Stat 9911
Various forms of preference optimization

Tao Wang and Sunay Joshi

March 18, 2025

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RLHF

- Standard workflow of reinforcement learning from human feedback
  - Supervised fine-tuning (SFT)
  - Reward model (RM) training
  - Proximal policy optimization (PPO)

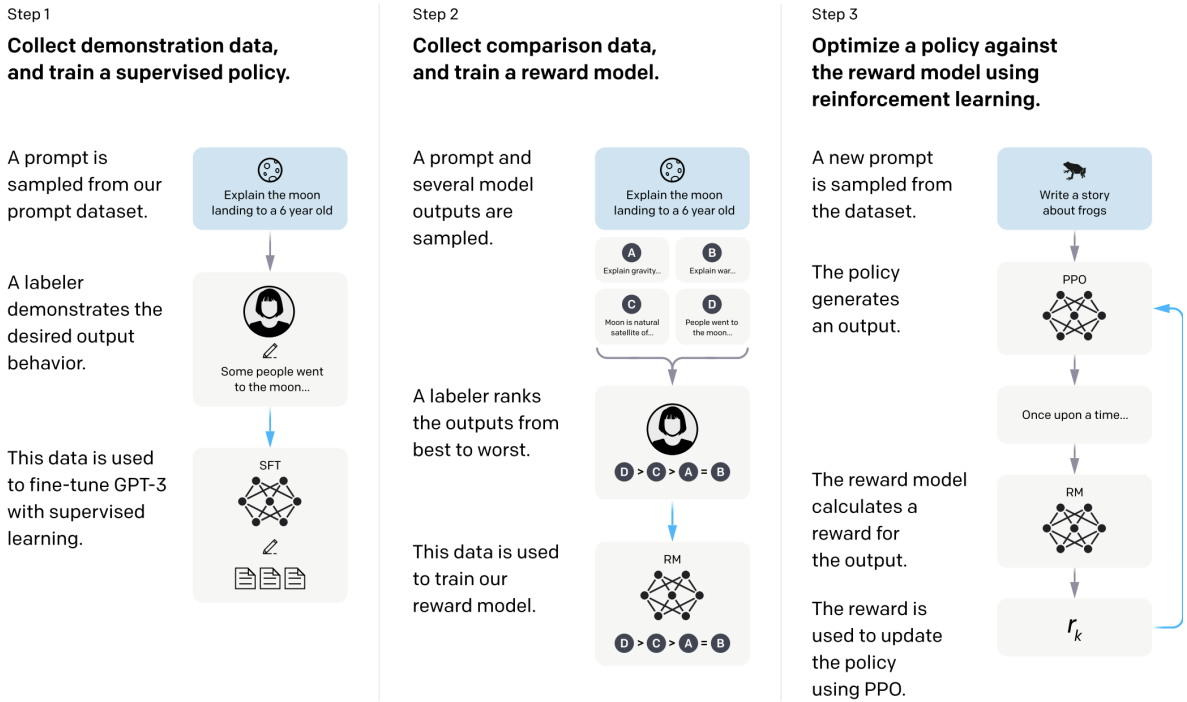

Figure: RLHF (Ouyang et al., 2022)

DPO

- RLHF objective:

$$\max_{\pi_\theta} \mathbb{E}_{X\sim\mathcal{D},Y\sim\pi_\theta}[r(X,Y)] - \beta \mathrm{KL}\left[\pi_\theta(Y \mid X) \middle|\middle| \pi_{\mathsf{ref}}(Y \mid X)\right]$$

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- Loss function for reward modeling:

$$\mathcal{L}_R(r, \mathcal{D}) = -\mathbb{E}_{(X,Y_w,Y_l)\sim\mathcal{D}}\left[\log \sigma\left(r\left(X, Y_w\right) - r\left(X, Y_l\right)\right)\right]$$

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- Direct Preference Optimization(DPO) Loss:

$$-\mathbb{E}_{(X,Y_w,Y_l)\sim\mathcal{D}}\left[\log \sigma\left(\beta \log \frac{\pi_\theta\left(Y_w \mid X\right)}{\pi_{\text{ref}}\left(Y_w \mid X\right)} - \beta \log \frac{\pi_\theta\left(Y_l \mid X\right)}{\pi_{\text{ref}}\left(Y_l \mid X\right)}\right)\right]$$

Is the DPO optimum well-posed?

- The conditional distributions $\pi^*(y|x)$ obtained through DPO **might not** correspond to a valid probability distribution $\pi^*(z)$ over all strings z. But this is not an issue if we parametrize r appropriately:

Theorem (Edgar)

DPO yields a valid probability distribution π^* if and only if there is a probability distribution q, and a constant c, such that for all strings z,

$$r(z)/\beta = \log(q(z)/\pi_{\text{ref}}(z)) + c.$$

Alternatives

- RRHF: Rank Responses with Human Feedback (Yuan et al., 2023)
- CPO: Contrastive Preference Optimization (Xu et al., 2024)
- KTO: Kahneman-Tversky Optimization (Ethayarajh et al., 2024)
- ORPO: Odds Ratio Preference Optimization (Hong et al., 2024)
- IPO: Identity Preference Optimization (Azar et al., 2024)
- SimPO: Simple Preference Optimization (Meng et al., 2024)

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RRHF: Rank Responses to Align Language Models with Human Feedback without tears

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Motivation: Drawbacks of PPO

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- PPO requires complex hyperparameter tuning, reward design and advantage estimation.
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- Goal: simplify the training pipeline.

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(5) Total Loss:

$$L = L_{rank} + L_{ft}$$

RRHF Workflow

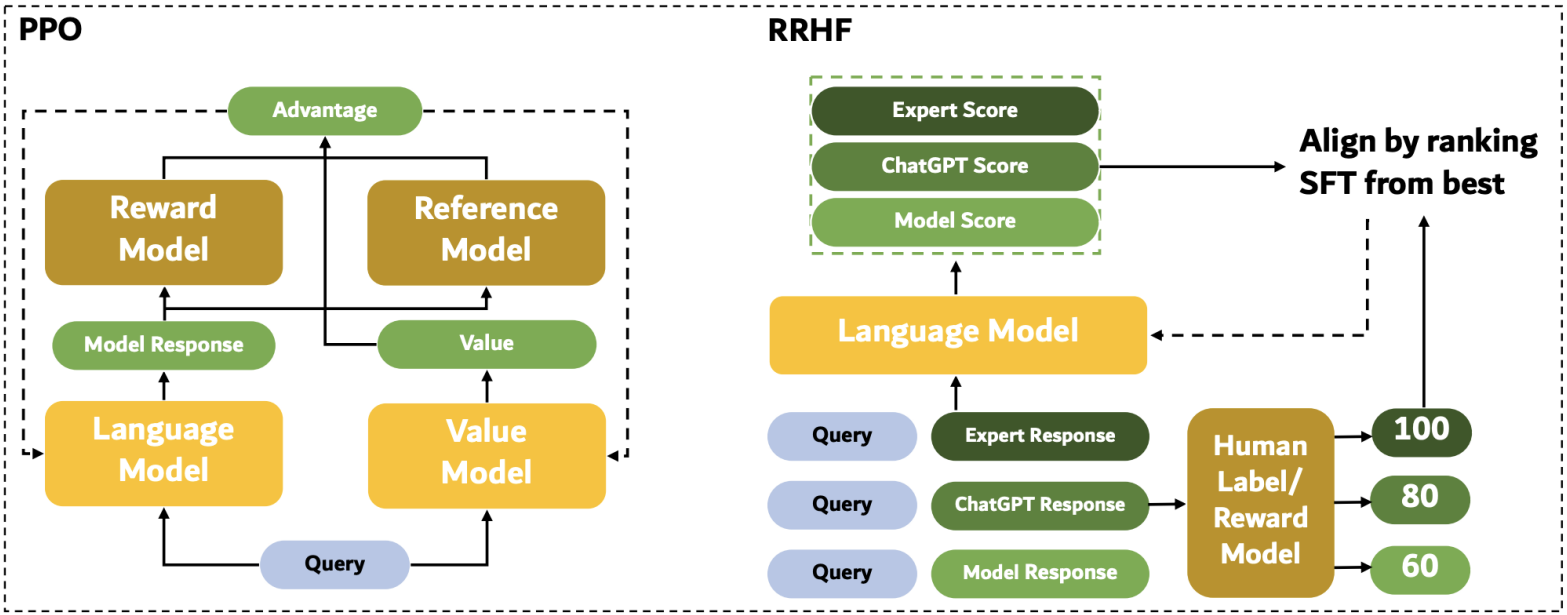

Figure: Workflow of RRHF compared with PPO

RRHF Experiments Setup

- Dataset: Anthropic's Helpfulness and Harmlessness dataset
- Proxy Reward Model: Dahoas/gptj-rm-static
- Models: Llama-7B, Alpaca-7B, Alpaca-7B SFT

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- Sampling Policy:

Table 1: Sampling policy used in our experiments. OP-k uses π for sampling (i.e. online sampling), we update π every k optimization steps. IP-n (Iterate update) uses updated policy ρ^* after training by IP-(n-1) and starts a new iteration. The dataset contains a good response and a bad response for each query which are used as ρ_5 and ρ_6, which are termed **P** (**P**rovided responses in datasets).

Setting	$\rho_1 \sim \rho_4$	ρ_5, ρ_6
BP	**B**eam search by ρ	**P**rovided responses
SP	top-p **S**ampling by ρ	**P**rovided responses
DP	**D**iverse beam search by ρ	**P**rovided responses
OP-k	**O**nline diverse beam by $\pi\dagger$	**P**rovided responses
IP-n	**I**terate diverse beam by ρ^*	**P**rovided responses
D	**D**iverse beam search by ρ	$\emptyset$
P	$\emptyset$	**P**rovided responses

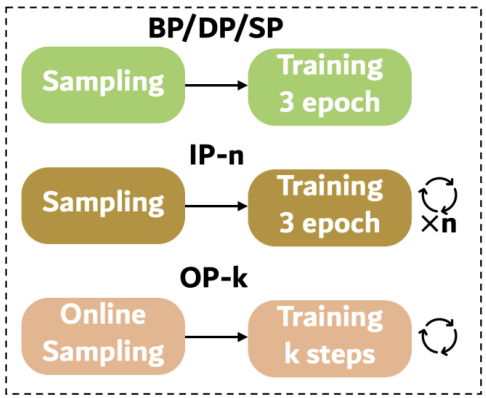

Figure 2: The workflow of sampling policy used in our experiments. IP-1 is equivalent to DP.

