

When Long Helps Short: How Context Length in Supervised Fine-tuning Affects Behavior of Large Language Models

Yingming Zheng^{1,3*} Hanqi Li^{1,3,4*} Kai Yu^{1,3,4} Lu Chen^{1,2,3,4†}

¹X-LANCE Lab, MoE Key Lab of Artificial Intelligence, AI Institute, School of Computer Science, Shanghai Jiao Tong University, Shanghai, China

²Shanghai Innovation Institution, Shanghai, China

³Jiangsu Key Lab of Language Computing, Suzhou, China

⁴Suzhou Laboratory, Suzhou, China

{zhengyingming, daqige, chenlusz}@sjtu.edu.cn

Abstract

Large language models (LLMs) have achieved impressive performance across natural language processing (NLP) tasks. As real-world applications increasingly demand longer context windows, continued pretraining and supervised fine-tuning (SFT) on long-context data has become a common approach. While the effects of data length in continued pretraining have been extensively studied, their implications for SFT remain unclear. In this work, we systematically investigate how SFT data length influences LLM behavior on short-context tasks. Counterintuitively, we find that long-context SFT improves short-context performance, contrary to the commonly observed degradation from long-context pretraining. To uncover the underlying mechanisms of this phenomenon, we first decouple and analyze two key components, Multi-Head Attention (MHA) and Feed-Forward Network (FFN), and show that both independently benefit from long-context SFT. We further study their interaction and reveal a knowledge preference bias: long-context SFT promotes contextual knowledge, while short-context SFT favors parametric knowledge, making exclusive reliance on long-context SFT suboptimal. Finally, we demonstrate that hybrid training mitigates this bias, offering explainable guidance for fine-tuning LLMs.

1 Introduction

Large Language Models have demonstrated remarkable potential in NLP and achieved substantial success across real-world applications (Brown et al., 2020; OpenAI et al., 2024; Zheng et al., 2025). As application scenarios diversify and task complexity intensifies, there is an increasing demand for extended context windows in LLMs. Conventionally, enhancing context length capabilities primarily involves two critical phases: continual

pretraining and SFT, where models are explicitly adapted to process long-context inputs.

Long-context continual pretraining (Fu et al., 2024) has garnered extensive investigation and established consensus conclusions. Specifically, continued pretraining with long-context data has been shown to consistently impair LLMs’ capabilities on short-context tasks. To mitigate this performance degradation, current methodologies advocate incorporating a proportion of short-context data into the pretraining corpus, thereby preserving model performance across short-context applications.

In contrast, previous studies on SFT have not established such consensus conclusions. Numerous works have focused on constructing long-context SFT datasets (Zhao et al., 2024; Xiong et al., 2025) to achieve promising performance improvements on long-context tasks. However, whether aligning training data length with evaluation benchmark, essential in continual pretraining, remains equally critical for SFT is still unclear. Two fundamental questions remain unresolved: (1) Does long-context SFT enhance or degrade performance on short-context tasks compared to conventional short-context SFT? (2) What underlying mechanisms drive these potential performance variations across context lengths?

To address these research gaps, we extend the framework established by Gao et al. (2025) by performing SFT with varied datasets on the same long-context-pretrained base model (Llama-3-8B-ProLong-512k-base), followed by comprehensive evaluation across diverse short-context domain benchmarks. Contrary to conventional expectations, our experiments yield counterintuitive results: **Models fine-tuned with long-context data demonstrate measurable improvements in aggregate metrics.**

We proceed to conduct research to explain the underlying mechanisms behind this counterintuitive phenomenon. First, we decouple the two main mod-

*Equal contribution.

