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Application of Reinforcement Learning Methods

Group 19 - Final Project Report

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1 Introduction

We shortly present two state-of the art reinforcement learning algorithms, the *Deep Deterministic Policy Gradient* and the *Natural Actor Critic*. Both algorithms are evaluated on the simulated Quanser Robots platforms *BallBalancerSim-v0*, *CartPoleStabShort-v0* and *Qube-v0*. We furthermore present the results of training both algorithms on the *BallBalancerSim-v0* and evaluating it on the pyhiscal *BallBalancerRR-v0* platform. Finally, we close with a discussion of the results.

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2 Deep Deterministic Policy Gradient

The *Deep Deterministic Policy Gradient* approach (Lillicrap et al. 2015) is an application of the *Deep Q-Learning* algorithm (Mnih et al. 2013) to actor-critic methods (Konda and Tsitsiklis 2000) in combination with the *Deterministic Policy Gradient* (Silver et al. 2014). It is a model-free and off-policy algorithm, learning a deterministic policy. We separated the learning process completely from the algorithm's other components. The critic is updated using the temporal difference error. It is calculated from using the target networks which are constrained to slow changes with rate τ to improve the stability of learning. The actor is trained by using the integrated update rule from Lillicrap et al. (2015) as it's loss function. Both networks are addressed and can be modified in a separate file, same as the replay buffer, which is used to sample independently and identically distributed mini-batches, randomly selected to temporarily decorrelate them. The action noise to ensure exploration was also kept completely independent from the training algorithm as intended by (Lillicrap et al. 2015) and is just added to the output of the actor. We clip this output to ensure it suits the environment.

2.1 Evaluation on BallBalancerSim-v0

The Quanser Robots *BallBalancerSim-v0* environment consist of a plate whose angles can be controlled by the input actions. The goal is to balance a ball on the plate, receiving a maximum reward of 1.0 per time-step for balancing it in the middle of the plate. The environment ends after a maximum of 1000 time-steps.

We started our evaluations with using two hidden layers with 100 and 300 hidden neurons for the actor and the critic networks and their targets. The learning rates are set to $\alpha_{actor} = 1e-4$ and $\alpha_{critic} = 1e-3$. In the left row of figure 2 one can find our first acceptable results. Discounting is set to $\gamma = 0.99$, we did soft target updates with $\tau = 1e-4$, used a mini-batch size of 64 and a total replay buffer size of 1e6. We slightly increased the noise to $\sigma_{OU} = 0.2$ and $\theta_{OU} = 0.25$ as the environments action space has an higher amplitude compared to the *Pendulum-v0* trained on in (Lillicrap et al. 2015).

The algorithm did learn to balance the ball, but was not very stable, which can also be read from the learning progress plot. To further increase the stability, we increased th mini-batch size used to sample from the replay buffer, and reduced the noise again. Using weight regularization did not seem to be helpful, so we set it to zero.

Figure 1 shows the training process where discounting is set to $\gamma = 0.2$ compared to $\gamma = 0.99$. One can see discounting is crucial to solve this environment.

We tried to reduce the computational effort by only using a single hidden layer with 100 hidden neurons instead of two layers. The impact on the performance is shown in the middle row of figure 2. The learning suffered from

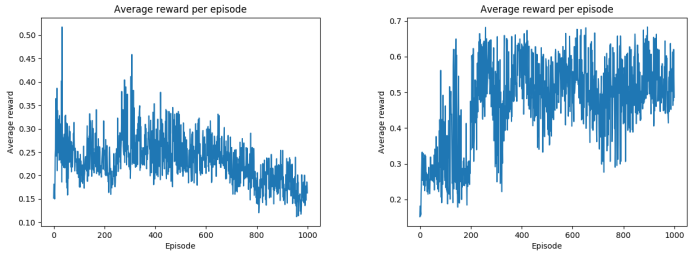

Fig. 1 The left figure shows the cumulative reward per episode during the training process with γ set to 0.2. The right one displays the process for $\gamma = 0.99$. Using discounting close to 1 was very important.

