:
            action = next_positions[np.random.randint(len(next_positions))]
            action.append(self.symbol)
            self.greedy[-1] = False
            return action

        values = []
        for hash_val, pos in zip(next_states, next_positions):
            values.append((self.estimations[hash_val], pos))
        # to select one of the actions of equal value at random due to Python's
        np.random.shuffle(values)
        values.sort(key=lambda x: x[0], reverse=True)
        action = values[0][1]
        action.append(self.symbol)
        return action

    def save_policy(self):
        with open('policy_%s.bin' % ('first' if self.symbol == 1 else 'second')
            pickle.dump(self.estimations, f)

    def load_policy(self):
        with open('policy_%s.bin' % ('first' if self.symbol == 1 else 'second')
            self.estimations = pickle.load(f)
            print("self.estimations from load_policy() function")
            print(self.estimations)


# human interface
# input a number to put a chessman
# | q | w | e |
# | a | s | d |
# | z | x | c |
class HumanPlayer:
    def __init__(self, **kwargs):
        self.symbol = None
        self.keys = ['q', 'w', 'e', 'a', 's', 'd', 'z', 'x', 'c']
        self.state = None

    def reset(self):
        pass
```

```
    def set_state(self, state):
        self.state = state

    def set_symbol(self, symbol):
        self.symbol = symbol

    def act(self):
        self.state.print_state()
        key = input("Input your position:")
        data = self.keys.index(key)
        i = data // BOARD_COLS
        j = data % BOARD_COLS
        return i, j, self.symbol


def train(epochs, print_every_n=500):
    player1 = Player(epsilon=0.01)
    player2 = Player(epsilon=0.01)
    judger = Judger(player1, player2)
    player1_win = 0.0
    player2_win = 0.0
    for i in range(1, epochs + 1):
        winner = judger.play(print_state=False)
        if winner == 1:
            player1_win += 1
        if winner == -1:
            player2_win += 1
        if i % print_every_n == 0:
            print('Epoch %d, player 1 winrate: %.02f, player 2 winrate: %.02f'
        player1.backup()
        player2.backup()
        judger.reset()
    player1.save_policy()
    player2.save_policy()


def compete(turns):
    player1 = Player(epsilon=0)
    player2 = Player(epsilon=0)
    judger = Judger(player1, player2)
    player1.load_policy()
    player2.load_policy()
    player1_win = 0.0
    player2_win = 0.0
    for _ in range(turns):
        winner = judger.play()
        if winner == 1:
            player1_win += 1
        if winner == -1:
            player2_win += 1
        judger.reset()
    print('%d turns, player 1 win %.02f, player 2 win %.02f' % (turns, player1_


# The game is a zero sum game. If both players are playing with an optimal stra
# So we test whether the AI can guarantee at least a tie if it goes second.
def play():
    while True:
        player1 = HumanPlayer()
        player2 = Player(epsilon=0)
```

```python
        judger = Judger(player1, player2)
        player2.load_policy()
        winner = judger.play()
        if winner == player2.symbol:
            print("You lose!")
        elif winner == player1.symbol:
            print("You win!")
        else:
            print("It is a tie!")


