PRIME: Large Language Model Personalization with Cognitive Dual-Memory and Personalized Thought Process

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Abstract

Large language model (LLM) personalization aims to align model outputs with individuals' unique preferences and opinions. While recent efforts have implemented various personalization methods, a unified theoretical framework that can systematically understand the drivers of effective personalization is still lacking. In this work, we integrate the well-established cognitive dual-memory model into LLM personalization, by mirroring *episodic memory* to historical user engagements and *semantic memory* to long-term, evolving user beliefs. Specifically, we systematically investigate memory instantiations and introduce a unified framework, PRIME, using episodic and semantic memory mechanisms. We further augment PRIME with a novel *personalized thinking* capability inspired by the slow thinking strategy. Moreover, recognizing the absence of suitable benchmarks, we introduce a dataset using Change My View (CMV) from Reddit[1], specifically designed to evaluate long-context personalization. Extensive experiments validate PRIME's effectiveness across both long- and short-context scenarios. Further analysis confirms that PRIME effectively captures dynamic personalization beyond mere popularity biases.

1 Introduction

Personalization (Schafer et al., 2001; Berkovsky et al., 2005) aims to tailor model outputs to individual users' needs, preferences and beliefs, moving beyond generic responses (Zhang et al., 2018; Huang et al., 2022; Tseng et al., 2024). While large language models (LLMs) excel at diverse NLP tasks, users' demand for personalized LLMs that reflect their unique histories and preferences has grown (Salemi et al., 2024; Liu et al., 2025). For instance, we have seen personalization adopted into commercial applications, such as OpenAI's customizable GPTs,[2] which are essential for building trust and reducing interaction friction (Castells et al., 2015). In this work, we formally define a *personalized LLM* as one adapted to align with the individual preferences, characteristics, and beliefs, by utilizing user-specific attributes, past engagements, and context the user was exposed to (Zhang et al., 2024f). Various techniques have been explored for LLM personalization, including prompt engineering (Petrov and Macdonald, 2023; Kang et al., 2023), retrieval-augmented generation (Salemi et al., 2024; Mysore et al., 2024), efficient fine-tuning (Tan et al., 2024; Zhang et al., 2024b), and reinforcement learning from human feedback (Li et al., 2024). Yet these piecemeal approaches lack a unified framework for systematically identifying what makes personalization effective. We posit that drawing inspiration from established cognitive models of human memory (Atkinson and Shiffrin, 1968b) offers a principled way to understand and advance LLM personalization. Specifically, we propose a **dual-memory model** (Tulving et al., 1972; Tulving, 1985; Schacter et al., 2009) with *episodic memory* (specific personal experiences) and *semantic memory* (abstract knowledge and beliefs) that parallels existing LLM personalization techniques.

Based on the cognitive model, we begin by examining memory instantiations to understand their strengths and weaknesses. Next, we present a unified framework, dubbed **PRIME** (**P**ersonalized **R**easoning with **I**ntegrated **ME**mory), to integrate both memory mechanisms in a principled manner (Figure 1). Such integration facilitates a holistic understanding of user queries and histories, enabling the model to generate responses that are both contextually relevant and aligned with the user's long-term beliefs. Furthermore, within PRIME, we introduce the generation of chain-of-thoughts

[1]Our project page can be found at http://github.com/launchnlp/LM_Personalization.

[2]https://openai.com/index/introducing-gpts/

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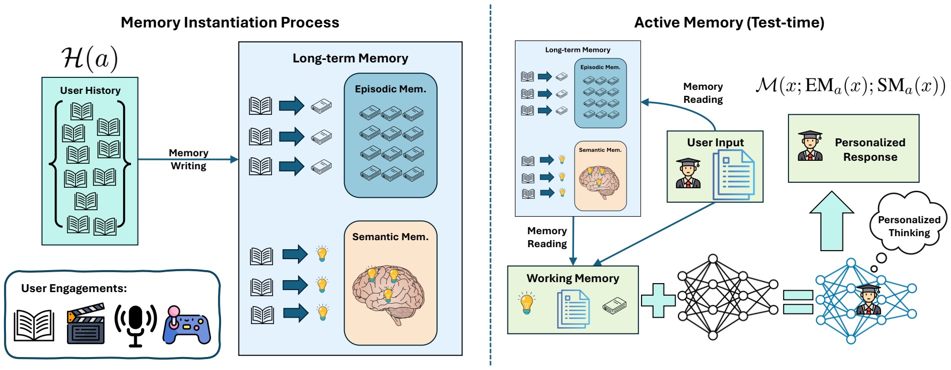

Figure 1: Overview of our unified framework, PRIME, inspired by dual-memory model (Tulving et al., 1972). PRIME is further augmented with personalized thinking, yielding more accurate, user-aligned responses.

(CoTs) using **personalized thinking**, which draws on the slow thinking strategy (Muennighoff et al., 2025; Chen et al., 2025). Yet, we find that generic CoT reasoning can hinder performance on tasks that require personalized perspectives (Guo et al., 2025). In contrast, by adapting the self-distillation strategy (Zhang et al., 2019; Pham et al., 2022; Wang et al., 2023), we unlock LLM's *personalized thinking capability*. This ability guides the model to perform customized reasoning, yielding more accurate, user-aligned responses and richer reasoning traces that reflect the user's history and traits.

Meanwhile, benchmarking LLM personalization capabilities is hindered by a lack of suitable datasets (Tseng et al., 2024). Most datasets focus on short-context queries and surface-level imitation (e.g., stylistic mimicry; Wu et al., 2020; Salemi et al., 2024), neglecting genuine personalization—*users' latent beliefs and perspectives*—which requires modeling deeper, long-term preferences and traits. To this end, we introduce a novel dataset derived from the *Change My View* (CMV) Reddit forum[3], which comprises 133 challenging evaluation posts by 41 active authors, along with their $7,514$ instances of historical engagements. CMV discussions feature *extended dialogues* where participants seek to change the original poster's (OP's) opinion on varied topics. We cast the interactions into a ranking-based recommendation task, where the objective is to identify the response that effectively alters the OP's point of view, as acknowledged by the OP.

We conduct extensive empirical experiments on our curated CMV data and an existing LLM personalization benchmark—LaMP (Salemi et al., 2024). Results show that 1) semantic memory model behaves generally more robust than episodic memory model; 2) our proposed PRIME is compatible with models of different families and sizes, yielding better results than competitive comparisons; 3) and *personalized thinking* plays a pivotal role in improving personalization. Further analysis also demonstrates that personalized thinking can be enabled in training-free settings, offering flexibility in handling users with limited history which is often framed as the "cold-start" challenge (Zhang et al., 2025b). To assess how effective our models capture user-specific characteristics, we inject other users' histories and measure the resulting performance drop, confirming that our method captures dynamic personalization rather than bandwagon biases.

In summary, our contributions are threefold:

- We propose PRIME, a cognitively inspired unified framework for LLM personalization, further augmented with personalized thinking.
- We introduce a challenging dataset, derived from the CMV forum, with nuanced user beliefs and preferences in long-context setting.
- Experiments showcase the effectiveness of PRIME, as well as the pivotal role of personalized thinking.

2 Related Work

2.1 LLM Personalization

Methods for Personalization. Early personalization in NLP relied on explicit user models, i.e., a structured representation of user traits, to tailor system outputs (Amato and Straccia, 1999; Purificato et al., 2024). They rely on static demographic features (e.g., age, gender, location) and use handcrafted rules to adapt outputs (Gou et al., 2014; Kim et al., 2013; Gao et al., 2013). Latent-factor techniques like matrix factorization (Koren et al., 2009; Jiang et al., 2014) decompose the user-item inter-

[3] https://www.reddit.com/r/changemyview/

action matrix into low-dimensional embeddings. Moreover, the Transformer architecture (Vaswani et al., 2017) enables and advances learnable user embedding approaches (Qiu et al., 2021; Deng et al., 2023). However, these methods all overlook *unstructured* user-written content and fail to generalize across tasks, yielding shallow, brittle personalization and underscoring the need for more robust methods.

With LLMs, three major paradigms have emerged: prompt engineering, retrieval-augmented generation, and training-based parameterization. Prompt-based approaches prepend user context, such as profile summaries (Richardson et al., 2023) or past interactions (Liu et al., 2023; Petrov and Macdonald, 2023; Kang et al., 2023), to the model input, but this method is constrained by LLMs' context window sizes. An improved version relies on retrievers like BM25 (Robertson and Zaragoza, 2009) and FAISS (Douze et al., 2024) to fetch relevant user history, which is then included in the model input (Madaan et al., 2022; Salemi et al., 2024; Mysore et al., 2024). However, noisy or irrelevant retrieval limits their ability to capture fine-grained user preferences. To address these challenges, recent studies have proposed to parameterize the historical engagement through training, by learning embeddings (Doddapaneni et al., 2024; Ning et al., 2024), by fine-tuning light-weight adapters (Tan et al., 2024; Zhang et al., 2024b), or by employing RLHF to align with individuals' preferences (Christiano et al., 2017; Ouyang et al., 2022; Li et al., 2024). While these piecemeal approaches improve personalization on its own, there lacks a unified framework to bring them together. In this work, we bridge the gap by mirroring the dual-memory model in the human cognition process for more effective LLM personalization.

Datasets. The advancement of personalized LLMs has been hampered by a shortage of comprehensive benchmarks (Tseng et al., 2024). Existing ones predominantly target short-context queries (Li et al., 2020; Salemi et al., 2024), and some only contain user-level metadata (Harper and Konstan, 2016; Wu et al., 2020). These tasks, while useful, assess personalization in a rather shallow way, such as simple rating prediction for short movie reviews (Ni et al., 2019) or capturing surface-level stylistic pattern in writing (Salemi et al., 2024). They overlook subtle dimensions of personalization, such as users' latent stance and evolving preferences during extended interactions. We also refer readers to Section B for additional discussions on the personalization evaluation.

2.2 Memory Mechanism for LLM

Decades of psychological research have converged on the following human memory components: sensory register, short-term memory, and long-term memory (Atkinson and Shiffrin, 1968a). Regarding the durable long-term memory, further distinction has been made between *episodic memory* and *semantic memory* (Tulving et al., 1972; Tulving, 1985). Episodic memory refers to autobiographical events we can re-experience (Tulving, 2002; Clayton et al., 2007), e.g., recalling a specific conversation that happened last night. Semantic memory, on the other hand, refers to general facts and knowledge we have accumulated (Saumier and Chertkow, 2002; McRae and Jones, 2013), such as knowing that NLP stands for Natural Language Processing. In this work, we posit that **the dual structure—episodic vs. semantic memories—is especially pertinent to LLM personalization**, as it mirrors the difference between remembering what happened in a particular interaction (*episodes*), and knowing what is true about the users' opinions, beliefs, and preferences (*semantics*).

