ORPO: Monolithic Odds Ratio Preference Optimization without Reference Model

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Abstract

While recently proposed preference alignment algorithms for language models have demonstrated promising results, supervised fine-tuning (SFT) remains imperative for achieving successful convergence in preference alignment. In this paper, we elaborate on the crucial role of SFT within the context of preference alignment, emphasizing that a minor penalty for the disfavored generation style is sufficient for preference-aligned SFT. Building on this foundation, we introduce a straightforward and innovative reference model-free monolithic odds ratio preference optimization algorithm, ORPO, eliminating the necessity for an additional preference alignment phase. Empirically and theoretically, we demonstrate that the odds ratio is a sensible choice for contrasting favored and unfavored styles during SFT across the diverse sizes from 125m to 7B. Specifically, by fine-tuning Phi-2 (2.7B), Llama-2 (7B), and Mistral (7B) with ORPO on the Ultrafeedback alone, surpasses the performance of state-of-the-art language models with more than 7B and 13B parameters, achieving up to 12.20% on AlpacaEval$_{2.0}$ and 7.32 in MT-Bench, as shown in Figures 1 and 11.

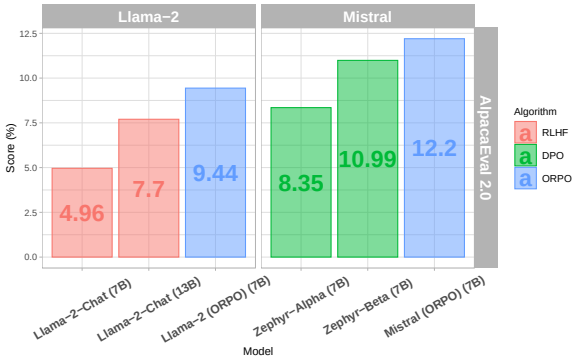

Figure 1: AlpacaEval$_{2.0}$ result of Llama-2 (7B) and Mistral (7B) fine-tuned with ORPO (blue) in comparison to the state-of-the-art models. Notably, Mistral (ORPO) surpasses Zephyr β and Llama-2-Chat (13B) with a single epoch training on the subset of UltraFeedback.

1 Introduction

Pre-trained language models (PLMs) with a vast training corpora such as web texts (Gokaslan and Cohen, 2019; Penedo et al., 2023) or textbooks (Li et al., 2023c) have shown remarkable abilities in diverse natural language processing (NLP) tasks (Brown et al., 2020; Zhang et al., 2022; Touvron et al., 2023; Jiang et al., 2023; Almazrouei et al., 2023). However, the models must undergo further tuning to be usable in general-domain applications (i.e., instruction-following), typically through *instruction tuning* and *model alignment*.

Instruction-tuning (Wei et al., 2022; Taori et al., 2023; Wang et al., 2023; Zhou et al., 2023a) trains models to follow task descriptions given in natural language, which enables models to generalize well to previously unseen tasks. However, despite the ability to follow instructions, models may generate harmful or unethical outputs (Carlini et al., 2021; Gehman et al., 2020; Pryzant et al., 2023). To further align these models with human values, additional training is required with pairwise preference data using techniques such as reinforcement learning with human feedback (Ziegler et al., 2020; Stiennon et al., 2022, RLHF) and direct preference optimization (Rafailov et al., 2023, DPO).

Preference alignment methods have demonstrated success in several downstream tasks beyond reducing harm. For example, improving factuality (Tian et al., 2023; Cheng et al., 2024; Chen and Li, 2024), code-based question answering (Gorbatovski and Kovalchuk, 2024), and machine translation (Ramos et al., 2023). The versatility of alignment algorithms over a wide range of downstream tasks highlights the necessity of understanding the alignment procedure and further improving the algorithms in terms of efficiency and performance. However, existing preference alignment methods are normally a multi-stage process, as shown in Figure 2, typically requiring a second reference model

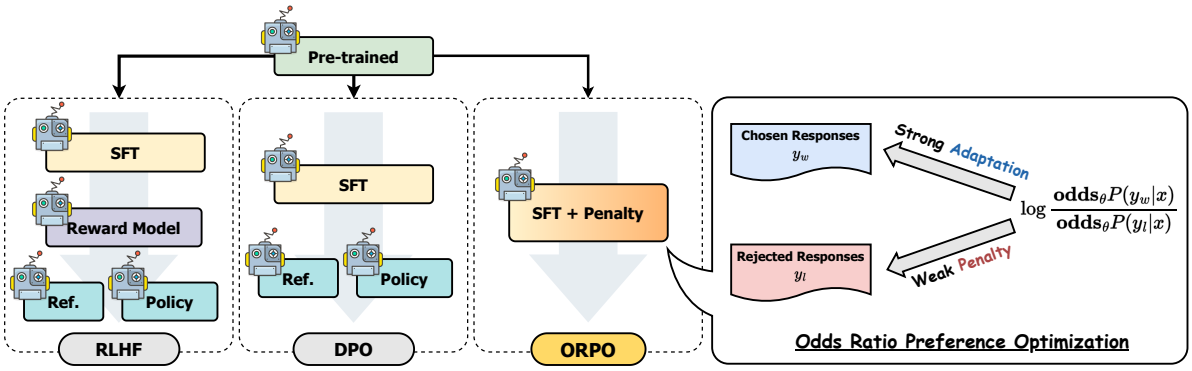

Figure 2: General diagram of preference alignment with ORPO. ORPO aligns the pre-trained language model in a non-segmented manner by giving a weak penalty to the rejected responses and a strong adaptation signal to the chosen responses with a simple log odds ratio term appended to the negative log-likelihood loss.

and a separate warm-up phase with supervised fine-tuning (SFT) (Ziegler et al., 2020; Rafailov et al., 2023; Wu et al., 2023).

In this paper, we study the impact of SFT in pairwise preference datasets and propose a simple and novel monolithic alignment method, odds ratio preference optimization (ORPO), which efficiently penalizes the model from learning undesired generation styles during SFT. Unlike previous works, our approach requires neither an SFT warm-up stage nor a reference model, enabling resource-efficient development of preference-based aligned models. We study the theoretical justification of using the odds ratio in Sections 4.3 and 4.4, and empirically show that our method benefits from the scale through fine-tuning 125M to 7B models in Section 6, including Llama-2 (7B) and Mistral (7B). As our best model, we present Mistral (ORPO), which is Mistral (7B) trained single-turn conversation dataset UltraFeedback (Tunstall et al., 2023) alone with ORPO surpasses Llama-2-Chat (7B) and (13B) (Touvron et al., 2023) and Zephyr (β) (Tunstall et al., 2023) by achieving 87.94% and 12.20% in AlpacaEval$_{1.0}$ and AlpacaEval$_{2.0}$ (Li et al., 2023b), as shown Figure 1.

2 Related Works

Alignment with Reinforcement Learning Reinforcement learning with human feedback (RLHF) commonly applies the Bradley-Terry model (Bradley and Terry, 1952) to estimate the probability of a pairwise competition between two independently evaluated instances. An additional reward model is trained to score instances. Reinforcement learning algorithms such as proximal policy optimization (PPO) (Schulman et al., 2017) are employed to train the model to maximize the score of the reward model for the chosen response, resulting in language models that are trained with human preferences (Ziegler et al., 2020; Stiennon et al., 2022). Notably, Ouyang et al. (2022) demonstrated the scalability and versatility of RLHF for instruction-following language models. Extensions such as language model feedback (RLAIF) could serve as a viable alternative to human feedback (Bai et al., 2022b; Lee et al., 2023; Pang et al., 2023). However, RLHF faces challenges of extensive hyperparameter searching due to the instability of PPO (Rafailov et al., 2023; Wu et al., 2023) and the sensitivity of the reward models (Gao et al., 2022; Wang et al., 2024). Therefore, there is a crucial need for stable preference alignment algorithms.