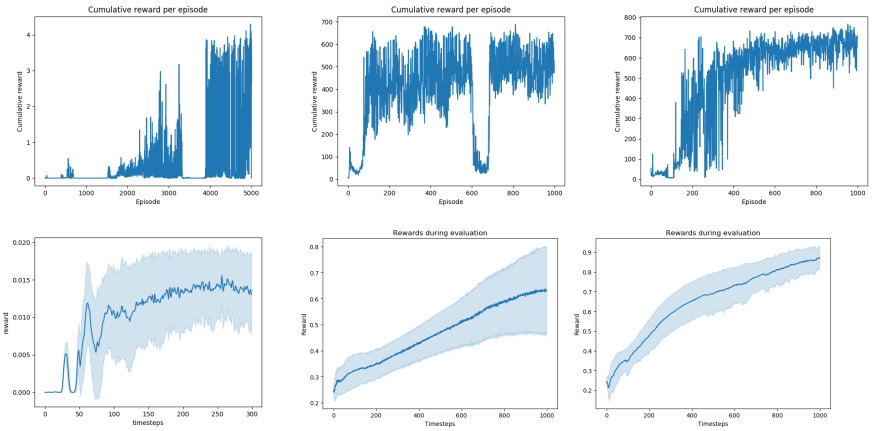

Fig. 2 The figure displays the training process in the first row and the evaluation results in the second row. Early learning successes can be found in the left column, while the middle column shows the influence of using only a single hidden layer. The right column gives the plots of our best training result.[EDIT: ALIGN PLOTS + LEFT PLOT IS WRONG (WRONG ENV...)]

instabilities, so we decided to weight the stability of using two hidden layers higher than the performance loss.

Our best results can be found in the right row of figure 2 where we set the OU action noise equal to the one used in the original paper with $\sigma_{OU} = 0.15$ and $\theta_{OU} = 0.2$. We used slightly harder updates with $\tau = 1e-3$, and achieved an average cumulative reward of about 650 for 25 episodes of evaluation. The learning process took about 3 hours for 1000 episodes. Further evaluations are needed to improve the training even more.

2.2 Evaluation on CartPoleStabShort-v0

The Quanser Robots *CartPoleStabShort-v0* environment consists of a movable car with a singular pendulum attached. The car can be controlled by input

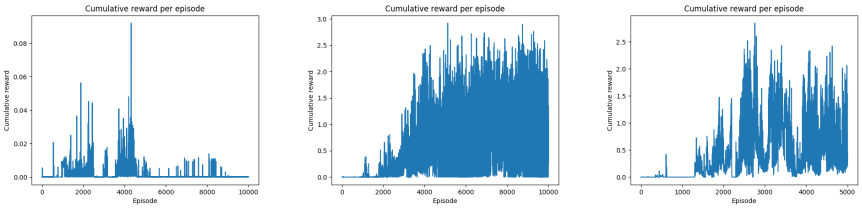

Fig. 3 Assuming the parameters from our best result on *BallBalancerSim-v0*, we achieved the performance shown in the left plot on *Qube-v0*. The middle plot shows the changes when using more OU noise, i.e. $\sigma = 3.2$. The right plot displays the result of training with a gaussian noise with mean zero and standard deviation $\sigma = 0.7$. The mini-batch size was also increased to 256.

actions. The goal is to balance the pendulum, starting from a vertical position and the reward is depending on the angle, with a maximum of 2.0 per time-step for balancing the pendulum straight upright.

We achieved some progress using [x]. The results are displayed in [x].

2.3 Evaluation on Qube-v0

The Quanser Robots *Qube-v0* environment implements the Furuta Pendulum, which consists of a motor controlling one horizontal arm. One end of the joint is attached to the motor, the other end is attached to another vertical arm, which can only be controlled indirectly by controlling the first arm. More details about the Furuta Pendulum can be found in our paper about it.

The goal is to balance the second arm in upright position, receiving a maximum reward of 0.02 per time-step. The environment stops after 300 time-steps. We did not get any useful results re-using the parameters we found for *BallBalancer-v0*. Using an Ornstein Uhlenbeck similar to the one used in citeplillicrap2015continuous, did not seem to help to deal with the local optima of the environment. Setting the randomness σ_{OU} too small resulted in too less exploration. Choosing a higher σ_{OU} resulted in better exploration but much less stability. Examples are displayed in figure 3.

No stable training process could be achieved. To address this issue we started using a consistent gaussian noise. Unfortunately this did also not help the training process, and seemed to be even more unstable. Figure 3 shows a result of using gaussian noise in the right plot. The algorithm seemed to learn well for a period of time, but tended to overwrite these progress. Lowering the target update rate τ did not help, nether did lowering the actor and critic learning rates.