Integrating memory into LLM-based systems quickly becomes a research frontier, as it holds the key to extending LLMs beyond fixed context windows, especially critical for LLM agents (Zhang et al., 2024a,e). A standard implementation of episodic memory is retrieval-based: past interactions (Park et al., 2023) and external facts (Yao et al., 2023) are indexed in a database and fetched on demand. In contrast, semantic memory is mostly realized parametrically:[4] model's parameters are updated by training on user data to embed user-level knowledge (Zhang et al., 2024b; Magister et al., 2024). Recent hybrid approaches attempt to combine these two by merely concatenating textual summaries with retrieved experiences (Tan et al., 2024; Zhong et al., 2024; Gupta et al., 2024), resulting in only superficial fusion. Recognizing the isolated usage and the shallow integration, we formulate a more principled approach that enables deep information flow between episodic and semantic memories, which enables the successful use of the newly proposed personalized thinking.

[4]The use of memory in this work is to realize personalization, unlike existing ones which employ it for injecting factual (Févry et al., 2020) or moral (Zhang et al., 2024d) knowledge.

3 CMV Dataset Construction

Change My View (CMV) is a Reddit forum (`r/ChangeMyView`) where participants discuss to understand different viewpoints on various topics. CMV has been widely used for studies on argumentation (Ji et al., 2018; Hua et al., 2019; Lin et al., 2024) and framing (Peguero and Watanabe, 2024). To our knowledge, we are the first to use CMV for LLM personalization, *defining personalization as recommending the most persuasive reply for a given OP (original post).* An evaluation example from our dataset is shown in Figure A8.

CMV Dataset Curation. We obtained the raw CMV data (OPs, comments, and reply threads) from Academic Torrents.[5] We split the data chronologically: interactions from 2013–2022 form the *historical engagement set* and those from 2023–2024 form the *evaluation set*. The 2023 cutoff is chosen to better mitigate the data contamination issue—evaluation data have been part of the training corpus—since many open-weight models used in this study have the knowledge cutoff in 2023 (Dong et al., 2024a). We restructure each interaction by flattening the original multi-branch structures into linear threads of (OP, direct reply, follow-ups). We discard any thread containing deleted contents or authors, marked with "[deleted]" or "[removed]", since they offer no helpful personalization signal.

To convert conversations into a recommendation task, we exploit CMV's *delta* mechanism[6] to label replies: A direct reply that receives a delta becomes a *positive* example; all other direct replies under the same OP form the *negative* pool. For the sake of simplicity, we only consider single-turn conversations and truncate all follow-ups.

User Selection and Query Construction We restrict to *active users* who awarded at least 10 deltas in the historical engagement set (2013–2022) and granted at least one delta in 2023–2024. This yields 56 authors. Each evaluation query contains an OP and one of its delta-awarded replies with non-delta replies to the same OP as negatives. Our initial evaluation set comprises 327 queries from 56 OP authors. We further filter data based on their difficulty level, with details in Section C to mitigate popularity heuristics (Ji et al., 2020).

Statistics. Our final evaluation set includes 133 queries by 41 OP authors, supported by $7,514$ historical conversations published from 2013 to 2022. For the evaluation set (2023-2024), OP posts average 409 tokens; positive and negative replies average 200.2 and 105.8 tokens, respectively. Each positive reply is paired with 47.5 negatives on average ($6,317$ negatives total). In the historical engagement set, active authors have on average 28.1 positive and 155.1 negative conversations each.

4 Memory Instantiation

Inspired by cognitive theories of memory (Tulving et al., 1972), we investigate how different instantiations of episodic and semantic memories affect the LLM personalization. More specifically, we are interested in instantiating the memory-writing mechanism, i.e., how experiences are *encoded* into memory, and the memory-reading mechanism, i.e., how that information is *utilized* at test time. This study aims to provide insights into the **strengths and limitations** of various memory configurations.

Personalization with Dual-Memory. We adopt the dual-memory architecture, comprising episodic memory (EM) and semantic memory (SM), to define a **personalized LLM**, denoted as $\tilde{\mathcal{M}}$. The model processes an input query x from user a as follows:

$$\tilde{\mathcal{M}}(x) = \mathcal{M}(x; \mathrm{EM}_a(x); \mathrm{SM}_a(x)) \tag{1}$$

$$= \mathcal{M}(x; \phi(x, \mathcal{H}(a)); \theta \oplus \Delta_{\mathcal{H}(a)}) \tag{2}$$

$\mathcal{M}$ represents the base LLM with parameters θ, $\mathcal{H}(a)$ denotes the historical engagements of user a, ϕ is the recall function for episodic memory, and $\Delta_{\mathcal{H}(a)}$ signifies the user-specific preference encoded in the personalized semantic memory. The operator $\oplus$ indicates the fusion of a base LLM and personalized adjustments.

For this set of preliminary experiments, we utilize LLAMA-3.1-8B (Dubey et al., 2024) and QWEN2.5-7B (Yang et al., 2024), for their representativeness. We conduct experiments on CMV data, and see Figure A8 for a sample query.

Episodic Memory Instantiation. The writing mechanism typically involves storing raw interaction data for efficiency and completeness. We thus focus on the reading mechanism, exploring several recall strategies, $\phi(\cdot)$: 1) recall *complete history* (i.e., Shinn et al., 2023), 2) recall *most recent*

[5] https://academictorrents.com/details/20520c420c6c846f555523babc8c059e9daa8fc5/

[6] OP authors award a "Δ" to replies that change their view.

	Non-P	Recent	Relevant
Llama-3.1-8B	26.58	26.88 (26.67)	25.68 (25.96)
Qwen2.5-7B	27.89	25.51 (25.51)	25.66 (26.18)

Table 1: Aggregated results on **episodic memory** instantiation (10 runs). Complete results refer to Table A2. Parenthesized numbers represent textual-summary augmentation (TSA), which is beneficial for some cases.

histories (i.a., Wang et al., 2024), and 3) recall *relevant histories* (i.a., Park et al., 2023). Since full-history recall is intractable for long-context conversations, we focus our experiments on both recent and relevant recall. We also explore augmenting episodic memory with semantic memory–derived profile summaries (Richardson et al., 2023), referred to as *textual-summary augmentation (TSA)*.[7]

Semantic Memory Instantiation. We first explore different instantiations of the memory-writing function, specifically focusing on deriving $\Delta_{\mathcal{H}(a)}$ by *internalizing* information from user history $\mathcal{H}(a)$, i.e., encoding abstract concepts (e.g., preferences) into semantic memory. There are two forms of personalized semantic memory: parametric and textual forms. We provide a brief summary and Table A4 presents the input–output mappings for each instantiation.

Parametric form, encodes user preferences into the model's parameters. We examine several training objectives:

- **Input-Only Training**: Suitable when human-written personalized outputs are unavailable (Tan et al., 2024). Objectives include *next token prediction (NTP)* and *conditional input generation (CIG)*, e.g., generate a post based on the title.
- **Fine-Tuning (FT)**: The most common practice to personalize model parameters (Zhang et al., 2024b; Magister et al., 2024; Tan et al., 2024), and we have two variants: *output-oriented FT (O-FT)* and *task-oriented FT (T-FT)*, depending on whether end task information is handy.
- **Preference Tuning**: Alternative to RLHF, employs methods like *DPO* (Rafailov et al., 2023) and *SIMPO* (Meng et al., 2024), an efficient variant without the need for the reference model, to align model outputs with user preferences. Although RLHF has been used to learn user preferences (Li et al., 2024), its simpler alternative, preference tuning, remains largely unexplored for LLM personalization.

Textual form represents user preferences as text, usually in the summary form. We explore:

- *Hierarchical Summarization (HSumm)*: hierarchically aggregates current interactions into concise summaries (Zhong et al., 2024).
- *Parametric Knowledge Reification (PKR)*: a novel method that leverages a model, trained on a user's engagement history[8] to infer a concise profile summary. *PKR* offers a speed gain over *HSumm*.

During the **memory reading** process, as shown in Equation (2), if semantic memory is in parametric form, the model parameters are adjusted as $\theta + \Delta_{\mathcal{H}(a)}$, i.e., $\oplus$ is matrix addition; if in the textual form, $\oplus$ is implemented as prefixing the generated profile summary to the input query q, i.e., $\tilde{\mathcal{M}}(x) = \mathcal{M}([\Delta_{\mathcal{H}(a)}; x]; \mathrm{EM}_a(x); \theta)$

For instantiations that involve training, we utilize LoRA (Hu et al., 2022) for its efficiency and interpretability, allowing $\Delta_{\mathcal{H}(a)}$ as an abstract state to represent user-specific preferences and beliefs.

Discussion and Analysis. Tables 1 and 2 present comprehensive results for episodic and semantic memory instantiations. Table A2 also provides insights into the efficiency aspect.

Our experiments reveal that episodic memory grounded in simple recency often outperforms a semantic-similarity retrieval strategy—both in accuracy and speed—because the most recent interactions tend to be the strongest predictors of immediate user behavior. In contrast, semantic memory allows us to infer user preferences and latent traits even without task-specific labels, as validated by the improved performances achieved through *input-only training*. The best performance is reached by the *task fine-tuning (T-FT)*, which directly learns the mapping from the input query to the final desired outcome. Surprisingly, preference-tuning methods underperform here, which deserves more investigation in the future. Overall, using semantic memory (SM) alone generally leads to higher performance compared to using episodic memory (EM) alone. This suggests that semantic abstraction of user preferences and history might be more effective for personalization than simply recalling specific interactions.

It is important to emphasize that most of these memory instantiations have been examined individ-

[7]TSA concatenates the textual summary with recalled histories. Despite the hybrid memory usage, we classify it under *Episodic Memory* per our adopted memory dichotomy.

[8]In our experiments, we use *T-FT* trained LoRAs.

	Non-P	Input Only		Fine Tuning		Preference Tuning		Textual	
		NTP	CIG	O-FT	T-FT	DPO	SIMPO	HSumm	PKR (ours)
Llama-3.1-8B	26.58	29.22	29.79	25.47	31.24	26.33	24.45	27.07	26.62
Qwen2.5-7B	27.89	28.11	28.41	28.01	30.20	28.04	17.37	26.83	27.02

Table 2: Average results of Hit@1, Hit@3, MRR, and DCG@3 on semantic memory configuration (10 runs) Complete results refer to Table A2 where we additionally analyze the **time efficiency**. Non-P is a non-personalized baseline. Overall, the best configuration is to instantiate *parametric semantic memory with task-oriented fine-tuning*, if the task information is available. Parametric semantic memory generally outperforms its textual counterpart, whereas the preference-tuning approach delivers suboptimal results and thus deserves further investigation.

ually in prior work, but never evaluated together on a common benchmark. To our knowledge, this study delivers the first comprehensive, head-to-head assessment of their personalization performance on long-context queries under a unified evaluation framework.