Alignment without Reward Model Several techniques for preference alignment mitigate the need for reinforcement learning (Rafailov et al., 2023; Song et al., 2023; Azar et al., 2023; Ethayarajh et al., 2023). Rafailov et al. (2023) introduce direct policy optimization (DPO), which merged the reward modeling stage into the preference learning stage. Azar et al. (2023) prevented potential overfitting problems in DPO through identity preference optimization (IPO). Ethayarajh et al. (2023) and Cai et al. (2023) proposed Kahneman-Tversky Optimisation (KTO) and Unified Language Model Alignment (ULMA) that does not require the pairwise preference dataset, unlike RLHF and DPO. Song et al. (2023) further suggests incorporation of the softmax value of the reference response set in the negative log-likelihood loss to merge the supervised fine-tuning and preference alignment.

Alignment with Supervised Fine-tuning In common, both preference alignment methods with

and without reinforcement learning mostly require supervised fine-tuning (SFT) (i.e., reference model). In contrast, there have been approaches to build human-aligned language models by conducting SFT only with filtered datasets (Zhou et al., 2023a; Li et al., 2023a; Haggerty and Chandra, 2024; Zhou et al., 2023b). Zhou et al. (2023a) demonstrated that SFT with a small amount of data with fine-grained filtering and curation could be sufficient for building helpful language model assistants. Furthermore, Li et al. (2023a) and Haggerty and Chandra (2024) proposed an iterative process of fine-tuning the supervised fine-tuned language models with their own generations after fine-grained selection of aligned generations, while Zhou et al. (2023b) suggested that the selected subset of preference dataset is sufficient for alignment. While these works highlight the impact and significance of SFT in the context of preference alignment, the actual role of SFT and the theoretical background for incorporating preference alignment in SFT is still understudied.

3 The Role of Supervised Fine-tuning

We study the role of supervised fine-tuning (SFT) as an initial stage of preference alignment methods (Ziegler et al., 2020; Rafailov et al., 2023) through analysis of the loss function in SFT and empirical demonstration of the preference comprehension ability of the trained SFT model. SFT plays a significant role in tailoring the pre-trained language models to the desired domain (Zhou et al., 2023a; Dong et al., 2024) by increasing the log probabilities of pertinent tokens. Nevertheless, this inadvertently increases the likelihood of generating tokens in undesirable styles, as illustrated in Figure 3. Therefore, it is necessary to explore the method capable of preserving the domain adaptation role of SFT while concurrently discerning and mitigating unwanted generation styles.

Absence of Penalty in Cross-Entropy Loss The goal of cross-entropy loss model fine-tuning is to penalize the model if the predicted logits for the reference answers are low, as shown in Equation 2.

$$\mathcal{L} = -\frac{1}{m}\sum_{k=1}^{m} \log P(\mathbf{x}^{(k)}, \mathbf{y}^{(k)}) \quad (1)$$

$$= -\frac{1}{m}\sum_{k=1}^{m}\sum_{i=1}^{|V|} y_i^{(k)} \cdot \log(p_i^{(k)}) \quad (2)$$

where y_i is a boolean value that indicates if ith token in the vocabulary set V is a label token, p_i refers to the probability of ith token, and m is the length of sequence. Using cross-entropy alone gives no penalty or compensation for the logits of non-answer tokens (Lin et al., 2017) as y_i will be set to 0. While cross-entropy is generally effective for domain adaptation (Mao et al., 2023), there are no mechanisms to penalize the rejected responses and compensate for the chosen responses. Therefore, we can infer that the increase in the relevant logits will happen invariant to the preference.

Generalization over Both Response Styles We conduct a pilot study to empirically demonstrate the miscalibration of chosen and rejected responses with supervised fine-tuning. We fine-tune OPT-350M (Zhang et al., 2022) on *the chosen responses only* with HH-RLHF (Bai et al., 2022b). Throughout the training, we monitor the log probability of rejected responses for each batch and plot this in Figure 3.

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.

Both the log probability of chosen and rejected responses exhibited a simultaneous increase. This can be interpreted from two different perspectives. First, the cross-entropy loss effectively guides the model toward the intended domain (e.g., multi-turn conversation). However, the absence of a penalty for unwanted generations results in rejected responses sometimes having even higher log probabilities than the chosen ones.

Penalizing Undesired Generations Appending penalty to the negative log-likelihood (NLL) loss was originally suggested in the unlikelihood train-

ing (Welleck et al., 2019; Li et al., 2020). By appending $(1 - p_i^{(k)})$ in Equation 2 if kth token is included in the unwanted token set, Welleck et al. (2019) relieved chronic problems (e.g., repetition) in autoregressive language models.

Based on the phenomenon in Figure 3 and the effectiveness of appending penalty to NLL loss, we design a monolithic preference alignment method that dynamically penalizes the disfavored response for each query without a static token set during supervised fine-tuning in Section 4.

4 Methodology

We introduce a novel preference alignment algorithm, Odds Ratio Preference Optimization (ORPO), which incorporates an odds ratio-based penalty to the conventional supervised fine-tuning loss for differentiating the generation styles between favored and disfavored responses.

4.1 Preliminaries

Given an input sequence x, the average log-likelihood of generating the output sequence y, of length m tokens, is computed as Equation 3. The odds of generating the output sequence y is defined in Equation 4:

$$\log P_\theta(y|x) = \frac{1}{m}\sum_{t=1}^{m} \log P_\theta(y_t|x, y_{<t}) \quad (3)$$

$$\textbf{odds}_\theta(y|x) = \frac{P_\theta(y|x)}{1 - P_\theta(y|x)} \quad (4)$$

Intuitively, $\textbf{odds}_\theta(y|x) = k$ implies that it is k times more likely for the model θ to generate the output sequence y than not generating it. Thus, the odds ratio of the chosen response y_w over the rejected response y_l, $\textbf{OR}_\theta(y_w, y_l)$, indicates how much more likely it is for the model θ to generate y_w than y_l given input x, defined in Equation 5.

$$\textbf{OR}_\theta(y_w, y_l) = \frac{\textbf{odds}_\theta(y_w|x)}{\textbf{odds}_\theta(y_l|x)} \quad (5)$$

4.2 Odds Ratio Preference Optimization

The objective function of ORPO in Equation 6 consists of two components: 1) supervised fine-tuning (SFT) loss ($\mathcal{L}_{SFT}$); 2) relative ratio loss ($\mathcal{L}_{Ratio}$).

$$\mathcal{L}_{ORPO} = \mathbb{E}_{(x,y_w,y_l)}\left[\mathcal{L}_{SFT} + \lambda \cdot \mathcal{L}_{Ratio}\right] \quad (6)$$

$\mathcal{L}_{SFT}$ follows the conventional causal language modeling negative log-likelihood (NLL) loss function to maximize the likelihood of generating the reference tokens as previously discussed in Section 3. $\mathcal{L}_{Ratio}$ in Equation 7 maximizes the odds ratio between the likelihood of generating the disfavored response y_w and the disfavored response y_l. We wrap the log odds ratio with the log sigmoid function so that $\mathcal{L}_{Ratio}$ could be minimized by increasing the log odds ratio between y_w and y_l.

$$\mathcal{L}_{Ratio} = -\log \sigma\left(\log \frac{\textbf{odds}_\theta(y_w|x)}{\textbf{odds}_\theta(y_l|x)}\right) \quad (7)$$

Together, $\mathcal{L}_{SFT}$ and $\mathcal{L}_{Ratio}$ weighted with the hyperparameter λ tailor the pre-trained language model to adapt to the specific subset of the desired domain, which excludes the type of generations in the rejected response sets.

