Actor Critic I

CISC 7404 - Decision Making

Steven Morad

University of Macau

Admin

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How is homework 2?

Admin

Quiz next week

Admin

Quiz next week

Study:

Admin

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Study:

- Actor critic (today)

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- Policy gradient

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- Deep Q learning

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Quiz next week

Study:

- Actor critic (today)
- Policy gradient
- Deep Q learning
- Expected returns

Final Project

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Final project information is released

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Suggest project and group members by next Friday (28th)

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https://ummoodle.um.edu.mo/pluginfile.php/6900679/mod_resource/content/6/project.pdf

Review

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Answer: Requires collecting an infinite sequence of rewards!

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I want to quickly repeat the relationship between V and Q

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Now that V and Q are clear, back to policy gradient

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Replace MC return with V/Q in policy gradient, call it **actor-critic**

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Actor pick action

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Critic gives actor score

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Definition: The actor-critic algorithm that jointly trains a policy network and value function

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$$\theta_{\pi, i+1} = \theta_{\pi, i} + \alpha \cdot \underbrace{V(s_0, \theta_{\pi, i}, \theta_{V, i})}_{\text{Expected return}} \cdot \nabla_{\theta_{\pi, i}} \log \pi(a_0 \mid s_0; \theta_{\pi, i})$$

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$$\theta_{V,i+1} =$$

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Repeat process until convergence: $\theta_{\pi,i+1} = \theta_{\pi,i}, \quad \theta_{V,i+1} = \theta_{V,i}$

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Can train policy with single transition s_0, a_0, s_1, r_0, d_0

Advantage Actor Critic

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Similar results if reward is always positive

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Sample k transitions $(s_0, a_0, r_0, d_0, s_1)$ for each policy update

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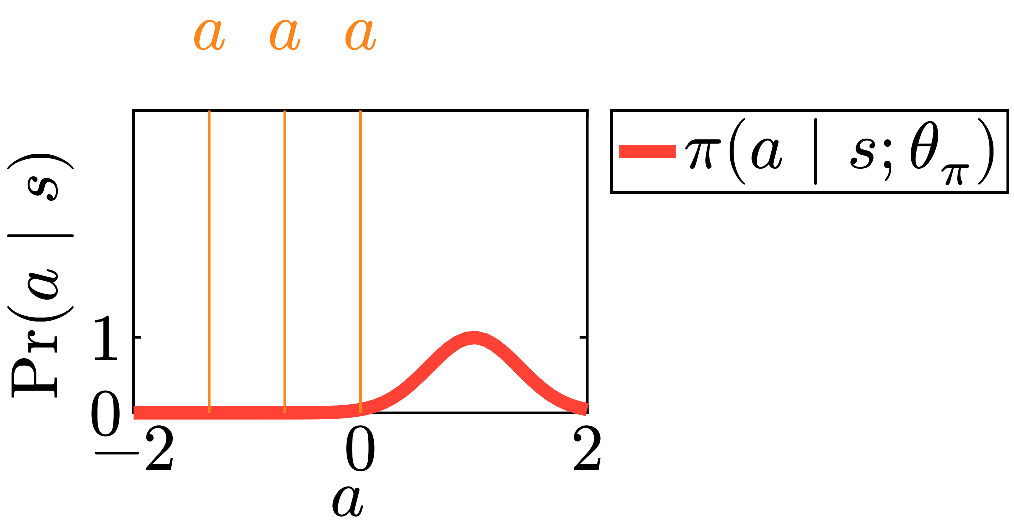

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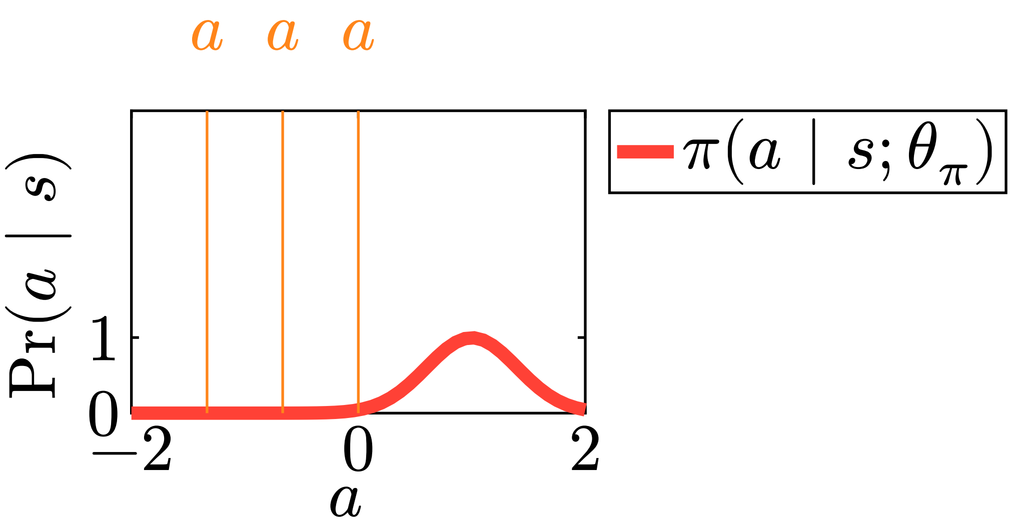

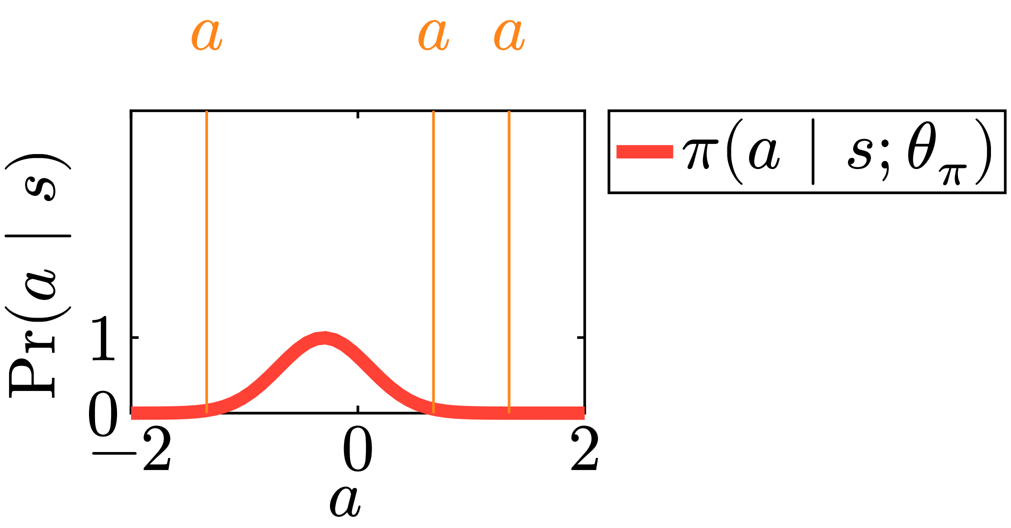

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https://media0.giphy.com/media/v1.Y2lkPTc5MGI3NjExeGdqZm56NDgzcmY2Ym95dG13Ynczdm9lbDY0cGpjczdtMHBmcnJmMSZlcD12MV9pbnRlcm5hbF9naWZfYnlfaWQmY3Q9Zw/MVUyVpyjakkRW/giphy.gif

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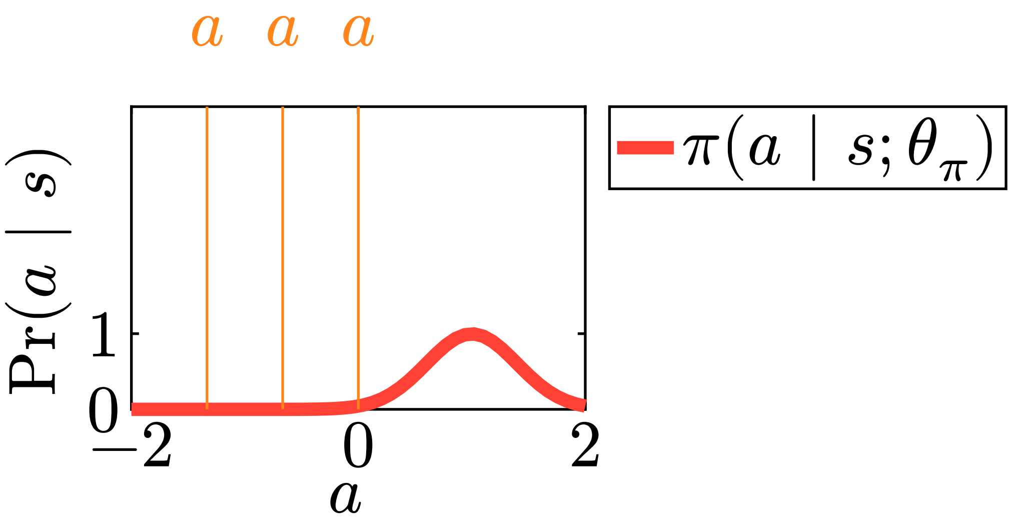