†Corresponding author.

ules of Transformer-based LLMs, Multi-Head Attention (MHA) and Feed-Forward Network (FFN), to independently test their performance. For the MHA module, we test its capabilities from three perspectives: *module replacement*, *retrieval score analysis*, and *attention entropy analysis*. Our findings reveal that SFT with long-context data enhances the standalone capabilities of MHA across all dimensions. Similarly for the FFN module, we employ *module replacement* and conduct detailed analysis of *FFN activation statistics*, reaching the same conclusion that long-context SFT improved the independent performance of FFN across various metrics. **Employing long-context data for SFT benefits both MHA and FFN modules.**

To more comprehensively explain the underlying mechanisms and better guide practical applications, we further analyze the interactions between the MHA and FFN modules using a knowledge conflict framework. Our findings reveal deeper insights: **The length of SFT training data introduces biases in the model’s knowledge preferences.** Specifically, models fine-tuned with long-context SFT data exhibit overconfidence in contextual knowledge, while those trained with short-context SFT data show excessive reliance on parametric knowledge. Although long-context SFT enhances the standalone performance of both MHA and FFN modules, the resulting knowledge preference bias makes exclusive reliance on long-context SFT suboptimal. By adjusting the ratio of long-context to short-context data in SFT training, we find that: **Hybrid training helps mitigate this bias, thereby enabling potentially superior performance.**

In summary, our contributions are as follows:

- We present the first systematic study on how SFT data length impacts short-context reasoning performance. By comparing models fine-tuned on datasets with different text lengths, we show that incorporating long-context data leads to overall performance improvements on a variety of short-context tasks.
- We provide an in-depth modular analysis revealing how long-context SFT alters LLM internals. By decoupling and separately analyzing MHA and FFN, we demonstrate that long-context SFT improves the standalone performance of both modules, offering new interpretability insights into how different SFT regimes shape model functionality.

- We employ a knowledge-conflict framework to study the interactions of MHA and FFN, revealing that varying SFT data lengths induce knowledge preference bias in models. Further, we demonstrate that hybrid training mitigates these biases, providing explainable guidance for SFT in LLM.

2 Related Work

2.1 SFT in Long-context LLMs

SFT is a critical step in aligning LLMs with human intent, typically using curated instruction-response pairs. In the early development of long-context models, such as Longformer (Beltagy et al., 2020), BigBird (Zaheer et al., 2020) and LongLLaMA (Workowski et al., 2023), researchers fine-tune models on long-context data to match the extended context window, such as multi-document QA (Kočický et al., 2018), scientific articles (Jin et al., 2019), or long dialogue transcripts (Zhong et al., 2021). These works aimed to improve the model’s ability to retain and utilize extended context during inference.

Recent work has shown that fine-tuning long-context LLMs on short-context datasets can be sufficient to achieve strong performance even on long-context tasks (Liu et al., 2024). For example, Gao et al. (2025) fine-tuned Llama-3 using the short-context UltraChat dataset to obtain the ProLong-8B model, and reported that incorporating long synthetic instructions did not yield additional gains in long-context scenarios. However, this line of work neither provides further analysis nor evaluates the model’s performance on short-context tasks, leaving open the question of whether long-context SFT offers broader benefits.

2.2 Modular Interpretability of Attention and FFN in Language Model

Understanding how different components of LLMs contribute to reasoning and knowledge encoding has become a central focus in interpretability research (Goldowsky-Dill et al., 2023; Zhang et al., 2022; Hao et al., 2021). In Transformer-based architectures, attention and FFN modules are believed to play complementary roles: attention layers primarily handle information routing and selection, while FFNs apply nonlinear transformations that can encode domain or factual knowledge (Ferrando et al., 2024; Jin et al., 2024). Geva et al. (2021) first demonstrated that FFN layers can func-

tion as key-value memories, retrieving token-level associations to support factual recall. In addition, Dai et al. (2022) identified "knowledge neurons" within FFNs whose activation states are strongly correlated with specific knowledge output, suggesting that FFNs serve as important carriers of parametric knowledge. On the attention side, Elhage et al. (2021) and Wang et al. (2024) revealed that attention heads exhibit functional specialization, such as copying, moving or induction, and play crucial roles in reasoning and task-specific representation structuring.