4.3 Why Odds Ratio?

The rationale for selecting the odds ratio instead of the probability ratio as a penalty term lies in its stability. The probability ratio for generating the disfavored response y_w over the disfavored response y_l given the input sequence x can be defined as Equation 8.

$$\textbf{PR}_\theta(y_w, y_l) = \frac{P_\theta(y_w|x)}{P_\theta(y_l|x)} \quad (8)$$

While this formulation has been used in previous preference alignment methods that precede SFT (Rafailov et al., 2023; Azar et al., 2023), the odds ratio is a better choice in the setting where the preference alignment is incorporated in SFT as the odds ratio is more sensitive to the model's preference understanding. In other words, the probability ratio leads to more extreme discrimination of the disfavored responses than the odds ratio.

We visualize this through the sample distributions of the log probability ratio $\log \textbf{PR}(X_2|X_1)$ and log odds ratio $\log \textbf{OR}(X_2|X_1)$. We sample 50,000 samples each with Equation 9 and plot the log probability ratio and log odds ratio in Figure 4. We multiply β for the probability ratio as it is practiced in the probability ratio-based methods and report the cases where $\beta = 0.2$ and $\beta = 1.0$.

$$X_1, X_2 \sim \text{Unif}(0, 1) \quad (9)$$

$$Y \sim \beta\left(\log X_1 - \log X_2\right) \quad (10)$$

$$Y \sim \log \frac{X_1}{1 - X_1} - \log \frac{X_2}{1 - X_2} \quad (11)$$

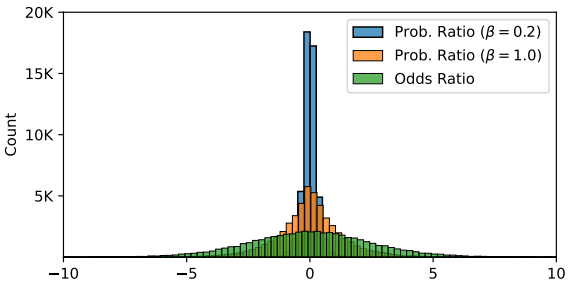

Figure 4: Sampled distribution of $\log \mathbf{PR}(X_2|X_1)$ and $\log \mathbf{OR}(X_2|X_1)$. $\log \mathbf{OR}(X_2|X_1)$ has a wider range given the same input probability pairs (X_1, X_2).

Recalling that the log sigmoid function is applied to the log probability ratio and log odds ratio, the scale of each ratio determines the amount of discrepancy between the likelihood of the favored style and the disfavored style when the loss is minimized. In that sense, the contrast should be relatively extreme to minimize the log sigmoid loss when $\mathbf{PR}(X_2|X_1)$ is inputted instead of $\mathbf{OR}(X_2|X_1)$ to the log sigmoid function, regarding the sharp distribution of $\log \mathbf{PR}(X_2|X_1)$ in Figure 4. This results in overly suppressing the logits for the tokens in the disfavored responses in the setting where SFT and preference alignment are incorporated, as the model is not adapted to the domain. We show this through the ablation study in Appendix B. Therefore, the odds ratio is a better choice when the preference alignment is done with SFT simultaneously due to the mild discrimination of disfavored responses and the prioritizing of the favored responses to be generated.

When comparing the log sigmoid loss with $\mathbf{PR}(X_2|X_1)$ to $\mathbf{OR}(X_2|X_1)$, In this context, it is essential to avoid an overly extreme contrast w. This caution is especially important given the sharp distribution of $\log \mathbf{PR}(X_2|X_1)$ depicted in Figure 4. The excessive discrepancy could lead to the unwarranted suppression of logits for tokens in disfavored responses within the incorporated setting, potentially resulting in issues of degeneration.

4.4 Gradients of ORPO

The gradient of $\mathcal{L}_{Ratio}$ further justifies the use of the odds ratio loss. It comprises two terms: one that penalizes the wrong predictions and one that contrasts between chosen and rejected responses, denoted in Equation 12[1] for $d = (x, y_l, y_w) \sim D$.

$$\nabla_\theta \mathcal{L}_{Ratio} = \delta(d) \cdot h(d) \tag{12}$$

[1]The full derivation for $\nabla_\theta \mathcal{L}_{Ratio}$ is in Appendix A.

$$\delta(d) = \left[1 + \frac{\mathbf{odds}_\theta P(y_w|x)}{\mathbf{odds}_\theta P(y_l|x)}\right]^{-1} \tag{13}$$

$$h(d) = \frac{\nabla_\theta \log P_\theta(y_w|x)}{1 - P_\theta(y_w|x)} - \frac{\nabla_\theta \log P_\theta(y_l|x)}{1 - P_\theta(y_l|x)} \tag{14}$$

When the odds of the favored responses are relatively higher than the disfavored responses, $\delta(d)$ in Equation 13 will converge to 0. This indicates that the $\delta(d)$ will play the role of a penalty term, which accelerates the parameter updates if the model is more likely to generate the rejected responses.

Meanwhile, $h(d)$ in Equation 14 implies a weighted contrast of the two gradients from the chosen and rejected responses. Specifically, $1 - P(y|x)$ in denominators amplifies the gradients of the corresponding side of the likelihood $P(y|x)$ is low. For the chosen responses, this accelerates the model's adaptation toward the distribution of chosen responses as the likelihood increases.

5 Empirical Study

We study the effectiveness of ORPO through several experimental settings. First, we assess the general instruction-following abilities of the models by comparing the preference alignment algorithms in Section 6.3. Second, we measure the win rate of OPT models trained with ORPO against other alignment methods training OPT 1.3B as a reward model in Section 6.2. We then perform further analyses to demonstrate the odds ratio increasing as intended while fine-tuning with ORPO in Section 6.1. And finally, we measure the lexical diversity of the models trained with ORPO and DPO in Section 6.5.

5.1 Training Configurations

Models We train OPT (Zhang et al., 2022) series with from 125M to 1.3B parameters using supervised fine-tuning (SFT), proximal policy optimization (PPO), direct policy optimization (DPO), and compare these to our ORPO. PPO and DPO models were fine-tuned with TRL library (von Werra et al., 2020) on top of SFT models trained for a single epoch on the chosen responses following Rafailov et al. (2023) and Tunstall et al. (2023), which we notate this by prepending "+" to each algorithm (e.g., +DPO). Additionally, we train Phi-2 (2.7B) (Javaheripi and Bubeck, 2023), a pre-trained language model with promising downstream performance (Beeching et al., 2023), as well as Llama-2 (7B)

(Touvron et al., 2023) and Mistral (7B) (Jiang et al., 2023). Further training details for each method are in Appendix C.

Datasets We test each training method and model on two datasets: 1) Anthropic's HH-RLHF (Bai et al., 2022a), 2) Binarized UltraFeedback (Tunstall et al., 2023). We filtered out instances where $y_w = y_l$ or where $y_w = \emptyset$ or where $y_l = \emptyset$.