Auto Evaluation

- perplexity (gpt2-medium)
- average reward score (Dahoas/gptj-rm-static)

ρ	Setting	PPL	Reward
Good responses	$\emptyset$	21.46	-1.24
Bad responses	$\emptyset$	121.29	-1.48
LLaMA	$\emptyset$	20.78	-1.89
Alpaca	$\emptyset$	14.34	-1.18
Alpaca-sft	$\emptyset$	18.98	-1.46
Alpaca	Best-of-4	-	-0.97
LLaMA	PPO	42.53	-1.62
Alpaca	PPO	13.84	-1.03
Alpaca-sft	PPO	19.10	-1.25
LLaMA	RRHF_{DP}	67.12	-1.34
Alpaca-sft	RRHF_{DP}	18.10	-1.19
Alpaca	RRHF_{DP}	14.75	-1.03
Alpaca	RRHF_{SP}	14.41	**-0.96**

Figure: Automatic evaluation on HH dataset

More Results

- Human Evaluation:

Table 3: Human evaluation on HH dataset. All settings use ρ=Alpaca.

A	B	win	tie	lose
RRHF_{DP}	Good responses	59	30	11
RRHF_{DP}	PPO	27	48	25
RRHF_{DP}	$\text{RRHF}_{\text{IP-2}}$	0	90	10

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- Accuracy as a Reward Model:

Table 5: Reward model accuracy evaluation.

Reward Model	Accuracy
`Dahoas/gptj-rm-static`	68.49%
LLaMA	45.09%
Alpaca	45.13%
Alpaca-PPO	46.03%
Alpaca-RRHF_{DP}	61.75%

Ablation

ρ	Setting	PPL	Reward	Mean	Std.	Max
LLaMA	DP	67.12	-1.34	-2.18	0.97	-1.27
Alpaca	DP	14.75	**-1.02**	-1.30	0.66	-0.95
Alpaca-sft	DP	18.10	-1.19	-1.49	0.79	-1.11
LLaMA	BP	17.03	-1.27	-2.26	0.96	-1.26
Alpaca	BP	14.37	-1.03	-1.31	0.67	-1.00
Alpaca-sft	BP	17.63	-1.14	-1.50	0.77	-1.15
LLaMA	P	18.49	-1.31	-1.50	0.79	-1.28
Alpaca	P	18.88	-1.31	-1.50	0.79	-1.28
Alpaca-sft	P	18.92	-1.31	-1.50	0.79	-1.28
Alpaca	D	13.66	-1.08	-1.21	0.65	-1.02
Alpaca	IP-1	14.75	-1.02	-1.30	0.66	-0.95
Alpaca	IP-2	14.31	-0.96	-1.13	0.57	-0.77
Alpaca	IP-3	14.51	-0.94	-1.05	0.56	-0.65
Alpaca	OP-32	63.78	0.34	-	-	-
Alpaca	OP-32+KL	19.76	**-0.86**	-	-	-

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Table 7: Ranking loss ablation.

ρ	Setting	PPL	Reward
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Alpaca	BP - L_{rank}	14.74	-1.14

Conclusion

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  - Simplified training pipeline
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- Advantage:
  - Simplified training pipeline
  - Stability
- Disadvantage:
  - Dependence on sampling qualities
  - Limited exploration of new responses

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CPO

Contrastive Preference Optimization: Pushing the Boundaries of LLM Performance in Machine Translation

Haoran Xu[♠] **Amr Sharaf**[♡] **Yunmo Chen**[♠] **Weiting Tan**[♠] **Lingfeng Shen**[♠] **Benjamin Van Durme**[♠]
Kenton Murray[*♠] **Young Jin Kim**[*♡]

Introduction

- Task: Machine Translation
  - Traditional SOTA models: Transformer Encoder-Decoder (e.g., NLLB-200, MT5)
  - Large-scale decoder-only LLMs (GPT-4, LLaMA)

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- Problems:
  - Moderate-sized LLMs (7B, 13B) underperform compared to GPT-4 and WMT winners.
  - Supervised Fine-Tuning (SFT) on reference translation, e.g., ALMA (Xu et al., 2023)
- Goal: Introduce Contrastive Preference Optimization (CPO) to train moderate-sized models beyond SFT limitations and match the performances of GPT-4 and WMT winners.

Shortcomings of SFT

- SFT forces models to mimic reference translations, which could be suboptimal or flawed.

Source: 这是马特利 (Martelly) 四年来第五次入选海地临时选举委员会 (CEP)。

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ALMA-13B-LoRA: This is Martelly's fifth time **being selected by the Provisional Electoral Council** (CEP) in four years.

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Figure: Example from FLORES-200 dataset

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- SFT lacks a mechanism to prevent the model from rejecting mistakes in translations.

CPO-Preference data construction

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- Keep highest-scoring and lowest-scoring translations

CPO Objective

- DPO Loss:

$$\mathcal{L}\left(\pi_\theta; \pi_{\text{ref}}\right) = -\,\mathbb{E}_{(x,y_w,y_l)\sim\mathcal{D}}\left[\log\sigma\left(\beta\log\frac{\pi_\theta\left(y_w \mid x\right)}{\pi_{\text{ref}}\left(y_w \mid x\right)} - \beta\log\frac{\pi_\theta\left(y_l \mid x\right)}{\pi_{\text{ref}}\left(y_l \mid x\right)}\right)\right]$$

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- Memory-inefficient and speed-inefficient (two models)
- Set π_{ref} as a uniform prior U:

$$\mathcal{L}\left(\pi_\theta; U\right) = -\mathbb{E}_{(x,y_w,y_l)\sim\mathcal{D}}\left[\log\sigma\left(\beta\log\pi_\theta\left(y_w \mid x\right) - \beta\log\pi_\theta\left(y_l \mid x\right)\right)\right].$$

CPO objective

Theorem (Xu et al. (2024))

When $\pi_{\text{ref}} = \pi_w$, an ideal policy that precisely aligns with the true data distribution of the preferred data, i.e. $\pi_w(y_w|x) = 1$, then the DPO loss $\mathcal{L}(\pi_\theta; \pi_w) + C$ is upper bounded by $\mathcal{L}(\pi_\theta; U)$, where C is a constant.

- The approximation in $\mathcal{L}(\pi_\theta; U)$ is effective because it minimizes the upper bound on the DPO loss.

Proof

$$
\begin{aligned}
&\mathcal{L}\left(\pi_\theta; \pi_w\right) \\
&= -\mathbb{E}_{(x,y_w,y_l)\sim\mathcal{D}}\left[\log\sigma\left(\beta\log\frac{\pi_\theta\left(y_w \mid x\right)}{\pi_w\left(y_w \mid x\right)} - \beta\log\frac{\pi_\theta\left(y_l \mid x\right)}{\pi_w\left(y_l \mid x\right)}\right)\right] \\
&= -\mathbb{E}_{(x,y_w,y_l)\sim\mathcal{D}}\left[\log\sigma\left(\beta\log\pi_\theta\left(y_w \mid x\right) - \beta\log\pi_\theta\left(y_l \mid x\right)\right.\right. \\
&\quad \left.\left. + \beta\log\pi_w\left(y_l \mid x\right)\right)\right] \\
&= -\mathbb{E}_{(x,y_w,y_l)\sim\mathcal{D}}\left[\log\left(\frac{1}{1+\frac{\pi_\theta(y_l|x)^\beta}{\pi_\theta(y_w|x)^\beta\cdot\pi_w(y_l|x)^\beta}}\right)\right] \\
&= -\mathbb{E}_{(x,y_w,y_l)\sim\mathcal{D}}\left[\log\pi_\theta\left(y_w \mid x\right)^\beta + \log\pi_w\left(y_l \mid x\right)^\beta\right. \\
&\quad \left. - \log\left(\pi_\theta\left(y_w \mid x\right)^\beta\cdot\pi_w\left(y_l \mid x\right)^\beta + \pi_\theta\left(y_l \mid x\right)^\beta\right)\right].
\end{aligned}
$$

Proof

$$
\begin{aligned}
&\mathcal{L}'\left(\pi_\theta; \pi_w\right) \\
\triangleq &\mathcal{L}\left(\pi_\theta; \pi_w\right) + \underbrace{\mathbb{E}_{(x,y_l)\sim\mathcal{D}}\left[\log \pi_w\left(y_l \mid x\right)^\beta\right]}_{C \text{ in the Theorem}} \\
= &-\mathbb{E}_{(x,y_w,y_l)\sim\mathcal{D}}\Bigg[\log \pi_\theta\left(y_w \mid x\right)^\beta \\
&\quad - \log\left(\pi_\theta\left(y_w \mid x\right)^\beta \cdot \pi_w\left(y_l \mid x\right)^\beta + \pi_\theta\left(y_l \mid x\right)^\beta\right) \\
\leq &-\mathbb{E}_{(x,y_w,y_l)\sim\mathcal{D}}\left[\log \pi_\theta\left(y_w \mid x\right)^\beta - \log\left(\pi_\theta\left(y_w \mid x\right)^\beta \cdot 1 + \pi_\theta\left(y_l \mid x\right)^\beta\right)\right] \\
= &\mathcal{L}\left(\pi_\theta; U\right).
\end{aligned}
$$

CPO Objective

- Add a behavior cloning (BC) regularizer to prevent distribution drift:

$$\min_{\theta} \mathcal{L}\left(\pi_\theta, U\right)$$
$$\text{s.t. } \mathbb{E}_{(x,y_w)\sim\mathcal{D}}\left[\mathbb{KL}\left(\pi_w\left(y_w \mid x\right) \| \pi_\theta\left(y_w \mid x\right)\right)\right] < \epsilon,$$

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- By Lagrangian duality, equivalent to

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- Set $\lambda = 1$, expand KL divergence with $\pi_w\left(y_w \mid x\right) = 1$ to get CPO loss:

$$\min_{\theta} \underbrace{\mathcal{L}\left(\pi_\theta, U\right)}_{\mathcal{L}_{\text{prefer}}} \underbrace{-\mathbb{E}_{(x,y_w)\sim\mathcal{D}}\left[\log \pi_\theta\left(y_w \mid x\right)\right]}_{\mathcal{L}_{\text{NLL}}}$$

Experimental Setup

- Training Data:
  - 10 translation directions: $\mathrm{cs} \leftrightarrow \mathrm{en}$,$\mathrm{de} \leftrightarrow \mathrm{en}$, $\mathrm{is} \leftrightarrow \mathrm{en}, \mathrm{zh} \leftrightarrow \mathrm{en}, \mathrm{ru} \leftrightarrow \mathrm{en}$
  - 20K paired sentences derived from FLORES-200
- Test data: WMT'21, WMT'22, WMT;23
- Baselines:
  - ALMA-13B-LoRA (Base Model)
  - GPT-4 Zero-shot Translation
  - WMT'21, WMT'22 Competition Winners
  - SFT & DPO Models
- Reference-free evaluation models: KIWI-XXL, XCOMET