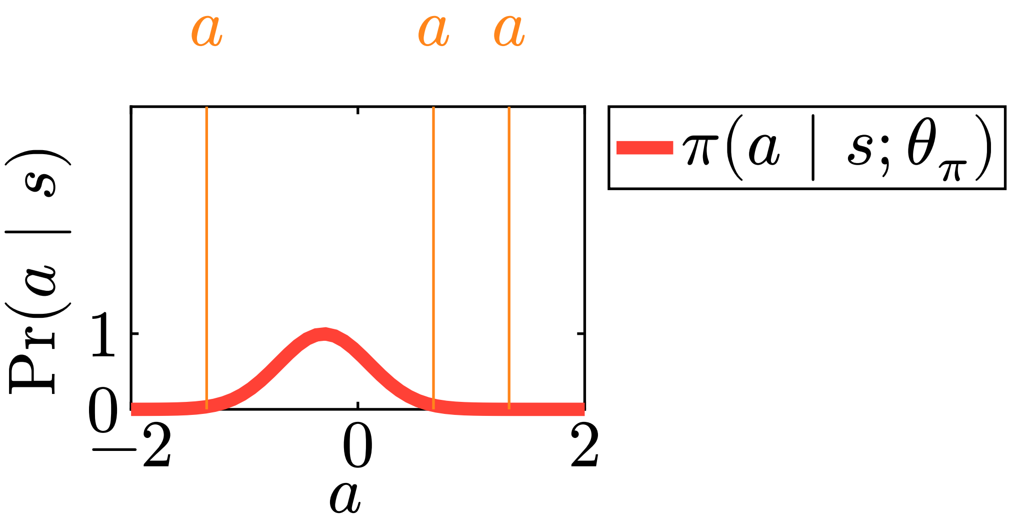

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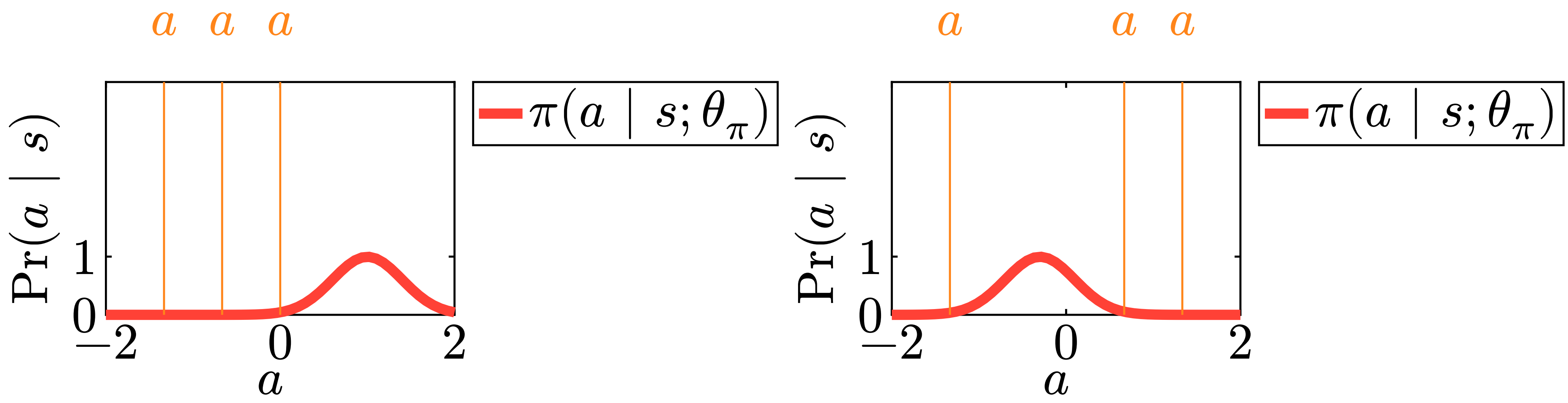

Policy keeps oscillating, can destabilize learning

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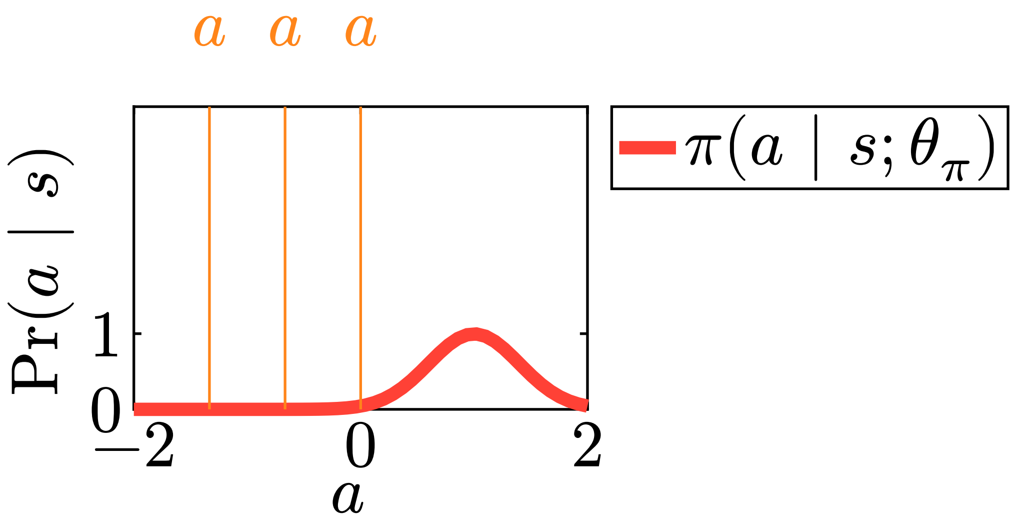
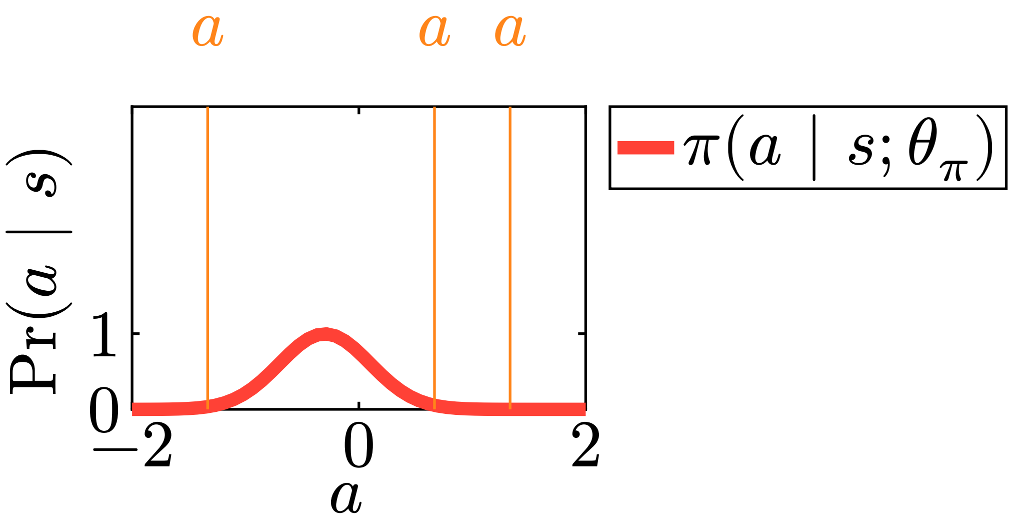
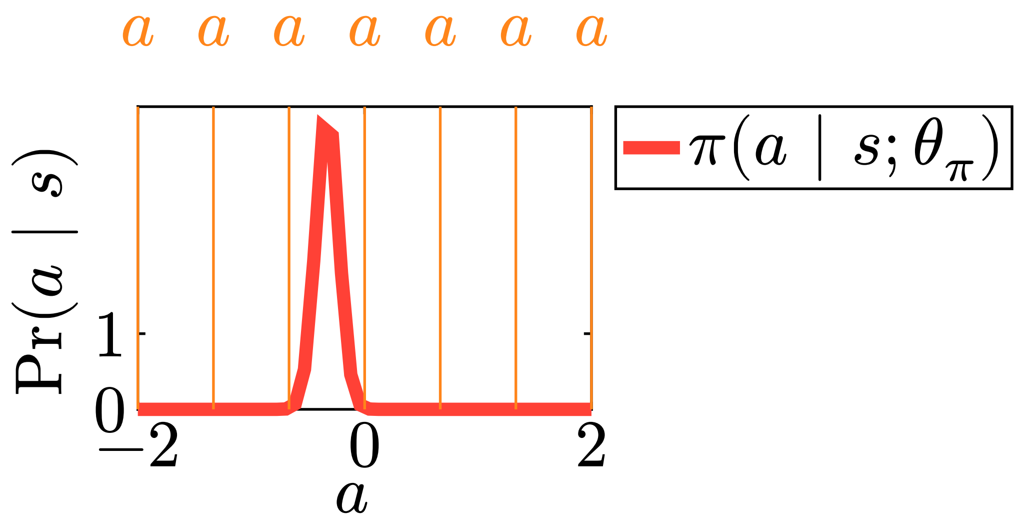




Policy keeps oscillating, can destabilize learning

Question: If we take 8 actions, will this fix it?