Reward Models We train OPT-350M and OPT-1.3B on each dataset for a single epoch for reward modeling with the objective function in Equation 15 (Ziegler et al., 2020). OPT-350M reward model was used for PPO, and OPT-1.3B reward model was used to assess the generations of final models. We refer to these models as RM-350M and RM-1.3B in Section 6.

$$-\mathbb{E}_{(x,y_l,y_w)}\left[\log \sigma\left(r(x,y_w) - r(x,y_l)\right)\right] \quad (15)$$

5.2 Leaderboard Evaluation

In Section 6.3, we perform evaluation using the AlpacaEval$_{1.0}$ and AlpacaEval$_{2.0}$ (Li et al., 2023b) benchmarks, comparing ORPO to other instruction-tuned models reported in the official leaderboard[2], including Llama-2 Chat (7B) and (13B) (Touvron et al., 2023), and Zephyr α and β (Almazrouei et al., 2023). Similarly, in Section 6.4, we evaluate the models with MT-Bench (Zheng et al., 2023) and report the results along with the scores of the same models reported in the official leaderboard[3]. Using GPT-4 (Achiam et al., 2023) as an evaluator in AlpacaEval$_{1.0}$, we assess if the trained model can be preferred over the responses generated from `text-davinci-003`. For AlpacaEval$_{2.0}$, we used GPT-4-turbo[4] as an evaluator following the default setting. We assess if the generated responses are favored over the responses generated from GPT-4. Finally, using GPT-4 as an evaluator in MT-Bench, we check if the models can follow the instructions with hard answers in a multi-turn conversation.

6 Results and Analysis

By starting with monitoring the empirical validity of the odds ratio penalty in Section 6.1, we evaluate if the models have precisely learned the preference through reward model win rate with RM-1.3B exclusively fine-tuned on each dataset in Section 6.2. Additionally, we test the general instruction-following skills on single-turn and multi-turn instruction-following benchmarks in Sections 6.3 and 6.4. Then, we expand our analysis to the lexical diversity of the models in Section 6.5.

6.1 Log Odds Ratio during Training

We demonstrate that models trained with ORPO learned the preference throughout the training process. We monitored the log probabilities of the chosen and rejected responses and the log odds ratio with $\lambda = 1.0$. With the same dataset and model as Figure 3, Figure 5 shows that the log probability of rejected responses is diminishing while that of chosen responses is on par with Figure 3 as the log odds ratio increases. This indicates that ORPO is successfully preserving the domain adaptation role of supervised fine-tuning (SFT) while the penalty term L_{Ratio} induces the model to lower the likelihood of unwanted generations. We further discuss the effect of λ in Equation 6 in Appendix D.

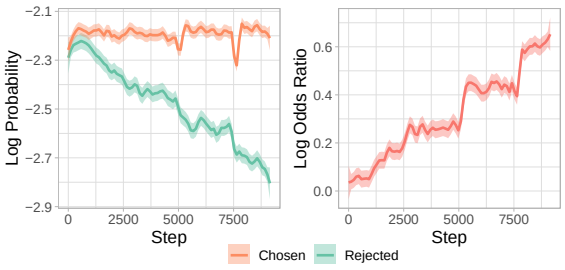

Figure 5: Average log-likelihood for chosen and rejected responses and log odds ratio per batch. The odds of disfavored style generations consistently increase during training with ORPO.

6.2 Reward Model Win Rate

We assess the win rate of ORPO over other preference alignment methods, including supervised fine-tuning (SFT), PPO, and DPO, using RM-1.3B fine-tuned for reward modeling to understand the effectiveness and scalability of ORPO in Tables 1 and 2. Additionally, we visually verify that ORPO can effectively enhance the expected reward in comparison to SFT in Figure 6.

HH-RLHF In Table 1, ORPO outperforms SFT and RLHF across all model scales. The highest win rate against SFT and RLHF across the size of the model was 78.0% and 79.4%, respectively. Meanwhile, the win rate over DPO was correlated

[2] https://tatsu-lab.github.io/alpaca_eval/

[3] https://huggingface.co/spaces/lmsys/chatbot-arena-leaderboard

[4] https://platform.openai.com/docs/models/gpt-4-and-gpt-4-turbo

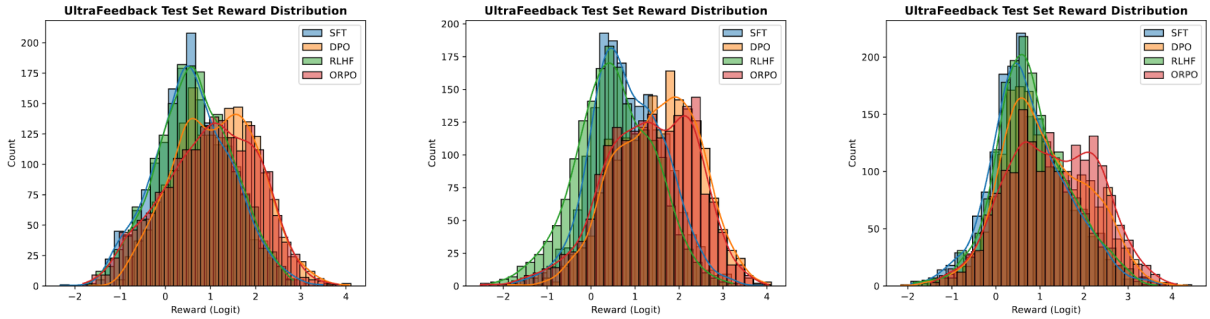

Figure 6: Reward distribution comparison between OPT-125M (left), OPT-350M (middle), and OPT-1.3B (right) trained with SFT (blue), RLHF (green), DPO (orange), and ORPO (red) on the test set of UltraFeedback using the RM-1.3B. While the rewards of the trained models are roughly normal and preference optimization algorithms (RLHF, DPO, and ORPO) tend to move the reward distribution in the positive direction, ORPO is on par or better than RLHF and DPO in increasing the expected reward. The same plot for HH-RLHF is in Appendix E.

to the model's size, with the largest model having the highest win rate: 70.9%

ORPO vs	SFT	+DPO	+PPO
OPT-125M	84.0 (0.62)	41.7 (0.77)	66.1 (0.26)
OPT-350M	82.7 (0.56)	49.4 (0.54)	79.4 (0.29)
OPT-1.3B	78.0 (0.16)	70.9 (0.52)	65.9 (0.33)

Table 1: Average win rate (%) and its standard deviation of ORPO and standard deviation over other methods on **HH-RLHF** dataset for three rounds. Sampling decoding with a temperature of 1.0 was used on the test set.

UltraFeedback The win rate in UltraFeedback followed similar trends to what was reported in HH-RLHF, as shown in Table 2. ORPO was preferred over SFT and PPO for maximum 80.5% and 85.8%, respectively. While consistently preferring ORPO over SFT and RLHF, the win rate over DPO gradually increases as the size of the model increases. The scale-wise trend in exceeding DPO will be further shown through 2.7B models in Section 6.3.

ORPO vs	SFT	+DPO	+PPO
OPT-125M	73.2 (0.12)	48.8 (0.29)	71.4 (0.28)
OPT-350M	80.5 (0.54)	50.5 (0.17)	85.8 (0.62)
OPT-1.3B	69.4 (0.57)	57.8 (0.73)	65.7 (1.07)

Table 2: Average win rate (%) and its standard deviation of ORPO and standard deviation over other methods on **UltraFeedback** dataset for three rounds. Same decoding strategy with Table 1.