Experiments

Models	de			cs			is		
	KIWI-22	KIWI-XXL	XCOMET	KIWI-22	KIWI-XXL	XCOMET	KIWI-22	KIWI-XXL	XCOMET
Gold Reference	82.67	84.01	**97.85**	83.19	81.83	90.27	80.51	85.20	91.52
WMT Winners	**83.56**	83.70	96.99	85.31	**87.27**	**94.38**	81.77	84.94	91.61
GPT-4	83.48	**84.91**	97.56	84.81	85.35	93.48	81.03	81.21	90.00
ALMA-13B-LoRA	82.62	81.64	96.49	84.14	84.24	92.38	81.71	83.31	91.20
+ SFT on preferred data	82.75	81.85	96.67	84.14	83.46	91.99	81.48	82.11	90.30
+ DPO	82.40	81.20	96.40	83.86	83.45	91.68	81.43	82.66	90.33
+ CPO (Ours, ALMA-13B-R)	83.28	84.25	97.48	**84.99**	87.06	93.61	**82.18**	**85.68**	**91.93**

Models	zh			ru			Avg.		
	KIWI-22	KIWI-XXL	XCOMET	KIWI-22	KIWI-XXL	XCOMET	KIWI-22	KIWI-XXL	XCOMET
Gold Reference	80.92	81.70	90.42	82.96	84.62	94.17	82.05	83.47	92.85
WMT Winners	82.04	81.13	91.14	**84.35**	87.01	94.79	**83.41**	84.81	93.78
GPT-4	81.73	81.53	90.79	83.64	86.15	94.3	82.94	83.83	93.23
ALMA-13B-LoRA	80.82	79.96	89.92	83.10	84.17	93.79	82.48	82.66	92.76
+ SFT on preferred data	81.25	80.51	90.18	83.23	84.15	93.54	82.57	82.42	92.54
+ DPO	80.74	79.64	89.58	82.94	83.40	93.25	82.27	82.07	92.25
+ CPO (Ours, ALMA-13B-R)	**82.25**	**84.32**	**92.03**	83.98	**87.37**	**95.22**	83.34	**85.74**	**94.05**

Figure: overall results in $\mathrm{en} \rightarrow \mathrm{xx}$ for WMT'21 and WMT'22

- Incorporating CPO, performance of ALMA matches or even surpass that of GPT-4 and WMT winners
- SFT enhances ALMA's performance for $\mathrm{xx} \rightarrow \mathrm{en}$ but decreases for $\mathrm{en} \rightarrow \mathrm{xx}$. Similarly, DPO slightly decreases performance.
- CPO consistently improves performance across all metrics.

Experiments

Models	de			cs			is		
	KIWI-22	KIWI-XXL	XCOMET	KIWI-22	KIWI-XXL	XCOMET	KIWI-22	KIWI-XXL	XCOMET
Gold Reference	78.74	78.56	88.82	82.08	83.11	84.60	80.88	85.04	76.16
WMT Winners	81.38	83.59	93.74	82.47	82.53	85.65	81.39	85.60	78.14
GPT-4	**81.50**	**84.58**	**94.47**	82.52	83.55	**88.48**	81.49	**85.90**	**81.11**
ALMA-13B-LoRA	81.14	83.57	93.30	81.96	82.97	83.95	80.90	85.49	76.68
+ SFT on preferred data	81.36	83.98	93.84	82.36	83.15	86.67	81.32	85.61	80.20
+ DPO	81.13	83.52	93.25	81.82	82.69	83.84	80.89	85.22	76.09
+ CPO (Ours, ALMA-13B-R)	**81.50**	83.97	94.20	**82.63**	**83.75**	88.03	**81.57**	85.73	80.49

Models	zh			ru			Avg.		
	KIWI-22	KIWI-XXL	XCOMET	KIWI-22	KIWI-XXL	XCOMET	KIWI-22	KIWI-XXL	XCOMET
Gold Reference	77.09	74.19	90.70	80.74	79.59	88.56	79.91	80.10	85.77
WMT Winners	77.66	73.28	87.2	81.71	80.97	90.91	80.92	81.19	87.13
GPT-4	**79.33**	**77.65**	**92.06**	81.57	81.34	90.95	81.28	**82.60**	**89.41**
ALMA-13B-LoRA	77.32	74.41	89.88	81.31	81.05	89.89	80.53	81.50	86.74
+ SFT on preferred data	78.32	76.03	90.65	81.46	81.17	90.65	80.96	81.99	88.40
+ DPO	77.50	74.50	89.94	81.19	80.88	89.76	80.51	81.36	86.58
+ CPO (Ours, ALMA-13B-R)	79.24	77.17	91.65	**81.72**	**81.54**	**91.18**	**81.33**	82.43	89.11

Figure: overall results in $\mathrm{xx} \rightarrow \mathrm{en}$ for WMT'21 and WMT'22

- Incorporating CPO, performance of ALMA matches or even surpass that of GPT-4 and WMT winners
- SFT enhances ALMA's performance for $\mathrm{xx} \rightarrow \mathrm{en}$ but decreases for $\mathrm{en} \rightarrow \mathrm{xx}$. Similarly, DPO slightly decreases performance.
- CPO consistently improves performance across all metrics.

More Results

	KIWI-22	KIWI-XXL	XCOMET
Gold Reference	78.74	75.56	86.30
WMT Winners	**80.57**	77.72	88.24
TowerInstruct	80.31	77.18	88.11
ALMA-13B-LoRA	79.48	76.00	87.16
+ CPO (Ours, ALMA-13B-R)	80.55	**78.97**	**89.74**

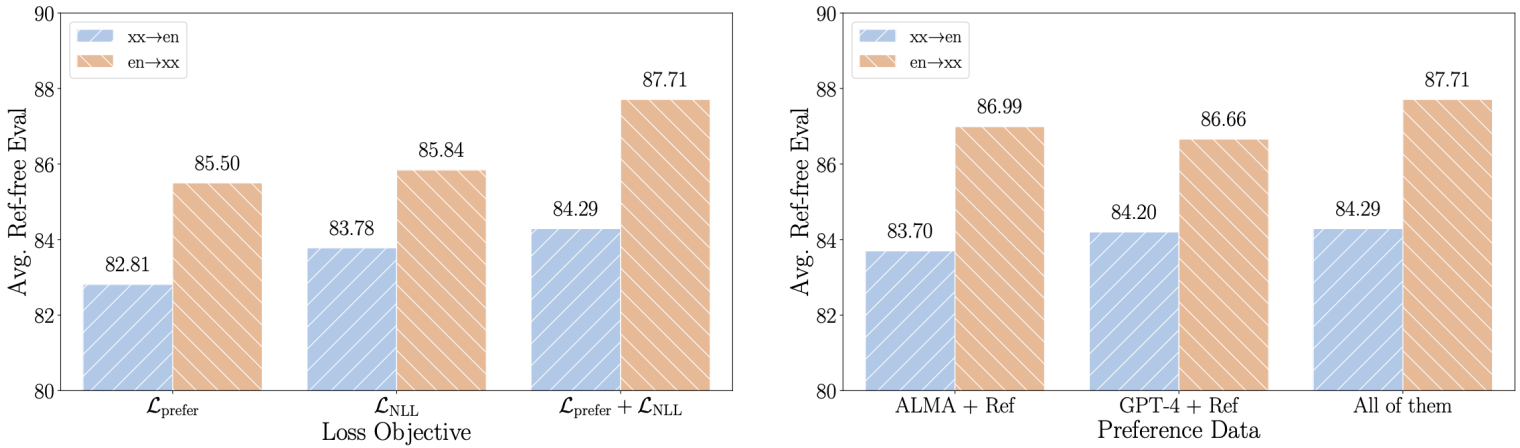
Figure: Overall Results for WMT'23

Table 7. The results of human evaluation on sampled `zh`→`en` WMT'22 test data. ↑ indicates that higher values are better, while ↓ indicates that lower values are better.

	Avg. score ↑	Avg. rank ↓	Avg. win ratio (%)	Ties (%)
ALMA-13B-LoRA	4.86	1.60	62.50	40.30
ALMA-13B-R	**5.16**	**1.40**	**77.80**	40.30

Figure: Human Evaluation

Ablation Study



- Removing L_{prefer} or L_{NLL} leads to lower performance.
- ALMA data is essential for $\text{en} \rightarrow \text{xx}$ while GPT-4's data is essential for $\text{xx} \rightarrow \text{en}$.

Ablation Study

Table 18. The impact of applying $\mathcal{L}_{\text{NLL}}$ to the original DPO loss.

Loss Objective	KIWI-22	KIWI-XXL	XCOMET	Memory Cost	FLOPs/tok
Translating to English (xx→en)					
$\mathcal{L}_{\text{DPO}}$	80.51	81.36	86.58	2×	2×
$\mathcal{L}_{\text{DPO}} + \mathcal{L}_{\text{NLL}}$	81.28	82.42	89.05	2×	2×
$\mathcal{L}_{\text{prefer}} + \mathcal{L}_{\text{NLL}}$ (CPO)	**81.33**	**82.43**	**89.11**	1×	1×
Translating from English (en→xx)					
$\mathcal{L}_{\text{DPO}}$	82.27	82.07	92.25	2×	2×
$\mathcal{L}_{\text{DPO}} + \mathcal{L}_{\text{NLL}}$	83.13	84.74	93.53	2×	2×
$\mathcal{L}_{\text{prefer}} + \mathcal{L}_{\text{NLL}}$ (CPO)	**83.34**	**85.74**	**94.05**	1×	1×

- Removing L_{prefer} or L_{NLL} leads to lower performance.
- ALMA data is essential for $\text{en} \rightarrow \text{xx}$ while GPT-4's data is essential for $\text{xx} \rightarrow \text{en}$.
- $\mathcal{L}_{\text{prefer}}$ is a successful approximation of the DPO loss, offering savings in memory and speed, and it can even outperform the original BC-regularized DPO loss $\mathcal{L}_{\text{DPO}} + \mathcal{L}_{\text{NLL}}$.