5 Personalization with PRIME

Section 4 offers insights into the instantiation of episodic memory and semantic memory separately, which is a common practice in the literature. Only a few works attempt to combine the two, and those mostly operate in the textual space only (Richardson et al., 2023; Zhong et al., 2024). To this end, we introduce DUAL (Section 5.1) to unify both memory types, so that *the model can leverage detailed event histories alongside generalized user profiles*. Eventually, we introduce PRIME (Figure 1), by augmenting DUAL with *personalized thinking* (section 5.2), which jointly leverages these memories to generate more faithful, user-aligned responses and exhibit richer personalized reasoning traces for improved interpretability.

5.1 A Unified Framework with Cognitive Memory

This DUAL framework draws inspiration from the well-established cognitive theory of the dual-memory model (Tulving et al., 1972). To maintain efficiency during training and inference, we implement episodic memory via *recency-based recall* and semantic memory via *task-oriented fine-tuning (T-FT)*. Importantly, our dual-memory framework is virtually compatible with all valid instantiation approaches, as confirmed in section 4. Once instantiated, we freeze both memories.

At test time (right part of Figure 1), we process each input query x from an arbitrary user a following Equation (2). That is, we activate the corresponding LoRA matrices trained for the user a to enable personalized semantic memory through parameters merging, $\theta + \Delta_{\mathcal{H}(a)}$. Next, we retrieve the most recent experiences for user a from the episodic memory to form a context-aware input query, $x \oplus \phi(x, \mathcal{H}(a))$, where $\oplus$ denotes text concatenation.

5.2 Personalized Thinking

Slow thinking, demonstrated by long CoT methods like DeepSeek-R1 (Guo et al., 2025) and s1 (Muennighoff et al., 2025), has shown promise, but its use in personalization is still in its infant stage. We are thus motivated to apply the slow thinking strategy to unlock personalized thinking

However, due to the fast thinking training paradigm (i.e., direct mapping from input to output), we find that fine-tuned LLMs have been turned into a specialist model and overfitted to the target space, i.e., losing the generalist capability of generating meaningful intermediate thoughts when prompted. A common error is repetition of tokens. To this end, we decide to unlock personalized thinking capabilities through training on *synthesized personalized thoughts*.

Personalized Thoughts Generation Capitalizing on the recent success of self-distillation (Zhang et al., 2019; Pham et al., 2022; Wang et al., 2023), we design the following algorithm to produce intermediate thoughts and feed them back to the model itself for learning the personalized thinking process. We start by an LLM with instantiated *parametric semantic memory*, i.e., $\tilde{\mathcal{M}}_{\mathrm{SE}_\alpha}(\cdot) = \mathcal{M}(\cdot; \emptyset; \mathrm{SM}_a(\cdot))$

- Step 1 (Profile Generation): We prompt $\tilde{\mathcal{M}}_{\mathrm{SE}_\alpha}(x)$ to generate a summary for a user, derived from the training on that user's history, following the same *Parametric Knowledge Reification* approach as described in Section 4.[9]
- Step 2 (Review History Engagement): We convert each historical engagement into a query as in the evaluation format (Figure A8), and we

[9]Despite the model fails to generate meaningful thoughts, we find it still capable to generate meaningful summaries.

prompt the $\tilde{\mathcal{M}}_{\mathrm{SE}_\alpha}(x)$ to revisit all past engagements, and produce answers on them.

- Step 3 (Fast-thinking Filtering): We compare the produced answer with the ground truth answer, and then apply rejection sampling (Zhu et al., 2023; Yuan et al., 2023) to keep the queries that the model is able to get right.
- Step 4 (Proxy LLM Initialization & Reasoning): We follow the *textual semantic memory* reading process in section 4 and use the summary generated by $\tilde{\mathcal{M}}_{\mathrm{SE}_\alpha}(\cdot)$ in Step 1 to instantiate a proxy model, $\tilde{\mathcal{M}}'_{\mathrm{SE}_\alpha}(\cdot) = \mathcal{M}(\cdot; \mathrm{EM}_\alpha(\cdot); \emptyset)$. Next, we conduct reverse engineering by providing the input query x along with its answer to $\tilde{\mathcal{M}}'_{\mathrm{SE}_\alpha}(\cdot)$. Using a prompt similar to Figure A10, we instruct $\tilde{\mathcal{M}}'_{\mathrm{SE}_\alpha}(\cdot)$ to generate structured intermediate thoughts in the same format as Figure A12, while requiring it to explicitly *reiterate* the profile summary in its response.
- Step 5 (Slow-thinking Filtering): After obtaining the intermediate thoughts and predicted answer produced by the proxy LLM, we perform another round of rejection sampling to keep the ones where the final answer matches the ground truth.

Training: After obtaining the synthesized personalized thoughts, we fine-tune $\tilde{\mathcal{M}}_{\mathrm{SE}_\alpha}(\cdot)$ for a single epoch using cross-entropy loss. The input is still a plain query q, but the model is expected to generate both the personalized thinking trace (*including the user's profile summary*[10]) and the final answer.

Our work also draws a clear distinction from concurrent work (Tsai et al., 2024; Tang et al., 2025; Zhang et al., 2025a) on eliciting slow-thinking for LLM personalization. Unlike theirs, which focus solely on recommendation, we address diverse personalization tasks. Methodology-wise, Tsai et al. (2024) rely on a larger teacher model for reasoning path distillation, whereas we employ cost-effective self-distillation. Tang et al. (2025); Zhang et al. (2025a) use virtual tokens, i.e., a sequence of vectors, as intermediate steps while we are producing real tokens for the intermediate reasoning step, offering users interpretable reasoning traces.

6 Experiments

Datasets and Tasks. We conduct a holistic evaluation of LLM personalization across four task types (ranking, classification, regression, and generation), and on both short- and long-context queries. To this end, we benchmark models on our curated CMV to specifically probe long-context understanding. We also include a public LLM personalization benchmark, LaMP (Salemi et al., 2024), offering a testbed for all aforementioned tasks except for the ranking task. Specifically, we include LaMP-1 (citation identification), LaMP-2 (movie tagging), LaMP-3 (Amazon product rating), LaMP-4 (news headline generation) and LaMP-5 (scholarly title generation), and remove LaMP-6 and 7.[11] Dataset statistics are included in Table A1, and Figure A8 shows an evaluation example from CMV dataset. Evaluation metrics for each task are in Section A.2,

Setup. We include recent, strong LLMs, showing promising results on various benchmarks. Specifically, we cover a diverse array of LLMs, ranging from mini LLMs (3B) to medium LLMs (14B), as shown in Table 3 and discussed in Section A.1.

On LaMP benchmark, for fair comparison with the SOTA approach (Tan et al., 2024), which is built upon LLAMA2-7B (Touvron et al., 2023), we only report performances based on LLAMA-3.1-8B.

Baselines and PRIME Variants. On both benchmarks, we compare PRIME with the non-personalized baseline, and *generic reasoners* like R1-DISTILL-LLAMA. We also compare our approach with the SOTA system on LaMP tasks, OPPU (Tan et al., 2024), which uses 100× more data by training on vast non-target users' history before fine-tuning on a target user's history.

Meanwhile, we compare PRIME with its variants: episodic memory only (EM), semantic memory only (SM), and DUAL. For PRIME variants, their memories are instantiated exactly as PRIME.

Implementation Details. EM uses 3 history interactions for CMV and 4 for LaMP benchmark. LoRAs used in SM are trained for up to 10 epochs for *NTP* objective, 500 steps for preference tuning, and 3 epochs for other objectives (but 2 epochs for LaMP). For preference tuning, we pair one positive example with up to 10 negative examples under the same OP as the positive. At inference-time, PRIME is allowed to generate up to $2,048$ tokens. In our final implementation of PRIME, we drop EM as it degrades performance (Table A3).

[10]In our preliminary study, we find it generally advantageous to include profile summary in response.

[11]We exclude LaMP-6 because it relies on a private dataset to which we have no access, and LaMP-7 because its GPT-3.5–generated labels do not truly represent real user behavior.

	Non-P		EM		SM		DUAL		PRIME	
	Hit@3	Avg	Hit@3	Avg	Hit@3	Avg	Hit@3	Avg	Hit@3	Avg
Llama-3.2-3B	38.65	26.44	37.89	26.27	**43.61**	**30.25**	41.95	28.87	42.93	29.95
Llama-3.1-8B	36.77	26.58	37.22	26.88	43.01	31.24	44.59	32.24	**45.79**	**34.13**
Ministral-8B	36.77	25.60	38.27	26.67	**40.83**	27.97	**40.83**	28.39	40.75	**28.99**
Qwen2.5-7B	39.10	27.89	37.47	25.51	43.38	30.20	41.58	28.71	**45.19**	**32.29**
Qwen2.5-14B	41.28	30.24	43.01	30.65	51.35	37.22	52.03	37.68	**52.03**	**38.15**
Phi-4	41.50	29.63	42.93	30.31	42.63	31.09	43.98	32.61	**47.29**	**35.15**

Table 3: Results on CMV evaluation set (average of 10 runs). Avg is the aggregated metric of Hit@1, Hit@3, DCG@3, and MRR. Refer to Table A3 for detailed breakdown results, as well as performances of *generic reasoners* (i.e., R1-distilled models) and retrieval-based EM. Best results for *each* base model are in **bold**. Non-P is a non-personalized baseline. PRIME performs better across the board, and is compatible with various base models. Note that we empirically do not include EM in PRIME; For results on the EM-included PRIME, refer to Table A3.

Task (Metric)	Non-P	R1	EM	SM	DUAL	PRIME	SOTA
LaMP1 (Acc) ↑	44.7	47.2	49.6	46.3	52.8	**54.5**	79.7
LaMP1 (F1) ↑	30.9	46.9	45.7	31.7	52.9	**54.5**	79.4
LaMP2 (Acc) ↑	33.6	29.6	43.6	53.3	50.0	**54.3**	64.8
LaMP2 (F1) ↑	28.2	26.5	34.4	40.5	39.1	**42.7**	54.0
LaMP3 (MAE) ↓	.313	.366	.268	.214	**.188**	.223	.143
LaMP3 (RMSE) ↓	.605	.620	.567	.482	**.453**	.491	.378
LaMP4 (R-1) ↑	12.4	11.5	13.8	16.9	18.6	**18.8**	19.4
LaMP4 (R-L) ↑	11.0	10.1	12.4	15.2	16.7	**16.8**	17.5
LaMP5 (R-1) ↑	44.8	40.7	47.0	50.1	**52.2**	47.3	52.5
LaMP5 (R-L) ↑	34.7	32.7	38.5	44.8	**47.3**	40.6	47.3

Table 4: Results on LaMP benchmark. Non-P is the non-personalized baseline, R1 denotes R1-DISTILL-LLAMA. SOTA results, OPPU (Tan et al., 2024), use 100× more data of non-target users for training. Best performance among non-OPPUs is in **bold**. In general, personalized thinking in PRIME leads to better results while the DUAL variant offers a competitive baseline.