# train(int(1e5))
# train(10)
# compete(int(1e3))
# play()
```

In [2]:
```python
# compete(int(3))
```

In [3]:
```python
play()
```

self.estimations from load_policy() function
{9841.0: 0.4999514633194276, 16402.0: 0.5, 14215.0: 0.5, 14944.0: 0.5, 14701.
0: 0.5, 14782.0: 0.5, 14755.0: 0.5, 14764.0: 0, 14758.0: 0.5, 14749.0: 0.5, 14
750.0: 0, 14757.0: 0.5, 14766.0: 0, 14756.0: 0, 14773.0: 0.5, 14800.0: 0.5, 14
797.0: 0.5, 14798.0: 0, 14799.0: 0.5, 14802.0: 0.5, 14776.0: 0.5, 14775.0: 0.
5, 14774.0: 0, 14779.0: 0.5, 14806.0: 0.5, 14805.0: 0.5, 14814.0: 0, 14788.0:
0, 14780.0: 0, 14781.0: 0.5, 14808.0: 0.5, 14790.0: 0, 14784.0: 0.5, 14728.0:
0.5, 14647.0: 0.5, 14656.0: 0.5, 14653.0: 1.0, 14655.0: 0.5, 14658.0: 0.5, 146
50.0: 0.5, 14641.0: 0.5, 14642.0: 0, 14649.0: 0.5, 14648.0: 0, 14719.0: 0.5, 1
4722.0: 0.5, 14721.0: 0.5, 14720.0: 0, 14725.0: 0.5, 14734.0: 0.5, 14733.0: 0.
5, 14726.0: 0, 14727.0: 0.5, 14736.0: 0.5, 14730.0: 0.5, 14710.0: 0.5, 14629.
0: 0.5, 14632.0: 0.5, 14605.0: 1.0, 14631.0: 0.5, 14630.0: 0.5, 14603.0: 1.0,
14627.0: 1.0, 14683.0: 0.5, 14686.0: 0.5, 14685.0: 0.5, 14684.0: 0.5, 14681.0:
0.5, 14762.0: 0, 14707.0: 0.5, 14708.0: 0.5, 14709.0: 0.5, 14712.0: 0.5, 1470
4.0: 0.5, 14623.0: 0.5, 14624.0: 0.5, 14597.0: 1.0, 14615.0: 0.5, 14677.0: 0.
5, 14678.0: 0.5, 14669.0: 0.5, 14695.0: 0.5, 14696.0: 0.5, 14703.0: 0.5, 1470
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| 0 | 0 | * |
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| * | x | x |
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You win!
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```
-------------
| 0 | 0 | 0 |
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| 0 | 0 | 0 |
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| 0 | 0 | 0 |
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```

```
---------------------------------------------------------------------------
KeyboardInterrupt                         Traceback (most recent call last)
/var/folders/tp/tgqd8prn2x1g474v7zwrxq7r0000gn/T/ipykernel_79414/3863113020.py
in <module>
----> 1 play()

/var/folders/tp/tgqd8prn2x1g474v7zwrxq7r0000gn/T/ipykernel_79414/1677033148.py
in play()
    345         judger = Judger(player1, player2)
    346         player2.load_policy()
--> 347         winner = judger.play()
    348         if winner == player2.symbol:
    349             print("You lose!")

/var/folders/tp/tgqd8prn2x1g474v7zwrxq7r0000gn/T/ipykernel_79414/1677033148.py
in play(self, print_state)
    162         while True:
    163             player = next(alternator)
--> 164             i, j, symbol = player.act()
    165             next_state_hash = current_state.next_state(i, j, symbol).h
ash()
    166             current_state, is_end = all_states[next_state_hash]

/var/folders/tp/tgqd8prn2x1g474v7zwrxq7r0000gn/T/ipykernel_79414/1677033148.py
in act(self)
    291     def act(self):
    292         self.state.print_state()
--> 293         key = input("Input your position:")
    294         data = self.keys.index(key)
    295         i = data // BOARD_COLS

~/opt/anaconda3/envs/pytorchenv/lib/python3.7/site-packages/ipykernel/kernelba
se.py in raw_input(self, prompt)
   1179             self._parent_ident["shell"],
   1180             self.get_parent("shell"),
-> 1181             password=False,
   1182         )
   1183 

~/opt/anaconda3/envs/pytorchenv/lib/python3.7/site-packages/ipykernel/kernelba
se.py in _input_request(self, prompt, ident, parent, password)
   1217             except KeyboardInterrupt:
   1218                 # re-raise KeyboardInterrupt, to truncate traceback
-> 1219                 raise KeyboardInterrupt("Interrupted by user") from No
ne
   1220             except Exception:
   1221                 self.log.warning("Invalid Message:", exc_info=True)

KeyboardInterrupt: Interrupted by user
```

In [ ]:

```
break
```

In [ ]:

```
# play()
```

In [ ]:

```
len(all_states.keys())
```

In [ ]:

```
all_states.keys()
```

In [ ]:
```
all_states[9841.0][0].data
```

In [ ]:
```
all_states[16402.0][0].data
```

In [ ]:
```
all_states[9575][0].data
```

In [ ]:
```

```

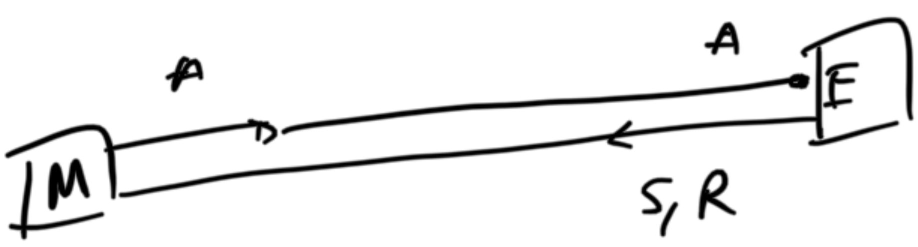
Lecture Notes - Lecutre 2

APS 1080 LECTURE 2

REINFORCEMENT LEARNING

If observability is missing and if what you see could be in different states

Markov Decision Processes require observability.



$A = \{A^{(1)}, \ldots, A^{(k)}\}$

↑ The goal

Goal

- $-1 \rightarrow$ for time steps missed
- $-100 \rightarrow$ Loss
- $100 \rightarrow$ win

Reward signal does not come intrinsically from the environment.

Agent's mechanism to generate an action A based on S is called a policy.

↓

$\pi(A|S)$

Policy of an action given a state.

is to design a distribution for the policy

Our goal is ...
so that an agent interacts with the
environment appropriately

$$A = \{ A^{(1)}, \dots, A^{(A)} \}$$

indices of action

$S_0 \; A_0$

time
index

Action selection problem

$$S_0 A_0 \mid R_1 \; S_1 A_1 \mid \dots \; S_i \mid A_i \; R_{i+1} \; S_{i+1} \; A_{i+1}, \dots R_T \; S_T$$

This sequence is called an episode or a Trace

what action do I select
given a state?

11

	$A^{(1)}$	$A^{(2)}$	$\dots$	$A^{(M)}$
$S^{(1)}$				
$\vdots$				
$S^{(N)}$				

Σ of prob $=1$

The sum of the Rows must equal 1.

We may initialize the policy to random values.
what matters is not the initial conditions but rather how those values evolve.

How is the agent selecting the best action?

Subsequent sequence of rewards is maximized.
From time step i to the end of the episode at time t.

We want to maximize the sum of future rewards.

Definition

Return:

$$G_T = \sum_{k=t+1}^{T} \gamma^{k-(t+1)} R_k$$

Return:
Cumulative sum of all future rewards

$\gamma \rightarrow$ discount factor

↳ A number between 0 and 1 if $T \rightarrow \infty$

$\gamma \in [0, 1)$ $\quad T \rightarrow \infty$

$\gamma \in [0, 1]$ $\quad T \rightarrow$ Finite.

Long term view

shorter term view

As $\gamma \rightarrow 0 \rightarrow$ Distant Rewards get attenuated

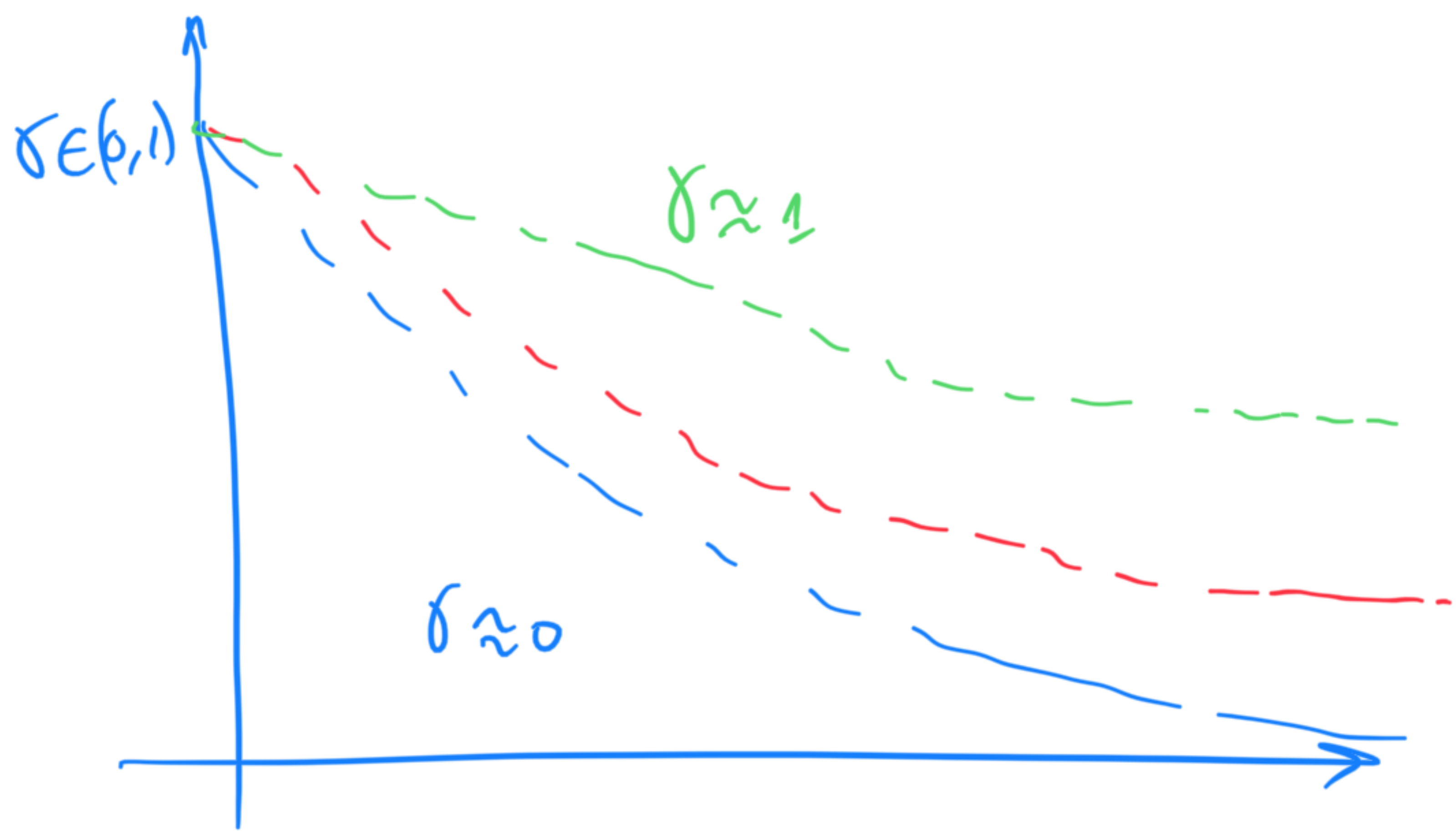
$\gamma \rightarrow 1 \rightarrow$ Short term rewards get attenuated

E	M
S_i	A_i $\quad \boxed{\begin{matrix} R_{i+1} \\ 1 \end{matrix}} \ \ldots \ R_{i+2} \ \ldots \ R_{i+3} \ \ldots \ R_T$