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KTO: Model Alignment as Prospect Theoretic Optimization

Kawin Ethayarajh [1] **Winnie Xu** [2] **Niklas Muennighoff** [2] **Dan Jurafsky** [1] **Douwe Kiela** [1 2]

Background: Prospect Theory

- Key Point: Relative to a **reference point**, humans are more sensitive to losses than gains, a property called **loss aversion**.
- Tversky and Kahneman (1992) proposed the following functional form for human value: ($\alpha \approx 0.88, \lambda \approx 2.25$)

$$v\left(z;\lambda,\alpha,z_0\right) = \begin{cases} \left(z-z_0\right)^{\alpha} & \text{if } z \geq z_0 \\ -\lambda\left(z_0-z\right)^{\alpha} & \text{if } z < z_0 \end{cases}$$

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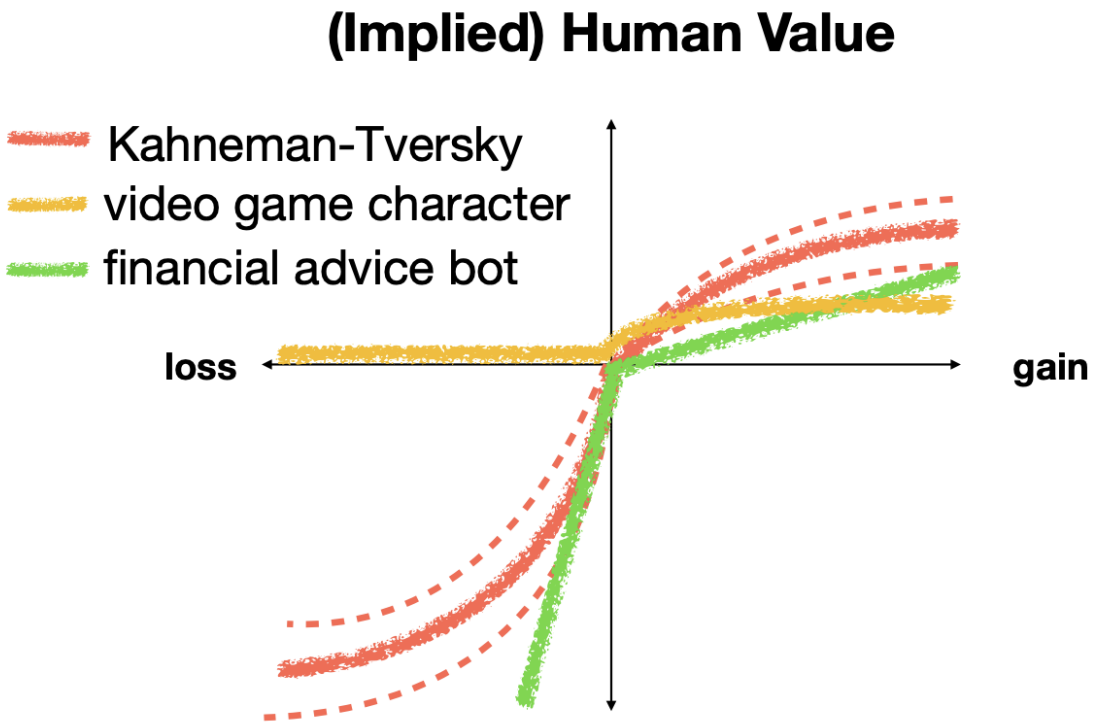


Why PPO/DPO Works?

- Popular alignment methods such as DPO and PPO-Clip implicitly model those human biases

Why PPO/DPO Works?

- Popular alignment methods such as DPO and PPO-Clip implicitly model those human biases
- Human-aware losses (HALOs):

Definition 3.4 (HALOs). Let θ denote the trainable parameters of the model $\pi_\theta : \mathcal{X} \to \mathcal{P}(\mathcal{Y})$ being aligned, π_{ref} the reference model, $l : \mathcal{Y} \to \mathbb{R}^+$ a normalizing factor, and $r_\theta(x, y) = l(y) \log[\pi_\theta(y|x)/\pi_{\text{ref}}(y|x)]$ the implied reward. Where $Q(Y'|x)$ is a reference point distribution over $\mathcal{Y}$ and $v : \mathbb{R} \to \mathbb{R}$ is non-decreasing everywhere and concave in $(0, \infty)$, the *human value* of (x, y) is

$$v(r_\theta(x, y) - \mathbb{E}_Q[r_\theta(x, y')]) \tag{5}$$

A function f is a *human-aware loss* for v if $\exists\ a_{x,y} \in \{-1, +1\}$ such that:

$$f(\pi_\theta, \pi_{\text{ref}}) = \mathbb{E}_{x,y\sim\mathcal{D}}[a_{x,y} v(r_\theta(x, y) - \mathbb{E}_Q[r_\theta(x, y')])] + C_\mathcal{D} \tag{6}$$

where $\mathcal{D}$ is the feedback data and $C_\mathcal{D} \in \mathbb{R}$ is a data-specific constant.

HALOs

- DPO and PPO-Clip are HALOs
- Example of DPO:

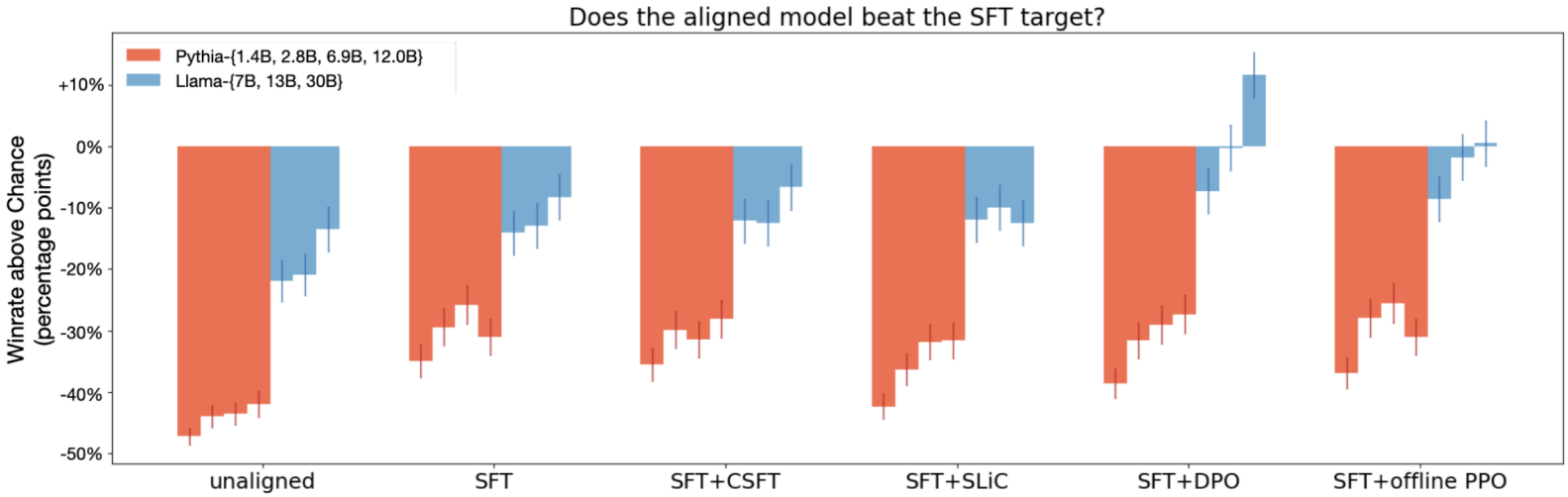
The DPO loss is

$$\mathcal{L}_{\text{DPO}}(\pi_\theta, \pi_{\text{ref}}) = \mathbb{E}_{x,y_w,y_l}\left[-\log\sigma\left(\beta\log\frac{\pi_\theta(y_w|x)}{\pi_{\text{ref}}(y_w|x)} - \beta\log\frac{\pi_\theta(y_l|x)}{\pi_{\text{ref}}(y_l|x)}\right)\right]$$

where $\beta > 0$ is a hyperparameter. DPO meets the criteria with the following construction: $l(y) = \beta$; $r_\theta = \beta\log\frac{\pi_\theta(y|x)}{\pi_{\text{ref}}(y|x)}$; $v(\cdot) = \log\sigma(\cdot)$ is increasing and concave everywhere; Q places all mass on (x, y_l), where y_l is a dispreferred output for x such that $y \succ y_l$; and $a_{x,y} = -1$.

- Conditional SFT (CSFT) and Sequence Likelihood Calibration (SLiC) are not HALOs.

Does being a HALO matter?



- HALOs either match or outperform non-HALOs at every scale
- Up to a scale of 7B parameters, alignment provides virtually no gains over SFT alone
- Despite only using dummy $+1/\text{-}1$ rewards, the offline PPO variant performs as well as DPO except for Llama-30B.

KTO

- KTO: a preference-free HALO that takes binary feedback as input and directly maximizes the utility of generations

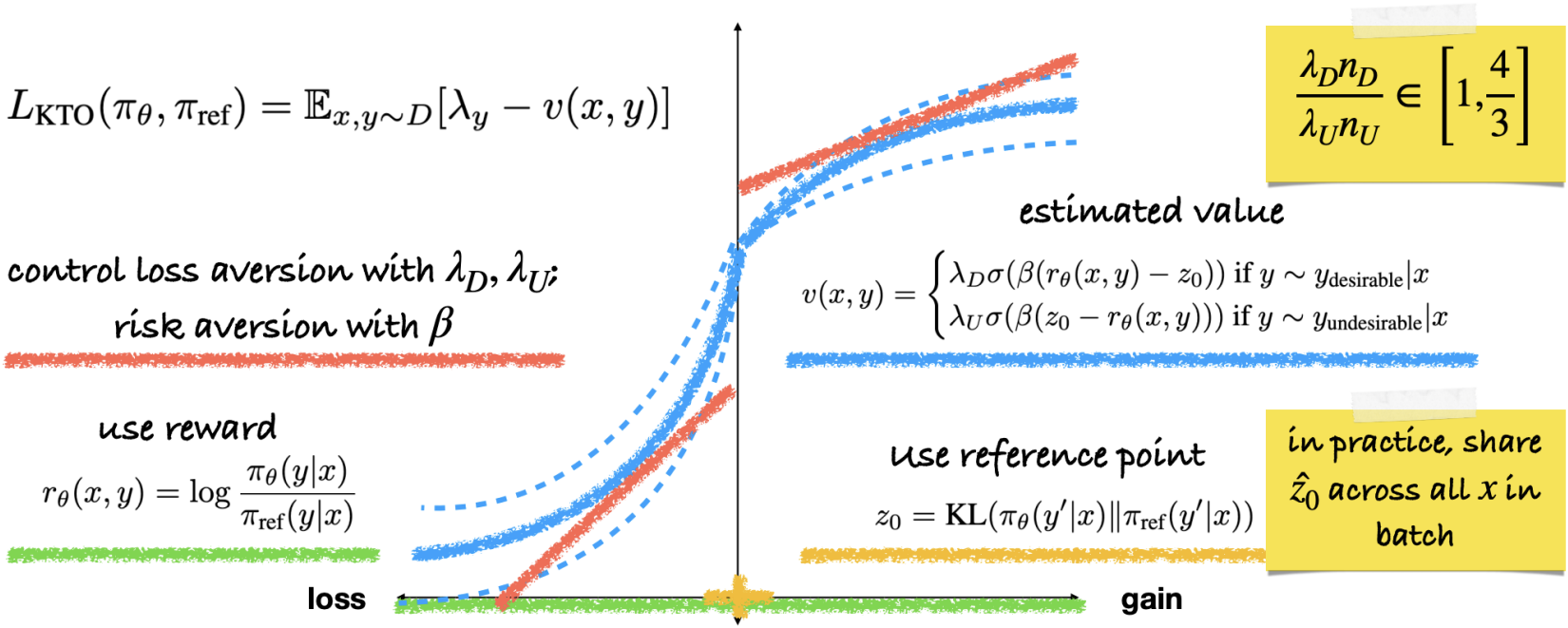
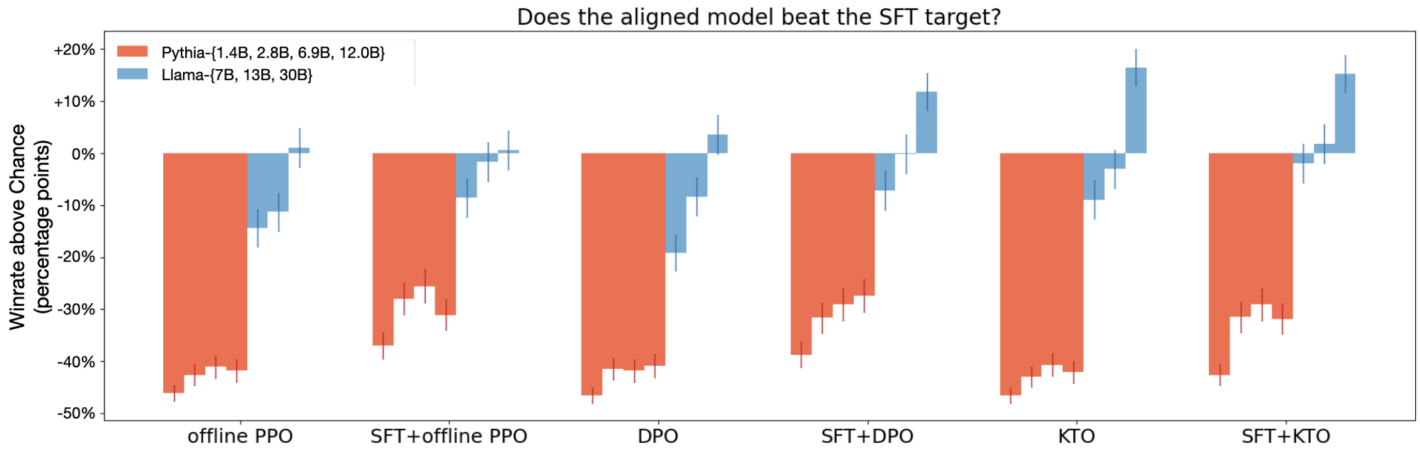