7 Results and Analyses

7.1 Main results

Major results are included in Table 3, and the full results (across all 5 metrics) can be found in Table A3. Below are our major findings.

1) *Generic Reasoning has limitations*: Enabling generic chain-of-thought often underperforms the non-thinking baseline (see Table A3). The uncustomized reasoning trace merely scratches the surface, seeking broad answers rather than to-the-point, user-specific responses. A detailed case study appears in Section E.

2) *Semantic Memory (*SM*) Beats Episodic Memory (*EM*)*: Consistent with our major finding in Section 4, SM alone generally outperforms EM alone, regardless of the model size or family.

3) DUAL *Often Underperforms* SM *Alone*: Surprisingly, integrating both memory types without personalized thinking (DUAL) occasionally yields lower or comparable results than SM along. This suggests that potential conflicts between episodic and semantic memories could backfire if not properly mediated.

4) *Model-agnostic Effectiveness*: PRIME consistently enhances performance across all base models at different scales, illustrating that our PRIME framework is robust and model-agnostic.

5) *Personalized Thinking is Crucial*: By augmenting DUAL with personalized thinking, PRIME achieves superior performance over nearly all variants. This highlights the pivotal role of customized reasoning in improving personalization. Further, Section E presents a case study comparing personalized and generic thinking traces, showcasing that our personalized thinking trace effectively adapts to the target user's profile.

Results on LaMP. LaMP is a public benchmark of short-context queries that mainly tests surface-level personalization (e.g., imitating writing style). Although PRIME is designed to capture latent, evolving preferences, we are also interested in PRIME's ability of handling short, simple queries.

As shown in Table 4, the trends mirror those on CMV: SM outperforms EM, and DUAL sometimes trails SM due to potential memory conflicts. Crucially, personalized thinking[12] in PRIME helps yield better results while DUAL is a competitive baseline for surface-level personalization tasks. This is inline with recent findings that overthinking might harm simple tasks (Sui et al., 2025). While PRIME surpasses all non-SOTA baselines, it remains behind the OPPU (Tan et al., 2024), which is trained on 100× more data and includes other users' histories. This cross-user training could violate privacy constraints in reality by exposing private data (Kim et al., 2025). Given PRIME's use of each user's own history only, we deem the remain-

[12]Thinking prompt is shown in Figure A11. Figure A15 and Figure A17 present personalized thinking traces on select LaMP tasks.

ing gap acceptable.

7.2 Further Analyses

Train-free Personalized Thinking. Cold-start—performing personalized tasks with minimal history (e.g., ≤ 5 engagements)—remains challenging (Zhang et al., 2025b). We thus decide to approach this challenge with our proposed *personalized thinking* but under the training-free setting. Specifically, we prompt the EM variant with the thinking prompt (Figure A10). We also contrast it with vanilla EM using the standard prompt.

As shown from Figure A2 to A6, personalized thinking boosts all metrics except Hit@1 for all base models, compared to non-thinking counterparts. Despite trailing the trained PRIME, it always outperforms other baselines including the strong generic reasoner (i.e., R1-distill LLMs), highlighting personalized thinking's promise even without training.

Profile Replacement. To evaluate the extent to which PRIME faithfully leverages and ingest a user's unique history, we perform a controlled "profile-replacement" experiment: for each test query, we substitute the *target user*'s engagement history——both episodic (e.g., textual profile summary) and semantic memories (LoRA weights)—with that of (i) the most similar user, (ii) a similar user, (iii) a mid-range user, or (iv) a dissimilar user.[13] We also include a *Self* condition, retaining the user's own history as a baseline.

We report average performance in Figure 2 and detailed breakdown (e.g., Hit@k) in Figure A1. For both evaluated models, performance is at peak when using the target user's own profile (*Self*). Replacement with any other user's profile reduces performances, and more interestingly, the drop is steepest when the replaced profiles are similar to the original, and then partially recovers as the replacement profile becomes more divergent.

Why worst performance with similar profiles? Our PRIME learns fine-grained, user-specific preferences—effectively a dedicated bias towards which replies persuade that user most when evaluated on the CMV dataset. Noticeably, due to the data scarcity of limited active users on the CMV forum, two users with superficially similar posting histories may differ sharply in which replies they find compelling. Replacement with similar profiles thus misleads the model way more than any other

[13] Implementation details of substitutions see Section D.

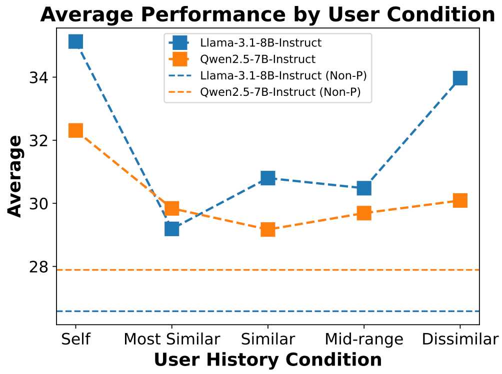

Figure 2: Average performance under five user-profile replacement conditions. Performance drops sharply when a target user's profile is replaced, confirming the faithfulness of PRIME to user history. Non-P refers to non-personalized baseline.

incorrect profiles: PRIME confidently applies the *wrong preferences*.

Why performance rebounds? When a replaced profile is quite different from the original, the loaded personalization signal, e.g., LoRA weights, is weak or irrelevant to the input query. PRIME then falls back on its general, pre-trained commonsense knowledge for interence, without exploiting the strong but unaligned personalized cues, injected in the learning stage (Section 5.2). As such, the model regains accuracy. Moreover, the improved performance over the non-personalized baseline also showcases the value of thinking mechanism for personalization tasks.

Overall, our observation confirms that PRIME's reasoning and predictions depend critically on *correct user history*, and cannot be explained by simple bandwagon or popularity heuristics (Ji et al., 2020). This further highlights that PRIME faithfully captures dynamic, user-specific preferences.

8 Conclusion

Inspired by the cognitive dual-memory model, we first systematically study different memory instantiations and then propose PRIME, a unified framework that integrates episodic and semantic memory mechanisms. We further augment PRIME with a novel personalized thinking capability, yielding more accurate, user-aligned responses and richer reasoning traces. To assess long-context personalization, we introduce the CMV dataset and conduct extensive experiments, which demonstrate the effectiveness of both PRIME and personalized thinking. Finally, our further analysis confirms that PRIME shows strong fidelity to each user's unique history.

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Limitations

Evaluation benchmarks. In this work, we have included two evaluation benchmarks, aiming to cover a diverse array of tasks, genres and domains. Yet, these two benchmarks cannot comprehensively represent the entire spectrum. For example, recent research efforts venture into long-form personalization (Kumar et al., 2024). For future research, we plan to extend PRIME to more applications, and examine its true generalizability in the wild.

Model Scales. In this study, we evaluate a diverse set of models ranging from $3B$ to $14B$ parameters. Owing to budget constraints, we do not extend our experiments to larger-scale models. Nonetheless, we expect our findings to hold on such models, as suggested by extrapolation from the trends observed in table 3. We leave the direct application of of PRIME to larger models in the future work.

GPU resources. The base LLMs used in this work are of 3 to 14 billions parameters. It is thus more time-consuming than traditionally small models like BERT (Devlin et al., 2019) at inference time, which in turn results in a higher carbon footprint. Specifically, we run each base LM on 1 single NVIDIA A40 or NVIDIA L40 with significant CPU and memory resources. The combined inference time for each LLM on the three benchmarks ranges from 10 to 20 hours, depending on the configurations.

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A Implementation Details

A.1 Models Used for Experiments on CMV

For all base models, we use their instruction-fine-tuned versions for experiments. We have provided model cards in the footnotes.

- **Mini LLM**: LLAMA-3.2-3B (Meta AI Team, 2024)[14]
- **Small LLM**: LLAMA-3.1-8B (Dubey et al., 2024),[15] QWEN2.5-7B (Yang et al., 2024),[16] MINISTRAL-8B (Mistral AI team, 2024)[17].
- **Medium LLM**: QWEN2.5-14B (Yang et al., 2024),[18] PHI-4 (Abdin et al., 2024)[19]

A.2 Evaluation Metrics

For our CMV benchmark, considering it is a ranking task (Manning et al., 2008), we adopt Hit@1, Hit@3, DCG@3 and MRR. For LaMP, we follow the official metrics (Salemi et al., 2024), and use accuracy and F1-score for classification tasks (LaMP-1 and LaMP-2), MAE and RMSE for the ordinal regression task (LaMP-3), and ROUGE-1 and ROUGE-L (Lin, 2004) for text generation tasks (LaMP-4 and LaMP-5). Note that all metrics are the higher the better, except for RMSE and MAE used for the LaMP-3.

B Additional Literature Review on Evaluation Challenge

Although benchmarks like PRISM (Kirk et al., 2024) and Empathetic Conversation (Omitaomu et al., 2022) offer a testbed for long-context query evaluation, their evaluation relies on generic metrics, e.g., ROUGE (Lin, 2004), or uses LLM-as-a-judge (Zheng et al., 2023). The former only measures surface-level similarity, while the latter demands extensive prompt engineering (Dong et al., 2024b; Szymanski et al., 2025) and still falls short of truly *imitating* individual users' preferences (Jiang et al., 2023), as the models do not consistently hold the target user's persona. To address these gaps, we introduce a new CMV-based benchmark focusing on long-form, persuasion-driven recommendation tasks, enabling direct and objective assessment of LLM personalization without relying on proxy judgments.

[14] meta-llama/Llama-3.2-3B-Instruct
[15] meta-llama/Llama-3.1-8B-Instruct
[16] Qwen/Qwen2.5-7B-Instruct
[17] mistralai/Ministral-8B-Instruct-2410
[18] Qwen/Qwen2.5-7B-Instruct
[19] microsoft/phi-4

Tasks	#Q	|Q|	#History	Output Format
CMV	133	1561.4	183.2	ranking
LaMP-1	123	29.0	317.5	2-way class
LaMP-2	3,302	48.6	55.6	15-way class
LaMP-3	112	183.9	959.8	[1, 2, 3, 4, 5]
LaMP-4	6,275	18.2	270.1	short generation
LaMP-5	107	161.9	442.9	short generation

Table A1: Basic statistics of evaluation sets. #Q indicates the number of queries. |Q| is token-based input query length, excluding template tokens. #History tells the number of historical engagements per user.

C CMV Data Filtering by Difficulty

To ensure queries demand personalization rather than commonsense reasoning or popularity heuristics (Ji et al., 2020), we apply two instruction-tuned small yet powerful LLMs, i.e., LLAMA-3.1-8B (Dubey et al., 2024) and QWEN2.5-7B (Yang et al., 2024), on each query[20] without providing user history. We perform 10 runs per model, computing Hit@1 and Hit@3. We retain queries with Hit@1 ≤ 0.3 and Hit@3 ≤ 0.5, removing 15 authors and 194 queries to focus on challenging personalization items.

