

Policy Learning Using Weak Supervision

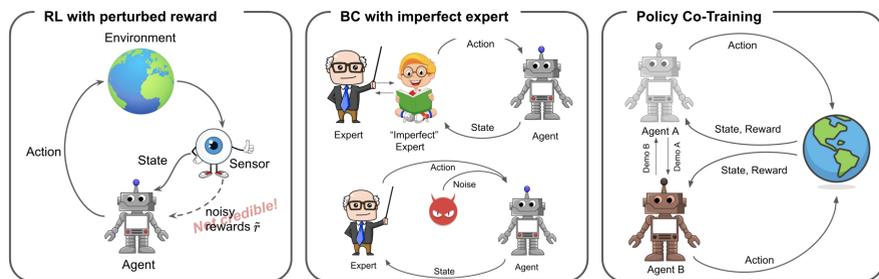
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Code available at: <https://github.com/wangjksjtu/PeerPL>

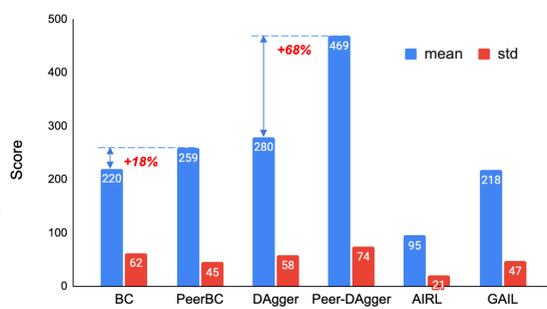
Motivation

- Weak supervision signals are everywhere (e.g., noisy reward or low-quality demonstrations) in sequential learning problems!



- Weak Supervision:**
 - RL: The reward may be collected through sensors thus noisy
 - IL: The demonstrations by an expert are often imperfect due to limited resources

Existing reinforcement learning (RL) and behavioral cloning (BC) algorithms rely on high-quality supervision signals, resulting in unstable or sub-optimal results when meeting weak supervisions.



- Some previous works have explored these topics separately in their specific domains. However, there lacks a unified solution for robust policy learning in imperfect situations.

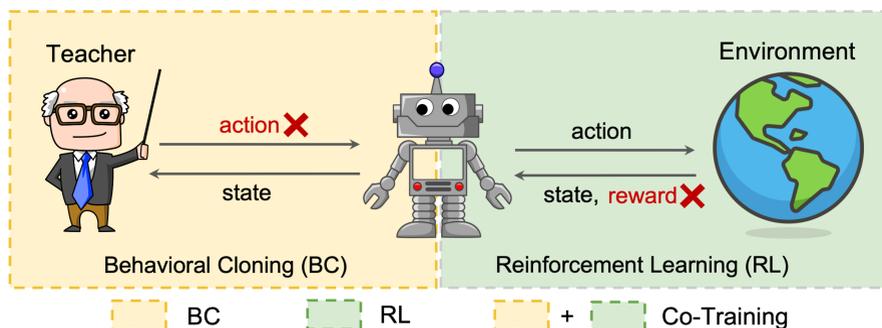
Policy Learning from Weak Supervision

- We use \tilde{Y} to denote a weak supervision. It could be noisy reward \tilde{r} for RL or noisy action \tilde{a} from an imperfect expert policy $\tilde{\pi}_E$ for BC.

Assumptions:

- We consider a discrete noise model where the noise corruption can be characterized via a unknown confusion matrix: $C_{|\mathcal{R}| \times |\mathcal{R}|}^{\text{RL}}$ or $C_{|\mathcal{A}| \times |\mathcal{A}|}^{\text{BC}}$.
- Only deterministic reward or expert policy is considered as it is hard to distinguish a clean case with noisy one without addition knowledge.

- Objective:** Learning the optimal policy π^* with only a weak supervision sequence denoted as $\{(s_t, a_t), \tilde{Y}_t\}_{t=1}^T$ (RL) or $\{(s_i, a_i), \tilde{Y}_i\}_{i=1}^N$ (BC).