Advantage Actor Critic



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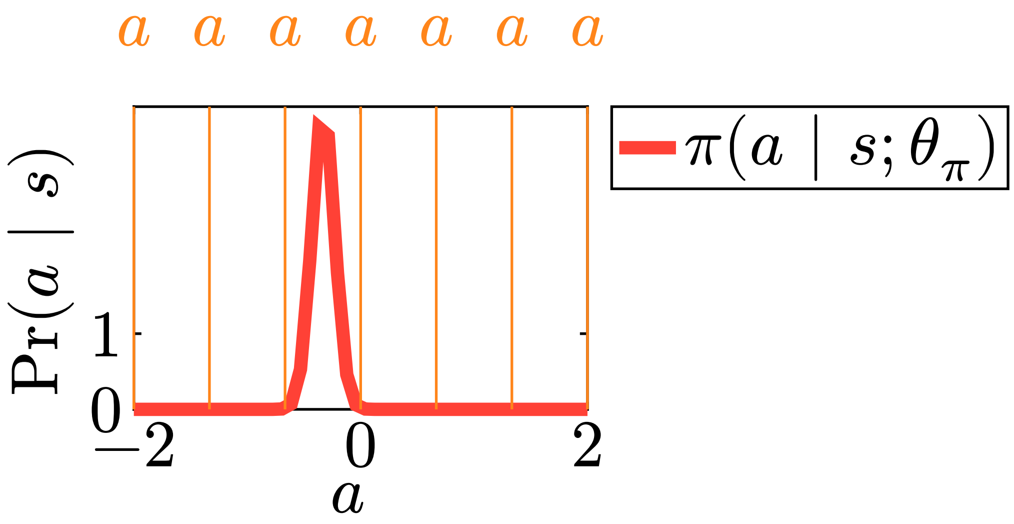

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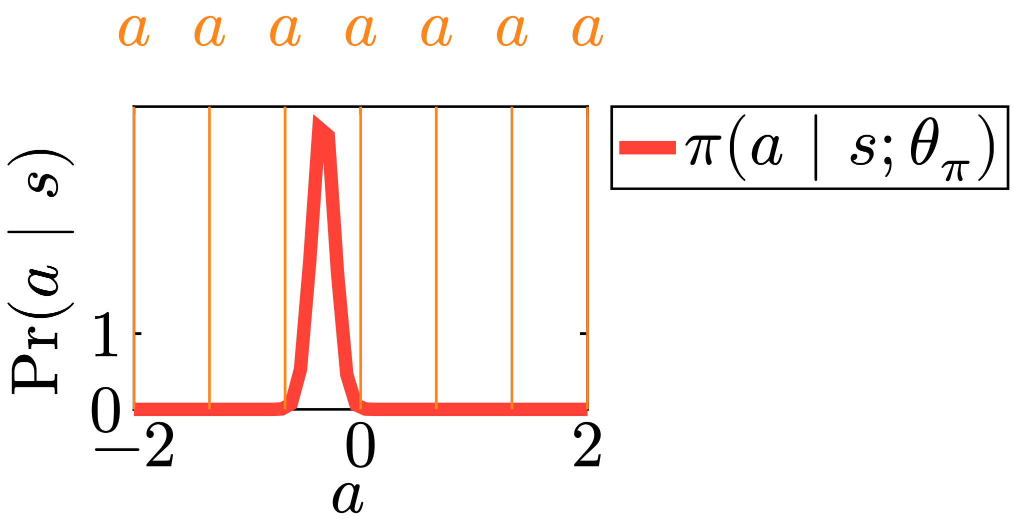

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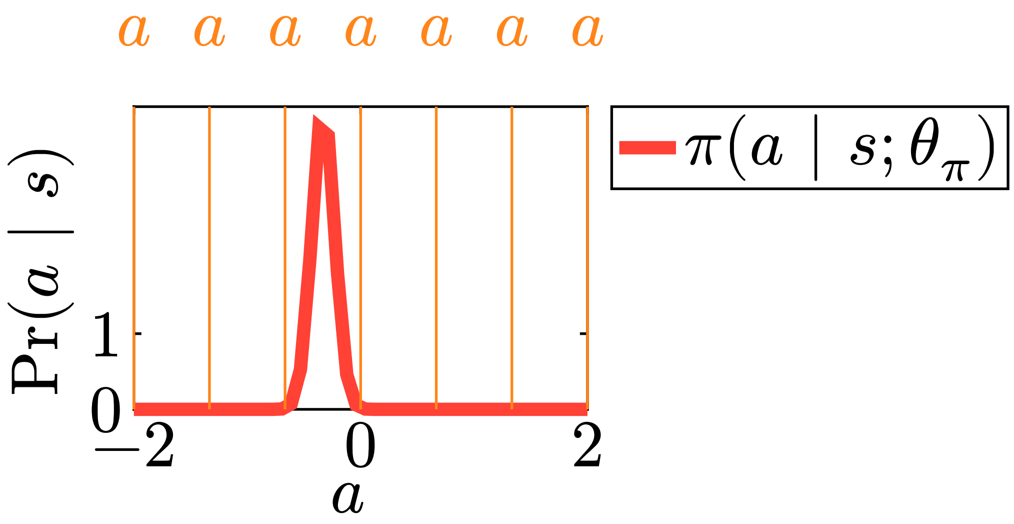

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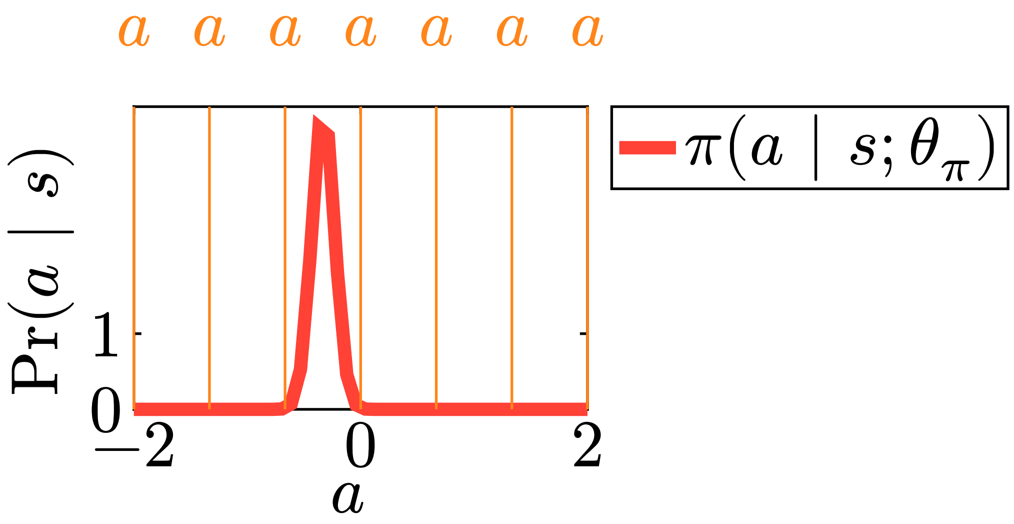

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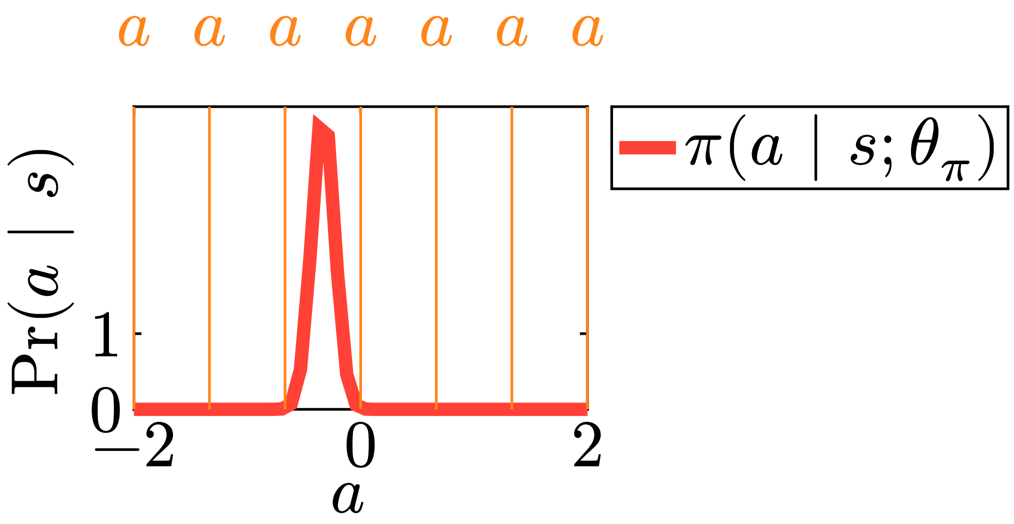

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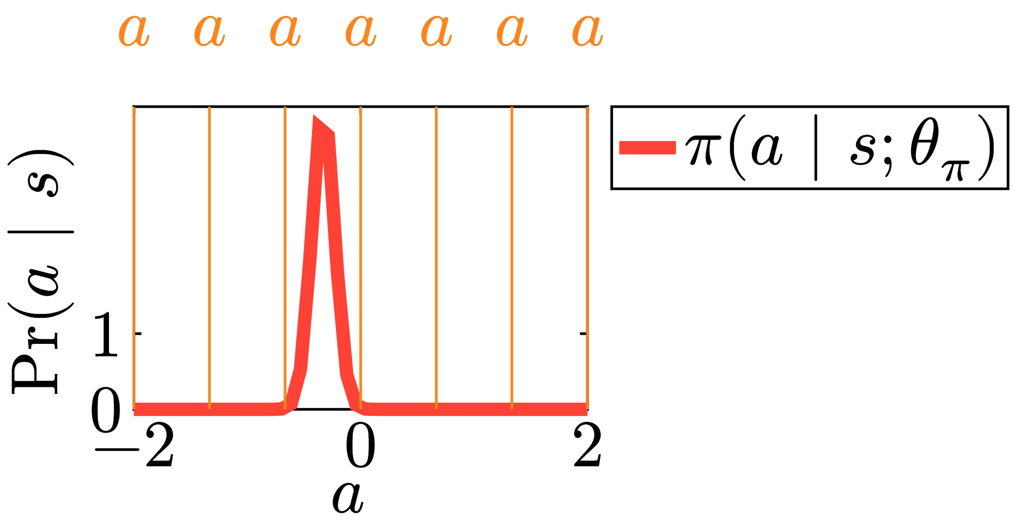

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What if we:

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- Update the policy **only** if action is better/worse than expected

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If action a_0 produced expected return, do nothing $\theta_{\pi,i+1} = \theta_{\pi,i} + 0$