D Implementation Details of Profile Replacement Study

Author Index. We build each user's profile by concatenating their OP titles and contents[21]. We then encode each profile with a sentence transformer model, ALL-MINILM-L6-V2, to obtain author-level embeddings, which form our author index.

Substitution. At test time, for each query we replace the target user's profile with that of a *replacement user*, chosen according to one of four replacement conditions below. That is, we swap in the replacement user's textual profile summary (episodic memory) and load their LoRA weights (semantic memory), swap out the original target user's memories, and then carry out the evaluation as follows.

We consider four replacement conditions:

- *Most Similar*: Replace with the user whose posting history is most similar to the original.
- *Similar*: Average performance when replacing with the 3rd- and 5th-most similar users.

[20] We only consider 9 sampled negatives to form a query, the same setting as in section 4.
[21] Including users' delta-awarding histories did not substantially change performance trends.

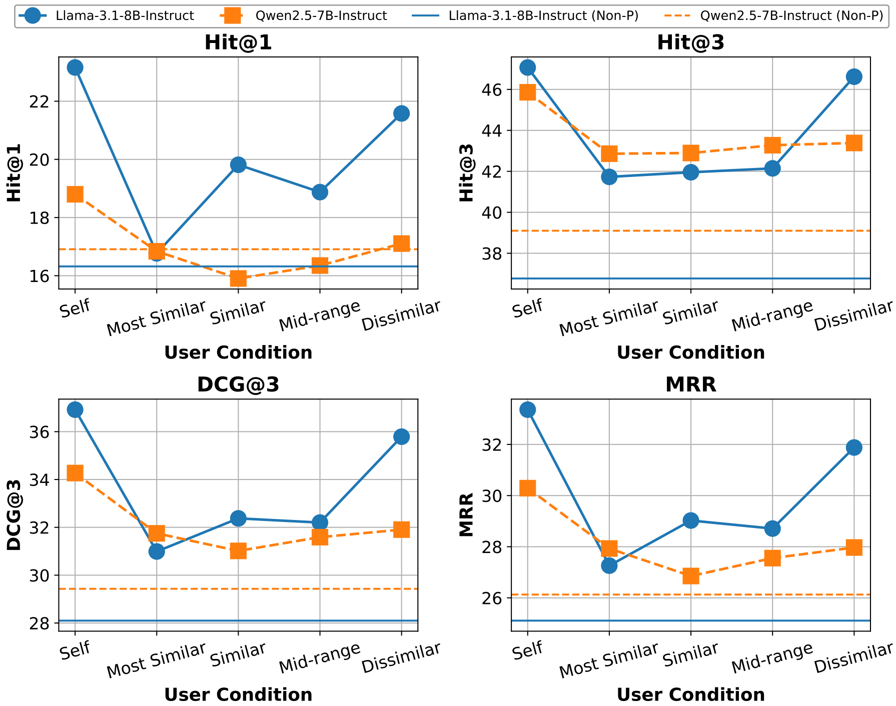

Figure A1: Hit@1, Hit@3, DCG@3 and MRR performances under five user-profile replacement conditions–self, most similar, similar, mid-range and dissimilar. Importantly, all metrics drop when the profile is replaced, confirming the sensitivity of PRIME to user history, showing that PRIME indeed captures the dynamic personalization rather than just bandwagon biases. Non-P refers to non-personalized baseline.

- *Mid-range*: Average performance when replacing with the 10th- and 20th-most similar users (20 is the median in our CMV dataset of 41 active users where one of them is the original target user).
- *Dissimilar*: Average performance when replacing with the least similar and the 10th-least similar users.

E Case study of Thinking Trace

This section provides a brief overview on the thinking traces by PRIME (Figure A12), i.e., personalized thinking, and by R1-DISTILL-LLAMA (Figure A13), which is a generic reasoner.

Specifically, our personalized thinking explicitly emphasizes on the *author's historical sensitivity to methodological rigor*, grounding its selection of option F ("data used to support their conclusion is flaw") in a nuanced understanding of the author's past engagements. This showcases how our thinking traces implements personalization. In contrast, the generic reasoner (R1-DISTILL-LLAMA) superficially mentions methodological issues in option F but ultimately prioritizes other responses (A, C, and D) based on *broader counter-evidence and direct contradictions*. Thus, R1-DISTILL-LLAMA's reasoning is weakened by a lack of personalization, failing to adequately weigh methodological precision aligned with the author's long-term behavior and patterns.

Model	Instantiation	Hit@1	Hit@3	DCG@3	MRR	Avg	W. Efficiency	R. Efficiency
				No Personalization				
Llama-3.1-8B	Baseline	16.32	36.77	28.10	25.11	26.58	N/A	N/A
Qwen2.5-7B		16.91	39.10	29.43	26.13	27.89		
				Episodic Memory (EM)				
Llama-3.1-8B	Recent	**16.62**	37.22	**28.36**	**25.33**	**26.88**	Fastest	Slow
Qwen2.5-7B		13.91	37.47	27.10	23.57	25.51		
Llama-3.1-8B	Relevant	16.17	35.41	27.00	24.12	25.68	Fastest	Slower
Qwen2.5-7B		13.23	38.50	27.36	23.56	25.66		
Llama-3.1-8B	Recent+PKR	**16.62**	36.84	28.10	25.10	26.67	Medium	Slower
Qwen2.5-7B		14.29	37.07	27.05	23.62	25.51		
Llama-3.1-8B	Relevant+PKR	15.64	36.32	27.45	24.41	25.96	Medium	Slowest
Qwen2.5-7B		13.76	**39.02**	27.88	24.07	26.18		
				Semantic Memory (SM)				
Llama-3.1-8B	NTP	17.44	41.20	30.93	27.31	29.22	Fast	Fast
Qwen2.5-7B		16.84	39.55	29.71	26.34	28.11		
Llama-3.1-8B	CIG	17.74	41.95	31.56	27.92	29.79	Fast	Fast
Qwen2.5-7B		16.77	40.23	30.05	26.57	28.41		
Llama-3.1-8B	Output FT	14.66	36.47	26.99	23.75	25.47	Medium-Fast	Fast
Qwen2.5-7B		16.54	39.85	29.58	26.08	28.01		
Llama-3.1-8B	Task FT	**19.62**	43.01	**32.96**	**29.36**	**31.24**	Medium	Fast
Qwen2.5-7B		16.99	**43.38**	32.15	28.28	30.20		
Llama-3.1-8B	DPO	15.41	37.37	27.89	24.64	26.33	Slowest	Fast
Qwen2.5-7B		16.77	39.55	29.61	26.22	28.04		
Llama-3.1-8B	SIMPO	14.21	34.81	25.89	22.88	24.45	Slow	Fast
Qwen2.5-7B		10.08	24.66	18.44	16.30	17.37		
Llama-3.1-8B	HSumm	16.32	37.89	28.62	25.44	27.07	Slowest	Medium
Qwen2.5-7B		15.04	38.80	28.50	24.97	26.83		
Llama-3.1-8B	PKR	16.69	36.39	28.12	25.26	26.62	Medium	Medium
Qwen2.5-7B		15.34	39.02	28.63	25.08	27.02		

Table A2: Complete results of the preliminary study where we study the strengths and limitations of various memory configurations. Results are the average of 10 runs. Recent/Relevant+PKR are effectively *hybrid approaches* using both episodic and textual semantic memories, but we decide to place them under the Episodic Memory (EM) category per out adopted *memory dichotomy*. *W. Efficiency* refers to memory writing or memory instantiation efficiency. For episodic memories, the writing time is the index creation time cost, which is extremely fast, compared to semantic memory writing. For semantic memory, we determine the efficiency label based on the train flops. For example, given a history of 15 engagements, the train flops of NSP/CIG is around 1e+16, while that of DPO is almost 1e+17. R. Efficiency measures the time overhead of both memory reading and the subsequent inference step. This overhead grows linearly with the number of retrieved past interactions, and increases further if a textual profile summary is prepended. In contrast, parametric semantic memories incur minimal inference cost, since all it needs to process is the input query without worrying about the past interaction retrieval.

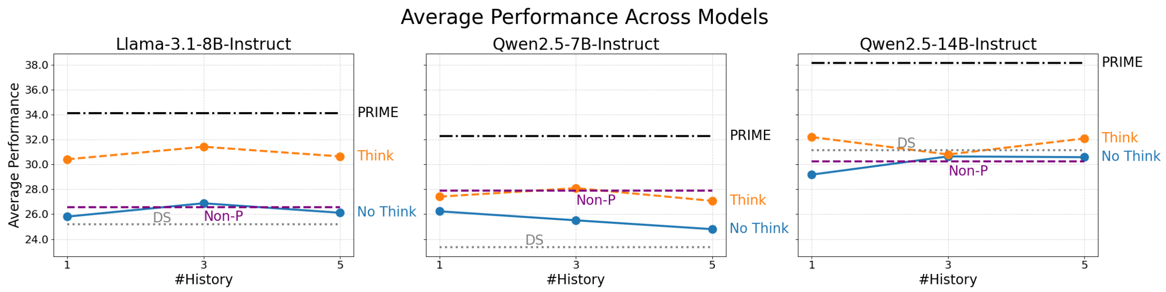

Figure A2: Average performance for Train-free Personalized Thinking study. *Think* refers to our train-free thinking approach, i.e., prompt the EM variant with the thinking prompt (Figure A10). *No Think* is the non-thinking baseline where we prompt vanilla EM with the standard prompt. *Non-P* is the no personalization baseline. *DS* denote the generic reasoner version of each base model. Concretely, we use DEEPSEEK-R1-DISTILL-LLAMA-8B, DEEPSEEK-R1-DISTILL-QWEN-7B, and DEEPSEEK-R1-DISTILL-QWEN-14B, respectively.