PeerPL with Correlated Agreement

- A unified evaluation function:** Eva_π to evaluate a taken policy π at agent state (s_i, a_i) using the weak supervision \tilde{Y}_i .

– (RL) instance-wise measure (negative loss): a function of the noisy reward \tilde{r} received at (s_i, a_i) : $\text{Eva}_\pi^{\text{RL}}((s, a), \tilde{r}) = -\ell(\pi, (s, a), \tilde{r})$

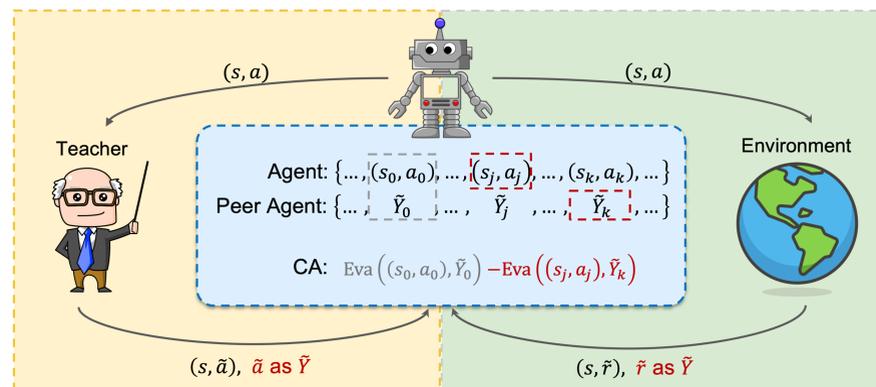
– (BC) loss to evaluate the predicted action given the expert action \tilde{a}_j : $\text{Eva}_\pi^{\text{BC}}((s, a), \tilde{a}) = \log \pi(\tilde{a}|s)$

- Goal:** maximize $J(\pi) = \mathbb{E}_{(s,a) \sim \tau} [\text{Eva}_\pi((s, a), \tilde{Y})]$, where τ is the trajectories collected by learned policy π or the demonstration dataset.

- Solution:** *Correlated Agreement with Weak supervision.*

For each weakly supervised state-action pair $((s_i, a_i), \tilde{Y}_i)$, we randomly sample a state-action pair $(s_j, a_j), j \neq i$, as well as another supervision signal $\tilde{Y}_k, k \neq i, j$ from a different state-action pair. Then we evaluate $((s_i, a_i), \tilde{Y}_i)$ according to the following:

$$\text{CA with Weak Supervision} : \text{Eva}_\pi((s_i, a_i), \tilde{Y}_i) - \text{Eva}_\pi((s_j, a_j), \tilde{Y}_k)$$



- Intuition:** (a) the first term above encourages an “agreement” with the weak supervision (b) the second term punishes a “blind” agreement that happens when the agent’s policy always matches with the weak supervision even on randomly paired traces.

Why Peer Reward Works?

- Hypothesis 1:** PeerRL reduces the bias (while with larger variance like Wang et al., 2020).

$$\text{noisy reward: } \mathbb{E}[\tilde{r}] = \eta \cdot \left(\mathbb{E}[r] + \frac{e_+}{1 - e_- - e_+} r_- + \frac{e_-}{1 - e_- - e_+} r_+ \right)$$

$$\text{peer reward: } \mathbb{E}[\tilde{r}_{\text{peer}}] = \eta \cdot (\mathbb{E}[r] - (1 - p_{\text{peer}})r_- - p_{\text{peer}}r_+)$$

potentially much larger than $(1 - p_{\text{peer}})$ and p_{peer} in high noise regime!