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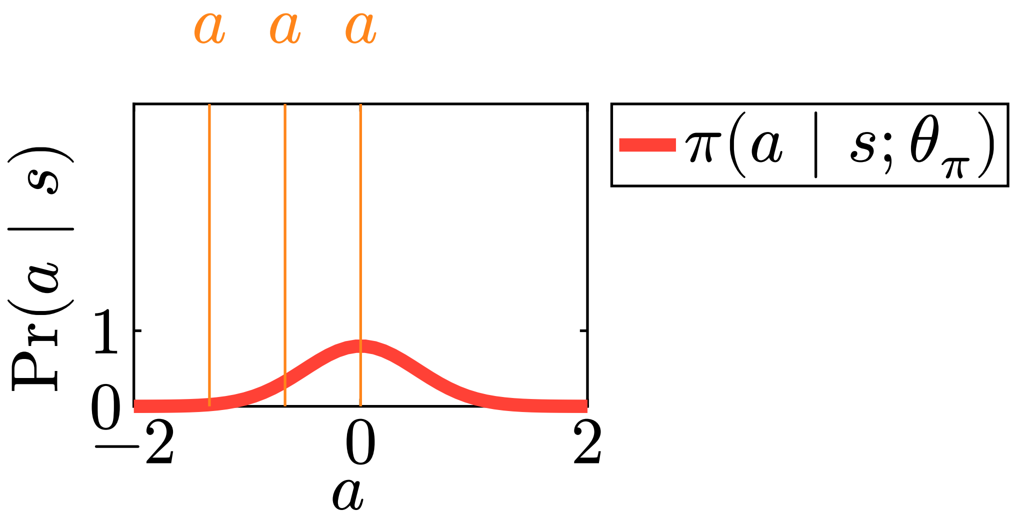

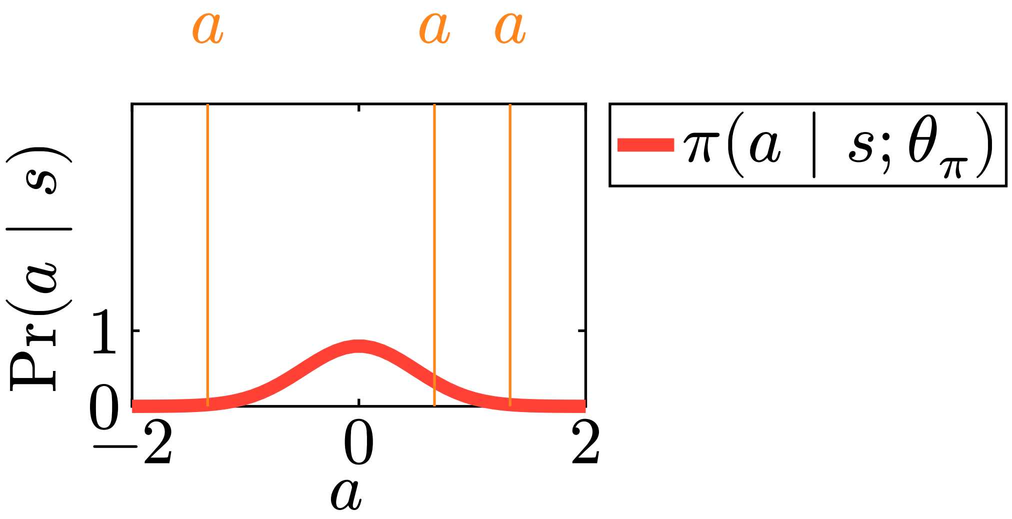

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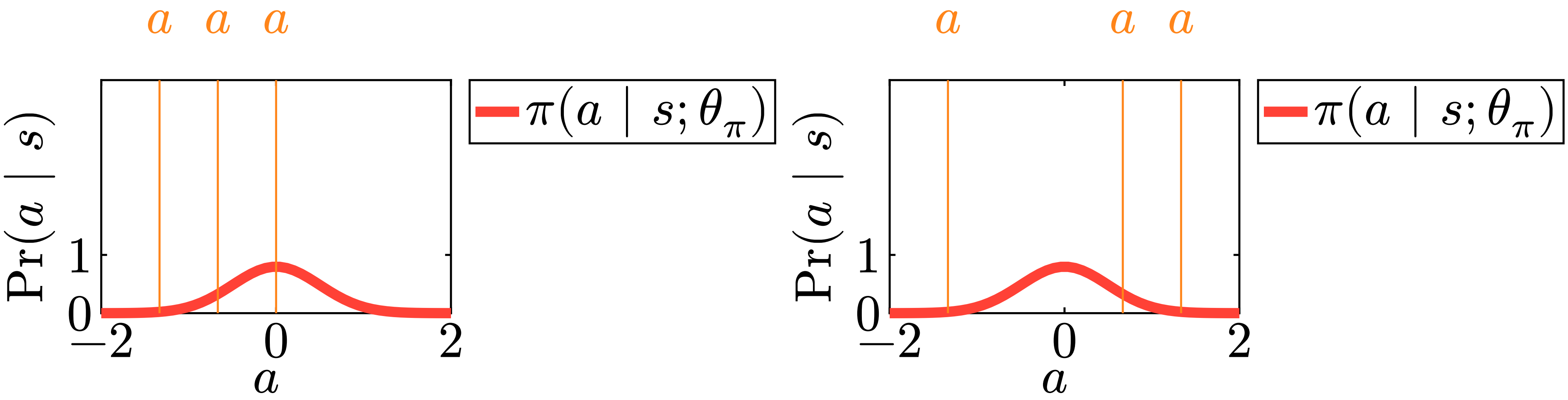

Results in more stable training and faster convergence

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Better than expected: $|A| > 0$, worse than expected $|A| < 0$

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$$\theta_{V, i+1} =$$

$$\arg\min_{\theta_{V, i}} \underbrace{\left(V(s_0, \theta_{\pi, i}, \theta_{V, i}) - \left(\hat{\mathbb{E}}[\mathcal{R}(s_1) \mid s_0; \theta_\pi] + \neg d \gamma V(s_0, \theta_{\pi, i}, \theta_{V, i})\right)\right)^2}_{\text{TD error}}$$

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Question: Any statistics students know how to do this?

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$$\mathbb{E}[f(x) \mid x \sim \Pr(X)]$$

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Question: How can we use this to make policy gradient off-policy?

Off-Policy Gradient

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Seems like magic, how does this actually work?

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$$\mathbb{E}[\mathcal{R}(s_1) \mid s_0; \theta_\beta] = \sum_{s_1 \in S} \mathcal{R}(s_1) \sum_{a_0 \in A} \mathrm{Tr}(s_1 \mid s_0, a_0) \pi(a_0 \mid s_0; \theta_\beta)$$

Off-Policy Gradient

$$\mathbb{E}\left[\mathcal{R}(s_1) \mid s_0; \theta_\beta\right] = \underbrace{\sum_{s_1 \in S} \mathcal{R}(s_1) \sum_{a_0 \in A} \mathrm{Tr}(s_1 \mid s_0, a_0) \pi\left(a_0 \mid s_0; \theta_\beta\right)}_{\text{Expected reward}} \underbrace{\frac{\pi(a_0 \mid s_0; \theta_\pi)}{\pi\left(a_0 \mid s_0; \theta_\beta\right)}}_{\text{Correction}}$$

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Off-Policy Gradient

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Off-Policy Gradient

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Left with expected reward following θ_π

Off-Policy Gradient

$$\mathbb{E}[\mathcal{R}(s_1) \mid s_0; \theta_\pi] = \mathbb{E}\left[\mathcal{R}(s_1) \cdot \frac{\pi(a \mid s_0; \theta_\pi)}{\pi(a \mid s_0; \theta_\beta)} \,\middle|\, s_0; \theta_\beta\right]$$

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We found a way to estimate the off-policy reward

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Apply the same approach to find the off-policy return (won't derive, trust me)

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Off-Policy Gradient

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$$\theta_{\pi,i+1} = \theta_{\pi,i} + \alpha \cdot \mathbb{E}[\mathcal{G}(\boldsymbol{\tau}) \mid s_0; \theta_\pi] \cdot \nabla_{\theta_{\pi,i}} \log \pi\left(a_0 \mid s_0; \theta_{\pi,i}\right)$$

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Note: Wrote MC version for clarity, but you can use V too

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$$V(s_0, \theta_\pi, \theta_\beta) = \mathbb{E}\left[\mathcal{G}(\boldsymbol{\tau}) \prod_{t=0}^{\infty} \frac{\pi(a_t \mid s_t; \theta_\pi)}{\pi(a_t \mid s_t; \theta_\beta)} \middle| s_0; \theta_\beta\right]$$

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Question: Why?