Overall Reward Distribution In addition to the win rate, we compare the reward distribution of the responses generated with respect to the test set of the UltraFeedback dataset in Figure 6 and HH-RLHF dataset in Appendix E. Regarding the SFT reward distribution as a default, RLHF, DPO, and ORPO shift it in both datasets. However, the magnitude of reward shifts for each algorithm differs.

In Figure 6, RLHF has some abnormal properties of the distribution with a low expected reward. We attribute this to empirical evidence of the instability and reward mismatch problem of RLHF (Rafailov et al., 2023; Gao et al., 2022; Shen et al., 2023) as the RLHF models were trained with RM-350M and assessed with RM-1.3B. Meanwhile, it is notable that the ORPO distribution (red) is mostly located on the very right side of each subplot, indicating higher expected rewards. Recalling the intent of preference alignment methods, the distributions in Figure 6 indicate that ORPO tends to fulfill the aim of preference alignment for all model sizes.

6.3 Single-turn Instruction Following

	Size	$\text{AlpacaEval}_{1.0}$	$\text{AlpacaEval}_{2.0}$
Phi-2 + SFT	2.7B	48.37% (1.77)	0.11% (0.06)
Phi-2 + SFT + DPO	2.7B	50.63% (1.77)	0.78% (0.22)
Phi-2 + ORPO *(Ours)*	2.7B	**66.17% (1.67)**	**4.24% (0.61)**
Llama-2 Chat *	7B	71.34% (1.59)	4.96% (0.67)
Llama-2 Chat *	13B	81.09% (1.38)	7.70% (0.83)
Llama-2 + ORPO *(Ours)*	7B	**81.26% (1.37)**	**9.44% (0.85)**
Zephyr (α) *	7B	85.76% (1.23)	8.35% (0.87)
Zephyr (β) *	7B	**90.60% (1.03)**	10.99% (0.96)
Mistral + ORPO *(Ours)*	7B	87.94% (1.15)	**12.20% (0.98)**
ORPO-Mistral *(Ours, Best)*	7B	**91.41% (0.99)**	**12.20% (0.98)**

Table 3: Table of instruction-following abilities of each checkpoint measured through AlpacaEval. While clearly showing the improvements in instruction-following abilities after training with ORPO, it is notable that ORPO models exceed open-source RLHF or DPO models of Llama-2 and Mistral (* indicates the results excerpted from the official leaderboard.)

Phi-2 (ORPO) In general, ORPO improved pre-trained Phi-2 to be a comparable instruction-following language model by *only using UltraFeedback* as the instruction-tuning dataset, as shown in Table 3. Within the same model family, ORPO is preferred over other training methods for OPT and Phi-2. It is notable that Phi-2 (ORPO) exceeds Alpaca and Vicuna with the win rate of 66.17%, which are 7B instruction-following models with the win rates of 26.46% and 64.41%.

Meanwhile, in AlpacaEval$_{2.0}$, Phi-2 (ORPO) was preferred for 4.24% with 2.7B parameters. It was on par with the Llama-2 Chat (7B) model, which is one of the state-of-the-art chat models trained with RLHF in the 7B scale.

Llama-2 (ORPO) Notably, instruction tuning with only UltraFeedback and ORPO on Llama-2-7B resulted in higher AlpacaEval scores than the -chat and version for both 7B and 13B scale, eventually showing 81.26% and 9.44% in two AlpacaEval.

In contrast, in our controlled experimental setting of conducting one epoch of SFT and three epochs of DPO following Tunstall et al. (2023) and Rafailov et al. (2023), Llama-2 + SFT and Llama-2 + SFT + DPO yielded models with outputs that could not be evaluated. This implies the efficiency of our method, in which the model can rapidly learn both the desired domain and the preference with a limited amount of data. This aligns with the $h(d)$ examination in the gradient of our method studied in Section 4.4.

Mistral (ORPO) Furthermore, fine-tuning Mistral (7B) with single-turn conversation dataset, UltraFeedback, and ORPO with the setting in Appendix C outperforms Zephyr series, which are the Mistral (7B) models fine-tuned with SFT on 20K UltraChat (Ding et al., 2023) and DPO on the full UltraFeedback. As shown in Table 3, Mistral (ORPO) achieves 87.94% and 12.20%, which exceeds Zephyr α by 1.21% Zephyr β by 1.21% in AlpacaEval$_{2.0}$. Notably, Zephyr was fine-tuned to UltraChat in the first place before DPO, and Misral (ORPO) was trained directly with Ultrafeedback only.

ORPO-Mistral (7B) Finally, we report the results for our best model, ORPO-Mistral (7B), which was fine-tuned with the same configuration as Mistral (ORPO), but with $\lambda = 0.1$. In the last row of Table 3, ORPO-Mistral (7B) exceeds the rest of the models by achieving 91.41% and 12.20% in AlpacaEval.

6.4 Multi-turn Instruction Following

With our best model, Mistral (ORPO), we also assess the multi-turn instruction-following skills with hard answers through MT-Bench.

As shown in Table 4, Mistral (ORPO) achieved 7.24 in MT-Bench. Furthermore, **ORPO-Mistral** (7B) got 7.32 in MT-Bench, which is on par with Zephyr (β). Mistral (ORPO) shows a comparable score to Zephyr β. While Zephyr β was fine-tuned on 200k instances of multi-turn conversation dataset before applying DPO with UltraFeedback, Mistral (ORPO) was trained on 61k instances of single-turn conversation dataset (UltraFeedback) only. We report the detailed scores for each category in Appendix F.

	Single	Multi	MT-Bench
Zephyr α *	✓	✓	6.88
Zephyr β *	✓	✓	**7.34**
Mistral + ORPO (*Ours*)	✓	×	7.24
ORPO-Mistral (*Ours, Best*)	✓	×	<u>7.32</u>

Table 4: MT-Bench scores of Zephyr and Mistral (ORPO). Although Mistral (ORPO) was exclusively trained on the single-turn dataset (UltraFeedback), it surpasses Zephyr α and is comparable to Zephyr β (* indicates the results excerpted from the official leaderboard.)

6.5 Lexical Diversity

The lexical diversity of the preference-aligned language models was studied in previous works (Kirk et al., 2024). We expand the concept of per-input and across-input diversity introduced in Kirk et al. (2024) by using the Gemini-Pro (Team et al., 2023) as an embedding model, which is suitable for assessing the diversity of instruction-following language models by encoding a maximum of 2048 tokens. The diversity metric with the given set of sampled responses is defined as Equation 17.

$$\mathcal{O}_\theta^i := \{y_j \sim \theta(y|x_i) | j = 1, 2, ..., K\} \quad (16)$$

$$D(\mathcal{O}_\theta^i) = \frac{1}{2} \cdot \frac{\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \cos(h_i, h_j)}{N \cdot (N-1)} \quad (17)$$

where $\cos(h_i, h_j)$ refers to the cosine similarity between the embedding h_i and h_j. 5 different responses are sampled with a temperature of 1.0 to 160 queries in AlpacaEval (i.e., $K = 5, N = 160$) using Phi-2 and Llama-2 trained with ORPO and DPO. We report the results in Table 5.