To better understand how these modules behave under different training conditions, recent work has proposed modular analysis techniques such as layer-level ablation, head attribution, and module replacement. Meng et al. (2022) developed a method to locate and edit factual knowledge in pretrained LLMs by replacing FFN modules and observing prediction changes. Similarly, Yao et al. (2025) traced how specific knowledge emerges and propagates through Transformer layers. Although most of these studies focus on models in the pre-training stage, few have examined how SFT, especially with varying instruction lengths, modifies the internal functionality of these modules. In this work, we extend the modular interpretability analysis to the SFT stage, examining how instruction length affects the functionality of attention and FFN modules.

3 Approach

3.1 Preliminary

In this work, we mainly focus on the autoregressive Transformer-based language models. Given a Transformer decoder with L layers and N heads and an input sequence $x = \{x_1, \dots, x_N\}$ consisting with N tokens, the output of the l -th layer can be denoted as $H_l = \{h_{l,1}, \dots, h_{l,T}\}$. Each Transformer layer consists of a multi-head attention (MHA) module and a FFN module with residual connections connecting them, as shown by the following formula:

$$\tilde{H}_l = \text{MHA}(H_{l-1}) + H_{l-1}, \quad (1)$$

$$H_l = \text{FFN}(\tilde{H}_l) + \tilde{H}_l. \quad (2)$$

A MHA block consists of M attention heads, which are capable of aggregating global information into hidden states. In the i -th head of the MHA module in the l -th layer, the hidden states

are first projected into query Q_l^i , key K_l^i and value V_l^i matrices. Positional information is then incorporated into the query and key matrices through the RoPE with rotation matrix R_θ (θ is the RoPE base). These matrices are subsequently processed through a dot product followed by a softmax operation to compute the attention scores A_l^i . Finally, the value representations are weighted by the attention scores, and all attention heads are concatenated and projected to produce the attention output of l -th layer as follows:

$$A_l^i = \text{Softmax}(Q_l^{iT} R_\theta K_l^i / \sqrt{d}), \quad (3)$$

$$\text{MHA}(H_{l-1}) = \text{Concat}(\{A_l^i V_l^i\}_{i=1}^N) W^O, \quad (4)$$

where d is the dimension of query and key, W^O is the projection matrix, and Concat is the concatenation of hidden states.

The FFN in Transformer block is composed of two learnable weight matrices: W_l^{in} and W_l^{out} . W_l^{in} reads the residual stream state. Its results passed through element-wise non-linear activation function $g(\cdot)$, producing neuron activations. These are then transformed by W_l^{out} to produce outputs:

$$\text{FFN}(\tilde{H}_l) = g(\tilde{H}_l W_l^{\text{in}}) W_l^{\text{out}}. \quad (5)$$

3.2 Module Replacement

Module replacement is a commonly used method in interpretability analysis, aiming to evaluate the contribution of specific components within a model. Rather than simply removing a module to observe performance degradation, researchers often replace it with an alternative implementation to gain deeper insight into its functional importance and potential for improvement. Moreover, by comparing performance metrics before and after replacement, one can quantitatively assess the relative effectiveness of modules in different models.

3.3 Retrieval Score

Followed by the work of Wu et al. (2024), we calculate the retrieval score of attention heads, which measures its ability to accurately extract relevant information from the context and use it to answer questions during generation. Specifically, given a question-answering instances where the correct answer must be explicitly retrieved from the input passage such as Needle-in-a-Haystack, and we track the overlap between the generated tokens of each head and the source text. Formally, we define:

$$\text{Retrieval score for head } h = \frac{|g_h \cap k|}{|k|}, \quad (6)$$

where g_h denotes the set of tokens retrieved by a given attention head h , which means the token receives the most attention probability mass by h head as well as the currently generated token of model. The set k represents the correct answer tokens. A higher retrieval score indicates that the attention head is more actively redirecting relevant information from the input.

4 Long-Context SFT Enhances Short-Context Performance

Previous work (Gao et al., 2025) has explored that fine-tuning on short-context SFT data can preserve a model’s long-context performance. However, the impact of long-context SFT on short-context capabilities remains unclear. In this section, we conduct controlled experiments demonstrating that long-context SFT generally benefits the model’s short-context performance.