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$$\prod_{t=0}^{\infty} \frac{\pi(a_t \mid s_t; \theta_\pi)}{\pi(a_t \mid s_t; \theta_\beta)} \to 0, \infty$$

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$$\prod_{t=0}^{\infty} \frac{\pi(a_t \mid s_t; \theta_\pi)}{\pi(a_t \mid s_t; \theta_\beta)} \rightarrow 0, \infty$$

Only works if $\pi(a_t \mid s_t; \theta_\pi) \approx \pi(a_t \mid s_t; \theta_\beta) \quad \forall t$

Trust Regions

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Training policies in RL is difficult

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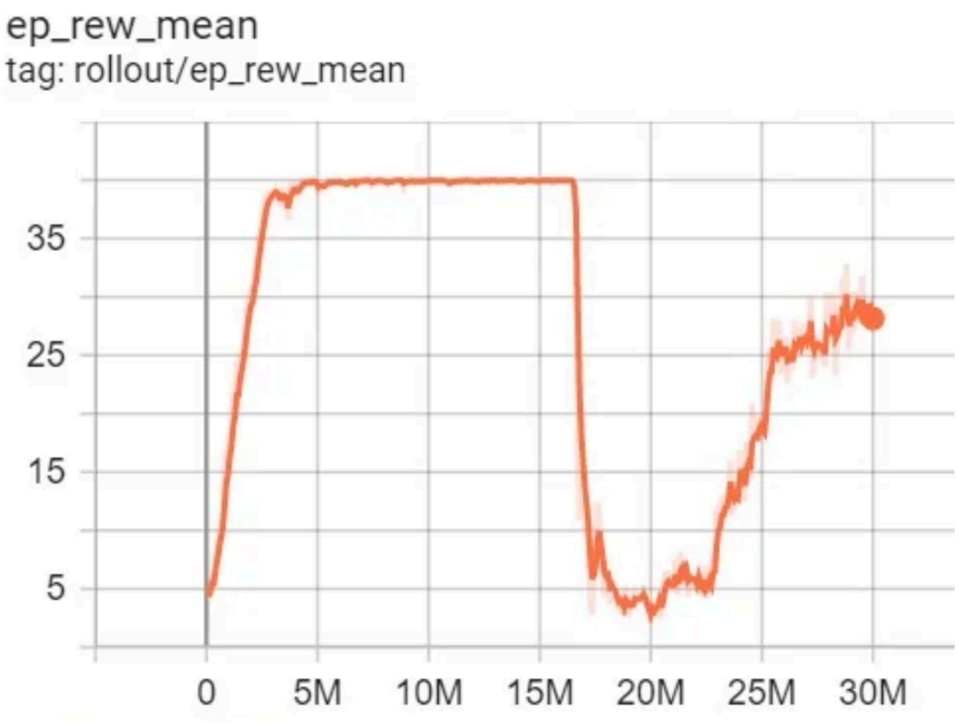

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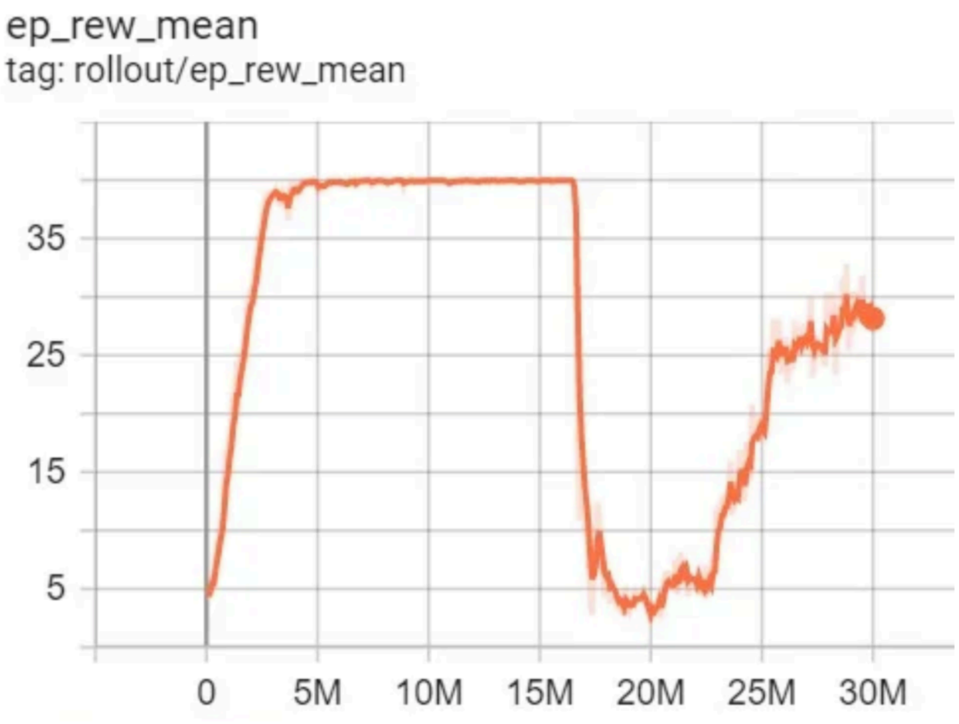

Question: Any idea why?

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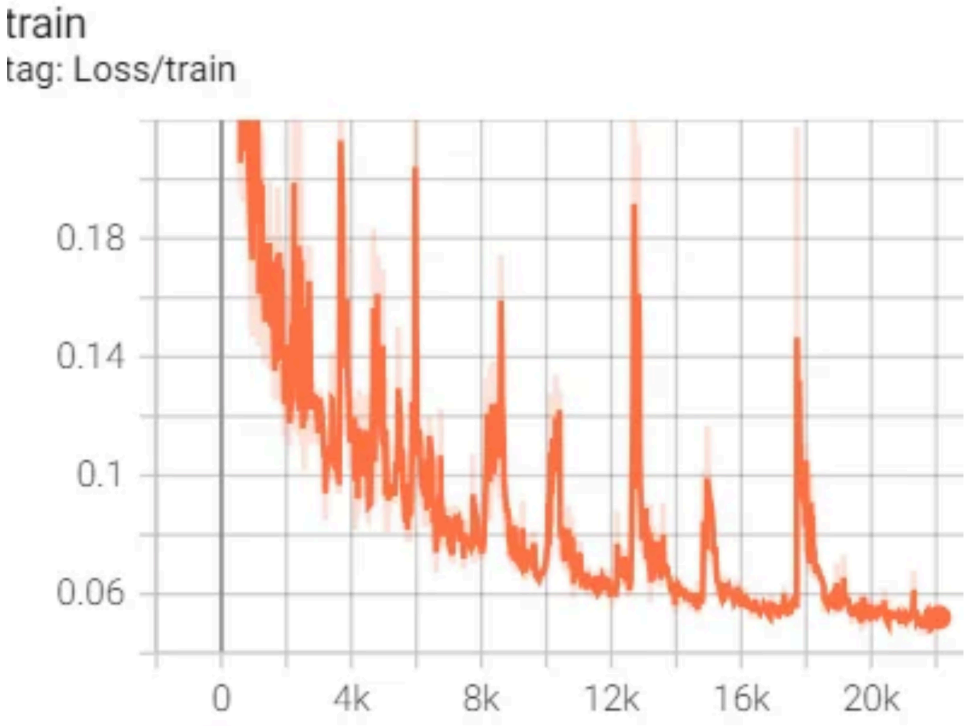

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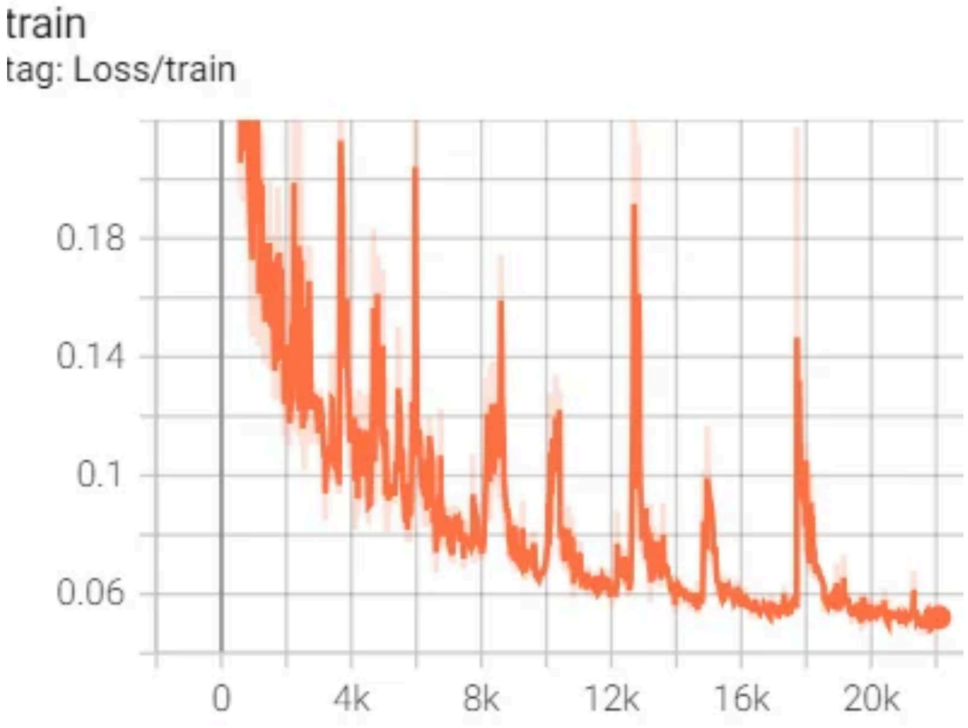
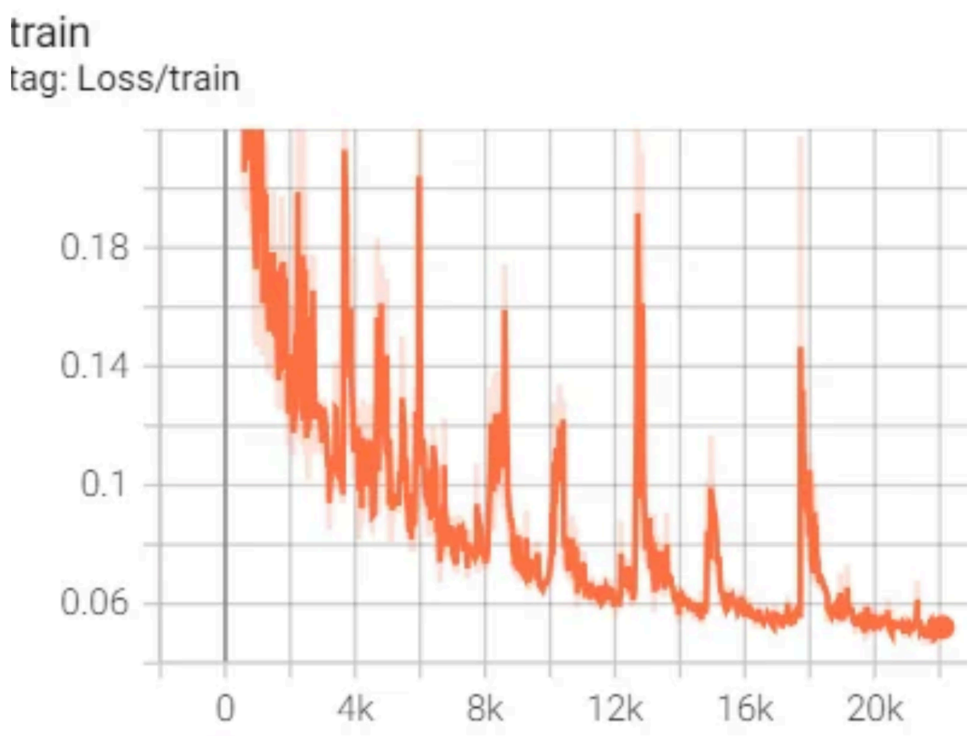