Model	Hit@1	Hit@3	DCG@3	MRR	Avg
		No Personalization			
Llama-3.2-3B	14.51	38.65	28.09	24.49	26.44
Llama-3.1-8B	16.32	36.77	28.10	25.11	26.58
Ministral-8B	14.36	36.77	27.27	24.00	25.60
Qwen2.5-7B	16.91	39.10	29.43	26.13	27.89
Qwen2.5-14B	19.40	41.28	31.77	28.51	30.24
Phi-4	17.97	41.50	31.27	27.77	29.63
DeepSeek-R1-Llama-3.1-8B	13.61	36.77	26.68	23.64	25.18
DeepSeek-R1-Qwen2.5-7B	13.08	33.76	24.70	21.91	23.36
DeepSeek-R1-Qwen2.5-14B	17.97	44.66	32.96	28.99	31.15
		EM (Recency)			
Llama-3.2-3B	14.74	37.89	27.94	24.50	26.27
Llama-3.1-8B	16.62	37.22	28.36	25.33	26.88
Ministral-8B	15.11	38.27	28.36	24.95	26.67
Qwen2.5-7B	13.91	37.47	27.10	23.57	25.51
Qwen2.5-14B	18.42	43.01	32.40	28.76	30.65
Phi-4	17.74	42.93	32.13	28.42	30.31
		EM (Retrieval)			
Llama-3.2-3B	14.59	37.97	27.93	24.49	26.25
Llama-3.1-8B	16.17	35.41	27.00	24.12	25.68
Ministral-8B	14.96	37.82	28.05	24.70	26.38
Qwen2.5-7B	13.23	38.50	27.36	23.56	25.66
Qwen2.5-14B	18.87	41.35	31.74	28.43	30.10
Phi-4	17.89	43.01	32.29	28.61	30.45
		SM			
Llama-3.2-3B	17.22	43.61	32.25	27.91	30.25
Llama-3.1-8B	19.62	43.01	32.96	29.36	31.24
Ministral-8B	15.34	**40.83**	29.78	25.94	27.97
Qwen2.5-7B	16.99	43.38	32.15	28.28	30.20
Qwen2.5-14B	23.38	51.35	39.16	34.99	37.22
Phi-4	19.85	42.63	32.65	29.24	31.09
		DUAL			
Llama-3.2-3B	16.09	41.95	30.78	26.65	28.87
Llama-3.1-8B	20.15	44.59	34.06	30.16	32.24
Ministral-8B	16.24	40.83	30.08	26.40	28.39
Qwen2.5-7B	15.71	41.58	30.66	26.90	28.71
Qwen2.5-14B	23.76	52.03	39.59	35.34	37.68
Phi-4	21.58	43.98	34.13	30.76	32.61
		EM-included PRIME			
Llama-3.2-3B	16.47	**44.44**	**32.54**	**28.38**	**30.46**
Llama-3.1-8B	22.33	43.46	34.29	31.08	32.79
Ministral-8B	16.47	39.25	29.47	25.94	27.78
Qwen2.5-7B	15.11	41.13	30.04	26.18	28.12
Qwen2.5-14B	24.14	50.08	39.00	35.19	37.10
Phi-4	21.95	**48.12**	**36.93**	33.08	35.02
		PRIME			
Llama-3.2-3B	**17.29**	42.93	31.81	27.78	29.95
Llama-3.1-8B	**22.56**	**45.79**	**35.87**	**32.28**	**34.13**
Ministral-8B	**17.14**	40.75	**30.81**	**27.26**	**28.99**
Qwen2.5-7B	**19.47**	**45.19**	**34.16**	**30.35**	**32.29**
Qwen2.5-14B	**24.29**	**52.03**	**40.17**	**36.09**	**38.15**
Phi-4	**23.01**	47.29	**36.93**	**33.37**	**35.15**

Table A3: Full results on CMV evaluation set (average of 10 runs). Avg is the aggregated metric of Hit@1, Hit@3, DCG@3, and MRR. Generic reasoners' performances are reported based on DeepSeek-R1-distilled models. Best results for *each* base model are in **bold**. PRIME performs better across the board, and is compatible with various base models. For EM, we include both recency- and retrieval-based memory instantiation, to help provide a more comprehensive understanding. For our proposed PRIME framework, we have two variants: EM-included PRIME is the exact implementation of Section 5, which integrates DUAL with personalized thinking capability; In the final version, simply dubbed PRIME, the EM component is dropped because we empirically observe that DUAL often underperforms SM alone (Section 7.1).

	Input	Output
NTP	"author": {author}. "title": {title}. "body": {body}<EOS>	author": {author}. "title": {title}. "body": {body}
CIG	For the topic "{title}", the author "{author}" states:	{body}
Output-FT (O-FT)	The author, "{author}", has engaged with users on the Change-My-View subreddit across various original posts (OPs). Based on the author"s preference and engagement patterns, generate a persuasive response that is highly likely to change their viewpoint on the following post. "title": {title}. "body": {body}	"reply": {positive_reply}
Task-FT (T-FT)	The author, "{author}", has engaged with users on the Change-My-View subreddit across various original posts (OPs) and is seeking alternative opinions to alter their viewpoint. Currently, the author is creating a new OP titled "{title}", with the content: ***{body}.*** From the "candidate replies" JSON file below, select the best reply (using "option ID") that best challenges the author"s view. {candidates}	["{option ID}"]
Preference Tuning	"author": {author}. "title": {title} "body": {body}	"reply": {positive_reply} / "reply": {negative_reply}

Table A4: Input-output mappings for training different instantiations of parametric semantic memory. In the context of a single-turn CMV conversation, there are always the following fields: *title*, *body*, *author* and *reply*. If a reply receives a Δ, then it is a positive reply; otherwise, it is a negative reply. Such pair can directly support the preference tuning. However, in reality, it is not always the case we have the access to aforementioned items. If the reply is unavailable, one may resort to **NTP** or **CIG**. For **NTP**, the output is essentially the left-shifted input. If output is available, one may utilize fine-tuning paradigm such as **O-FT** or **T-FT**, where the latter will be preferred if we are able to know the task information. For **T-FT**, we convert raw data into the desired task format following the prompt shown in Figure A7. Note, $\{\cdot\}$ is a placeholder which is to be replaced with concrete content.

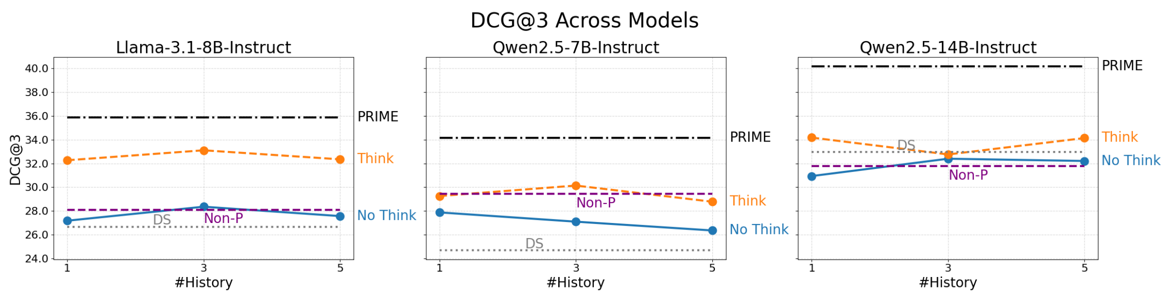

Figure A3: DCG@3 metric for Train-free Personalized Thinking study. Legend explanations are in Figure A2.

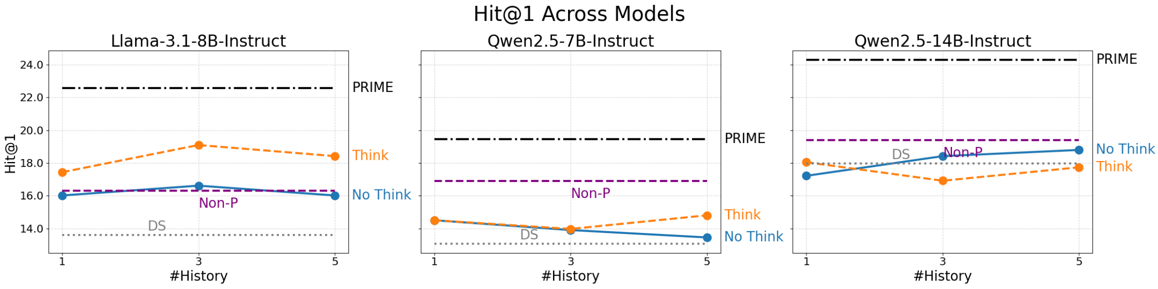

Figure A4: Hit@1 metric for Train-free Personalized Thinking study. Legend explanations are in Figure A2.

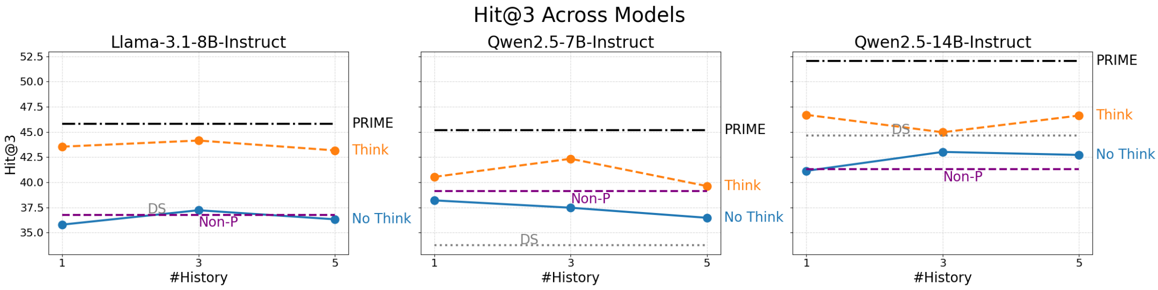

Figure A5: Hit@3 metric for Train-free Personalized Thinking study. Legend explanations are in Figure A2.

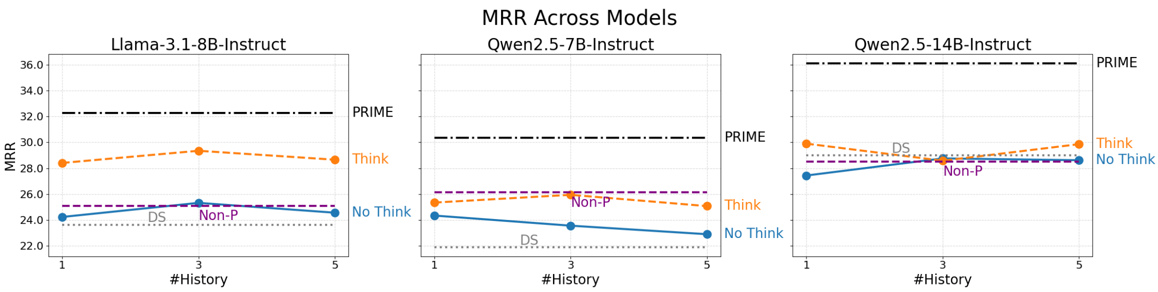

Figure A6: MRR metric for Train-free Personalized Thinking study. Legend explanations are in Figure A2.

Evaluation Template

The author, `{AUTHOR}`, has engaged with users on the Change-My-View subreddit across various original posts (OPs) and is seeking alternative opinions to alter their viewpoint.
Currently, the author is creating a new OP titled

{OP TITLE}

with the following content:

{OP CONTENT}

From the `candidate replies` JSON file below, select the top 3 replies (using `option ID`) that best challenge the author's view. Rank them from most to least compelling.

```
[
  { 'option ID': '...','challenger':'...','reply':'...'},
  { 'option ID': '...','challenger':'...','reply':'...'},
]
```

Output a valid JSON array of "`option ID`" strings representing the selected replies. Each element must be a double-quoted string. The response should contain nothing but the JSON array and end with "#END".