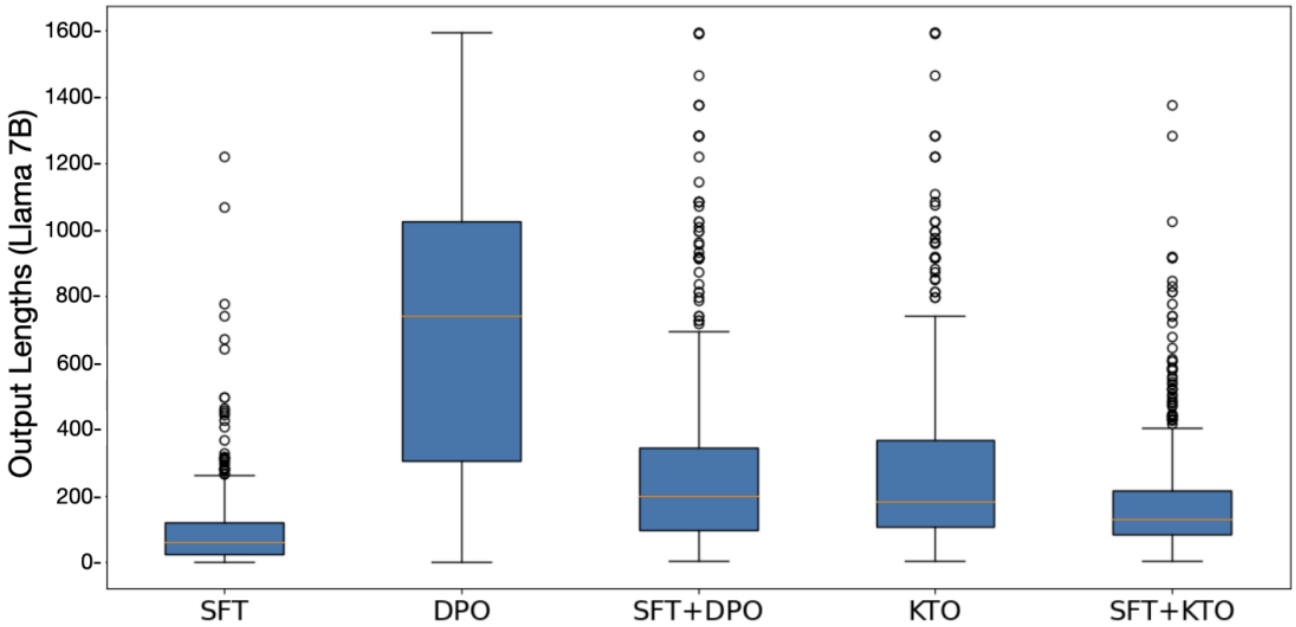
Figure: Kawin's Slide on KTO Loss

Experiments



- KTO matches or exceeds the performance of DPO

Experiments



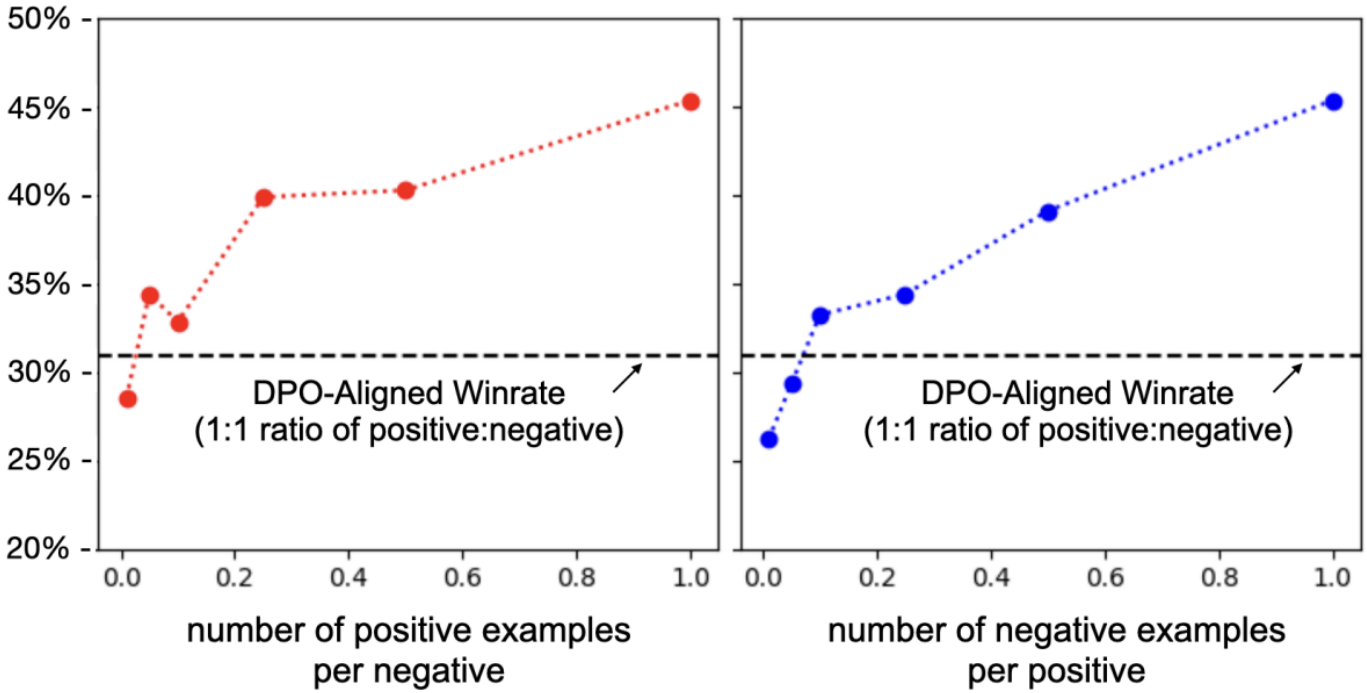
- KTO matches or exceeds the performance of DPO
- At sufficient scale, KTO does not need SFT

Experiments

Dataset (→) Metric (→)	MMLU EM	GSM8k EM	HumanEval pass@1	BBH EM
SFT	57.2	39.0	30.1	46.3
DPO	58.2	40.0	30.1	44.1
ORPO ($\lambda = 0.1$)	57.1	36.5	29.5	47.5
KTO ($\beta = 0.1, \lambda_D = 1$)	**58.6**	**53.5**	**30.9**	**52.6**
KTO (one-y-per-x)	58.0	50.0	30.7	49.9
KTO (no z_0)	58.5	49.5	30.7	49.0
KTO (concave, $v = \log \sigma$)	58.3	42.5	30.6	43.2
KTO (risk-neutral, $v(\cdot) = \cdot$)	57.3	42.0	28.8	6.1
KTO (no π_{ref}, $\lambda_D = 1.75$)	57.5	47.5	29.5	51.6

- KTO matches or exceeds the performance of DPO
- At sufficient scale, KTO does not need SFT
- KTO is also better than DPO on other benchmarks, e.g. GSM8K, a mathematical reasoning dataset
- Changing the design of KTO makes it significantly worse

More Results



- KTO can handle highly imbalanced datasets by adjusting

$$\frac{\lambda_D n_D}{\lambda_U n_U} \in \left[1, \frac{3}{2}\right]$$

DPO vs KTO: Which alignment method to use

- When human feedback is in a binary format $\rightarrow$ KTO

DPO vs KTO: Which alignment method to use

- When human feedback is in a binary format $\rightarrow$ KTO
- When data is in the form of preferences:
  - sufficiently little noise and intransitivity $\rightarrow$ DPO
  - high enough noise and intransitivity $\rightarrow$ KTO
  - Most publicly available preference datasets (e.g., SHP, OpenAssistant) contain noisy feedback

DPO vs KTO: Which alignment method to use

- When human feedback is in a binary format $\rightarrow$ KTO
- When data is in the form of preferences:
  - sufficiently little noise and intransitivity $\rightarrow$ DPO
  - high enough noise and intransitivity $\rightarrow$ KTO
  - Most publicly available preference datasets (e.g., SHP, OpenAssistant) contain noisy feedback
- Open research: design your HALO. There is no one-loss-fits-all!