Maximize feature reward

we want to maximize all the things related to my work

We always account for next reward with full strength



Long term view $\rightarrow \gamma > 0$

Short term view $\rightarrow \gamma = 0$.

The ACTION SELECTION PROBLEM

Given S_i, chose A_i such that we maximize the cumulative future rewards (G_i) which is called the return.

Our goal is to create a policy that maximizes the Cumulative Return G_i.

$\rightarrow$ How will the rewards look like for every combination of actions

→ Suppose we can learn by historical episodes how being in state S_i relates to the return G_i for all states.

→ How being in S_1

Combinations of states and Actions and how they relate to the returns that they generate

VALUE FUNCTIONS

Keep track of what results in the best result historically

State value function $$V_\pi(s) = \mathbb{E}\left[\underbrace{G_t}_{\text{Return}} \mid S_t = s\right] \underbrace{\forall s}_{\text{For all states}}$$

s	Expected value of Future returns.
$s^{(1)}$	# $\mathbb{E}(G_t \mid S_t = s^{(1)})$
$s^{(2)}$	#
⋮	⋮
$s^{(n)}$	#

We populate this table by processing the traces or sequences that we pick up by having the agent interacting with the environment.

ACTION VALUE FUNCTIONS ($q_\pi(s,a)$)

Expected future return given a current state and a current action.

$$q_\pi(s,a) = \mathbb{E}\left[G_t \mid S_t = s, A_t = a \right]$$

$S \times A$	
$S^{(1)}$ $A^{(1)}$	# $\mathbb{E}\left[G_i \mid S_i = S^{(1)}, A_i = A^{(1)} \right]$
$A^{(2)}$	#
$\vdots$	
$A^{(k)}$	
$S^{(2)}$ $A^{(1)}$	
$A^{(2)}$	
$\vdots$	
$A^{(k)}$	
$\vdots$	
$S^{(N)}$ $A^{(1)}$	
$A^{(2)}$	
$\vdots$	
$A^{(k)}$	

Given a state, choose the action that maximizes the reward.

$q_\pi(s,a)$ → helps to solve the Action SELECTION PROBLEM as the maximum value can be computed directly.

value function

If you have access to the v value function

$V_\pi(s)$ → What is the expected Return being in each state? which state is the best one to be in?

$s^{(1)}$	#
$s^{(2)}$	#
⋮	⋮
$s^{(t)}$	#

Some states are more desirable than others, $V_\pi(s)$ tells you which are the most desirable states to be in.

Know what the tables look like for the TEST

You can select a value with q only

→ with v, you don't have a mean to select an action.

with V alone you need a model of the environment to make it useful.

