ddpg_sample

April 8, 2022

0.1 Implementation of DDPG paper inspired from: DDPG Video by Machine learning with phil

0.2 Some notes from DDPG paper for implementation purposes

- Need a replay buffer class
- Need a class for target Q network (function of s,a)
- Need to use batch norm
- Use off-policy learning (learn from behavioural policy B = mu(s)) to handle explore-exploit dilemma as policy becomes deterministic
- Deterministic policies means the algorithm outputs the actual policies instead of probabilities. Need a way to bound actions to env limits
- Two actor and two critic networks (two on-policy, two off-policy), one target network for each
- Updates are soft, according to theta_prime = tau*theta + (1-tau)*theta_prime, with tau « 1 (0.01 or less)
- The target actor is just the evaluation actior + noise (ornstein ulhenbeck) -> need a class for noise
- Action chosen as per target network
- ai is from the action buffer
- Adam optimiser, lr = 10^-4 for actor, 10^-3 for critic
- For Q(critic), L2 weight decay of 10^-2 and gamma = 0.99
- For soft updates, tau = 0.001
- Relu for all hidden layers
- final output layer for actor -> tanh
- action as separate input to second hidden layer of Q
- final layer weights and biases uniform distribution in a range
- theta = 0.15, sigma = 0.2 for noise (ornstein ulhenbeck)

```python
[1]: import os
     import numpy as np
     import torch
     import torch.nn as nn
     import torch.nn.functional as F
     import gym
```

```python
[2]: import matplotlib.pyplot as plt
     import numpy as np

     def plotLearning(scores, filename, x=None, window=5):
```

1

```python
        N = len(scores)
        running_avg = np.empty(N)
        for t in range(N):
            running_avg[t] = np.mean(scores[max(0, t-window):(t+1)])
        if x is None:
            x = [i for i in range(N)]
        plt.ylabel('Score')
        plt.xlabel('Game')
        plt.plot(x, running_avg)
        plt.savefig(filename)
```

```python
[3]:    # ornstein-uhlenbeck noise class
        class OUNoise(object):
            def __init__(self, mu, sigma=0.15, theta=0.2,dt = 1e-2, x0=None):
                self.theta = theta
                self.mu = mu
                self.sigma = sigma
                self.dt = dt
                self.x0 = x0
                self.reset()

            def __call__(self):
                x = self.x_prev + self.theta * (self.mu - self.x_prev) * self.dt + \
                    self.sigma * np.sqrt(self.dt) * np.random.normal(size=self.mu.shape)
                self.x_prev = x
                return x

            def reset(self):
                self.x_prev = self.x0 if self.x0 is not None else np.zeros_like(self.mu)
```

```python
[4]:    # replay buffer class
        class ReplayBuffer(object):
            def __init__(self, max_size, input_shape, n_actions):
                self.mem_size = max_size
                self.mem_counter = 0
                self.state_memory = np.zeros((self.mem_size, *input_shape))
                self.new_state_memory = np.zeros((self.mem_size, *input_shape))
                self.action_memory = np.zeros((self.mem_size, n_actions))
                self.reward_memory = np.zeros(self.mem_size)
                self.terminal_memory = np.zeros(self.mem_size, dtype=np.float32)

            def store_transitions(self, state, action, reward, state_, done):
                index = self.mem_counter % self.mem_size
                self.state_memory[index] = state
                self.new_state_memory[index] = state_
                self.reward_memory[index] = reward
                self.action_memory[index] = action
```

```python
        self.terminal_memory[index] = 1-int(done)
        self.mem_counter+=1

    def sample_buffer(self, batch_size):
        max_memory = min(self.mem_counter, self.mem_size)
        batch = np.random.choice(max_memory, batch_size)

        states = self.state_memory[batch]
        new_states = self.new_state_memory[batch]
        actions = self.action_memory[batch]
        rewards = self.reward_memory[batch]
        terminal = self.terminal_memory[batch]

        return states, actions, rewards, new_states, terminal
```

[5]:
```python
# class for critic network
class CriticNetwork(nn.Module):
    def __init__(self, beta, input_dims, fc1_dims, fc2_dims, n_actions, name,␣
 ↪chkpt_dir = 'models/ddpg'):
        super(CriticNetwork, self).__init__()

        self.input_dims = input_dims
        self.fc1_dims = fc1_dims
        self.fc2_dims = fc2_dims
        self.n_actions = n_actions
        self.chkpt_file = os.path.join(chkpt_dir, name+'_ddpg')

        # define network achitecture
        self.fc1 = nn.Linear(*self.input_dims, self.fc1_dims)
        f1 = 1/np.sqrt(self.fc1.weight.data.size()[0])
        torch.nn.init.uniform_(self.fc1.weight.data, -f1, f1)
        torch.nn.init.uniform_(self.fc1.bias.data, -f1, f1)
        self.bn1 = nn.LayerNorm(self.fc1_dims) ## apply layer normalisation

        self.fc2 = nn.Linear(self.fc1_dims, self.fc2_dims)
        f2 = 1/np.sqrt(self.fc2.weight.data.size()[0])
        torch.nn.init.uniform_(self.fc2.weight.data, -f2, f2)
        torch.nn.init.uniform_(self.fc2.bias.data, -f2,  f2)
        self.bn2 = nn.LayerNorm(self.fc2_dims) ## apply layer normalisation


        self.action_value = nn.Linear(self.n_actions, self.fc2_dims)
        f3 = 0.003
        self.Q = nn.Linear(self.fc2_dims, 1)
        torch.nn.init.uniform_(self.Q.weight.data, -f3,  f3)