Per Input Diversity (PID) We average the input-wise average cosine similarity between the generated samples with Equation 18 to assess the per-input diversity. In Table 5, ORPO checkpoints have the highest average cosine similarity in the first column for both models, which implies the lowest diversity per input. This indicates that ORPO generally assigns high probabilities to the desired tokens, while DPO has a relatively smoother logit distribution.

$$\text{PID}_D(\theta) = \frac{1}{N}\sum_{i=1}^{N} D(\mathcal{O}_\theta^i) \tag{18}$$

Across Input Diversity (AID) Using 8 samples generated per input, we sample the first item for each input and examine their inter cosine similarity with Equation 19 for across-input diversity. Unlike per-input diversity, it is noteworthy that Phi-2 (ORPO) has lower average cosine similarity in the second row of Table 5. We can infer that ORPO triggers the model to generate more instruction-specific responses in comparison to DPO.

$$\text{AID}_D(\theta) = D\left(\bigcup_{i=1}^{N} \mathcal{O}^{i}{}_{,\theta,j=1}\right) \tag{19}$$

	Per Input↓	Across Input↓
Phi-2 + SFT + DPO	**0.8012**	0.6019
Phi-2 + ORPO	0.8909	**0.5173**
Llama-2 + SFT + DPO	**0.8889**	0.5658
Llama-2 + ORPO	0.9008	**0.5091**

Table 5: Lexical diversity of Phi-2 and Llama-2 fine-tuned with DPO and ORPO. Lower cosine similarity is equivalent to higher diversity. The highest value in each column is bolded.

7 Conclusion

In this paper, we introduced a reference-free monolithic preference alignment method, odds ratio preference optimization (ORPO), by revisiting and understanding the value of the supervised fine-tuning (SFT) phase in the context of preference alignment. ORPO was consistently preferred by the fine-tuned reward model against SFT and RLHF across the scale, and the win rate against DPO increased as the size of the model increased. Furthermore, we validate the scalability of ORPO with 2.7B and 7B pre-trained language models by exceeding the larger state-of-the-art instruction-following language models in AlpacaEval. Specifically, Llama-2 (ORPO) and Mistral (ORPO) achieved 81.26% and 87.94% in $\text{AlpacaEval}_{1.0}$, 9.44% and 12.20% in $\text{AlpacaEval}_{2.0}$, thereby underscoring the efficiency and effectiveness of ORPO. We release code to aid reproducibility (see supplementary material).

Limitations

While conducting a comprehensive analysis of the diverse preference alignment methods, including DPO and RLHF, we did not incorporate a wider range of preference alignment algorithms. We leave the wider range of comparison against other methods as future work, along with scaling our method to over 7B models. In addition, we will expand the fine-tuning datasets into diverse domains and qualities, thereby verifying the generalizability of our method in various NLP downstream tasks. Finally, we would like to study the internal impact of our method on the pre-trained language model, expanding the understanding of preference alignment procedure to not only the supervised fine-tuning stage but also consecutive preference alignment algorithms.

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A Derivation of $\nabla_\theta \mathcal{L}_{Ratio}$ with Odds Ratio

Suppose that $g(x, y_l, y_w) = \frac{\textbf{odds}_\theta P(y_w|x)}{\textbf{odds}_\theta P(y_l|x)}$

$$\nabla_\theta \mathcal{L}_{Ratio} = \nabla_\theta \log \sigma \left(\log \frac{\textbf{odds}_\theta P(y_w|x)}{\textbf{odds}_\theta P(y_l|x)} \right) \tag{20}$$

$$= \frac{\sigma' \left(\log g(x, y_l, y_w) \right)}{\sigma \left(\log g(x, y_l, y_w) \right)} \tag{21}$$

$$= \sigma \left(- \log g(x, y_l, y_w) \right) \cdot \nabla_\theta \log g(x, y_l, y_w) \tag{22}$$

$$= \frac{\sigma \left(- \log g(x, y_l, y_w) \right)}{g(x, y_l, y_w)} \cdot \nabla_\theta g(x, y_l, y_w) \tag{23}$$

$$= \sigma \left(- \log g(x, y_l, y_w) \right) \cdot \nabla_\theta \log g(x, y_l, y_w) \tag{24}$$

$$= \left(1 + \frac{\textbf{odds}_\theta P(y_w|x)}{\textbf{odds}_\theta P(y_l|x)} \right)^{-1} \cdot \nabla_\theta \log \frac{\textbf{odds}_\theta P(y_w|x)}{\textbf{odds}_\theta P(y_l|x)} \tag{25}$$

In Equation 25, the remaining derivative can be further simplified by replacing $1 - P_\theta(y|x)$ terms where $P(y|x) = \sqrt[N]{\prod_t^N P_\theta(y_t|x, y_{<t}}$ in $\textbf{odds}_\theta(y|x)$ as follows.

$$\nabla_\theta \log \left(1 - P_\theta(y|x) \right) = \frac{\nabla_\theta \left(1 - P_\theta(y|x) \right)}{1 - P_\theta(y|x)} \tag{26}$$

$$= \frac{-\nabla_\theta P_\theta(y|x)}{1 - P_\theta(y|x)} \tag{27}$$

$$= -\frac{P_\theta(y|x)}{1 - P_\theta(y|x)} \cdot \nabla_\theta \log P_\theta(y|x) \tag{28}$$

$$= \textbf{odds}_\theta(y|x) \cdot \nabla_\theta \log P_\theta(y|x) \tag{29}$$

$$\nabla_\theta \log \frac{\textbf{odds}_\theta P(y_w|x)}{\textbf{odds}_\theta P(y_l|x)} = \nabla_\theta \log \frac{P_\theta(y_w|x)}{P_\theta(y_l|x)} - \Big(\nabla_\theta \log(1 - P_\theta(y_w|x)) - \nabla_\theta \log(1 - P_\theta(y_l|x)) \Big) \tag{30}$$

$$= \left(1 + \textbf{odds}_\theta P(y_w|x) \right) \nabla_\theta \log P_\theta(y_w|x) - \left(1 + \textbf{odds}_\theta P(y_l|x) \right) \nabla_\theta \log P_\theta(y_l|x) \tag{31}$$

Therefore, the final form of $\nabla_\theta \mathcal{L}_{Ratio}$ would be

$$\nabla_\theta \mathcal{L}_{Ratio} = \frac{1 + \textbf{odds}_\theta P(y_w|x)}{1 + \frac{\textbf{odds}_\theta P(y_w|x)}{\textbf{odds}_\theta P(y_l|x)}} \cdot \nabla_\theta \log P_\theta(y_w|x) - \frac{1 + \textbf{odds}_\theta P(y_l|x)}{1 + \frac{\textbf{odds}_\theta P(y_w|x)}{\textbf{odds}_\theta P(y_l|x)}} \cdot \nabla_\theta \log P_\theta(y_l|x) \tag{32}$$

$$= \left(1 + \frac{\textbf{odds}_\theta P(y_w|x)}{\textbf{odds}_\theta P(y_l|x)} \right)^{-1} \cdot \left(\frac{\nabla_\theta \log P_\theta(y_w|x)}{1 - P(y_w|x)} - \frac{\nabla_\theta \log P_\theta(y_l|x)}{1 - P(y_l|x)} \right) \tag{33}$$

B Ablation on Probability Ratio and Odds Ratio

In this section, we continue the discussion in Section 4.3 through empirical results comparing the log probabilities of chosen and rejected responses in UltraFeedback when trained with probability ratio and odds ratio. Recalling the sensitivity of each ratio discussed in Section 4.3, it is expected for the probability ratio to lower the log probabilities of the rejected responses with a larger scale than the odds ratio. This is well-shown in Figure 7, which is the log probabilities of each batch while fine-tuning with probability ratio (left) rapidly reaches under -4, while the same phenomenon happens after the over-fitting occurs in the case of odds ratio (right).