Figure A7: Standard prompt template for CMV evaluation, used by no-personalization baseline and generic reasoners. The template contains the *input template* (top) and *output instruction* (bottom). For EM variants that requires the access to recalled histories, the histories are prepended to the current OP, i.e., right before the word "*Currently*". This design is inspired by the recent work on using structured outputs (Zhang et al., 2024c), and we also prompt LLMs to produce outputs in JSON format to ease the post-hoc processing.

Evaluation Query

The author, `kingpatzer`, has engaged with users on the Change-My-View subreddit across various original posts (OPs) and is seeking alternative opinions to alter their viewpoint.
Currently, the author is creating a new OP titled

> "CMV: Those who attribute gun ownership rates as the cause of the problem of gun violence in terms of criminal gun deaths are not merely mistaken; they are disingenuous"

with the following content:

> The data has been clear for a very long time: the relationship between guns and gun homicides doesn't show any strong correlation.
>
> I have personally taken the cause-of-death data from https://wonder.cdc.gov/, grouping results by year and state, and selecting *Homicide, Firearm* as the cause of death. I then matched that data to the per-capita gun-ownership statistics by state from the ATF, as reported by Hunting Mark (https://huntingmark.com/gun-ownership-stats/).
>
> A standard correlation analysis between firearm homicide rates per 100,000 and per-capita gun ownership yields an r^2 of 0.079 (no meaningful correlation). A similar global analysis by nation gives an r^2 of 0.02...
>
> The only way to associate gun ownership with gun violence is by including suicides by firearm, which I argue is disingenuous. We don't count suicide by hanging as "rope violence" when discussing strangulation, nor overdoses as "drug violence," etc.

From the `candidate replies` JSON file below, select the top 3 replies (using `option ID`) that best challenge the author's view. Rank them from most to least compelling.

```
[
  { 'option ID': '...','challenger':'...','reply':'...'},
  { 'option ID': '...','challenger':'...','reply':'...'},
]
```

Output a valid JSON array of "`option ID`" strings representing the selected replies. Each element must be a double-quoted string. The response should contain nothing but the JSON array and end with "#END".

Figure A8: A sample evaluation query from our CMV dataset, formatted using the standard prompt (Figure A7). Due to space limit, we are unable to show the entire `candidate replies` list, but we have provided a candidate reply in Figure A9.

Positive Candidate Reply (option F)

- **Option ID**: `option F`
- **Challenger**: `An-Okay-Alternative`
- **Reply**:

> Your data for gun-ownership is weapons per capita, not individual gun owners per capita. If we're testing access to guns vs. gun homicides, someone who owns 30 guns wouldn't be 30× as likely to commit a homicide.
> Secondly, the ATF list includes only specially regulated firearms (e.g. fully automatic weapons, short-barreled shotguns) and NFA items bought by law enforcement.
> Thus, the data omits common firearms, is biased by collectors and hobbyists, and is confounded by law-enforcement purchases.
> Overall, this calculation is weak evidence against a gun–homicide correlation and doesn't imply critics are dishonest.

Figure A9: Positive candidate reply to the evaluation query shown in Figure A8, which receives Δ awarded by the OP author.

Personalized Thinking Prompt (Output Instruction Part Only)

You are an AI assistant designed with **bionics-inspired episodic memory** capabilities. Your objective is to approach the task by emulating human-like episodic recall, drawing from past interactions, contextual understanding, and nuanced reasoning to deliver informed and thoughtful judgments.
Treat the author's past conversations as episodic memories that guide your reasoning and decision-making throughout the process. Prioritize capturing the user's values and patterns from past interactions and integrating these into your reasoning.

Instructions

1. **Ingest Author History:**
    - Leveraging your trained semantic memory, extract and synthesize insights from the author's prior interactions. Summarize the author's past patterns, preferences, values, and beliefs to establish an episodic memory.
    - Write a concise summary of history conversations within <user experience> tags. This summary should serve as your episodic memory for later steps.
2. **Summarize the New OP:**
    - Review the content of the new OP carefully, identifying salient events, major arguments, core themes, and the author's explicit and implicit viewpoints.
    - Write a concise summary of the new OP within <OP summary> tags.
3. **Sketch an Outline:**
    - Combine insights from your episodic memory (<user experience>) with the context from the new OP (<OP summary>). Conduct reasoning that incorporates the author's past preferences and patterns to create a strategic outline for how to challenge or respond to the author's viewpoint.
    - Highlight the most important points or questions for challenging the author's view and encapsulate these in a concise outline within <sketch outline> tags.
4. **Evaluate Candidate Replies:**
    - Analyze each candidate reply from the provided JSON file in terms of strength, relevance, and weaknesses. Base your evaluations on your episodic memory, OP reasoning, and the outlined strategy.
    - Present this evaluation as a dictionary within <analysis> tags, e.g., {'option A': [analysis], 'option B': [analysis], . . . }.
5. **Reflect and Rank Top Replies:**
    - Reflect on and integrate all insights to determine the most compelling replies—those engaging the author's view and providing reasoned, respectful, and novel insights.
    - Identify the top three replies by option ID, ranking them from highest to lowest compellingness. Include your concise reflection within <reflection> tags.
6. **Answer and Conclude:**
    - Output your selection as a valid JSON array of strings within <answer> tags, e.g., ["option ID", "option ID", "option ID"].
    - End your response immediately with #END.

Output Format:

```
<user experience>[concise user experience summary]</user experience>
<OP summary>[concise OP summary]</OP summary>
<sketch outline>[concise sketched outline]</sketch outline>
<analysis>{'option A': [analysis], 'option B': [analysis], ...}</analysis>
<reflection>[concise reflection]</reflection>
<answer>["option ID","option ID","option ID"]</answer>
#END
```

Figure A10: The *output instruction* part of our personalized thinking prompt, designed for CMV evaluation. The complete prompt used by PRIME is the concatenation of the *input template* part as shown in Figure A7 and the *output instruction* part shown here.

Personalized Thinking Prompt for LaMP

The user, {AUTHOR}, is performing a {TASK} task to {TASK DESCRIPTION}.
Currently,

{CONTENT}

You are an AI assistant designed with **bionics-inspired episodic memory** capabilities. Your objective is to approach the task by emulating human-like episodic recall, drawing from past interactions, contextual understanding, and nuanced reasoning to deliver informed and thoughtful judgments.
Treat the author's past conversations as episodic memories that guide your reasoning and decision-making throughout the process. Prioritize capturing the user's values and patterns from past interactions and integrating these into your reasoning.

Instructions

1. **Ingest User History:**
   - Leveraging your trained semantic memory, extract and synthesize insights from the author's prior interactions. Summarize the author's past patterns, preferences, values, and beliefs to establish an episodic memory.
   - Write a concise summary of history engagement within `<user experience>` tags. This summary should serve as your episodic memory for the later steps.
2. **Summarize the New Query:**
   - Review the content of the new query carefully, identifying salient aspects and key objectives reflected in the user's input.
   - Write a concise summary of the new query within `<query summary>` tags.
3. **Reflect:**
   - Combine insights from your episodic memory (`<user experience>`), the context from the new query (`<query summary>`), and the task description (`<task description>`).
   - `<task description> {TASK}: {DETAILED TASK DESCRIPTION} </task description>`
   - Based on the task description, conduct reasoning that incorporates the user's past preferences and patterns to reflect on the new query.
   - Include the concise reflection within `<reflection>` tags.
4. **Answer and Conclude:**
   - {OUTPUT INSTRUCTION}
   - Enclose this final answer within `<answer>` tags.
   - End your response immediately with #END.

Output Format:

```
<user experience>[concise user experience summary]</user experience>
<query summary>[concise query summary]</query summary>
<reflection>[concise reflection]</reflection>
<answer>[final answer]</answer>
#END
```

Figure A11: Personalized thinking prompt designed for LaMP evaluation. $\{\cdot\}$ are placeholders to be replaced with corresponding contents (Table A5).

Task	Task Description	Detailed Task Description	Output Instruction
Citation Identification	Select citations for articles authored by the user	The citation behavior of researchers is dependent on their interests and is commonly used to evaluate and develop personalized systems for recommending papers.	Respond with only "[1]" or "[2]" and end with "#END".
Movie Tagging	Assign tags to movies based on the user's preferences	Users tagging behavior for media such as movies and books are known to be idiosyncratic and depends on their understanding of the tag and the aspects of the item they focus on.	Respond with only a valid tag and end with "#END".
Product Rating	Provide scores for purchased products based on the user's preferences	Product reviews commonly express a nuanced set of user preferences for a product and which in turn determine their rating for the product.	Respond with only a valid rating and end with "#END".
News Headline Generation	Write headlines for news articles authored by the user	Authors writing displays distinct stylistic elements influenced by both personal and social factors.	Respond with only the generated headline and end with "#END".
Scholarly Title Generation	Generate titles for scholarly articles authored by the user	Authors writing displays distinct stylistic elements influenced by both personal and social factors.	Respond with only the generated title and end with "#END".

Table A5: Overview of five personalized tasks in LaMP benchmark (Salemi et al., 2024), their task descriptions, detailed task descriptions, and output instructions.

Personalized Thinking Trace

User Experience: The author, `kingpatzer`, has engaged with users on the Change-My-View subreddit across various original posts (OPs), seeking alternative opinions to alter their viewpoint. In past discussions, they've shown openness to different perspectives and a willingness to consider data and evidence about gun ownership and gun violence. However, they can become defensive when challenged and sometimes dismiss opposing viewpoints.

OP Summary: The author is creating a new OP titled

> CMV: Those who attribute gun ownership rates as the cause of the problem of gun violence in terms of criminal gun deaths are not merely mistaken; they are disingenuous

They argue that available data show no strong correlation between gun ownership rates and gun homicides, and that including firearm suicides is disingenuous—comparing it to "rope violence" or "drug violence" when discussing strangulation or overdoses.

Sketch Outline:
To challenge the author's view, we need to address the following points:
1. The author's interpretation of the data: We need to examine the author's methodology and data analysis to see if it is sound and if it supports their conclusion. 2. The inclusion of suicide by guns: We need to discuss the relevance of including suicide by guns in the data set and why it is not disingenuous to do so. 3. The comparison to other causes of death: We need to compare the author's approach to other causes of death, such as drug overdoses, to see if it is consistent and fair. 4. The author's tone and language: We need to address the author's tone and language, which some may perceive as dismissive and condescending.
Key questions to ask:
* What is the author's definition of "disingenuous" and how does it apply to including suicide by guns in the data set? * Is the author's methodology sound and does it support their conclusion? * How does the author's approach to gun ownership and gun violence compare to other causes of death? * Why is the author using a tone and language that some may perceive as dismissive and condescending?