- Hypothesis 2:** PeerRL helps break ties

- “tie” states indicate that the rewards for different states are the same - unstable and uncertain
- randomness in discretization model thus breaking ties - more informative for optimization

2-state Markov process (no actions)

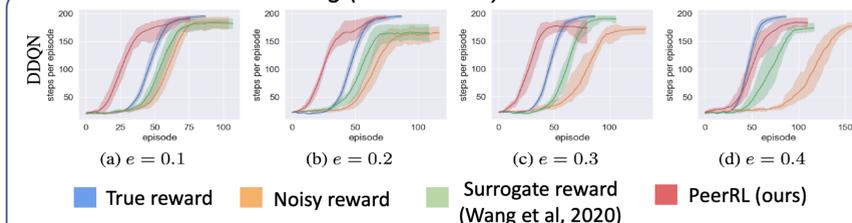
s_1 s_2
 $r_1 \sim \text{clamp}[\mathcal{N}(0.6, 1), \min = 0, \max = 1]$
 $r_2 \sim \text{clamp}[\mathcal{N}(0.4, 1), \min = 0, \max = 1]$

	Correct	Tie	Incorrect
Baseline	54.6%	5.6%	39.8%
PeerRL	58.0%	0.3%	41.7%

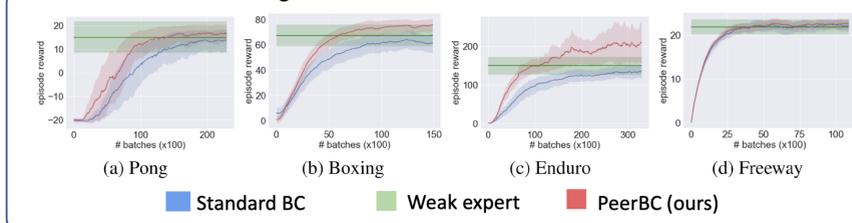
Tie breaking!

Experimental Results

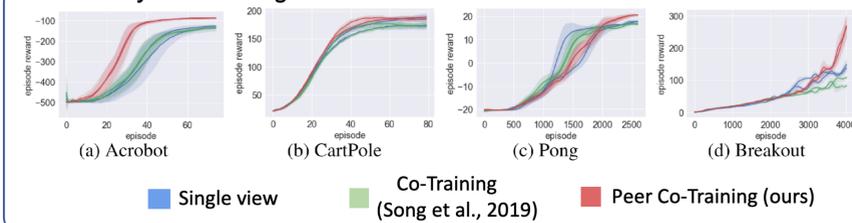
Reinforcement Learning (CartPole-v0)



Behavioral Cloning



Policy Co-Training



Environment	Pong	Boxing	Enduro	Freeway	Lift (\uparrow)	
Expert						
Standard BC	15.1 \pm 6.6	67.5 \pm 8.5	150.1 \pm 23.0	21.9 \pm 1.7	-	
PeerBC	14.7 \pm 3.2	56.2 \pm 7.7	138.9 \pm 14.1	22.0 \pm 1.3	-6.6%	
PeerBC	$\xi = 0.2$	18.8 \pm 0.6	67.2 \pm 8.4	177.9 \pm 29.3	22.5 \pm 0.6	+11.3%
	$\xi = 0.5$	16.6 \pm 4.0	75.6 \pm 5.4	230.9 \pm 73.0	22.4 \pm 1.3	+19.5%
	$\xi = 1.0$	16.7 \pm 4.3	69.7 \pm 4.7	230.4 \pm 61.6	8.9 \pm 4.9	+2.0%
Fully converged PPO	20.9 \pm 0.3	89.3 \pm 5.4	389.6 \pm 216.9	33.3 \pm 0.8	-	

Conclusion

- We formulated “*weakly supervised policy learning*” to unify a series of RL/BC problems with low-quality supervision signals.
- A theoretical principled framework PeerPL that builds on evaluating a learning policy’s correlated agreements with the weak supervisions.

Past Works:

- Reinforcement Learning with Perturbed Reward. Wang et al., AAI 2020.
- Peer Loss Functions: Learning from Noisy Labels without Knowing Noise Rates. Liu et al., ICML 2020.