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IPO

A General Theoretical Paradigm to Understand Learning from Human Preferences

Mohammad Gheshlaghi Azar **Mark Rowland** **Bilal Piot**
Daniel Guo **Daniele Calandriello** **Michal Valko** **Rémi Munos**
Google DeepMind

IPO: overview

- IPO = Identity Preference Optimization algorithm
- A special case of ΨPO, when $\Psi = \mathrm{id}$
- Proposed by Azar et al. (2024) (DeepMind)
- ΨPO is a general optimization framework that learns directly from preference data, and encompasses RLHF/DPO as a special case
- IPO is advantageous over DPO in the case of deterministic preferences
- Relies on a reference model

ΨPO: objective

- Given a reference model π, behavior policy μ, nondecreasing $\Psi : [0, 1] \to \mathbb{R}$, we have the **ΨPO objective**:

$$\max_{\pi} \mathop{\mathbb{E}}_{\substack{x\sim\rho \\ y\sim\pi(.|x) \\ y'\sim\mu(.|x)}} [\Psi(p^*(y \succ y'|x))] - \tau D_{\mathrm{KL}}(\pi \,||\, \pi_{\mathrm{ref}})\,.$$

- When $\Psi = \mathrm{id}$, we obtain IPO
- However, note that at this stage, one would need to learn $p^*(y \succ y'|x)$ in order to actually optimize this objective
- We will avoid this with some tricks

ΨPO: recovering RLHF/DPO

- **Claim:** if $\Psi(q) = \log \frac{q}{1-q}$ is the logit map, and if the BT model holds, we recover the optimal policy for RLHF/DPO.
- Proof: since BT holds, we have:

$$p^*(y \succ y'|x) = \sigma(r(x,y) - r(x,y'))$$

Apply Ψ to both sides:

$$\Psi(p^*(y \succ y'|x)) = (\Psi \circ \sigma)(r(x,y) - r(x,y')) = r(x,y) - r(x,y')$$

The objective becomes:

$$\mathbb{E}[r(x,y) - r(x,y')] - \tau D_{KL}(\pi||\pi_{ref}) \simeq \mathbb{E}[r(x,y)] - \tau D_{KL}(\pi||\pi_{ref})$$

Issues with $\Psi = \text{logit}$

- The main criticism of taking $\Psi = \text{logit}$: overfitting in the case of "deterministic preferences"
- Imagine that $p^*(y \succ y'|x) = 1$ for some y, y'. Then because $\Psi(1) = +\infty$, we have $r(x, y) - r(x, y') = +\infty$, which implies $\frac{\pi^*(y'|x)}{\pi^*(y|x)} = 0$, regardless of the regularization strength τ

$$\pi^*(y) \propto \pi_{\text{ref}}(y) \exp\left(\tau^{-1} \mathbb{E}_{y' \sim \mu}[\Psi(p^*(y \succ y'))]\right).$$

- In finite samples, a given y might "win" (or "lose") in 100% of its comparisons
- Thus, it is natural to consider alternatives that are bounded on $[0, 1]$, like $\Psi = \text{id}$

IPO: rewriting objective

- **Simplification 1:** use the "DPO trick" to reduce it to solving an equation. Then, solve this equation by minimizing $(\text{LHS} - \text{RHS})^2$
- Fix a single context x throughout.
  Defining the "reward" $g(y) := \mathbb{E}_{y' \sim \mu}[\Psi(p^*(y \succ y'))]$:

$$\pi^*(y) \propto \pi_{\text{ref}}(y) \exp(\tau^{-1} g(y)) .$$

$$\frac{\pi^*(y)}{\pi^*(y')} = \frac{\pi_{\text{ref}}(y)}{\pi_{\text{ref}}(y')} \exp(\tau^{-1}(g(y) - g(y'))) .$$

$$h^*(y, y') = \log \left(\frac{\pi^*(y)\pi_{\text{ref}}(y')}{\pi^*(y')\pi_{\text{ref}}(y)} \right)$$

$$h^*(y, y') = \tau^{-1}\big(g(y) - g(y')\big) .$$

$$h_\pi(y, y') = \log \left(\frac{\pi(y)\pi_{\text{ref}}(y'}{\pi(y')\pi_{\text{ref}}(y)} \right) ,$$

$$h_\pi(y, y') = \tau^{-1}\big(g(y) - g(y')\big) .$$

IPO: rewriting objective

- **Simplification 1**, continued: specialize to $\Psi = \mathrm{id}$:

$$h_\pi(y, y') = \tau^{-1}\big(g(y) - g(y')\big)\,.$$

$$h_\pi(y, y') = \tau^{-1}\big(p^*(y \succ \mu) - p^*(y' \succ \mu)\big)\,.$$

  where we use the notation $p^*(y \succ \mu) := \mathbb{E}_{y' \sim \mu}[p^*(y \succ y')]$
- We would like to solve this equation for π. Assuming that a solution exists, this is equivalent to minimizing $(\mathrm{LHS} - \mathrm{RHS})^2$ with respect to π. We arrive at the **preliminary IPO objective**:

$$L(\pi) = \mathop{\mathbb{E}}_{y,y' \sim \mu}\left[\left(h_\pi(y, y') - \frac{p^*(y \succ \mu) - p^*(y' \succ \mu)}{\tau}\right)^2\right].$$

- Intuition for h_π: write $h_\pi(y, y') = \log \frac{\pi(y)}{\pi_{ref}(y)} - \log \frac{\pi(y')}{\pi_{ref}(y')}$

IPO: rewriting objective

- **Simplification 2**: replace $p^*(y \succ \mu) - p^*(y' \succ \mu)$ with the random variable $I(y, y') \sim \text{Bern}(p^*(y \succ y'))$
- **Population IPO objective**:

$$\mathop{\mathbb{E}}_{y,y' \sim \mu} \left[\left(h_\pi(y, y') - \tau^{-1} I(y, y') \right)^2 \right],$$

where we also average over the Bernoulli randomness

IPO: rewriting objective

- Let's prove that the objectives agree, up to an additive constant:

$$\begin{aligned}&\mathbb{E}[(h_\pi(y,y') - \tau^{-1}(p^*(y \succ \mu) - p^*(y' \succ \mu)))^2] \\ &\simeq \mathbb{E}[(h_\pi(y,y') - \tau^{-1} I(y,y'))^2]\end{aligned}$$

- It suffices to consider the cross-term:

$$\mathbb{E}[h_\pi(y,y')(p^*(y \succ \mu) - p^*(y' \succ \mu)))] = \mathbb{E}[h_\pi(y,y') I(y,y')]$$

- Note that

$$h_\pi(y,y') = \log \frac{\pi(y)}{\pi_{ref}(y)} - \log \frac{\pi(y')}{\pi_{ref}(y')} =: f(y) - f(y')$$

is additively separable. Also, $h_\pi(y,y') = -h_\pi(y',y)$

IPO: rewriting objective

- (Continuing the proof:)

$$
\begin{aligned}
\text{RHS} &= \mathbb{E}[h_\pi(y, y')I(y, y')] \\
&= \mathbb{E}[h_\pi(y, y')p^*(y \succ y')] \\
&= \mathbb{E}[f(y)p^*(y \succ y')] - \mathbb{E}[f(y')p^*(y \succ y')] \\
&= \mathbb{E}[f(y)p^*(y \succ y')] - \mathbb{E}[f(y')(1 - p^*(y' \succ y))] \\
&= \mathbb{E}[f(y)p^*(y \succ y')] + \mathbb{E}[f(y')p^*(y' \succ y)] - \mathbb{E}[f(y')] \\
&= \mathbb{E}[f(y)(2p^*(y \succ y') - 1)]
\end{aligned}
$$

IPO: rewriting objective

- (Continuing the proof:)

$$
\begin{aligned}
\text{LHS} &= \mathbb{E}[h_\pi(y, y')(p^*(y \succ \mu) - p^*(y' \succ \mu))] \\
&= \mathbb{E}[h_\pi(y, y')p^*(y \succ \mu)] - \mathbb{E}[h_\pi(y, y')p^*(y' \succ \mu)] \\
&= \mathbb{E}[h_\pi(y, y')p^*(y \succ \mu)] + \mathbb{E}[h_\pi(y', y)p^*(y' \succ \mu)] \\
&= \mathbb{E}[h_\pi(y, y') \cdot 2p^*(y \succ \mu)] \\
&= \mathbb{E}[f(y) \cdot 2p^*(y \succ \mu)] - \mathbb{E}[f(y') \cdot 2p^*(y \succ \mu)] \\
&= \mathbb{E}[f(y) \cdot 2p^*(y \succ \mu)] - \mathbb{E}[f(y')]\mathbb{E}[2p^*(y \succ \mu)] \\
&= \mathbb{E}[f(y) \cdot 2p^*(y \succ y')] - \mathbb{E}[f(y')] \cdot 2 \cdot \frac{1}{2} \\
&= \mathbb{E}[f(y)(2p^*(y \succ y') - 1)],
\end{aligned}
$$

which agrees with the RHS

IPO: empirical objective

- Consider a single x. Given a preference dataset $\{(y_w^{(i)}, y_l^{(i)}) : i \in [N]\}$, we augment the dataset by including the "flip" of each (y_w, y_l). The first term of the objective becomes:

$$\frac{1}{2}(h_\pi - \tau^{-1} \cdot 1)^2 + \frac{1}{2}(h_\pi - \tau^{-1} \cdot 0)^2 \simeq \left(h_\pi - \frac{\tau^{-1}}{2}\right)^2$$

- **Empirical IPO loss**:

$$\mathop{\mathbb{E}}_{(y_w, y_l) \sim D} \left[\left(h_\pi(y_w, y_l) - \frac{\tau^{-1}}{2} \right)^2 \right].$$

- Intuition: we're fitting the difference $h_\pi(y, y') = f(y) - f(y')$ in log-likelihood ratios to $\frac{\tau^{-1}}{2}$ using least-squares
- (SimPO, which we will discuss later, calls $\frac{\tau^{-1}}{2}$ a "margin")

IPO: effect of regularization

- Toy dataset of size three: $y_1 \succ y_2$, $y_1 \succ y_3$, and $y_2 \succ y_3$
- Uniform reference model: $\pi_{ref} = \frac{1}{3}\delta_{y_1} + \frac{1}{3}\delta_{y_2} + \frac{1}{3}\delta_{y_3}$
- IPO regularization τ has an effect, unlike DPO, which converges to $\pi^* = \delta_{y_1}$, regardless of τ