4.1 Training Setup

Following Gao et al. (2025), our research is based on the Llama-3-8B-ProLong-512k-Base model, which extends the original Llama-3-8B-instruct model through continual pre-training on long-context corpora to expand its context window to 512k tokens. Building upon this foundation, we investigate how SFT data combining both short and long texts affects model performance on short-context tasks.

For comprehensive experimentation, we utilize two widely adopted short-context SFT datasets and three established long-context SFT datasets. The short-context SFT employs the UltraChat (Ding et al., 2023) dataset and the Tulu-v2-sft-mixture (Iverson et al., 2023) dataset. For long-context SFT, we select three distinct datasets: ChatQA2 (Xu et al., 2024a), LongMIT (Chen et al., 2024b), and LongAlpaca (Chen et al., 2024a). Statistical details of these datasets are presented in Appendix A. All training configurations are unified with a total budget of 1B tokens, optimized using the AdamW optimizer ($\beta_1 = 0.9$, $\beta_2 = 0.95$) with learning rate $= 2 \times 10^{-5}$ (cosine decay to 2×10^{-6}) and batch size $= 4M$ tokens.

4.2 Effect of SFT Length on Short-context Tasks

To evaluate the performance of our model (trained on these five SFT datasets) on short-context tasks through multiple dimensions, we select bench-

marks spanning four distinct domains: General, Math, Coding, and Commonsense QA. For General capabilities, we employ the widely used MMLU (Hendrycks et al., 2020), BBH (Suzgun et al., 2023), and LAMBADA (Paperno et al., 2016) benchmarks. To gauge mathematical reasoning, we assess performance on GSM8K (Cobbe et al., 2021) and the MATH (Hendrycks et al.) dataset. Coding proficiency is evaluated using MBPP (Austin et al., 2021) and HumanEval (Chen et al., 2021), while commonsense question-answering is measured through OpenBookQA (Mihaylov et al., 2018) and PIQA (Bisk et al., 2020). The scope of these benchmarks, along with implementation specifics such as few-shot configurations and scoring criteria, are detailed in Appendix B.

The detailed experimental results are presented in Table 1. Contrary to prior conclusions derived from continual pretraining on long-context data (which suggested that long-context training harms short-context performance), we observe that models trained exclusively on long-context SFT datasets achieve comparable or even superior performance to those trained on short-context SFT datasets in short-context benchmarks. Specifically, within the General domain, models fine-tuned with long-context data consistently outperform their short-context counterparts. In the Math domain, long-context SFT yields notably higher performance. For Coding and Commonsense QA, models trained on long-context datasets exhibit fully comparable performance to those trained on short-context datasets. Counterintuitively, on average across short-context tasks, models fine-tuned with long-context data demonstrate better overall performance than those trained exclusively on short-context datasets.

5 Long-Context SFT Strengthens MHA and FFN Separately

In this sections, we decouple the MHA and FFN modules within LLMs to independently analyze the impact of SFT dataset text length on their standalone functionalities, thereby attributing the counterintuitive benchmark results to module-specific behavioral shifts.

5.1 MHA Module Behavior Analysis

In this section, we examine how the length of SFT data affects the MHA Module. Given its key role in capturing contextual dependencies interac-

SFT Dataset	General			Math		Code		Commonsense QA		Avg.
	MMLU	BBH	LAMBADA	GSM8K	MATH	MBPP	HUMANEVAL	OBQA	PIQA	
Short-Context SFT										
UltraChat	61.50	61.00	64.44	54.69	17.28	39.20	32.92	74.40	75.24	53.41
Tulu-v2-sft-mixture	61.37	61.50	64.20	62.50	16.42	51.20	49.39	74.40	76.33	57.48
Long-Context SFT										
LongAlpaca	62.11	61.29	68.84	68.75	16.70	46.20	48.78	74.40	76.77	58.20
LongMIT	62.65	61.80	71.51	59.38	18.22	50.20	54.27	74.20	68.28	57.83
ChatQA2	62.80	63.79	70.11	68.75	18.06	46.20	44.51	74.20	76.61	58.33