Analysis (option F):
This reply challenges the author's view by pointing out that the data used to support their conclusion is flawed, and that the author's methodology is not sound. The reply also highlights the importance of considering the social and cultural context in which gun ownership and gun violence occur.

Reflection:
Based on the analysis, the top 3 replies that best challenge the author's view are:
1. Option F: This reply challenges the author's view by pointing out that the data used to support their conclusion is flawed, and that the author's methodology is not sound. The reply also highlights the importance of considering the social and cultural context in which gun ownership and gun violence occur. 2. Option D: This reply challenges the author's view by pointing out that there is a strong link between gun ownership and impulsive suicide, and that including suicide by guns in the data set is not disingenuous. The reply also highlights the importance of considering the cultural and social context in which gun ownership and gun violence occur. 3. Option C: This reply provides a detailed and well-researched argument that challenges the author's view, pointing out that there is a significant correlation between gun ownership and gun violence. The reply also highlights the importance of considering the social and cultural context in which gun ownership and gun violence occur.
These replies are the most compelling because they engage with the author's perspective, provide reasoned and respectful arguments, and challenge the author's view in a thoughtful and nuanced way.

Answer:

$$\left[\text{"option F"},\ \text{"option D"},\ \text{"option C"}\right]$$

Figure A12: Personalized thinking trace generated by our PRIME to the evaluation query shown in Figure A8. Due to space limit, we only show the analysis for option F here (refer to A18 for the complete analysis), but we keep the presentation of all the other components intact.

Generic Reasoning Trace by R1-DISTILL-LLAMA

Think:
Alright, I need to figure out which of the provided replies best challenge the author's viewpoint. The author argues that there's no strong correlation between gun ownership rates and gun homicides, and that including suicides in the data is disingenuous.
Looking at the replies, I should focus on those that either provide counterarguments, point out flaws in the author's methodology, or present evidence contradicting their claims.
Option A: This reply points out that ignoring suicides is misleading because many suicides could be prevented by restricting gun access. It also mentions that while suicides by other means are controlled, there's no such regulation for guns. This directly challenges the author's exclusion of suicides, making it a strong point.
Option B: This uses an analogy about other causes of death to question the author's approach. It's a clever way to highlight that the author's reasoning might be inconsistent, suggesting the argument is flawed. This is compelling because it questions the validity of the author's methodology.
Option C: This reply cites a study that found a positive correlation between gun ownership and firearm homicides. It's strong evidence against the author's claim, making it a solid challenge.
Option D: This argues that there's a correlation between gun ownership and gun deaths, including suicides, and criticizes the author's exclusion of suicides. It's a direct counterargument, supporting the idea that the author is being disingenuous.
Option E: This reply references a global study showing a link between gun ownership and gun violence, which directly contradicts the author's data. It's a good point because it uses external evidence to challenge the author.
Option F: This critique points out methodological issues with the author's data, such as not measuring individual gun owners and including restricted firearms. It's detailed and highlights the limitations of the author's approach, making it a strong challenge.
Option G: This reply calls the author's statement absurd, stating that gun homicides are clearly correlated with gun presence. It's a strong, straightforward counterargument.
Option H: This argues that while the author excludes suicides, measures are taken for other causes, but not for gun suicides. It's relevant because it highlights the inconsistency in excluding suicides, supporting the idea of disingenuousness.
Option I: This defends the author's character, saying disagreement doesn't make someone disingenuous. It's more of a defense rather than a direct challenge, so it's less compelling.
Option J: This points out that the global study the author cited was flawed and incorrect. It's a good challenge because it questions the validity of the author's global data.
After evaluating, the top three replies that most effectively challenge the author's viewpoint are A, C, and D. They each present strong arguments, either by providing counter-evidence, highlighting methodological flaws, or pointing out inconsistencies in the author's reasoning.

Answer:

$$\left[\text{"option A"},\ \text{"option C"},\ \text{"option D"}\right]$$

Figure A13: Generic reasoning trace generated by R1-DISTILL-LLAMA to the evaluation query shown in Figure A8.

Evaluation Query (LaMP-1)

Query: The author has written a paper with the title "Image splicing verification based on pixel-based alignment method", which reference is related? Just answer with [1] or [2] without explanation. [1]: "Understanding Intra-Class Knowledge Inside CNN" [2]: "Multi-Dimensional hash chains and application to micropayment schemes"

Golden Label: [1]

Author: 7000791

Figure A14: A sample evaluation query from LaMP-1: *citation identification*.

Personalized Thinking Trace (LaMP-1)

User Experience: As an experienced researcher with a strong background in the field, `7000791` has demonstrated a keen interest in exploring innovative methods for identifying relevant citations in academic literature. Their past work has focused on developing AI-powered tools for citation analysis, showcasing a preference for data-driven approaches that prioritize accuracy and efficiency. With a track record of publishing in top-tier journals, `7000791` has established themselves as a thought leader in the field, often advocating for the importance of contextualizing citations within the broader research landscape. This perspective suggests that they will value citations that not only provide direct support for their arguments but also offer nuanced insights into the underlying theoretical frameworks and methodological considerations. Furthermore, their experience working with large datasets implies a comfort with complex information systems, which may influence their selection of citations that demonstrate a high degree of interoperability and scalability.

Query Summary: The author has written a paper with the title

> Image splicing verification based on pixel-based alignment method

and we need to identify the related reference.

Reflection: Considering the user's past work on developing AI-powered tools for citation analysis and their preference for data-driven approaches, I would expect them to value citations that provide direct support for their arguments. The paper *Understanding Intra-Class Knowledge Inside CNN* likely involves concepts of image representation and verification that are highly relevant to image splicing detection. This makes it a direct and meaningful citation for the author's work, while also aligning with their preference for contextually grounded, data-driven approaches.

Answer:

["1"]

Figure A15: Personalized thinking trace generated by our PRIME to the evaluation query shown in Figure A14, sampled from LaMP-1: *citation identification*.

Evaluation Query (LaMP-2)

Query: Which tag does this movie relate to among the following tags? Just answer with the tag name without further explanation. tags: [sci-fi, based on a book, comedy, action, twist ending, dystopia, dark comedy, classic, psychology, fantasy, romance, thought-provoking, social commentary, violence, true story] description: A married workaholic,

Michael Newman doesn't have time for his wife and children, not if he's to impress his ungrateful boss and earn a well-deserved promotion. So when he meets Morty, a loopy sales clerk, he gets the answer to his prayers: a magical remote that allows him to bypass life's little distractions with increasingly hysterical results.

Golden Label: comedy

Author: 8000005

Figure A16: A sample evaluation query from LaMP-2: *movie tagging*.

Personalized Thinking Trace (LaMP-2)

User Experience: User `8000005` appears to be an avid film enthusiast with a penchant for complex narratives and thought-provoking themes. Their past engagement with movies suggests a preference for critically acclaimed dramas and sci-fi epics, as evidenced by frequent tagging of films like *Inception* and *Blade Runner*. This affinity for intellectually stimulating cinema is further reinforced by their fondness for directors like Christopher Nolan and Denis Villeneuve, who are known for pushing boundaries and exploring abstract ideas. User `8000005` also exhibits a strong appreciation for atmospheric soundtracks and visually stunning cinematography, often highlighting these aspects when tagging movies like *Interstellar* and *Mad Max: Fury Road*. Overall, their tagging behavior indicates a deep love for cinematic storytelling that challenges conventional norms and sparks introspection, suggesting a highly engaged and discerning viewer.

Query Summary: The user is asking which tag the movie corresponds to. The description revolves around a married workaholic, Michael Newman, who gets a magical remote that allows him to bypass life's little distractions with increasingly hysterical results.

Reflection: Considering the user's past preferences for complex narratives, thought-provoking themes, and intellectually stimulating cinema, it is likely that they would appreciate a movie that incorporates elements of comedy, particularly one that is satirical or ironic in nature. The description highlights the increasingly hysterical results of Michael Newman's use of the magical remote, suggesting a comedic tone. Furthermore, the user's fondness for directors like Christopher Nolan and Denis Villeneuve, who often push boundaries and explore abstract ideas, may also be relevant, as the movie's use of a magical remote could be seen as a commentary on modern society's obsession with technology and distraction. However, the primary focus of the movie appears to be on its comedic aspects, making *comedy* the most appropriate tag.

Answer:

comedy

Figure A17: Personalized thinking trace generated by our PRIME to the evaluation query shown in Figure A16, sampled from LaMP-2: *movie tagging*.

Personalized Thinking Trace (Analysis Part)

Analysis (option A):
This reply challenges the author's view by pointing out that including suicide by guns in the data set is not disingenuous, but rather a necessary part of understanding the relationship between gun ownership and gun violence. The reply also highlights the importance of considering the cultural and social context in which gun ownership and gun violence occur.

Analysis (option B):
This reply uses a clever analogy to challenge the author's view, pointing out that just because there is no strong correlation between water and water deaths, it doesn't mean that water is not a factor in those deaths. The reply also highlights the importance of considering the role of guns in gun violence.

Analysis (option C):
This reply provides a detailed and well-researched argument that challenges the author's view, pointing out that there is a significant correlation between gun ownership and gun violence. The reply also highlights the importance of considering the social and cultural context in which gun ownership and gun violence occur.

Analysis (option D):
This reply challenges the author's view by pointing out that there is a strong link between gun ownership and impulsive suicide, and that including suicide by guns in the data set is not disingenuous. The reply also highlights the importance of considering the cultural and social context in which gun ownership and gun violence occur.

Analysis (option E):
This reply provides a brief and to-the-point challenge to the author's view, pointing out that there is a clear link between gun ownership and gun violence on a global level.

Analysis (option F):
This reply challenges the author's view by pointing out that the data used to support their conclusion is flawed, and that the author's methodology is not sound. The reply also highlights the importance of considering the social and cultural context in which gun ownership and gun violence occur.

Analysis (option G):
This reply uses a clever and humorous analogy to challenge the author's view, pointing out that just because there is no strong correlation between guns and gun violence, it doesn't mean that guns are not a factor in those deaths.

Analysis (option H):
This reply challenges the author's view by pointing out that there are steps that can be taken to limit drug overdoses, but not gun suicides, and that this is a relevant factor in understanding the relationship between gun ownership and gun violence.

Analysis (option I):
This reply challenges the author's tone and language, pointing out that being wrong about something doesn't make someone a liar, and that disagreeing with the meaning of "violence" doesn't make someone disingenuous.

Analysis (option J):
This reply challenges the author's view by pointing out that the data used to support their conclusion is flawed, and that the author's methodology is not sound. The reply also highlights the importance of considering the social and cultural context in which gun ownership and gun violence occur.

Figure A18: Complete analysis of all candidate options, part of the generated personalized thinking trace as shown in Figure A12.