$$p(S', R, S, A) = Pr\{S_{t+1} = S', R_{t+1} = R \mid S_t = S, A_t = A\}$$

Next states (up to N) | Next rewards up to M.

$S \times A$		$S^{(1)}$	$S^{(2)}$	$\dots$	$S^{(N)}$	$R^{(1)}$	$R^{(2)}$	$\dots$	$R^{(M)}$
$S^{(1)}$	$A^{(1)}$								
	$A^{(2)}$								
	$\vdots$								
	$A^{(K)}$								
$S^{(2)}$	$A^{(1)}$								
	$A^{(2)}$								
	$\vdots$								
	$A^{(K)}$								
$\vdots$									
$S^{(N)}$	$A^{(1)}$								
	$A^{(2)}$								
	$\vdots$								
	$A^{(K)}$								

$\Sigma = 1$ for each state action

$\Sigma = 1$ for each state action

We want to choose an action that has the highest likelihood of getting me to the state that gives me the highest value. (S^*)

Given a stochastic model of the environment and a value function, how can you solve the Action selection Problem

... that all you need

If you have $q \rightarrow$ thats ...

If you have $v \rightarrow$ You need V_π and p

$$V_\pi(s) = \sum_{\forall a \in A} \pi(a|s) \sum_{s',R} p(s', R, s, a)\left[R + \gamma V_\pi(s')\right]$$

Next Lecture:

How to obtain V and q given p

Next Next lecture

How to obtain V and q if we do not have p.

S : state space → Surface or abstract state.

A : Action space → Click, Impression, Repin...

q : Transition rate function → Likelihood of going from one state to the other.

R : Reward function

π : Policy.

- Assign points for things you know
- Initialize to a random value for things you don't know

γ : Discount factor.

↳ How much you care about the future.

ACTION VALUE FUNCTION (one hop)

	Next states				Next state Reward			
	$S^{(1)}$	$S^{(2)}$	...	$S^{(N)}$	$R^{(1)}$	$R^{(2)}$	..	$R^{(N)}$
$S^{(1)}$ $A^{(1)}$				$\Sigma = 1$				$\Sigma = 1$
$A^{(2)}$								
⋮								
$A^{(K)}$								

$S^{(2)}$ $A^{(1)}$

$A^{(2)}$

$\vdots$

$A^{(k)}$

$S^{(3)}$ $A^{(1)}$

$A^{(2)}$

$A^{(3)}$

$S^{(1)} \to$ HF

$S^{(2)} \to$ Search

$S^{(3)} \to$ Closeup

$A^{(1)} \to$ Click

$A^{(2)} \to$ Impression

RETURNS AND EPISODES

The Agent's goal is to maximize the cumulative reward it receives over time.

Downstream Rewards @ Natalia.

Instant gratification ⟹ Long term objective optimization

↓ Repins.

↓ optimize for best sequence (long term)

Markov Decision Processes.

$A: \{A_1, A_2 .. A_n\}$ → Action space

Click
Repin