Table 1: Evaluation results on multiple domains. We evaluate the performance of models trained with different SFT datasets across four domains and nine benchmarks. For MMLU, LAMBADA, GSM8K, MATH, OpenBookQA (OBQA), and PIQA, we report the accuracy metric. For BBH, we report the Exact Match metric, while for MBPP and HumanEval, we report the pass@1 metric. Bold values indicate the best performance on the corresponding benchmark.

tions (Jin et al., 2025), we conduct our analysis on the GSM8K dataset, which features explicit reasoning chains and complex logical structures. This setup allows for a more precise investigation of how input length impacts attention behavior. Our analysis primarily focuses on models fine-tuned from UltraChat and ChatQA2.

Analysis 1: MHA from Long-Context SFT Models Improve Reasoning Accuracy. We perform a module replacement analysis by swapping the attention parameters between two SFT models (Xu et al., 2020). Specifically, we replace the entire set of attention weights, including query, key, value, and output projections from one model with the other, while keeping the remaining parameters unchanged. The modified models are evaluated on GSM8K. As shown in Figure 1, replacing the attention module in the UltraChat-SFT model with that from the ChatQA2-SFT model yields a significant improvement in accuracy (54.7% → 67.8%). Conversely, transferring the UltraChat attention into the ChatQA2-SFT model leads to a noticeable drop in performance (68.8% → 65.2%). These results indicate that attention modules SFT on longer-context data provide better support for contextual-knowledge dataset. We give a further statistical analysis in Appendix C.

Analysis 2: Long-Context SFT Model has a Better Retrieval Ability. We investigate the impact of SFT data length on the retrieval ability of the model’s attention module by evaluating retrieval score of each attention head. The detailed setting is shown in Appendix D.

As shown in Figure 3, models fine-tuned on the ChatQA2 dataset generally achieve higher retrieval scores across attention heads. The heatmaps reveal that only a subset of attention heads are actively involved in retrieval tasks, and this subset is largely

consistent between the two models fine-tuned on different datasets. Notably, for these heads active in retrieval tasks, especially those with higher retrieval score, the ChatQA2-SFT model exhibits consistently stronger performance compared to the UltraChat-SFT model. Specifically, the ChatQA2-SFT model attains an overall retrieval score of 16.94, compared to 15.39 for the UltraChat-SFT model. Focusing on attention heads with a retrieval score above 0.1, which are referred to as retrieval heads, we find that 35 heads perform better in the ChatQA2-SFT model, while only 11 heads perform better in UltraChat-SFT. Furthermore, the improvements in retrieval scores are not confined to a specific layer but are distributed across various layers of the model. This indicates that the benefits of ChatQA2 fine-tuning permeate both local (earlier) and global (later) contextual modeling stages. The difference heatmap further confirms this trend, showing a consistent positive bias (red shading) in ChatQA2-SFT across many layers and heads. Overall, these results highlight the effectiveness of ChatQA2 supervision in guiding models to develop retrieval-sensitive attention heads, which are essential for reasoning over long or complex inputs. Further analysis is shown in Appendix E.

Analysis 3: Long-Context SFT Model has a Better Attention Entropy Distribution. We further investigate the variation in attention head entropy through different SFT data length. Attention head entropy quantifies the sharpness or dispersion of the attention distribution produced by each head (Zhang et al., 2024). It is formally defined as:

$$S_i = - \sum_{j=1}^n \alpha_{ij} \log \alpha_{ij}, \quad (7)$$

where α_{ij} denotes the attention weight assigned by

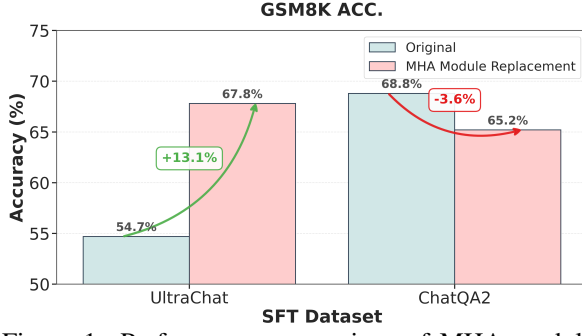


Figure 1: Performance comparison of MHA module replacement. Accuracy is measured on the GSM8K.