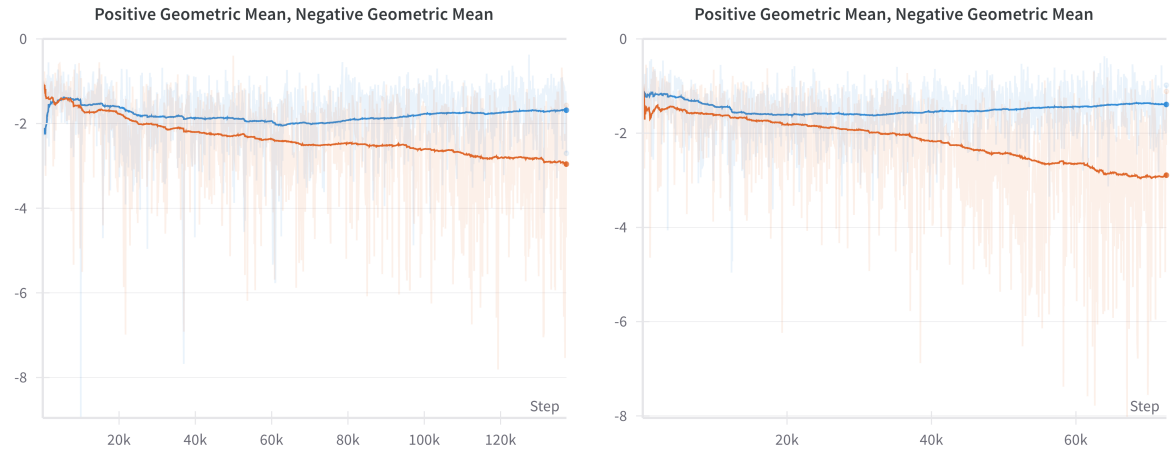

Figure 7: The log probability trace when the model is trained with the probability ratio (left) and the odds ratio (right) given the same hyperparameters. The probability ratio leads the rejected responses to have relatively lower log probabilities.

C Experimental Details

Flash-Attention 2 (Dao, 2023) is applied for all the pre-trained models for computational efficiency. In particular, the OPT series and Phi-2 (2.7B) were trained with DeepSpeed ZeRO 2 (Rasley et al., 2020), Llama-2 (7B) and Mistral (7B) were trained with Fully Sharded Data Parallel(FSDP) (Zhao et al., 2023). 7B and 2.7B models were trained with four and two NVIDIA A100, and the rest were trained on four NVIDIA A6000. For optimizer, AdamW optimizer (Loshchilov and Hutter, 2019) and paged AdamW (Dettmers et al., 2023) were used, and the linear warmup with cosine decay was applied for the learning rate. For input length, every instance was truncated and padded to 1,024 tokens and 2,048 tokens for HH-RLHF and UltraFeedback, respectively. To guarantee that the models can sufficiently learn to generate the proper response to the conversation history or the complex instruction, we filtered instances with prompts with more than 1,024 tokens.

Supervised Fine-tuning (SFT) For SFT, the maximum learning rate was set to 1e-5. Following Ziegler et al. (2020) and Rafailov et al. (2023), the training epoch is set to 1.

Reinforcement Learning with Human Feedback (RLHF) For RLHF, the hyperparameters were set as Table 6 for UltraFeedback. For the HH-RLHF dataset, the `output_min_length` and `output_max_length` were set to 64 and 256.

Direct Preference Optimization (DPO) For DPO, β was set to 0.1 for every case. The learning rate was set to 5e-6, and the model was trained for 3 epochs to select the best model by evaluation loss in each epoch. But in most cases, the first or the second checkpoint was selected as the best model as the evaluation loss increased from the third epoch.

Hyperparameter	Setting
ppo_epoch	4
init_kl_coef	0.1
horizon	2,000
batch_size	64
mini_batch_size	8
gradient_accumulation_steps	1
output_min_length	128
output_max_length	512
optimizer	AdamW
learning_rate	1e-05
gamma	0.99

Table 6: Hyperparameter settings for RLHF.

Odds Ratio Preference Optimization (`ORPO`) As `ORPO` does not require any special hyperparameter, only the learning rate and epoch were the only hyperparameter to set. For `ORPO`, the maximum learning rate was set to 8e-6 and trained for 10 epochs. The best model is selected by the lowest evaluation loss.

D Ablation on the Weighting Value (λ)

For the weighting value λ in Equation 6, we conduct an ablation study with $\{0.1, 0.5, 1.0\}$. Mistral (7B) and UltraFeedback were used for the base model and dataset. In Section D.1, we compare the log probability trends by the value of λ, and we assess the downstream effect of λ in Section D.2.

D.1 By Log Probability Trend

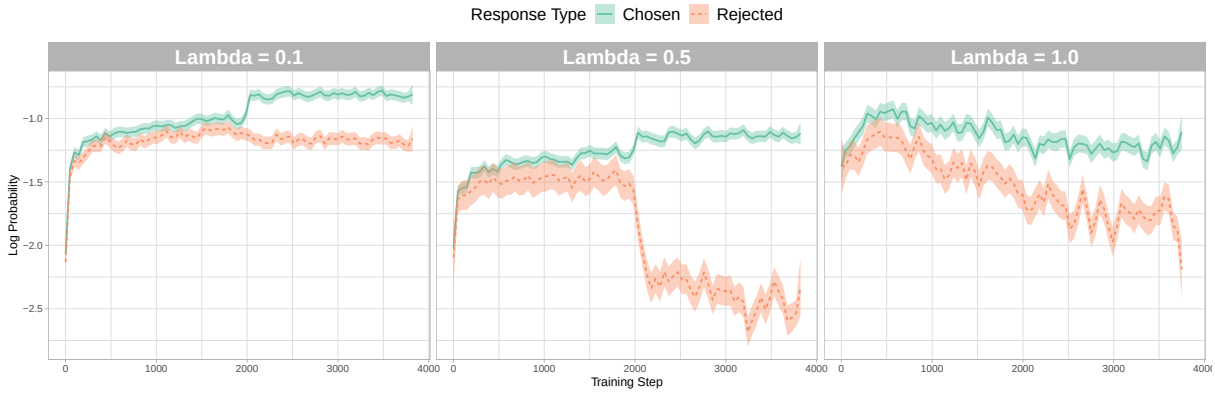

Figure 8: The log probability trend by λ. With larger λ (e.g., $\lambda = 1.0$), $\mathcal{L}_{Ratio}$ gets more influential in fine-tuning the models with ORPO.

In Figure 8, we find that larger λ leads to stronger discrimination of the rejected responses in general. With $\lambda = 0.1$, the average log probability of the chosen and the rejected responses stay close as the fine-tuning proceeds. Also, unlike other settings, the log probabilities for the rejected responses does not decrease, but rather the log probabilities of the chosen responses increase to minimize $\mathcal{L}_{Ratio}$ term.

Moreover, in $\lambda = 0.5$, there exists a similar trend of further increasing the log probabilities of the chosen responses, but the log probabilities of the rejected responses are diminishing simultaneously. Lastly, in $\lambda = 1.0$, the chosen responses tend to diminish along with the rejected responses while enlarging the margin between them. However, this does not mean smaller λ is always the better, it will depend on the specific need and model.