Impression ...

$S: \{S_1, S_2, ... S_k\}$ → State space.

Abstract state → Exploration, consideration, Fulfillment.

Surfaces.

T: Transition Rate function.

R : Reward Function. → Relative value of different Actions and states.

→ Hide → -100

→ Share → 100

π : Policy

γ : Discount factor.

↳ How much you care about the future.

	Next state (up to K) $S^{(1)}$ $S^{(2)}$ ... $S^{(K)}$	Reward from the next state. $R^{(1)}$ $R^{(2)}$ ... $R^{(K)}$
$S^{(1)}$ $A^{(1)}$ $A^{(2)}$ ⋮ $A^{(N)}$	$\Sigma = 1$	
$S^{(2)}$ $A^{(1)}$ $A^{(2)}$ ⋮ $A^{(N)}$		
⋮		
$S^{(K)}$ $A^{(1)}$		

$A^{(2)}$
$\vdots$
$A^{(N)}$

Choosing upto 3-5 Actions

Starting with one surface, i.e. Home Feed.

$S^{(1)}$: Home feed
$S^{(2)}$: Search
$S^{(3)}$: Related Pins

- User ID
- time stamp begin
- time stamp end
- action (~~CR~~, repin, click, etc)
- Surface origin
- Surface Destination
- Pin ID.

- Web / Mobile
- Country
- Date joined
- Gender
- Age
- L1 interest
- iOS / Android
- Version

To normalize population.

$S \times A$	
$S^{(1)}$ $A^{(1)}$	# $\mathbb{E}\left[G_i \mid S_i = S^{(1)}, A_i = A^{(1)}\right]$
$A^{(2)}$	#
$\vdots$	
$A^{(k)}$	
$S^{(2)}$ $A^{(1)}$	
$A^{(2)}$	
$\vdots$	
$A^{(k)}$	
$\vdots$	
$S^{(n)}$ $A^{(1)}$	
$A^{(2)}$	
$\vdots$	
$A^{(k)}$	

Lecture Notes - Lecture 3

APS 1080 - LECTURE 3
MODEL BASED RL - DYNAMIC PROGRAMMING

$$M \underset{S,\, R}{\overset{A}{\rightleftharpoons}} E$$

~Goal

$$S_0 \quad A_0 \quad R_1 \quad S_1 \quad A_1 \quad \dots \quad S_i \quad A_i \quad R_{i+1} \quad S_{i+1} \quad A_{i+1} \quad \dots \quad S_T$$

What Action to take if you're in state i.

Return: Sum of subsequent rewards as a result of our actions

$$G_i = R_{i+1} + \gamma R_{i+2} + \gamma^2 R_{i+3} + \dots$$

Goal: select A_i such that the expected value of the return is maximized

$\downarrow$
Action

$$\max \mathbb{E}[G_i]$$

VALUE FUNCTION

$$V_\pi(s) = \mathbb{E}[G_t \mid S_t = s]$$

$$q_\pi(s) = \dots$$

Given V_π

p : model of the environment

We can solve Action Selection Problem.

To solve Action Selection Problem, you need either:

① V and $p \Rightarrow \pi$

② $Q \Rightarrow \pi$

The Policy, which is the mechanism for action selection.

The states are drawn from $\mathbb{S} = \{ S^{(1)}, S^{(2)}, \ldots, S^{(N)} \}$

S	$V_\pi(s)$
$S^{(1)}$	$\mathbb{E}[G_t \mid S_t = S^{(1)}]$