Our experiments induced several things: Using a higher batch size seemed to increase the stability to a certain level, but also highly increased the computational effort. 256 seemed to be a good batch-size. The decisions harder or softer updates, controlled by τ, and the amount of action noise for exploration seemed to be very important but also very hard to tune. E.g. choosing

$\tau = 1e-2$ resulted in an agent tending to overwrite what he already learned, while setting $\tau = 1e-4$ prevented him from learning anything. So we chose $\tau = 1e-3$, but this alone was not sufficient for effective learning. Reducing the action noise added to the actor output did also not help. Further evaluations are needed to find the right set of hyper-parameters for this environment.

3 Natural Actor Critic

The *Natural Actor Critic (NAC)* (Peters and Schaal 2008) is a model-free, off-policy algorithm, which learns the optimal policy of a reinforcement learning problem by applying the natural gradient (Amari 1998) on an actor-critic approach (Sutton et al. 1998). We implemented the episodic NAC (Peters and Schaal 2008) which takes a fixed number of steps (equals one or more trajectories) in the environment before applying updates to the actor and critic. The actor is an approximation of the policy and the critic is an approximation of the value function. We implemented both, the actor and the critic, by using neural networks in tensorflow.

3.1 The Critic Network

For the critic, we introduced a neural network with a single hidden layer. The input layer equals the state dimension of the environment. It is fully connected to the hidden layer, which again is fully connected to a single output node and uses a ReLu activation function (Glorot et al. 2011).

To train the network, we calculate the discounted return for all states we visited since the last update and compare it to the discounted return approximation of the critic. Then, we take the least squares error between the two arrays as loss and minimize it by applying an Adam optimizer (Kingma and Ba 2014).

Parameters: We used a hidden layer with 10 nodes and a learning rate of 0.1 for all environments. We tried to add more hidden nodes and experimented with the learning rate, but could not depict any significant improvements.

3.2 The Actor Network

The actor network has an input and an output layer, which are fully connected, and uses a softmax activation function. The input layer matches the dimension of the state, the output layer matches the dimension of the action space. If we feed an observation into the network, the output is an array of probabilities for each action. To select which action to take, we stochastically sample an action w.r.t these probabilities.

To train the network, we use the critic to calculate the advantages for all states we visited since the last update. Then we feed the advantages, states and actions to the actor and update the actors parameters with the natural

gradient. For this, we compute the cost function, it's gradient w.r.t the actor network parameters and the inverse of the Fisher information matrix. To get the inverse, we apply singular value decomposition (Golub and Kahan 1965).

Parameters: We trained all of the environments without a hidden layer and with a learning rate of 0.001. We tried to add a hidden layer and change the learning rate, but did not get any improved results.

3.3 Evaluation on the BallBalancerSim-v0

The NAC algorithm learned to solve the ball balancer extremely well. Already with 300 updates and 2000 steps per update, the ball balancer manages to hold the ball on the platform and navigate it slowly into the middle. The more steps the environment was allowed to do between updates, the greater became the cumulative reward. Our best run was a simulation with 1000 updates, 7000 steps per update and a discount factor of 1. This hyper parameter setting returned an cumulative average trajectory reward of 600.53. We believe that we would get an even higher average cumulative trajectory reward with more steps per update.

The number of updates was not as important as the number of steps between updates. Figure 4 shows in the top left corner that already after 300 steps we reached trajectories with cumulative rewards of 600. From this point onwards, the longer we update the more stable the algorithm gets (less trajectories with cumulative rewards under 600), but the average trajectory reward does not improve anymore.

Further, we can see in the bottom left corner of figure 4 that even for our best run, the average reward per time step increased very slowly. This reflects the behavior of the environment, which moves the ball very slowly to the middle, where the environment returns increased rewards. Our idea was to apply a basis function to the rewards which pulls the high rewards from the low rewards even further, but did not have any success with it's implementation.

3.4 Evaluation on CartPoleStabShort-v0

We managed to get a nearly perfect result for the cart pole balancing task. The average cumulative trajectory reward of our model is 19768.60, which is slightly less than the possibly maximum of 20000. We used 300 updates with 2000 steps and a discount factor of 0.99 to achieve these results.