See it in supervised learning too

Trust Regions



See it in supervised learning too

Sometimes, the gradient is inaccurate producing a bad update

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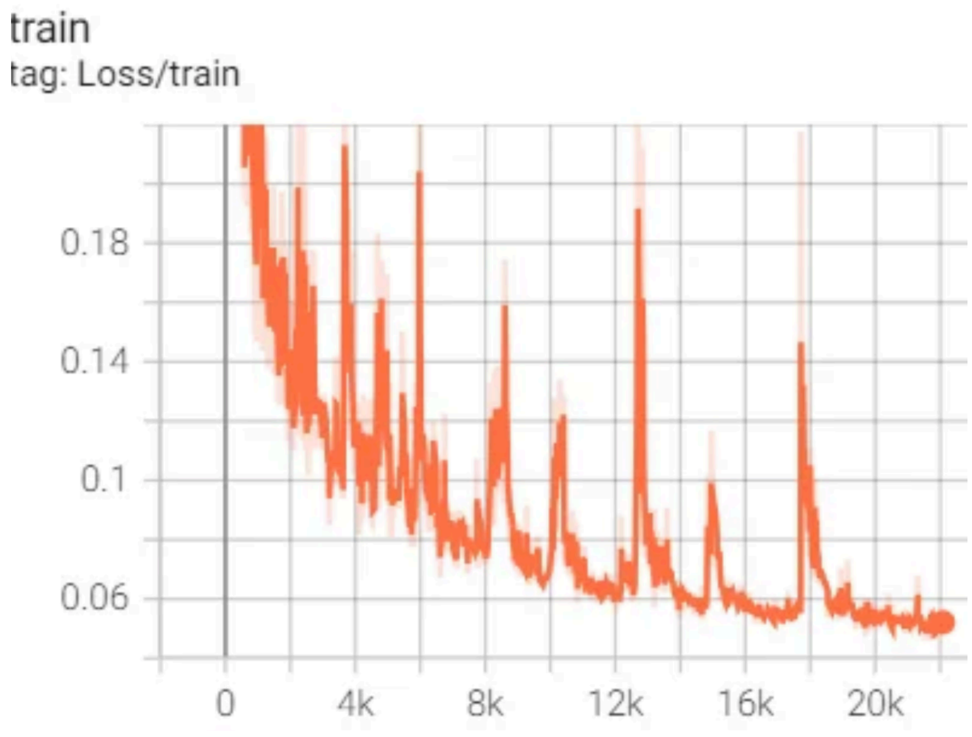

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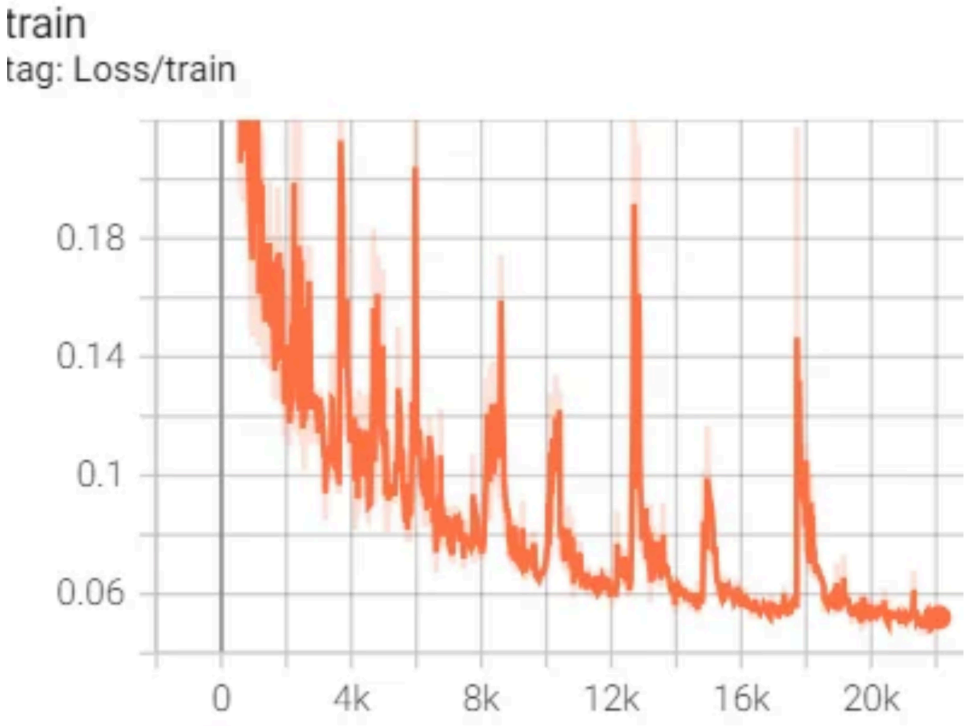
Sometimes, the gradient is inaccurate producing a bad update

In supervised learning, the network can easily recover

Trust Regions



See it in supervised learning too

Sometimes, the gradient is inaccurate producing a bad update

In supervised learning, the network can easily recover

With policy gradient, it is much harder to recover

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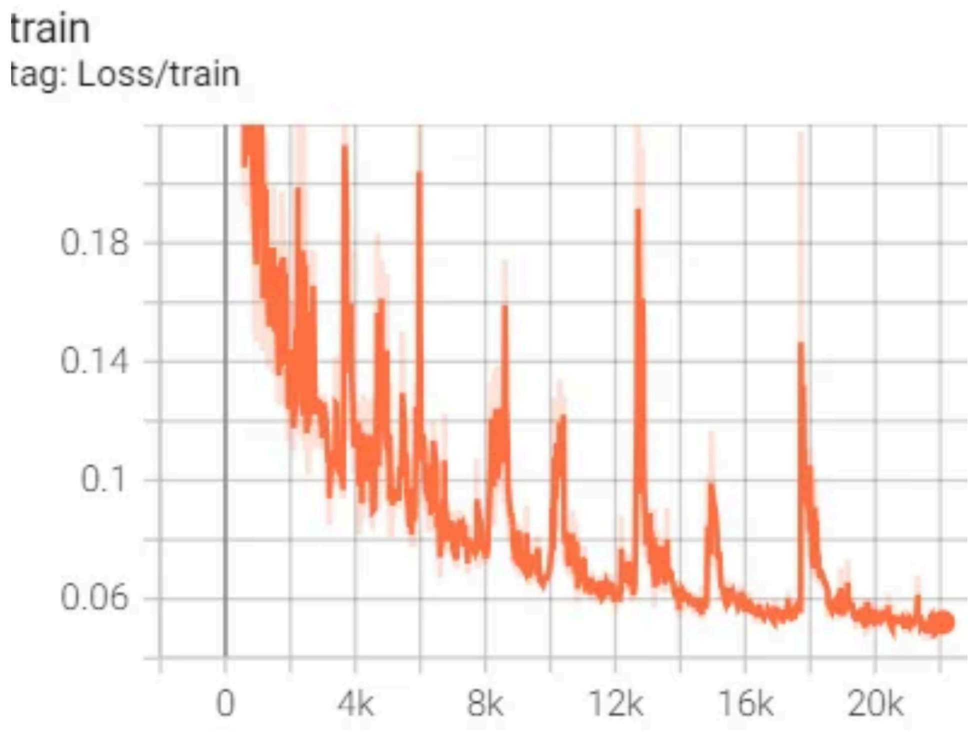

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Question: Why is it harder to recover with policy gradient?