D.2 By Downstream Accuracy

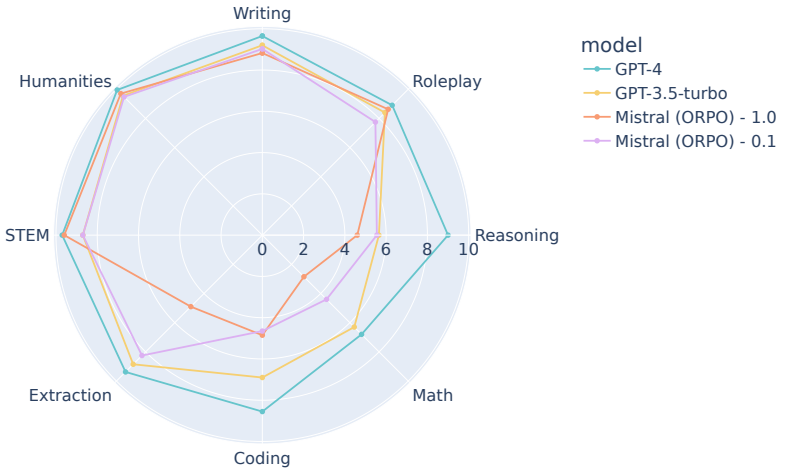

Figure 9: MT-Bench result comparison by differing $\lambda = 0.1$ and $\lambda = 1.0$.

The downstream impact of λ stands out in the MT-Bench result. In comparison to $\lambda = 0.1$, Mistral (ORPO) with $\lambda = 1.0$ performs worse in extraction, math, and reasoning, which are the categories that generally require deterministic answers. On the other hand, it performs better in STEM, humanities, and roleplay, which ask the generations without hard answers. Along with the amount of discrepancy between the trend in the logits of chosen and rejected responses, we can infer that making a larger margin between the chosen and the rejected responses through higher λ in ORPO leads to overly adapting to the chosen responses set in the training dataset. This proclivity results in open-ended generations generally being preferred by the annotator while showing weaker performance in the hard-answered questions.

E Test Set Reward Distribution on HH-RLHF

Along with Figure 10, which depicts the reward distribution of OPT2-125M, OPT2-350M, and OPT2-1.3B on the UltraFeedback dataset, we report the reward distribution of each pre-trained checkpoint trained on the HH-RLHF dataset. As discussed in Section 6.2, ORPO consistently pushes the reward distribution of SFT to the right side.

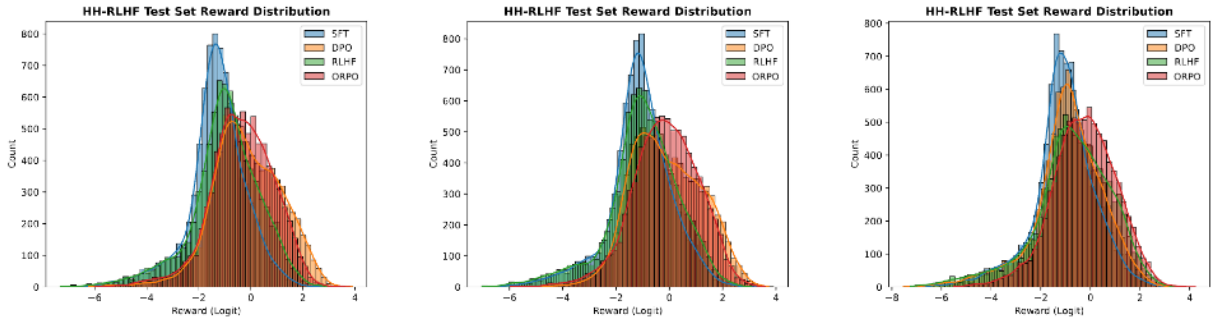

Figure 10: Reward distribution comparison between OPT-125M (left), OPT-350M (middle), and OPT-1.3B (right) trained with SFT (blue), RLHF (green), DPO (orange), and ORPO (red) on the test set of HH-RLHF using the 1.3B reward model. General tendency follows that of Figure 6.

F MT-Bench Result of ORPO-Mistral (7B)

For the MT-Bench result in Section 6.4, we report the category-wise scores of **ORPO-Mistral** (7B) in Figure 11. While surpassing Llama-2 Chat (13B) and Llama-2 Chat (70B) in most cases, **ORPO-Mistral** (7B) is comparable to GPT-3.5-turbo in the categories that require descriptive generations. However, it lacks coding and math, which we speculate is due to the lack of training data, as we used 61k instances in UltraFeedback.

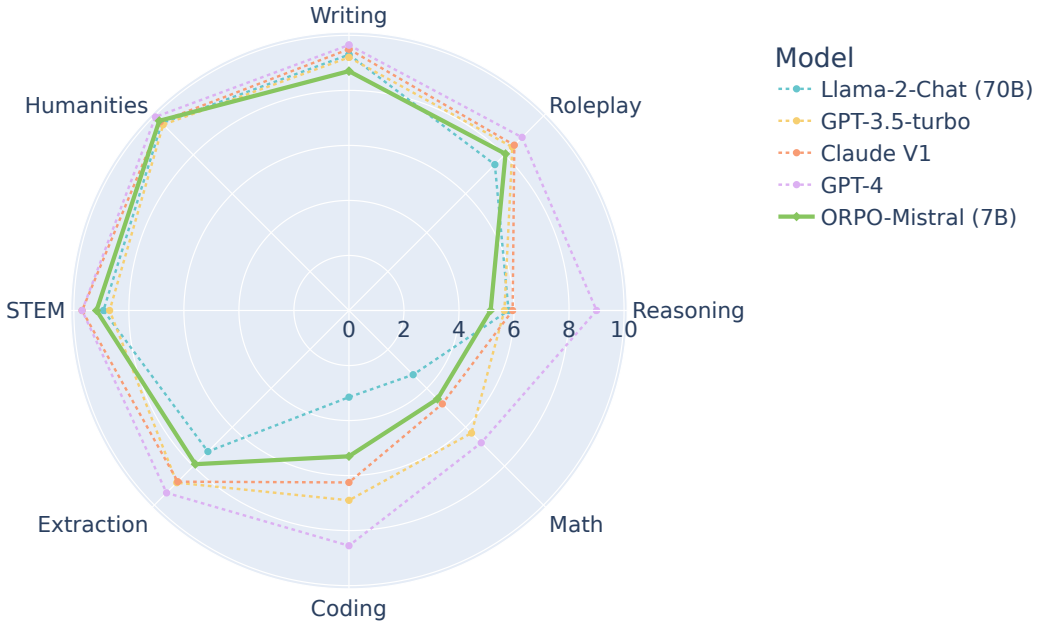

Figure 11: MT-Bench result of **ORPO-Mistral** (7B) by the category.

G Special Instructions for Verbosity Assessment

For the succinctness and verboseness instructions, we generated 5 different instructions, each with ChatGPT [5]. From the instructions in Table 7, we randomly sampled one prompt each for every batch to prevent potential word bias.

#	Succinctness	Verboseness
1	Please generate a short and concise response.	Please generate an elaborative and chatty response.
2	Provide a brief and concise answer.	Provide a detailed answer.
3	Keep your reply short and to the point.	Keep your reply elaborative and intricate.
4	Keep your answer brief for clarity.	Keep your answer detailed.
5	Generate a brief and to-the-point answer.	Generate a chatty and step-wise answer.

Table 7: Instructions prepended to the queries from AlpacaEval. Each instruction set asks the model to generate either shorter or longer responses given the query, respectively.

[5] https://chat.openai.com/