3.5 Evaluation on Qube-v0

The results we achieved for the Qube were moderate. Our best run had an average cumulative trajectory reward of 0.92278. The Qube manages to swing up the pendulum from time to time, but does not hold it in an upright position. We used 500 updates with 4000 steps and a discount factor of 0.99.

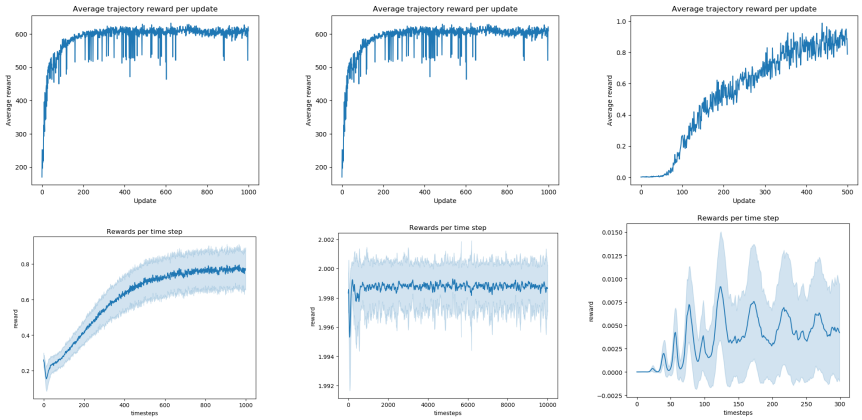

Fig. 4 This figure shows the application of the natural actor critic algorithm on the simulated ball balancer (left column), cart pole (middle column) and qube (right column). The *top row* shows the training of the respective environment and displays the average cumulative trajectory reward for each update. The NAC algorithm uses a fixed step size, which means that one update consists of one or more trajectories. The *bottom row* shows the evaluation of the respective environments, which has been done over 100 trajectories (which may vary in length). The figures show the average reward for each time step and it's standard deviation.

Figure 4 shows the training of the qube in the top right corner. We can see that a large number of updates is very important for the system. The average cumulative trajectory reward per update still improved during the 500th update. In the bottom right corner of figure 4, the average reward per time step can be found. The high standard deviation and the jumpy average illustrate the incapability of the qube to hold the pendulum in an upright position.

4 Evaluation of Pretrained Models on real systems

Ball Balancer System: Evaluating our best DDPG model trained in simulation on the real ball balancer was not successful (Figure 5, left). The chosen actions were too big and the plate instantly tilted. Additionally, it was not possible for us to reset the environment between the evaluation episodes.

With our best pretrained NAC model, the actions of our policy seemed to strong as well. We tried to execute a model with 10 times smaller actions, but got the same disappointing results.

Cart Pole System: Evaluating our best NAC model with nearly perfect rewards on the real cart pole system was not successful (Figure 5, right). The actions of the cart had to much power, which is why we clipped the actions from originally [-24, 24] to [-6, 6], but the cart was still far to jumpy to hold the stick upright.

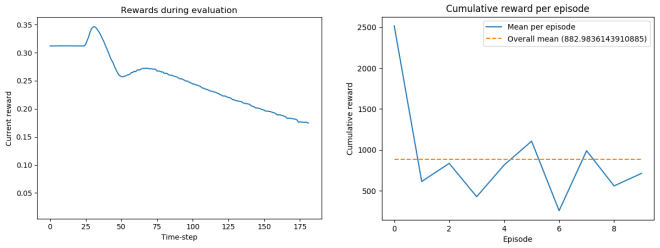

Fig. 5 On the left side, we can see one episode of DDPG on the real ball balancer system and on the right side, ten episodes of NAC on the real cart pole system. Both algorithms did not perform very well although they run smoothly in simulation.

5 Discussion

We implemented the DDPG and NAC algorithms and evaluated them on the Quanser Robots environments *BallBalancerSim-v0*, *CartPoleStabShort-v0* and the *Qube-v0*. Both algorithms were able to learn a well performing policy for the first two environments, where the NAC needed less computational time and was more sample efficient. Nonetheless, both algorithms did have troubles to learn a close to optimal policy for the *Qube-v0* environment. They suffered from a very difficult exploration / exploitation trade-off, often with stable learning in the beginning which is overwritten later, or not having enough exploration drive to escape local optima. Further evaluation is needed to optimize the algorithms especially for this environment. Due to technical difficulties it was not really possible to evaluate our pretrained models on the real Quanser Robots systems. Further investigation is needed.

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