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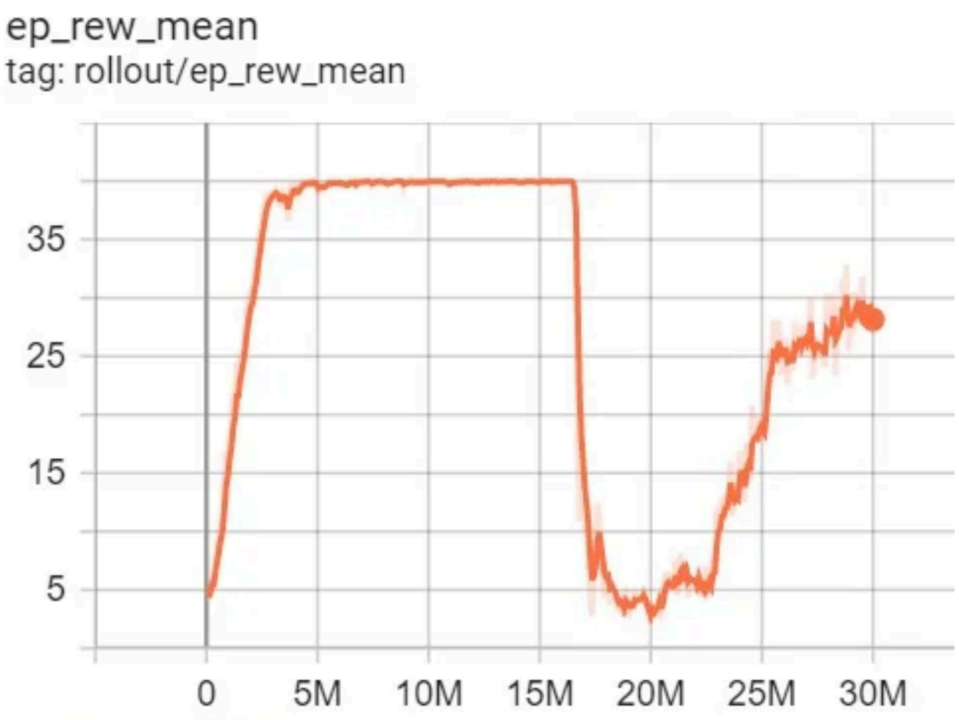

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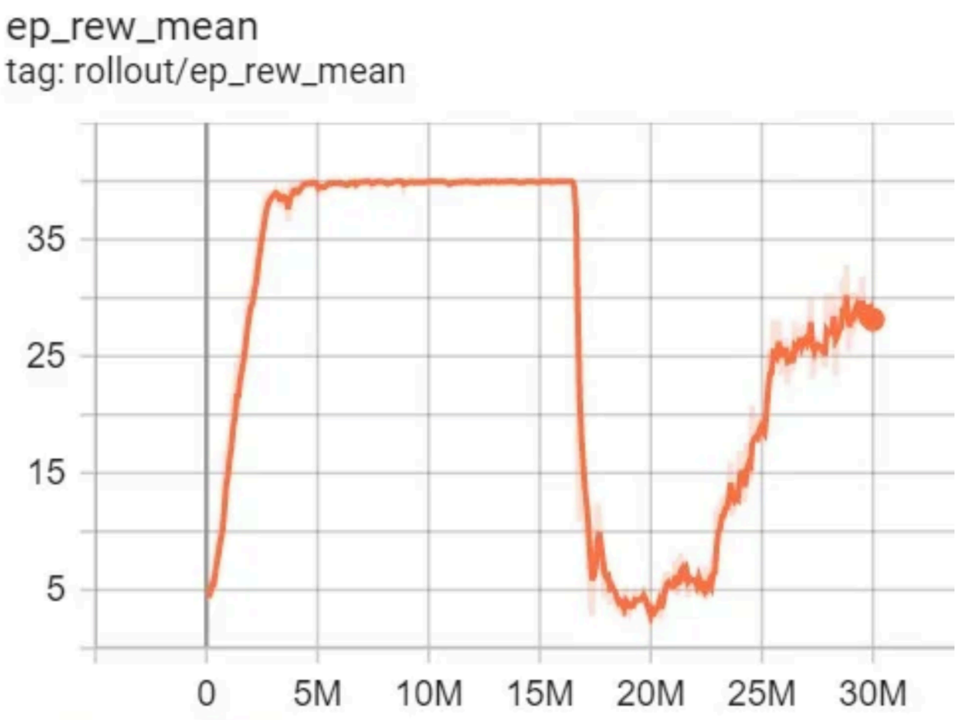

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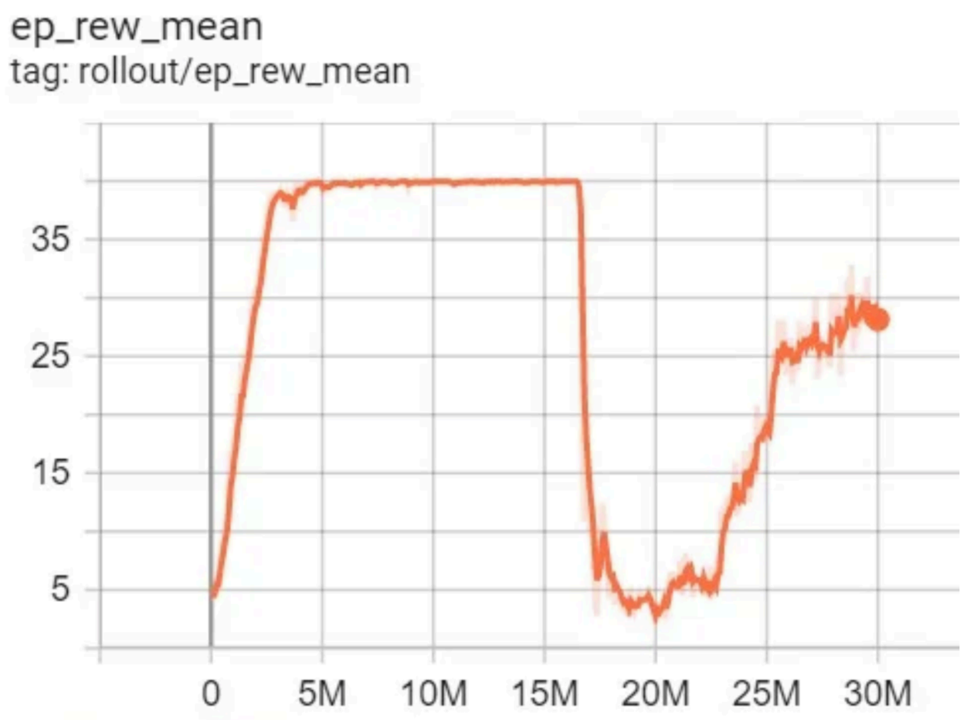

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One bad update breaks the policy

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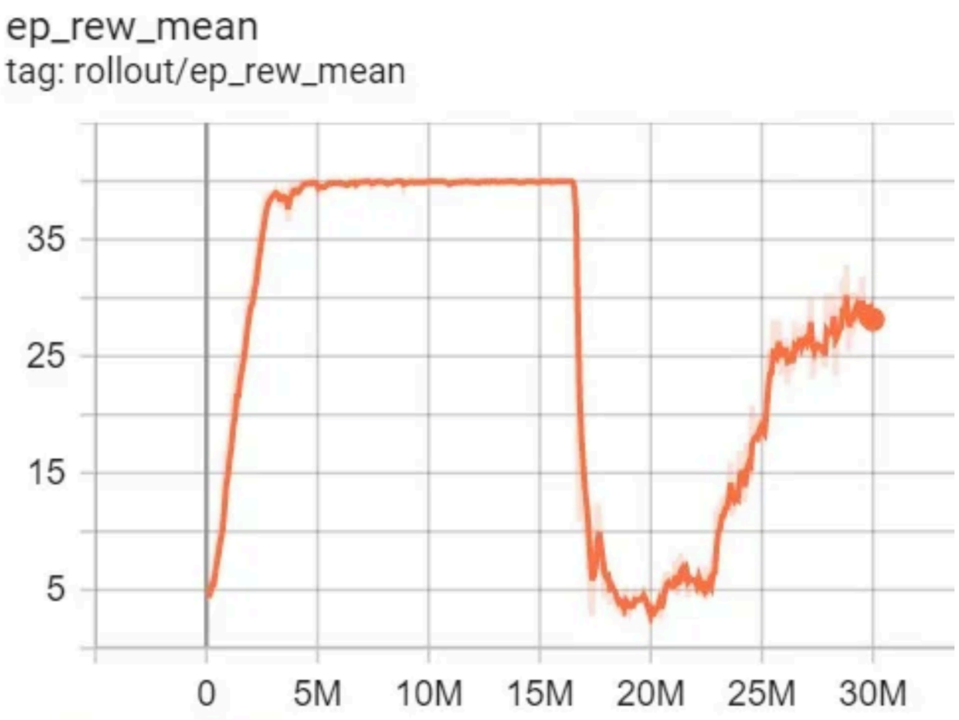

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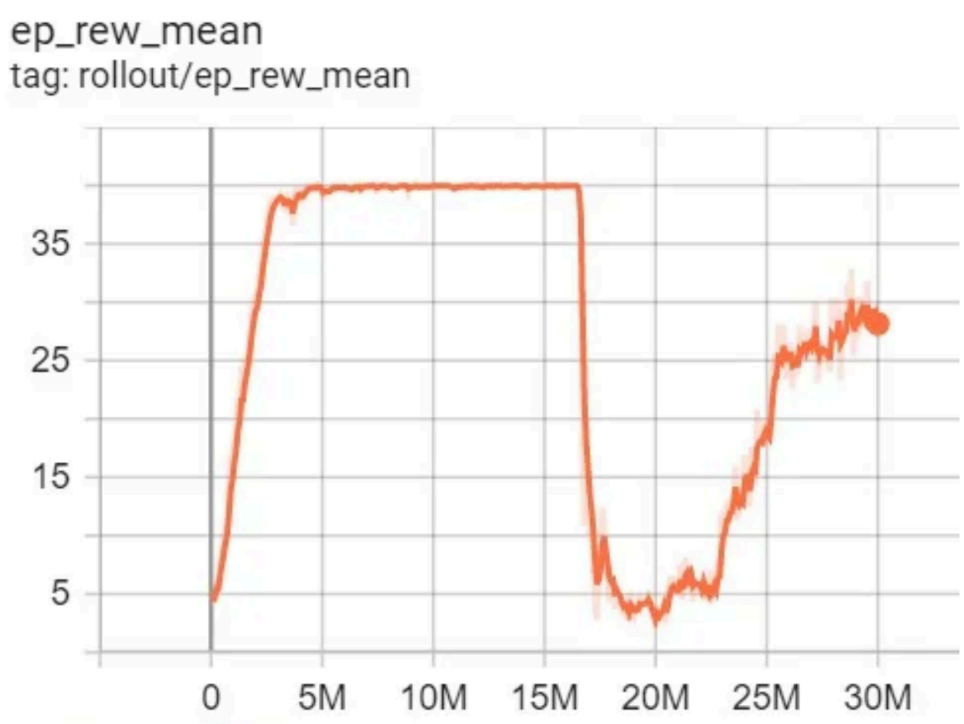