$S^{(2)}$	
$\vdots$	
$S^{(N)}$	

Target state: which state to go to

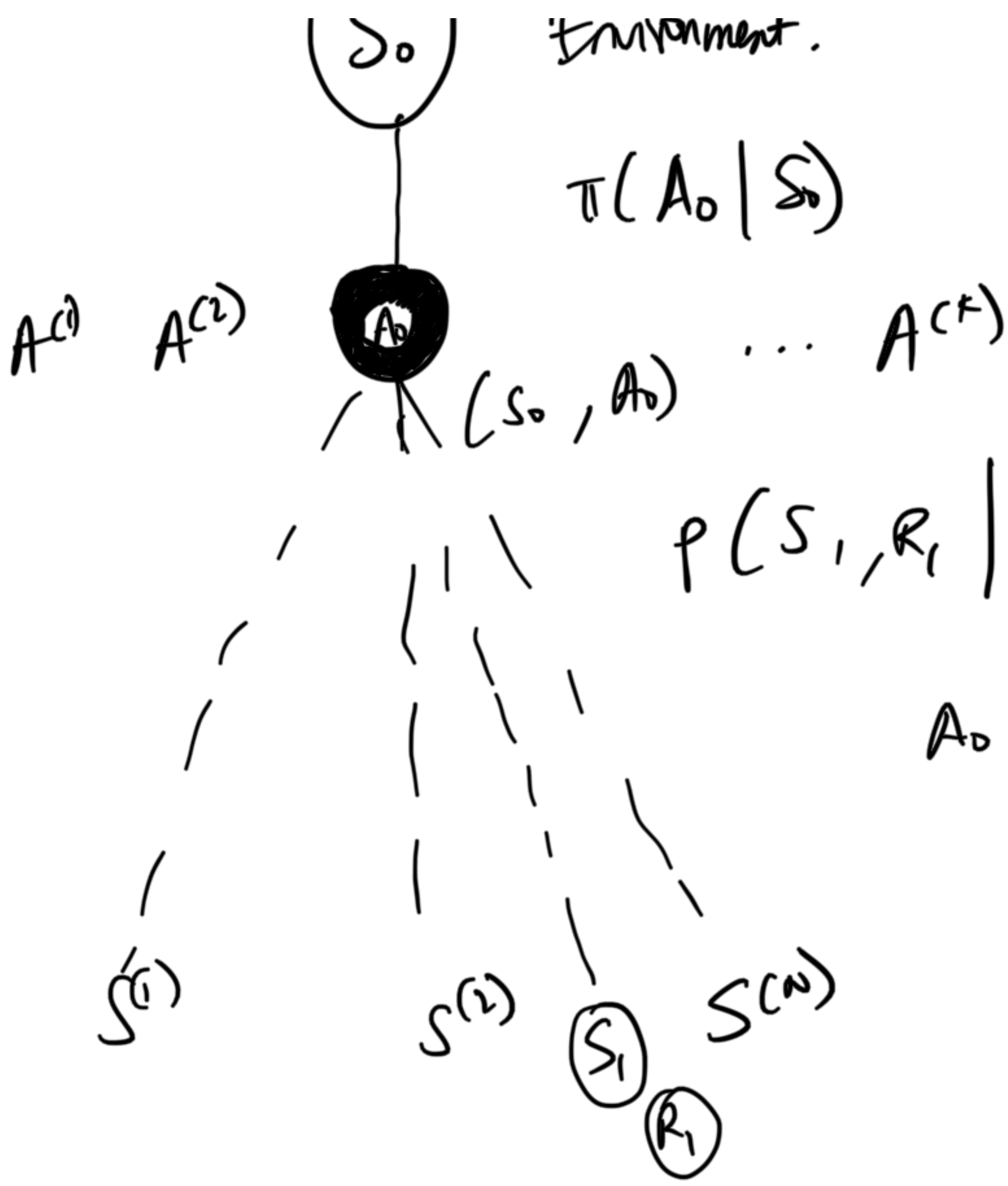
then consult "p" to see what action to take to get to that probability.

$$V_\pi(s) = \mathbb{E}[G_t \mid S_t = s]$$

Subscript: Time sequence

Superscript: Selection from the set.

environment. to states the time t, which is drawn from the state of possible actions.



$p(S_1, R_1 | S_0, A_0) \rightarrow$ Model.

$A_0 \in \{ A^{(1)}, A^{(2)}, \dots A^{(K)} \}$

This is how π and p interplay in continuous state/action rewards.
$S \rightarrow A$ transition

Action $\rightarrow$ State (weighted by distribution p)

The model we may or may not have it.

The

with p we can calculate V_π, π and π^*
$\downarrow$
optimal policy.

Dynamic programming does NOT use experience

How we determine V_π and π when we don't have P?
$\rightarrow$ you need experience + learning to be surrogates of

Probability of selecting an action given you're in state s.

$$V_\pi(s) = \sum_{a \in A} \pi(a|s) \sum_{s' \in S} \sum_{r \in R} \left[p(s', r | s, a) \left[r + \gamma V_\pi(s') \right] \right]$$

Indices of a for loop

for loop

consider all possible states

over all possible rewards

Expected value → Weighted Average over the entire tree.

You're building the Agent.

No knowledge about the problem → π would be an equiprobable distribution.

→ Eventually, you'd get to a more granular π, with a less naive distribution.

We have an equation that is recursively defined.

$$V_\pi(s) = \Gamma \; V_\pi(\cdot)$$

gamma

We can calculate $V_\pi(\cdot)$ via linear system methods but it's not very scalable because you end up with too many variables and it's very computationally expensive. Also, it would only work if you have "p".

Instead of doing that, we calculate $V_\pi(\cdot)$ via a successive approximation.

$$f(\cdot) = \underset{\text{Contraction}}{\Gamma}(f(\cdot))$$

$f(\cdot) \leftarrow$ initiate $-$ function $\forall x$

loop

  loop $\forall x$

    $prev \leftarrow f(x)$

    $next \leftarrow \Gamma(prev)$

    $f(x) \leftarrow next$

    $\Delta(x) \leftarrow |next - prev|$

  if $\|\Delta\| < \theta$

    $\rightarrow$ break.

Initialize $V_\pi(x)$ for all x arbitrarily.
We set the terminal states to zero and all the other values at an arbitrary number.