        torch.nn.init.uniform_(self.Q.bias.data, -f3,  f3)
```

```python
        # define an optimiser
        self.optimiser = torch.optim.Adam(self.parameters(), lr = beta)

        # setting model to run on a device
        self.device = torch.device('cuda' if torch.cuda.is_available() else
 'cpu')
        self.to(self.device)


    # define forward class
    def forward(self, state, action):
        state_value = self.fc1(state)
        state_value = self.bn1(state_value)
        state_value = F.relu(state_value)
        state_value = self.fc2(state_value)
        state_value = self.bn2(state_value)

        action_value = F.relu(self.action_value(action))
        state_action_value = F.relu(torch.add(state_value, action_value))
        state_action_value = self.Q(state_action_value)

        return state_action_value


    # save model at checkpoint
    def save_checkpoint(self):
        print(f'saving checkpoint')
        torch.save(self.state_dict(), self.chkpt_file)

    # load model from checkpoint
    def load_checkpoint(self):
        print('loading model from checkpoint')
        self.load_state_dict(torch.load(self.chkpt_file))
```

[6]:
```python
# defining the actor network
class ActorNetwork(nn.Module):
    def __init__(self, alpha, input_dims, fc1_dims, fc2_dims, n_actions, name,
 chkpt_dir = 'models/ddpg'):
        super(ActorNetwork, self).__init__()
        self.input_dims = input_dims
        self.fc1_dims = fc1_dims
        self.fc2_dims = fc2_dims
        self.n_actions = n_actions
        self.chkpt_file = os.path.join(chkpt_dir, name+'_ddpg')
```

```python
        # define network achitecture
        self.fc1 = nn.Linear(*self.input_dims, self.fc1_dims)
        f1 = 1/np.sqrt(self.fc1.weight.data.size()[0])
        torch.nn.init.uniform_(self.fc1.weight.data, -f1, f1)
        torch.nn.init.uniform_(self.fc1.bias.data, -f1, f1)
        self.bn1 = nn.LayerNorm(self.fc1_dims) ## apply layer normalisation

        self.fc2 = nn.Linear(self.fc1_dims, self.fc2_dims)
        f2 = 1/np.sqrt(self.fc2.weight.data.size()[0])
        torch.nn.init.uniform_(self.fc2.weight.data, -f2, f2)
        torch.nn.init.uniform_(self.fc2.bias.data, -f2, f2)
        self.bn2 = nn.LayerNorm(self.fc2_dims) ## apply layer normalisation

        f3 = 0.003
        self.mu = nn.Linear(self.fc2_dims, self.n_actions)
        torch.nn.init.uniform_(self.mu.weight.data, -f3, f3)
        torch.nn.init.uniform_(self.mu.bias.data, -f3, f3)

         # define an optimiser
        self.optimiser = torch.optim.Adam(self.parameters(), lr = alpha)

        # setting model to run on a device
        self.device = torch.device('cuda' if torch.cuda.is_available() else
↪'cpu')
        self.to(self.device)

    def forward(self, state):
        output = self.fc1(state)
        output = self.bn1(output)
        output = F.relu(output)
        output = self.fc2(output)
        output = self.bn2(output)
        output = F.relu(output)
        output = torch.tanh(self.mu(output))

        return output

    # save model at checkpoint
    def save_checkpoint(self):
        print(f'saving checkpoint')
        torch.save(self.state_dict(), self.chkpt_file)

    # load model from checkpoint
    def load_checkpoint(self):
        print('loading model from checkpoint')
        self.load_state_dict(torch.load(self.chkpt_file))
```

```python
[7]: class Agent(object):
    def __init__(self, alpha, beta, input_dims, tau, env, gamma = 0.99,
    ↪n_actions=2, max_size = 1000000,\
        layer1_size=400, layer2_size=300, batch_size=64):

        self.gamma = gamma
        self.tau = tau
        self.memory = ReplayBuffer(max_size, input_dims, n_actions)
        self.batch_size = batch_size

        # define actor and target actor networks
        self.actor = ActorNetwork(alpha, input_dims, layer1_size, layer2_size,
    ↪n_actions, 'Actor')
        self.target_actor = ActorNetwork(alpha, input_dims, layer1_size,
    ↪layer2_size, n_actions, 'TargetActor')

        # define critic and target critic networks
        self.critic = CriticNetwork(beta, input_dims, layer1_size, layer2_size,
    ↪n_actions, 'Critic')
        self.target_critic = CriticNetwork(beta, input_dims, layer1_size,
    ↪layer2_size, n_actions, 'TargetCritic')

        self.noise = OUNoise(mu=np.zeros(n_actions))

        self.update_network_parameters(tau=1) # solves problem of moving target

    def choose_action(self, observation):
        self.actor.eval()
        observation = torch.tensor(observation, dtype=torch.float).to(self.
    ↪actor.device)
        mu = self.actor(observation).to(self.actor.device)
        mu_prime = mu + torch.tensor(self.noise(), dtype=torch.float).to(self.
    ↪actor.device)

        self.actor.train()
        return mu_prime.cpu().detach().numpy()


    def remember(self, state, action, reward, new_state, done):
        self.memory.store_transitions(state, action, reward, new_state, done)

    def learn(self):
        if self.memory.mem_counter < self.batch_size:
            return
```

```python
        state, action, reward, new_state, done = \
            self.memory.sample_buffer(self.batch_size)

        # place the observations into critic network
        reward = torch.tensor(reward, dtype=torch.float).to(self.critic.device)
        done = torch.tensor(done, dtype=torch.float).to(self.critic.device)
        new_state = torch.tensor(new_state, dtype=torch.float).to(self.critic.