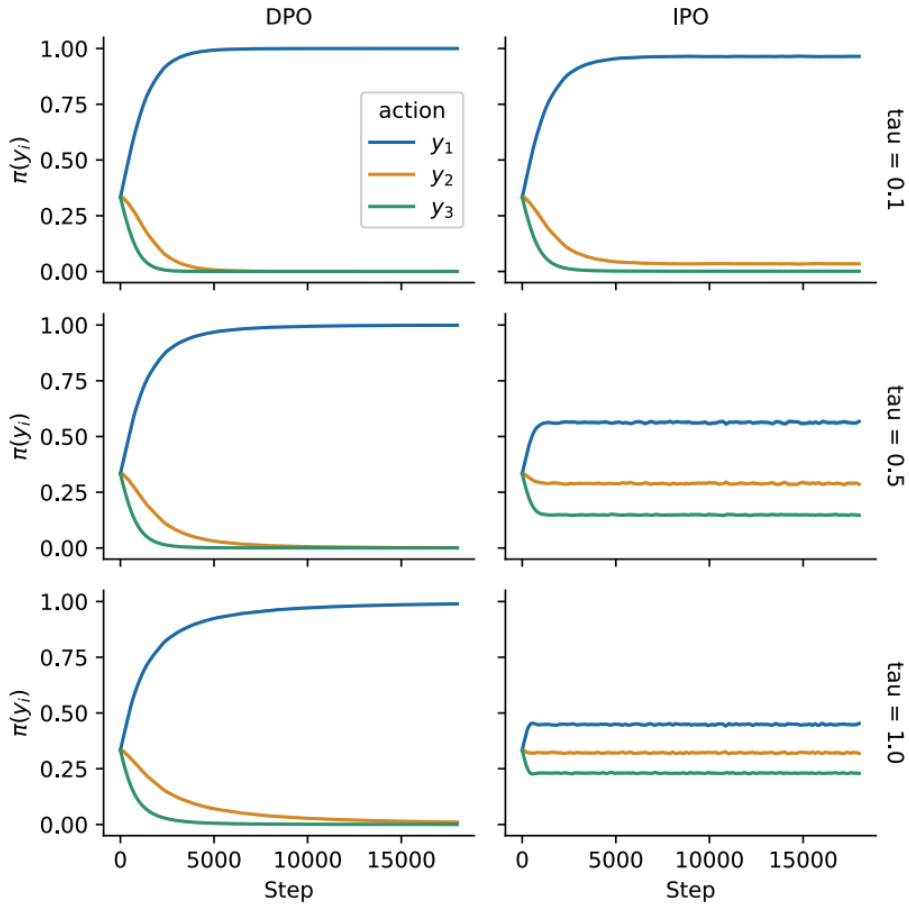

Figure 1: Comparison Between the Learning Curves of Action Probabilities of `IPO` and `DPO` for $\mathcal{D}_1$

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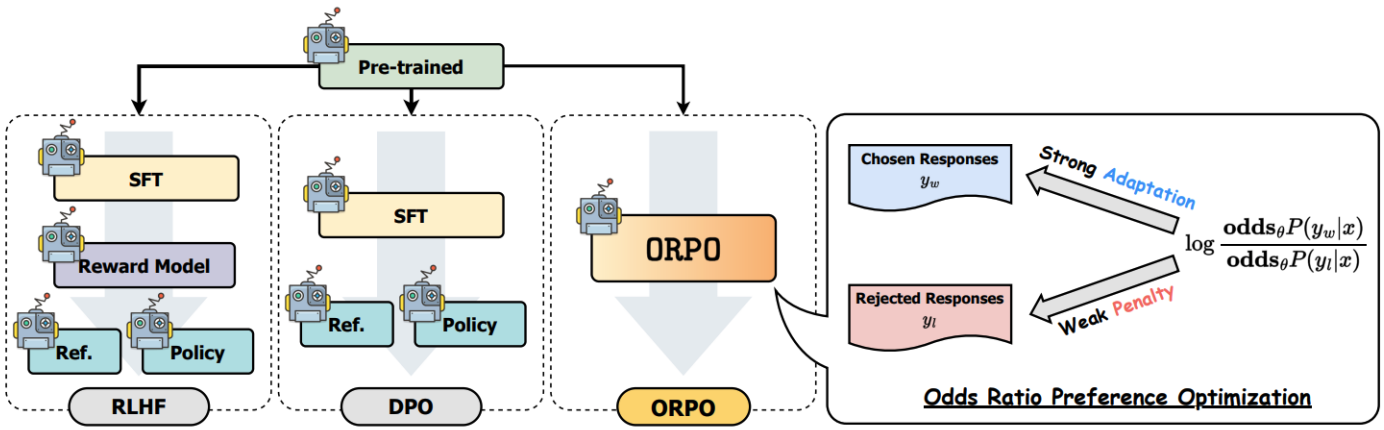
ORPO: Monolithic Preference Optimization without Reference Model

Jiwoo Hong **Noah Lee** **James Thorne**

KAIST AI

ORPO: overview

- ORPO = Odds Ratio Preference Optimization algorithm
- Proposed by Hong et al. (2024) (KAIST)
- Prior works use a two-stage alignment procedure: (1) SFT, (2) Preference Optimization
- ORPO: merge the Preference Optimization step into the SFT step with an added penalty
- Since this is a one-stage procedure, no need for a reference model



ORPO: choice of penalty

- SFT by itself increases the log-probs of tokens in the finetuning dataset, but is unconstrained on unseen tokens
- Empirically, SFT increases the log-probs of unwanted generations

Figure 3: Log probabilities for chosen and rejected responses during OPT-350M model fine-tuning on HH-RLHF dataset. Despite only chosen responses being used for supervision, rejected responses show a comparable likelihood of generation.

ORPO: choice of penalty

- To prevent this, we use the **log odds ratio**, defined as:

$$\mathbf{OR}_\theta(y_w, y_l) = \frac{\mathbf{odds}_\theta(y_w|x)}{\mathbf{odds}_\theta(y_l|x)}$$

where $P_\theta(y|x)$ and $\text{odds}_\theta(y|x)$ are defined as:

$$\log P_\theta(y|x) = \frac{1}{m}\sum_{t=1}^{m} \log P_\theta(y_t|x, y_{<t})$$

$$\mathbf{odds}_\theta(y|x) = \frac{P_\theta(y|x)}{1 - P_\theta(y|x)}$$

- Intuition: the reward associated to y is $r_\theta(x, y) = \log \text{odds}_\theta(y|x)$
- (The intuitive choice, the probability ratio, is “too harsh" of a penalty, according to the authors)

ORPO: objective

- **ORPO objective**:

$$\mathcal{L}_{ORPO} = \mathbb{E}_{(x,y_w,y_l)} \left[\mathcal{L}_{SFT} + \lambda \cdot \mathcal{L}_{OR} \right]$$

where the penalty is given by

$$\mathcal{L}_{OR} = -\log \sigma \left(\log \frac{\mathbf{odds}_\theta(y_w|x)}{\mathbf{odds}_\theta(y_l|x)} \right)$$

- Note that we pass the log odds ratio through $-\log \sigma(\cdot)$ to obtain a negative log likelihood

ORPO: effect on unwanted generations

- ORPO performs finetuning while reducing the likelihood of unwanted generations

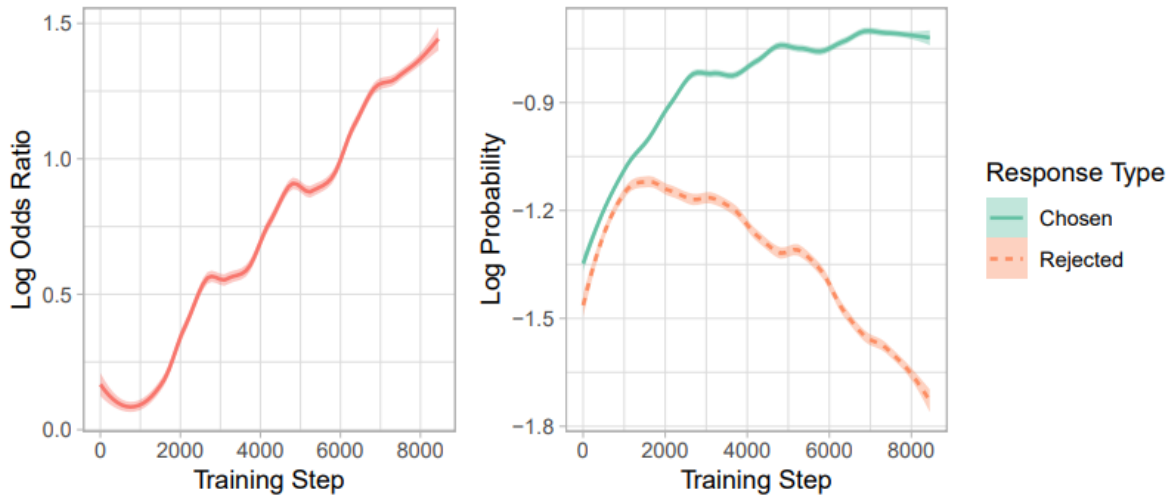


Figure 7: Average log-likelihood for chosen and rejected responses and log odds ratio per batch. The odds consistently increase during training with ORPO.

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SimPO: Simple Preference Optimization with a Reference-Free Reward

Yu Meng[1]* **Mengzhou Xia**[2]* **Danqi Chen**[2]
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SimPO: overview

- SimPO = Simple Preference Optimization algorithm
- Proposed by Meng et al. (2024) (UVA, Princeton)
- Replaces the implicit reward model in DPO with the average log-prob of y's tokens given x
- Also, includes a reward margin γ (aka “home advantage")
- No need for a reference model
- Performs an extensive experimental comparison of previous methods

SimPO: objective

- Recall the DPO objective:

$$\mathcal{L}_{\text{DPO}}(\pi_\theta; \pi_{\text{ref}}) = -\mathbb{E}_{(x,y_w,y_l)\sim\mathcal{D}}\left[\log\sigma\left(\beta\log\frac{\pi_\theta(y_w \mid x)}{\pi_{\text{ref}}(y_w \mid x)} - \beta\log\frac{\pi_\theta(y_l \mid x)}{\pi_{\text{ref}}(y_l \mid x)}\right)\right],$$

- The implicit reward model in DPO is:

$$r(x,y) = \beta\log\frac{\pi_\theta(y \mid x)}{\pi_{\text{ref}}(y \mid x)} + \beta\log Z(x),$$

- **Issue**: $r(x, y_w) > r(x, y_l)$ does not imply $p_\theta(y_w|x) > p_\theta(y_l|x)$, where

$$p_\theta(y \mid x) = \frac{1}{|y|}\log\pi_\theta(y \mid x) = \frac{1}{|y|}\sum_{i=1}^{|y|}\log\pi_\theta(y_i \mid x, y_{<i}).$$

  is the average log likelihood
- "In our experiments, we observed that only 50% of the triples from the training set satisfy this condition when trained with DPO."
- **Idea**: simply set $r(x, y)$ to be $\beta p_\theta(y|x)$, for some $\beta > 0$

SimPO: objective

- **SimPO objective**:

$$\mathcal{L}_{\text{SimPO}}(\pi_\theta) = -\mathbb{E}_{(x,y_w,y_l)\sim\mathcal{D}}\left[\log\sigma\left(\frac{\beta}{|y_w|}\log\pi_\theta(y_w|x) - \frac{\beta}{|y_l|}\log\pi_\theta(y_l|x) - \gamma\right)\right].$$

- Here $\gamma > 0$ is a reward margin term. (Not clear why they included it, but it helps)
- Note that we no longer require a reference model
- Choice of hyperparameters: $\beta \in [2.0, 2.5]$, $\gamma \in [0.5, 1.5]$
- No explicit KL regularization, but empirically low KL divergence from the base model

$$\mathcal{L}_{\text{DPO}}(\pi_\theta; \pi_{\text{ref}}) = -\mathbb{E}\left[\log\sigma\left(\beta\log\frac{\pi_\theta(y_w \mid x)}{\pi_{\text{ref}}(y_w \mid x)} - \beta\log\frac{\pi_\theta(y_l \mid x)}{\pi_{\text{ref}}(y_l \mid x)}\right)\right]$$

$$\mathcal{L}_{\text{SimPO}}(\pi_\theta) = -\mathbb{E}\left[\log\sigma\left(\frac{\beta}{|y_w|}\log\pi_\theta(y_w \mid x) - \frac{\beta}{|y_l|}\log\pi_\theta(y_l \mid x) - \gamma\right)\right]$$