V_π

States	
$s^{(1)}$	
$s^{(2)}$	
$\vdots$	
$s^{(n)}$	

$$V_\pi(s_T) = 0$$

π	$a^{(1)}$	$a^{(2)}$	$\dots$	$a^{(k)}$	
$s^{(1)}$					$\Sigma = 1$
$s^{(2)}$					$\Sigma = 1$
$\vdots$					
$s^{(n)}$					

Input π

Init $V_\pi(s)$ arbitrarily $\forall s$

loop $\Delta \leftarrow 0$

loop $\forall s$

$prev \leftarrow V_\pi(s)$

$Next \leftarrow \Gamma(V_\pi(\cdot))$

$\Sigma \pi \ldots \Sigma\Sigma \, [r_p + \gamma V_\pi(s')]$

$\Delta \leftarrow \max[\Delta, (prev - next)]$

if $\Delta < \theta$:

Break

Iterate over the states, successively estimating the values of the value functions

when the deltas are low enough then you stop.

Given an arbitrary model and policy, we can determine a value function

$p, \pi \longrightarrow V_\pi(\cdot)$ → Evaluation of the policy.

Evaluation of π in $\mathcal{E}$ ~ "Prediction"

$\pi \xrightarrow{eval} V_\pi(\cdot)$

$\pi \longrightarrow \pi'$

eval

$$\begin{cases} \pi' \longrightarrow V_{\pi'}(\cdot) \\ \pi' \xrightarrow[\text{Improvement}]{V_{\pi'}} \pi'' \end{cases}$$

$$\begin{cases} \pi'' \longrightarrow V_{\pi''}(\cdot) \\ \pi'' \longrightarrow \pi''' \end{cases}$$

until $V_\pi(i) \approx V_\pi(i+1)$
$\pi(i) \simeq \pi(i+1)$ Fixed Point π_*

You modify the policy to help you improve the likelihood of going to the most desirable states.

Summarize Dynamic Programming

① $P, \pi_0 \longrightarrow V_{\pi_0}$ (Prediction)

② $\pi_0, V_0 \longrightarrow \pi_1$ $(\pi_1 \geq \pi_0)$ (Improvement)

③ Generalized Policy Iteration (G.P.I)

Prediction
Improvement

until fixed Point is reached $\longrightarrow \pi_*$

④ GPI $\rightarrow$ Evaluation ①
Improvement ②

Evaluation ①
Improvement ②

GPI: Eval Improv. Eval Improv. | ... | Eval Improv. Eval

π_0 1 2 1 2 | ... | $\underbrace{V_{\pi_n} \quad V_{\pi_n} \quad V_{\pi_n}}_{\text{Fixed Point}}$

$V_{\pi*}, \pi*$

This is an asymptotic Process

Other approach

Run it a few times and truncate the evaluation.

Select the best value amongst bag of truncated evaluations.

Step 4 helps us move away from the need of having a model.

What are other ways to approximate a value function that would not require the use of a "p"?

Next week:

How to approximate V_π without P by leveraging experience?

→ How can we approximate q_π and a policy from experience?

$\hookrightarrow \pi$