↪device)
        action = torch.tensor(action, dtype=torch.float).to(self.critic.device)
        state = torch.tensor(state, dtype=torch.float).to(self.critic.device)

        # sending target networks and critic network into eval mode
        self.target_actor.eval()
        self.target_critic.eval()
        self.critic.eval()

        target_actions = self.target_actor.forward(new_state)
        critic_value_ = self.target_critic.forward(new_state, target_actions)
        critic_value = self.critic.forward(state, action)

        # calculate targets which we will move towards
        target = []
        for j in range(self.batch_size):
            target.append(reward[j] + self.gamma*critic_value_[j]*done[j])
        target = torch.tensor(target).to(self.critic.device)

        target = target.view(self.batch_size, 1)


        self.critic.train()
        self.critic.optimiser.zero_grad()
        critic_loss = F.mse_loss(target, critic_value)
        critic_loss.backward()
        self.critic.optimiser.step()

        # calculating actor model loss
        self.critic.eval()
        self.actor.optimiser.zero_grad()
        mu = self.actor.forward(state)
        self.actor.train()
        actor_loss = -self.critic.forward(state, mu)
        actor_loss = torch.mean(actor_loss)
        actor_loss.backward()
        self.actor.optimiser.step()

        # update network params
        self.update_network_parameters()
```

```python
    def update_network_parameters(self, tau=None):
        if tau is None:
            tau = self.tau
        actor_params = self.actor.named_parameters()
        critic_params = self.critic.named_parameters()

        target_actor_params = self.target_actor.named_parameters()
        target_critic_params = self.target_critic.named_parameters()

        critic_state_dict = dict(critic_params)
        actor_state_dict = dict(actor_params)
        target_critic_dict = dict(target_critic_params)
        target_actor_dict = dict(target_actor_params)


        # update target network params for critic and actor
        for name in critic_state_dict:
            critic_state_dict[name] = tau*critic_state_dict[name].clone() +↵
↪(1-tau)*target_critic_dict[name].clone()

        self.target_critic.load_state_dict(critic_state_dict)

        for name in actor_state_dict:
            actor_state_dict[name] = tau*actor_state_dict[name].clone() +↵
↪(1-tau)*target_actor_dict[name].clone()

        self.target_actor.load_state_dict(actor_state_dict)

    def save_models(self):
        self.actor.save_checkpoint()
        self.critic.save_checkpoint()
        self.target_actor.save_checkpoint()
        self.target_critic.save_checkpoint()

    def load_models(self):
        self.actor.load_checkpoint()
        self.critic.load_checkpoint()
        self.target_actor.load_checkpoint()
        self.target_critic.load_checkpoint()
```

```python
[8]: # create a gym environment
     env = gym.make('LunarLanderContinuous-v2')
```

```
[9]: agent = Agent(alpha = 0.000025, beta = 0.00025, input_dims=[8], tau = 0.001,␣
     ↪env = env, batch_size=64, layer1_size=400, layer2_size=300, n_actions=2)
     np.random.seed(0)
     score_history = []

     for i in range(1000):
         score = 0
         done = False
         observation = env.reset()

         while not done:
             a = agent.choose_action(observation)
             new_state, reward, done, _ = env.step(a)
             agent.remember(observation, a, reward, new_state, done)
             agent.learn()
             score+=reward
             observation = new_state

         score_history.append(score)
         print(f'episode : {i}, score: .%2f{score}, 100 game average: %.2f{np.
     ↪mean(score_history[-100:])}')

         if i%25==0:
             agent.save_models()

     filename = 'lunar-lander.png'
     plotLearning(score_history, filename)
```

```
episode : 0, score: .%2f-277.88187756426225, 100 game average:
%.2f-277.88187756426225
saving checkpoint
saving checkpoint
saving checkpoint
saving checkpoint
episode : 1, score: .%2f-309.68873931087, 100 game average:
%.2f-293.78530843756613
episode : 2, score: .%2f-255.94803551637378, 100 game average:
%.2f-281.17288413050204
episode : 3, score: .%2f-90.89583599766124, 100 game average:
%.2f-233.60362209729183
episode : 4, score: .%2f-118.71726393101619, 100 game average:
%.2f-210.6263504640367
episode : 5, score: .%2f-118.82008779502584, 100 game average:
%.2f-195.3253066858682
episode : 6, score: .%2f-137.20555595671118, 100 game average:
%.2f-187.0024851531315
episode : 7, score: .%2f-129.74845877660715, 100 game average:
%.2f-179.86323185606597
```

```
episode : 8, score: .%2f-137.27106160160338, 100 game average:
%.2f-175.130768494459
episode : 9, score: .%2f-150.69561723488277, 100 game average:
%.2f-172.6872533685014
episode : 10, score: .%2f-196.02274062555003, 100 game average:
%.2f-174.80866130096035
episode : 11, score: .%2f-138.0863881185002, 100 game average:
%.2f-171.7484718690887
episode : 12, score: .%2f-117.62951931399792, 100 game average:
%.2f-167.5854755186971
episode : 13, score: .%2f-122.92385119988604, 100 game average:
%.2f-164.39535949592488
episode : 14, score: .%2f-156.19263068708543, 100 game average:
%.2f-163.84851090866894
episode : 15, score: .%2f-149.40338197775978, 100 game average:
%.2f-162.9456903504871
episode : 16, score: .%2f-15.818984385501821, 100 game average:
%.2f-154.29117823489972
episode : 17, score: .%2f-365.8903783390141, 100 game average:
%.2f-166.04668935179495
episode : 18, score: .%2f-129.91347451105133, 100 game average:
%.2f-164.14494120228215
episode : 19, score: .%2f-118.90823897861341, 100 game average:
%.2f-161.8831060910987
episode : 20, score: .%2f-162.27177468033562, 100 game average:
%.2f-161.9016141191576
episode : 21, score: .%2f-114.09623710928467, 100 game average:
%.2f-159.72864243689065
episode : 22, score: .%2f-150.6210588961084, 100 game average:
%.2f-159.33266054381318
episode : 23, score: .%2f-218.16064299136005, 100 game average:
%.2f-161.7838264791276
episode : 24, score: .%2f-105.67715292535192, 100 game average:
%.2f-159.53955953697658
episode : 25, score: .%2f-147.55171557925914, 100 game average:
%.2f-159.07848861552594
saving checkpoint
saving checkpoint
saving checkpoint
saving checkpoint
episode : 26, score: .%2f-138.1864063128277, 100 game average:
%.2f-158.30470778950007
episode : 27, score: .%2f-160.42720192395518, 100 game average:
%.2f-158.3805111514449
episode : 28, score: .%2f-91.19527539713965, 100 game average:
%.2f-156.06377888405507
episode : 29, score: .%2f-96.73731051466132, 100 game average:
%.2f-154.08622993840862
```

episode : 30, score: .%2f-135.56710054672675, 100 game average: %.2f-153.48883866770922
episode : 31, score: .%2f-161.62902363016008, 100 game average: %.2f-153.74321944778575
episode : 32, score: .%2f-40.202614857276636, 100 game average: %.2f-150.30259506625518
episode : 33, score: .%2f-62.46469032814793, 100 game average: %.2f-147.71912727984025
episode : 34, score: .%2f-102.0793218803455, 100 game average: %.2f-146.4151328398547
episode : 35, score: .%2f-180.57629333044997, 100 game average: %.2f-147.36405396459344
episode : 36, score: .%2f-14.18922569782967, 100 game average: %.2f-143.76473428170794
episode : 37, score: .%2f-219.2682356882985, 100 game average: %.2f-145.7516685292498
episode : 38, score: .%2f-444.2759976218841, 100 game average: %.2f-153.40613850598402
episode : 39, score: .%2f-274.9980687985787, 100 game average: %.2f-156.4459367632989
episode : 40, score: .%2f-381.30679454069013, 100 game average: %.2f-161.93034792860112
episode : 41, score: .%2f-278.56207901691516, 100 game average: %.2f-164.7072939068943
episode : 42, score: .%2f-270.2149572779267, 100 game average: %.2f-167.1609604969183
episode : 43, score: .%2f-255.00568181871157, 100 game average: %.2f-169.15743143604996
episode : 44, score: .%2f-287.86642680256085, 100 game average: %.2f-171.7954091108613
episode : 45, score: .%2f-133.52360519228083, 100 game average: %.2f-170.96341337350086
episode : 46, score: .%2f-250.39238787638092, 100 game average: %.2f-172.65339155441322
episode : 47, score: .%2f-286.68933573443917, 100 game average: %.2f-175.0291403914971
episode : 48, score: .%2f-206.52488574926528, 100 game average: %.2f-175.67191070492095
episode : 49, score: .%2f-256.2012123672332, 100 game average: %.2f-177.2824967381672
episode : 50, score: .%2f-303.1975806609836, 100 game average: %.2f-179.7514199523401
saving checkpoint
saving checkpoint
saving checkpoint
saving checkpoint
episode : 51, score: .%2f-238.6123937183945, 100 game average: %.2f-180.88336175553346

episode : 52, score: .%2f-255.97030141343183, 100 game average:
%.2f-182.30009646605984
episode : 53, score: .%2f-327.5692687242446, 100 game average:
%.2f-184.9902663226929
episode : 54, score: .%2f-273.92844262293505, 100 game average:
%.2f-186.60732407360638
episode : 55, score: .%2f-263.22025762731346, 100 game average:
%.2f-187.97541217277967
episode : 56, score: .%2f-266.8938314521947, 100 game average:
%.2f-189.35994584434835
episode : 57, score: .%2f-441.296330732439, 100 game average:
%.2f-193.70367661828095
episode : 58, score: .%2f-449.14780993246404, 100 game average:
%.2f-198.03323819987725
episode : 59, score: .%2f-312.72831162037926, 100 game average:
%.2f-199.94482275688563
episode : 60, score: .%2f-223.50214656837787, 100 game average:
%.2f-200.33100839313963
episode : 61, score: .%2f-411.74626734839967, 100 game average:
%.2f-203.7409319246761
episode : 62, score: .%2f-572.5321052663031, 100 game average:
%.2f-209.5947600729559
episode : 63, score: .%2f-483.04722700762494, 100 game average:
%.2f-213.86745486881006
episode : 64, score: .%2f-464.2388115169259, 100 game average:
%.2f-217.71932189416566
episode : 65, score: .%2f-403.9158018797858, 100 game average:
%.2f-220.54048068182658
episode : 66, score: .%2f-331.86130018350195, 100 game average:
%.2f-222.20198545050832
episode : 67, score: .%2f-307.14159747587314, 100 game average:
%.2f-223.4510973920578
episode : 68, score: .%2f-256.4834355653771, 100 game average:
%.2f-223.92982693080154
episode : 69, score: .%2f-237.23466586085922, 100 game average:
%.2f-224.1198960583738
episode : 70, score: .%2f-361.072827685188, 100 game average:
%.2f-226.0488105883289
episode : 71, score: .%2f-250.64834830303226, 100 game average:
%.2f-226.3904708343665
episode : 72, score: .%2f-161.94281759155, 100 game average:
%.2f-225.5076262693964
episode : 73, score: .%2f-190.10457321110835, 100 game average:
%.2f-225.02920663347362
episode : 74, score: .%2f-240.97282685851957, 100 game average:
%.2f-225.24178823647424
episode : 75, score: .%2f-217.5265139237968, 100 game average:
%.2f-225.14027146920216

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episode : 76, score: .%2f-202.77560297628844, 100 game average:
%.2f-224.84982122903446
episode : 77, score: .%2f-301.24998575588313, 100 game average:
%.2f-225.8293105178402
episode : 78, score: .%2f-377.8854731425992, 100 game average:
%.2f-227.75407207005236
episode : 79, score: .%2f-201.4472867342682, 100 game average:
%.2f-227.42523725335505
episode : 80, score: .%2f-323.6362763472415, 100 game average:
%.2f-228.61302785945242
episode : 81, score: .%2f-116.58506288886647, 100 game average:
%.2f-227.24683316468918
episode : 82, score: .%2f-340.26457584436207, 100 game average:
%.2f-228.60849271504665
episode : 83, score: .%2f-181.19430403481752, 100 game average:
%.2f-228.04403808790107
episode : 84, score: .%2f-43.08379879150443, 100 game average:
%.2f-225.86803527264934
episode : 85, score: .%2f-103.77115925475387, 100 game average:
%.2f-224.44830415616215
episode : 86, score: .%2f-56.79707397005755, 100 game average:
%.2f-222.52127852183912
episode : 87, score: .%2f-105.25022373685279, 100 game average:
%.2f-221.18865289928246
episode : 88, score: .%2f-217.63354551555608, 100 game average:
%.2f-221.14870787249905
episode : 89, score: .%2f-28.835681840984563, 100 game average:
%.2f-219.01189647214886
episode : 90, score: .%2f-178.73100155281534, 100 game average:
%.2f-218.56924927523312
episode : 91, score: .%2f-200.30998097441415, 100 game average:
%.2f-218.3707789676155
episode : 92, score: .%2f-167.49690502163963, 100 game average:
%.2f-217.8237480649706
episode : 93, score: .%2f-32.61778704216289, 100 game average:
%.2f-215.85347188387692
episode : 94, score: .%2f-152.1327182755677, 100 game average:
%.2f-215.1827271090526
episode : 95, score: .%2f-207.27625634759295, 100 game average:
%.2f-215.10036803862076
episode : 96, score: .%2f-174.8173939396506, 100 game average:
%.2f-214.68507964584788
episode : 97, score: .%2f-20.23698986523155, 100 game average:
%.2f-212.70091546441301
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episode : 98, score: .%2f-171.14533964096057, 100 game average: %.2f-212.281162173267
episode : 99, score: .%2f-240.02538066481787, 100 game average: %.2f-212.55860435818252
episode : 100, score: .%2f-419.1792344035454, 100 game average: %.2f-213.97157792657538
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episode : 101, score: .%2f93.32962844839285, 100 game average: %.2f-209.94139424898273
episode : 102, score: .%2f-352.6324878903773, 100 game average: %.2f-210.90823877272277