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Models

- Two setups: **Base** and **Instruct**
- Llama-3-8B and Mistral-7B
- **Base**: finetune on the UltraChat-200k dataset, do preference optimization with the UltraFeedback dataset
- **Instruct**: treat Llama-3-Instruct + Mistral-Instruct as post-SFT models; **regenerate** the Instruct preference data by sampling from the Instruct models
  - To select y_w and y_l, they score five generations using the pairwise reward model PairRM from LLM-Blender, and take the top + bottom
- Yields Llama-3-Base, Llama-3-Instruct, Mistral-Base, and Mistral-Instruct

Benchmarks

- Open-ended instruction-following benchmarks:
  - AlpacaEval 2 (805 questions from 5 datasets)
  - MT-Bench (multi-turn, 8 categories with 80 questions)
  - Arena-Hard v0.1 (a hard version of MT-Bench, 500 technical queries)

	# Exs.	Baseline Model	Judge Model	Scoring Type	Metric
AlpacaEval 2	805	GPT-4 Turbo	GPT-4 Turbo	Pairwise comparison	LC & raw win rate
Arena-Hard	500	GPT-4-0314	GPT-4 Turbo	Pairwise comparison	Win rate
MT-Bench	80	-	GPT-4/GPT-4 Turbo	Single-answer grading	Rating of 1-10

Hyperparameters

Setting	β	γ	Learning rate
Mistral-Base	2.0	1.6	3e-7
Mistral-Instruct	2.5	0.3	5e-7
Llama-3-Base	2.0	1.0	6e-7
Llama-3-Instruct	2.5	1.4	1e-6

Method	Objective	Hyperparameter
RRHF [91]	$\max\left(0, -\frac{1}{\lvert y_w\rvert}\log \pi_\theta(y_w\lvert x) + \frac{1}{\lvert y_l\rvert}\log \pi_\theta(y_l\lvert x)\right) - \lambda \log \pi_\theta(y_w\lvert x)$	$\lambda \in [0.1, 0.5, 1.0, 10.0]$
SLiC-HF [96]	$\max\left(0, \delta - \log \pi_\theta(y_w\lvert x) + \log \pi_\theta(y_l\lvert x)\right) - \lambda \log \pi_\theta(y_w\lvert x)$	$\lambda \in [0.1, 0.5, 1.0, 10.0]$ $\beta \in [0.1, 0.5, 1.0, 2.0]$
DPO [66]	$-\log \sigma\left(\beta \log \frac{\pi_\theta(y_w\lvert x)}{\pi_{\text{ref}}(y_w\lvert x)} - \beta \log \frac{\pi_\theta(y_l\lvert x)}{\pi_{\text{ref}}(y_l\lvert x)}\right)$	$\beta \in [0.01, 0.05, 0.1]$
IPO [6]	$\left(\log \frac{\pi_\theta(y_w\lvert x)}{\pi_{\text{ref}}(y_w\lvert x)} - \log \frac{\pi_\theta(y_l\lvert x)}{\pi_{\text{ref}}(y_l\lvert x)} - \frac{1}{2\tau}\right)^2$	$\tau \in [0.01, 0.1, 0.5, 1.0]$
CPO [88]	$-\log \sigma\left(\beta \log \pi_\theta(y_w\lvert x) - \beta \log \pi_\theta(y_l\lvert x)\right) - \lambda \log \pi_\theta(y_w\lvert x)$	$\lambda = 1.0,\ \beta \in [0.01, 0.05, 0.1]$
KTO [29]	$-\lambda_w \sigma\left(\beta \log \frac{\pi_\theta(y_w\lvert x)}{\pi_{\text{ref}}(y_w\lvert x)} - z_{\text{ref}}\right) + \lambda_l \sigma\left(z_{\text{ref}} - \beta \log \frac{\pi_\theta(y_l\lvert x)}{\pi_{\text{ref}}(y_l\lvert x)}\right)$, where $z_{\text{ref}} = \mathbb{E}_{(x,y)\sim\mathcal{D}}\left[\beta \text{KL}\left(\pi_\theta(y\lvert x)\lvert\lvert \pi_{\text{ref}}(y\lvert x)\right)\right]$	$\lambda_l = \lambda_w = 1.0$ $\beta \in [0.01, 0.05, 0.1]$
ORPO [42]	$-\log p_\theta(y_w\lvert x) - \lambda \log \sigma\left(\log \frac{p_\theta(y_w\lvert x)}{1-p_\theta(y_w\lvert x)} - \log \frac{p_\theta(y_l\lvert x)}{1-p_\theta(y_l\lvert x)}\right)$, where $p_\theta(y\lvert x) = \exp\left(\frac{1}{\lvert y\rvert}\log \pi_\theta(y\lvert x)\right)$	$\lambda \in [0.1, 0.5, 1.0, 2.0]$
R-DPO [64]	$-\log \sigma\left(\beta \log \frac{\pi_\theta(y_w\lvert x)}{\pi_{\text{ref}}(y_w\lvert x)} - \beta \log \frac{\pi_\theta(y_l\lvert x)}{\pi_{\text{ref}}(y_l\lvert x)} + (\alpha\lvert y_w\rvert - \alpha\lvert y_l\rvert)\right)$	$\alpha \in [0.05, 0.1, 0.5, 1.0]$ $\beta \in [0.01, 0.05, 0.1]$
SimPO	$-\log \sigma\left(\frac{\beta}{\lvert y_w\rvert}\log \pi_\theta(y_w\lvert x) - \frac{\beta}{\lvert y_l\rvert}\log \pi_\theta(y_l\lvert x) - \gamma\right)$	$\beta \in [2.0, 2.5]$ $\gamma \in [0.3, 0.5, 1.0, 1.2, 1.4, 1.6]$

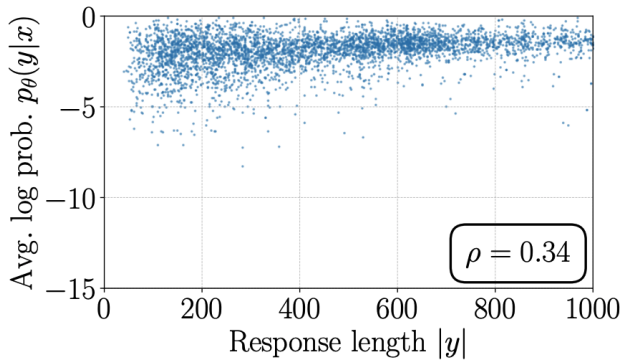
Comparison

- "We find that many variants of DPO do not empirically present an advantage over standard DPO."

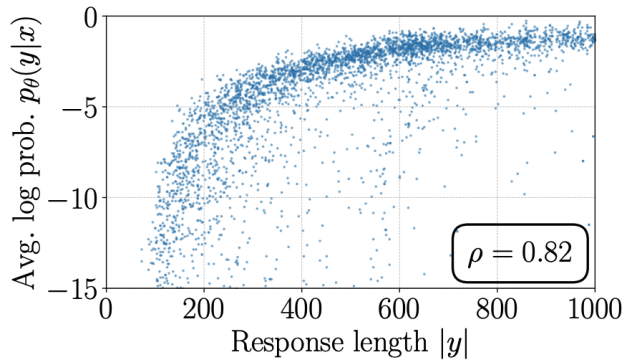
Method	Mistral-Base (7B)					Mistral-Instruct (7B)				
	AlpacaEval 2		Arena-Hard	MT-Bench		AlpacaEval 2		Arena-Hard	MT-Bench	
	LC (%)	WR (%)	WR (%)	GPT-4 Turbo	GPT-4	LC (%)	WR (%)	WR (%)	GPT-4 Turbo	GPT-4
SFT	8.4	6.2	1.3	4.8	6.3	17.1	14.7	12.6	6.2	7.5
RRHF [91]	11.6	10.2	5.8	5.4	6.7	25.3	24.8	18.1	6.5	7.6
SLiC-HF [96]	10.9	8.9	7.3	5.8	**7.4**	24.1	24.6	18.9	6.5	**7.8**
DPO [66]	15.1	12.5	10.4	5.9	7.3	26.8	24.9	16.3	6.3	7.6
IPO [6]	11.8	9.4	7.5	5.5	7.2	20.3	20.3	16.2	6.4	**7.8**
CPO [88]	9.8	8.9	6.9	5.4	6.8	23.8	28.8	**22.6**	6.3	7.5
KTO [29]	13.1	9.1	5.6	5.4	7.0	24.5	23.6	17.9	6.4	7.7
ORPO [42]	14.7	12.2	7.0	5.8	7.3	24.5	24.9	20.8	6.4	7.7
R-DPO [64]	17.4	12.8	8.0	5.9	**7.4**	27.3	24.5	16.1	6.2	7.5
SimPO	**21.5**	**20.8**	**16.6**	**6.0**	7.3	**32.1**	**34.8**	21.0	**6.6**	7.6

SimPO ablations

- Ablation studies using the Mistral-Base setting
- Length normalization $\frac{1}{|y|}$:

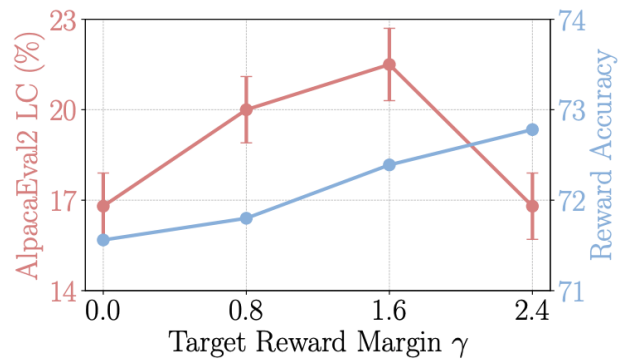


(b) SimPO.

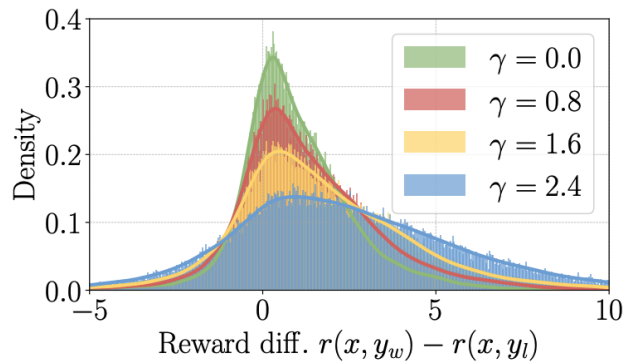


(c) SimPO without LN.

- Reward margin γ:



(a) Performance w/ different γ.



(b) Reward diff. distribution.

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