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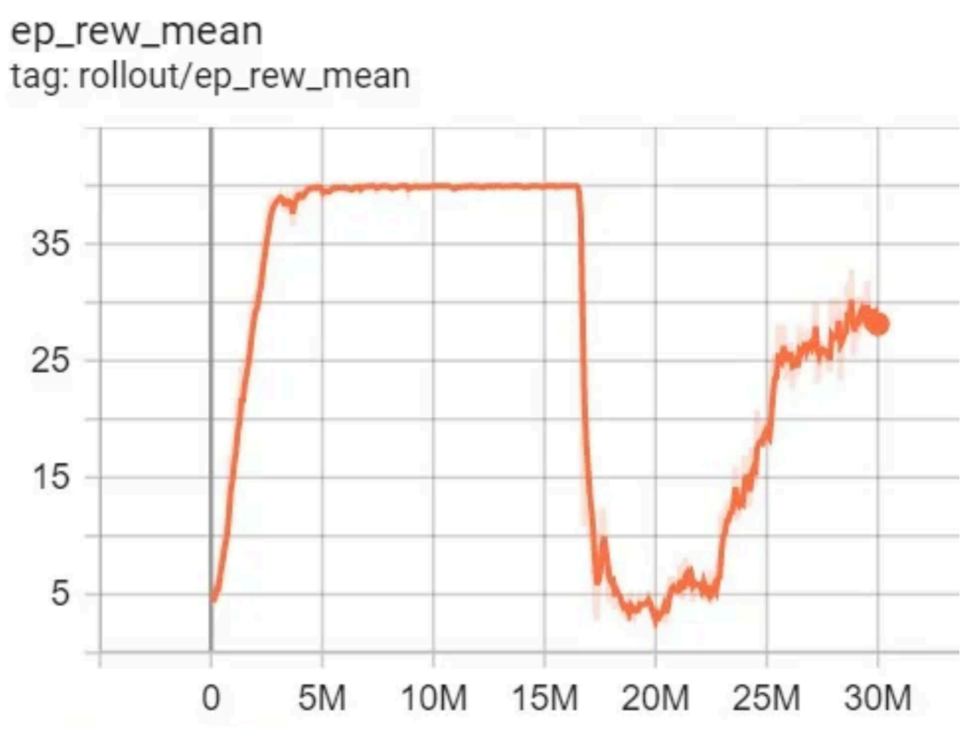

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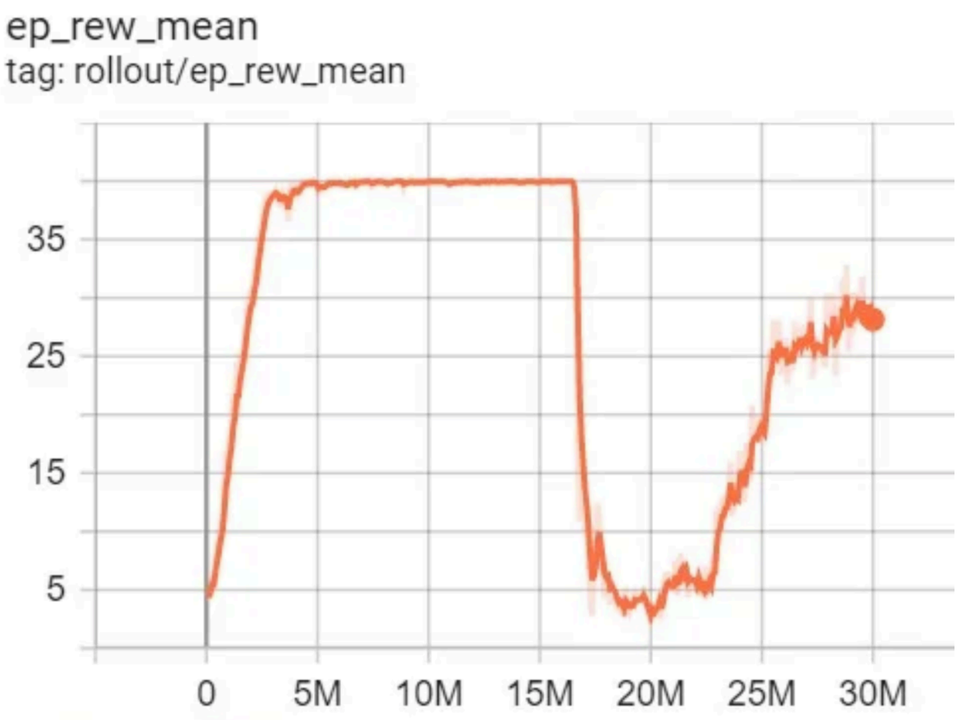

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Must be very careful when updating policy using on-policy algorithms

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We can fix this issue with small changes to the policy

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Parameter-space constraints (learning rate) does not work very well!

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Answer: The action distributions

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See Trust Region Policy Optimization (TRPO), Natural Policy Gradient

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Hack: Add KL term to the objective (soft constraint)

$$\theta_{\pi, i+1} = V(s_0, \theta_{\pi, i}) \cdot \nabla_{\theta_{\pi, i}} [\log \pi(a_0 \mid s_0; \theta_{\pi, i})]$$

$$- \rho \nabla_{\theta_{\pi, i+1}} [\mathrm{KL}[\pi(a \mid s; \theta_{\pi, i}), \pi(a \mid s; \theta_{\pi, i+1})]]$$

Proximal Policy Optimization

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Proximal policy optimization (PPO) combines all we learned today

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Let us see a pseudocode PPO update

Proximal Policy Optimization

```python
for epoch in range(epochs):
    batch = collect_rollout(theta_beta)
    # Minibatching learns much faster
    # but is very slightly off-policy!
    for minibatch in batch:
        theta_pi = update_pi(
            theta_pi, theta_beta, theta_V, batch
        )
        theta_V = update_V(theta_V, batch)
    theta_beta = theta_pi
```

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There are different variations of PPO

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- PPO clip
- PPO KL penalty
- PPO clip + KL penalty
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We will focus on the simplest version (PPO KL penalty)

Proximal Policy Optimization

$$\theta_{\pi,i+1} =$$

Proximal Policy Optimization

$$\theta_{\pi, i+1} = \theta_{\pi, i} + \alpha \cdot \underbrace{\left(\frac{\pi(a \mid s; \theta_{\pi, i})}{\pi(a \mid s; \theta_\beta)} A(s_0, s_1, r_0, \theta_\beta, \theta_V) \right)}_{\text{Value}}$$

$$\cdot \left(\nabla_{\theta_{\pi, i}} \left[\log \pi(a_0 \mid s_0; \theta_{\pi, i}) \right] - \rho \nabla_{\theta_{\pi, i+1}} \left[\mathrm{KL}\left[\pi(a_0 \mid s_0; \theta_\beta), \pi(a_0 \mid s_0; \theta_{\pi, i+1}) \right] \right] \right)$$

Proximal Policy Optimization

Off-policy correction for minibatch

$$\theta_{\pi,i+1} = \theta_{\pi,i} + \alpha \cdot \underbrace{\left(\frac{\pi(a \mid s; \theta_{\pi,i})}{\pi(a \mid s; \theta_\beta)} A(s_0, s_1, r_0, \theta_\beta, \theta_V) \right)}_{\text{Value}}$$

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Proximal Policy Optimization

$$\theta_{\pi, i+1} = \theta_{\pi, i} + \alpha \cdot \underbrace{\left(\overbrace{\frac{\pi(a \mid s; \theta_{\pi, i})}{\pi(a \mid s; \theta_{\beta})}}^{\text{Off-policy correction for minibatch}} \overbrace{A(s_0, s_1, r_0, \theta_\beta, \theta_V)}^{\text{Advantage}} \right)}_{\text{Value}}$$

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Proximal Policy Optimization

Off-policy correction for minibatch

Advantage

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Policy gradient

Trust region

Proximal Policy Optimization

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$$A(s_0, s_1, r_0, \theta_\beta, \theta_V) = -V(s_0, \theta_\beta, \theta_V) + \left(\hat{\mathbb{E}}\left[\mathcal{R}(s_1) \mid s_0; \theta_\beta\right] + \neg d \gamma V(s_1, \theta_\beta, \theta_V) \right)$$

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$$\theta_{V,i+1} = \arg\min_{\theta_{V,i}} \left(V(s_0, \theta_\beta, \theta_{V,i}) - \left(\hat{\mathbb{E}}[\mathcal{R}(s_1) \mid s_0; \theta_\beta] + \neg d \gamma V(s_0, \theta_\beta, \theta_{V,i}) \right) \right)^2$$

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- Large batches and regularization (weight decay, layer norm) helpful
- You can make any algorithm work with enough effort!

Proximal Policy Optimization

PPO plays Pokemon!

Video describes the RL experiment process, helpful for your final project

https://youtu.be/DcYLT37ImBY?si=jJfZyYwFkPYMJYMy