episode : 103, score: .%2f-268.5251594695221, 100 game average: %.2f-212.68453200744136
episode : 104, score: .%2f-171.852190561112, 100 game average: %.2f-213.21588127374235
episode : 105, score: .%2f-284.539944562234, 100 game average: %.2f-214.8730798414144
episode : 106, score: .%2f-159.9266925454079, 100 game average: %.2f-215.10029120730138
episode : 107, score: .%2f-329.7569877617656, 100 game average: %.2f-217.10037649715295
episode : 108, score: .%2f-122.92256176357188, 100 game average: %.2f-216.9568914987726
episode : 109, score: .%2f-178.48066291213746, 100 game average: %.2f-217.23474195554513
episode : 110, score: .%2f-215.72885842901448, 100 game average: %.2f-217.43180313357982
episode : 111, score: .%2f-165.97183844678113, 100 game average: %.2f-217.71065763686263
episode : 112, score: .%2f-210.44991318196583, 100 game average: %.2f-218.63886157554234
episode : 113, score: .%2f-139.77150380722935, 100 game average: %.2f-218.80733810161576
episode : 114, score: .%2f-173.48086910797872, 100 game average: %.2f-218.98022048582467
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episode : 117, score: .%2f-172.62014359615728, 100 game average: %.2f-219.09720879962907
episode : 118, score: .%2f-86.00716132085964, 100 game average: %.2f-218.65814566772718
episode : 119, score: .%2f-148.12577743766667, 100 game average: %.2f-218.95032105231778

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episode : 121, score: .%2f-95.35684265388852, 100 game average:
%.2f-218.61396335297377
episode : 122, score: .%2f-49.629729967558134, 100 game average:
%.2f-217.60405006368822
episode : 123, score: .%2f-426.85217607359107, 100 game average:
%.2f-219.69096539451053
episode : 124, score: .%2f-192.45077327519303, 100 game average:
%.2f-220.55870159800892
episode : 125, score: .%2f-70.27257775117918, 100 game average:
%.2f-219.78591021972815
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episode : 126, score: .%2f-95.28245760254428, 100 game average:
%.2f-219.3568707326253
episode : 127, score: .%2f-88.67501207717235, 100 game average:
%.2f-218.6393488341575
episode : 128, score: .%2f-159.41194187203888, 100 game average:
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%.2f-219.68153577092482
episode : 130, score: .%2f-237.30481631699374, 100 game average:
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episode : 131, score: .%2f-114.68215765251696, 100 game average:
%.2f-220.22944426885107
episode : 132, score: .%2f-184.2231388812752, 100 game average:
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%.2f-222.11328981949111
episode : 135, score: .%2f-134.69347009701673, 100 game average:
%.2f-221.65446158715673
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episode : 138, score: .%2f-90.11506598939533, 100 game average:
%.2f-216.11499643811047
episode : 139, score: .%2f126.11851520505962, 100 game average:
%.2f-212.1038305980741
episode : 140, score: .%2f-129.92983612095415, 100 game average:
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episode : 141, score: .%2f-69.1850770012658, 100 game average:
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episode : 143, score: .%2f-132.5106790562374, 100 game average:
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episode : 144, score: .%2f-129.16189825780503, 100 game average:
%.2f-203.2593108667549
episode : 145, score: .%2f-169.2094287854989, 100 game average:
%.2f-203.61616910268714
episode : 146, score: .%2f-65.46517257868666, 100 game average:
%.2f-201.76689694971017
episode : 147, score: .%2f-95.36015905294776, 100 game average:
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episode : 148, score: .%2f-246.05109031057341, 100 game average:
%.2f-200.2488672285084
episode : 149, score: .%2f-33.72424102059561, 100 game average:
%.2f-198.02409751504194
episode : 150, score: .%2f-59.45019411970809, 100 game average:
%.2f-195.58662364962922
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episode : 151, score: .%2f-147.23219301983792, 100 game average:
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episode : 152, score: .%2f-172.91078629058978, 100 game average:
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%.2f-190.44598369841475
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%.2f-188.60945994277634
episode : 156, score: .%2f-238.05109250508968, 100 game average:
%.2f-188.32103255330532
episode : 157, score: .%2f-230.25119942985933, 100 game average:
%.2f-186.21058124027945
episode : 158, score: .%2f-146.93809074390884, 100 game average:
%.2f-183.18848404839392
episode : 159, score: .%2f-183.9788632198356, 100 game average:
%.2f-181.90098956438848
episode : 160, score: .%2f-187.32906485794354, 100 game average:
%.2f-181.53925874728415
episode : 161, score: .%2f-239.13862715302045, 100 game average:
%.2f-179.81318234533035
episode : 162, score: .%2f-156.34002922860356, 100 game average:
%.2f-175.65126158495335
episode : 163, score: .%2f-175.5564181123824, 100 game average:
%.2f-172.57635349600093
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episode : 167, score: .%2f-157.18986654097688, 100 game average:
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episode : 169, score: .%2f-287.241405723257, 100 game average:
%.2f-164.16625732940057
episode : 170, score: .%2f-114.70655501376672, 100 game average:
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episode : 171, score: .%2f-195.16152855080696, 100 game average:
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%.2f-161.18712805791495
episode : 175, score: .%2f-123.6133224862502, 100 game average:
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episode : 274, score: .%2f-196.22789755606127, 100 game average: %.2f-42.8404941696241
episode : 275, score: .%2f140.19879333384196, 100 game average: %.2f-40.202373011423184

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episode : 276, score: .%2f-39.2895437579733, 100 game average:
%.2f-39.514782211537685
episode : 277, score: .%2f-38.35598395171131, 100 game average:
%.2f-39.02321830302831
episode : 278, score: .%2f-8.57065999844161, 100 game average:
%.2f-37.20888446782378
episode : 279, score: .%2f-13.867572731270538, 100 game average:
%.2f-33.91375319904805
episode : 280, score: .%2f13.211628175600277, 100 game average:
%.2f-32.71867766236808
episode : 281, score: .%2f-9.566351169787268, 100 game average:
%.2f-32.10467352064859
episode : 282, score: .%2f213.1166668258603, 100 game average:
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%.2f-27.151411420090103
episode : 286, score: .%2f8.71632821414422, 100 game average:
%.2f-26.591854180623145
episode : 287, score: .%2f-10.906951963336013, 100 game average:
%.2f-26.21337259281638
episode : 288, score: .%2f2.012305342885904, 100 game average:
%.2f-25.663204796206323
episode : 289, score: .%2f275.84505403771743, 100 game average:
%.2f-22.416706096221514
episode : 290, score: .%2f17.060262373644505, 100 game average:
%.2f-21.781561647078203
episode : 291, score: .%2f251.53275515025248, 100 game average:
%.2f-18.524784579995906
episode : 292, score: .%2f32.80783955074804, 100 game average:
%.2f-17.4609897976504
episode : 293, score: .%2f217.68920755567854, 100 game average:
%.2f-14.240717480903813
episode : 294, score: .%2f187.07201964227409, 100 game average:
%.2f-10.93528464146772
episode : 295, score: .%2f278.21105844122997, 100 game average:
%.2f-8.250171418088575
episode : 296, score: .%2f-10.849057369266077, 100 game average:
%.2f-7.582449423734082
episode : 297, score: .%2f-43.39669988342245, 100 game average:
%.2f-5.819067596981862
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%.2f-3.6075729272578463
episode : 299, score: .%2f-89.23518065372058, 100 game average:
%.2f-5.120120630917227
episode : 300, score: .%2f253.64394292891294, 100 game average:
%.2f-0.08115129622505407
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episode : 301, score: .%2f197.50577434593123, 100 game average:
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episode : 302, score: .%2f170.71594019893598, 100 game average:
%.2f6.25277773801195
episode : 303, score: .%2f-106.6392008063, 100 game average:
%.2f5.669060125690395
episode : 304, score: .%2f-4.783569836520897, 100 game average:
%.2f7.534368025219488
episode : 305, score: .%2f-10.59811315686209, 100 game average:
%.2f7.206218182431322
episode : 306, score: .%2f192.74774467461225, 100 game average:
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%.2f14.22515809812301
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%.2f15.924467188914534
episode : 309, score: .%2f-44.82021529248216, 100 game average:
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%.2f35.49194933340754
episode : 318, score: .%2f192.57492271525388, 100 game average:
%.2f37.71877436416191
episode : 319, score: .%2f196.1143654032409, 100 game average:
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%.2f45.08192585244447
episode : 322, score: .%2f274.65341527925085, 100 game average:
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episode : 323, score: .%2f-202.53672207929057, 100 game average:
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episode : 324, score: .%2f-269.2237810569186, 100 game average:
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episode : 325, score: .%2f-184.3427284447568, 100 game average:
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episode : 341, score: .%2f210.48789755497998, 100 game average:
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episode : 346, score: .%2f-214.81402682422907, 100 game average:
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episode : 349, score: .%2f-53.29156778001354, 100 game average:
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episode : 363, score: .%2f-334.93187913970604, 100 game average:
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episode : 371, score: .%2f23.53776181488996, 100 game average:
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episode : 372, score: .%2f161.65708666193592, 100 game average:
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episode : 373, score: .%2f214.35631455456905, 100 game average:
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episode : 375, score: .%2f134.95935809971803, 100 game average:
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episode : 376, score: .%2f-151.86647117160317, 100 game average:
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episode : 385, score: .%2f216.74847309145738, 100 game average:
%.2f97.95297354738445
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episode : 403, score: .%2f-28.27986080919561, 100 game average:
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episode : 404, score: .%2f233.88205035545033, 100 game average:
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episode : 406, score: .%2f255.72454856759032, 100 game average:
%.2f101.30011531730788
episode : 407, score: .%2f222.91074990331958, 100 game average:
%.2f101.04301648908618
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episode : 426, score: .%2f220.476504892136, 100 game average:
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episode : 427, score: .%2f241.24504968333045, 100 game average:
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episode : 429, score: .%2f234.0174596125935, 100 game average:
%.2f114.61309633672478
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episode : 450, score: .%2f162.21516894658882, 100 game average:
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episode : 451, score: .%2f-26.16255407917481, 100 game average:
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%.2f142.5934110568175
episode : 475, score: .%2f92.00306668589712, 100 game average:
%.2f142.16384814267929

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episode : 476, score: .%2f259.3981457565862, 100 game average:
%.2f146.2764943119612
episode : 477, score: .%2f224.06657191915076, 100 game average:
%.2f148.0930600836073
episode : 478, score: .%2f257.55782743986526, 100 game average:
%.2f148.2378095820858
episode : 479, score: .%2f-19.098136260967834, 100 game average:
%.2f145.43571941710462
episode : 480, score: .%2f-65.36327504023187, 100 game average:
%.2f142.68783833799466
episode : 481, score: .%2f176.13758955570657, 100 game average:
%.2f142.1920175334431
episode : 482, score: .%2f250.71989824653957, 100 game average:
%.2f144.66748229437948
episode : 483, score: .%2f-202.520380192524, 100 game average:
%.2f140.58447284420467
episode : 484, score: .%2f204.06684744432908, 100 game average:
%.2f140.43225443538688
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%.2f137.60299124062152
episode : 486, score: .%2f219.85859670592197, 100 game average:
%.2f139.5678057110104
episode : 487, score: .%2f247.2645442296001, 100 game average:
%.2f139.70499430178108
episode : 488, score: .%2f153.51546004206733, 100 game average:
%.2f143.05703693636448
episode : 489, score: .%2f170.6037461813828, 100 game average:
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episode : 490, score: .%2f245.62785000846833, 100 game average:
%.2f149.38226649710566
episode : 491, score: .%2f197.74102943355967, 100 game average:
%.2f153.36907857457788
episode : 492, score: .%2f236.55122138291472, 100 game average:
%.2f153.68382228018402
episode : 493, score: .%2f217.47934363254097, 100 game average:
%.2f154.04812887715914
episode : 494, score: .%2f-102.9677724006512, 100 game average:
%.2f150.63938095919218
episode : 495, score: .%2f190.68446585813354, 100 game average:
%.2f150.59651906728243
episode : 496, score: .%2f234.81486395876948, 100 game average:
%.2f150.06732002093457
episode : 497, score: .%2f173.992078859221, 100 game average:
%.2f151.74142111446116
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episode : 498, score: .%2f-134.8714491020379, 100 game average: %.2f147.93369229298153
episode : 499, score: .%2f15.670602566217696, 100 game average: %.2f145.7193607718711
episode : 500, score: .%2f191.38847067114608, 100 game average: %.2f145.0911145266905
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episode : 501, score: .%2f-78.87419367814685, 100 game average: %.2f144.44415732200716
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episode : 503, score: .%2f-53.044265228509865, 100 game average: %.2f141.43724355758448
episode : 504, score: .%2f218.46006582560258, 100 game average: %.2f141.28302371228597
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episode : 506, score: .%2f252.19380746962975, 100 game average: %.2f140.9442813585562
episode : 507, score: .%2f213.02006507842225, 100 game average: %.2f140.84537451030724
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episode : 513, score: .%2f233.1080233917901, 100 game average: %.2f141.0706127994085
episode : 514, score: .%2f213.5935907904573, 100 game average: %.2f141.60083544897017
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episode : 517, score: .%2f246.52438913926912, 100 game average: %.2f143.76316097950183
episode : 518, score: .%2f203.84943925059213, 100 game average: %.2f143.51753833146685
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episode : 520, score: .%2f-17.743333523689515, 100 game average: %.2f141.70781050857298
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episode : 523, score: .%2f212.28364375708577, 100 game average: %.2f142.23033311634907
episode : 524, score: .%2f197.84976658639158, 100 game average: %.2f141.35600953877025
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episode : 526, score: .%2f225.69996845648427, 100 game average: %.2f140.72469266424926
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episode : 537, score: .%2f8.032879431408702, 100 game average: %.2f134.35323227740346
episode : 538, score: .%2f256.9089412568292, 100 game average: %.2f134.38449168644206
episode : 539, score: .%2f243.57665963371502, 100 game average: %.2f134.41994434168313
episode : 540, score: .%2f200.37679922259676, 100 game average: %.2f137.40091956224148
episode : 541, score: .%2f240.3829913734782, 100 game average: %.2f139.88659103760114

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episode : 543, score: .%2f235.02455829412963, 100 game average:
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episode : 544, score: .%2f228.85973669651196, 100 game average:
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episode : 545, score: .%2f273.92851395760545, 100 game average:
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episode : 546, score: .%2f107.94795224951332, 100 game average:
%.2f143.08844796904552
episode : 547, score: .%2f-165.63309380836984, 100 game average:
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episode : 548, score: .%2f224.53265659369953, 100 game average:
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episode : 550, score: .%2f257.6150119442175, 100 game average:
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episode : 552, score: .%2f-61.11936245222146, 100 game average:
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episode : 553, score: .%2f265.2681533528985, 100 game average:
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%.2f138.21849791408903
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episode : 561, score: .%2f216.25715300773243, 100 game average:
%.2f133.84095877395086
episode : 562, score: .%2f-50.909593424118206, 100 game average:
%.2f130.76037998511856
episode : 563, score: .%2f-32.68095543758628, 100 game average:
%.2f127.89254537261778
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%.2f128.29852688702954
episode : 565, score: .%2f258.68178816047526, 100 game average:
%.2f128.87971400951037
episode : 566, score: .%2f-39.7697602015932, 100 game average:
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episode : 567, score: .%2f267.0824666863699, 100 game average:
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episode : 568, score: .%2f257.07230617987284, 100 game average:
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episode : 569, score: .%2f-144.56313316763104, 100 game average:
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episode : 570, score: .%2f186.90048027950976, 100 game average:
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episode : 572, score: .%2f-198.62098064270785, 100 game average:
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episode : 574, score: .%2f203.4740981827246, 100 game average:
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episode : 575, score: .%2f253.66618674596248, 100 game average:
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episode : 576, score: .%2f-92.44789752472282, 100 game average:
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%.2f126.11005402123419
episode : 579, score: .%2f236.05057943786463, 100 game average:
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episode : 580, score: .%2f207.4510108660475, 100 game average:
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%.2f130.75085131322487
episode : 582, score: .%2f-31.63028696607816, 100 game average:
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%.2f132.0199078562869
episode : 584, score: .%2f-146.6601125035192, 100 game average:
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episode : 585, score: .%2f252.91456101872973, 100 game average:
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episode : 589, score: .%2f178.89196587415586, 100 game average:
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episode : 601, score: .%2f142.29116459118384, 100 game average:
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episode : 602, score: .%2f108.96457382587559, 100 game average:
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episode : 606, score: .%2f-166.13746256847924, 100 game average:
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episode : 607, score: .%2f208.9327870943813, 100 game average:
%.2f129.458682836988
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episode : 608, score: .%2f-272.67934344423827, 100 game average: %.2f124.36069865268895
episode : 609, score: .%2f230.7939985163021, 100 game average: %.2f124.42771849425742
episode : 610, score: .%2f146.93605338079652, 100 game average: %.2f126.55946590602319
episode : 611, score: .%2f84.35466145048706, 100 game average: %.2f124.80378551661839
episode : 612, score: .%2f-51.153928902875634, 100 game average: %.2f121.95424783476004
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saving checkpoint
saving checkpoint
saving checkpoint
episode : 626, score: .%2f194.67058015333538, 100 game average: %.2f109.9100911588928
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episode : 628, score: .%2f74.4531602049703, 100 game average: %.2f107.44766624150857
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episode : 637, score: .%2f225.5607019019096, 100 game average:
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episode : 649, score: .%2f223.00633592753604, 100 game average:
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episode : 650, score: .%2f189.0014878656757, 100 game average:
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saving checkpoint
saving checkpoint
saving checkpoint
episode : 651, score: .%2f182.2549044639366, 100 game average:
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episode : 674, score: .%2f181.87762925631168, 100 game average:
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episode : 675, score: .%2f222.33901810491838, 100 game average:
%.2f103.8630386446078
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saving checkpoint
episode : 676, score: .%2f206.28745517956932, 100 game average:
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%.2f103.35052092392385
episode : 680, score: .%2f-207.87978079204134, 100 game average:
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episode : 686, score: .%2f241.6047747762541, 100 game average:
%.2f101.58453327173753
episode : 687, score: .%2f207.34775648025817, 100 game average:
%.2f101.62354722145663
episode : 688, score: .%2f191.34709121784257, 100 game average:
%.2f102.98418449896353
episode : 689, score: .%2f-54.291199114345034, 100 game average:
%.2f100.65235284907851
episode : 690, score: .%2f13.773637761134694, 100 game average:
%.2f98.1626821068551
episode : 691, score: .%2f209.23266571845224, 100 game average:
%.2f97.99420026705526
episode : 692, score: .%2f253.349591867869, 100 game average:
%.2f98.21812091762853
episode : 693, score: .%2f233.04129352052502, 100 game average:
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episode : 694, score: .%2f283.86847965434606, 100 game average:
%.2f99.19567682462399
episode : 695, score: .%2f270.4268662783461, 100 game average:
%.2f99.6178120905866
episode : 696, score: .%2f248.80220519664672, 100 game average:
%.2f104.0984937204069
episode : 697, score: .%2f255.28314363893716, 100 game average:
%.2f104.16455629678296
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episode : 698, score: .%2f215.44997749413122, 100 game average:
%.2f107.0111883664492
episode : 699, score: .%2f-240.31454163255336, 100 game average:
%.2f102.41614062333949
episode : 700, score: .%2f200.8063407756904, 100 game average:
%.2f101.76901275608162
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episode : 701, score: .%2f8.239906463184326, 100 game average:
%.2f100.42850017480163
episode : 702, score: .%2f-130.62546168850452, 100 game average:
%.2f98.03259981965783
episode : 703, score: .%2f3.3211503379011873, 100 game average:
%.2f95.90145148043489
episode : 704, score: .%2f-189.76697404501587, 100 game average:
%.2f94.61453229600242
episode : 705, score: .%2f-132.68182082587631, 100 game average:
%.2f94.94619020330123
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episode : 709, score: .%2f244.10478490301935, 100 game average:
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%.2f112.07302885568586
episode : 719, score: .%2f221.78552626499916, 100 game average:
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episode : 747, score: .%2f38.96132813385438, 100 game average:
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%.2f53.483240530090185
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%.2f50.68115745705884
episode : 895, score: .%2f219.25013449000917, 100 game average:
%.2f50.49616640948939
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%.2f53.287820820045134
episode : 897, score: .%2f-197.3297493330871, 100 game average:
%.2f48.68607581282144
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saving checkpoint
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episode : 902, score: .%2f-91.91727950834174, 100 game average:
%.2f30.509677838344523
episode : 903, score: .%2f-266.942435900266, 100 game average:
%.2f25.07220754352178
episode : 904, score: .%2f260.5040991179813, 100 game average:
%.2f24.710297929912084
episode : 905, score: .%2f218.3270348940225, 100 game average:
%.2f24.388598917447265
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%.2f24.228061106070072
episode : 907, score: .%2f214.11923193528403, 100 game average:
%.2f26.771637795172165
episode : 908, score: .%2f-363.39862426121135, 100 game average:
%.2f23.177637915743517
episode : 909, score: .%2f201.27478424909728, 100 game average:
%.2f22.78653995430317
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episode : 920, score: .%2f227.77738069317496, 100 game average:
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episode : 922, score: .%2f276.5627079726361, 100 game average:
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%.2f25.12882044079815
episode : 928, score: .%2f208.189115368374, 100 game average:
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episode : 929, score: .%2f244.83139492333575, 100 game average:
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%.2f31.961409045696005
episode : 935, score: .%2f274.7704358206631, 100 game average:
%.2f34.92224370833408
episode : 936, score: .%2f281.2619510139755, 100 game average:
%.2f37.93101322586367
episode : 937, score: .%2f241.87629388312328, 100 game average:
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episode : 938, score: .%2f-70.91902712896629, 100 game average:
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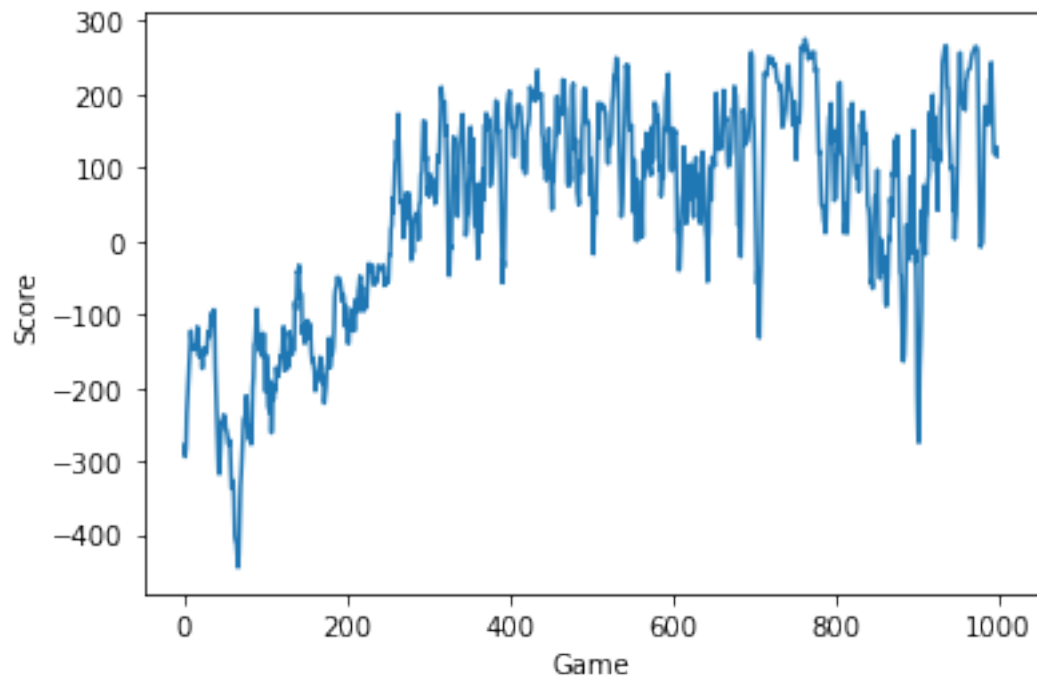episode : 941, score: .%2f157.3361825668711, 100 game average:
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