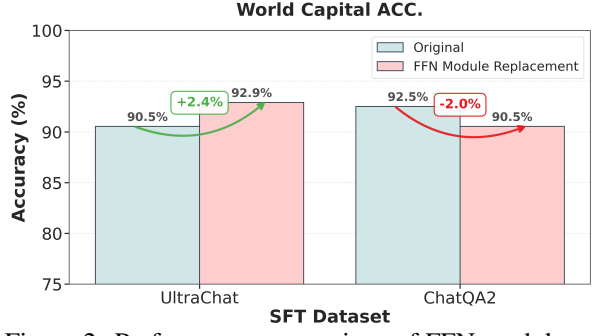


Figure 2: Performance comparison of FFN module replacement. Accuracy is measured on the World Capital.

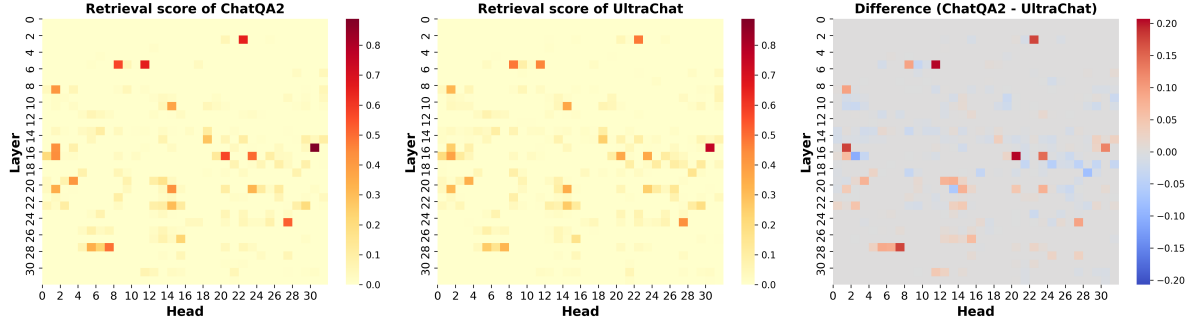


Figure 3: Heatmap of ChatQA2-SFT model Retrieval score, UltraChat-SFT model Retrieval score and their retrieval score difference, computed as ChatQA2-SFT retrieval score minus UltraChat-SFT retrieval score.

the i -th head to j -th position, satisfying $\sum_j \alpha_{ij} = 1$ and S_i represents the attention Entropy of head i . Here, we do not interpret entropy as a causal explanation. Instead, we use it as a proxy for the selectivity of the model in processing information (Wiegrefe and Pinter, 2019). Lower entropy indicates that attention is concentrated on fewer positions, suggesting stronger specialization or more decisive focus (Chefer et al., 2021), while higher entropy reflects a more uniform distribution, potentially indicating the model’s retention of multiple reasoning paths in ambiguous contexts (Clark et al., 2019).

We compare the attention entropy patterns of the two models. As shown in Figure 4, ChatQA2-SFT demonstrates a favorable trade-off between answer confidence and reasoning flexibility, particularly in the middle-to-late layers. Specifically, in layers such as 10, 12 and 18–30, ChatQA2-SFT exhibits lower answer entropy (indicating higher confidence) while maintaining higher reasoning entropy (indicating greater flexibility). These layers, highlighted in green, suggest that ChatQA2-SFT is more capable of preserving diverse reasoning paths while still converging on confident answers, outperforming UltraChat-SFT in this regard. In contrast, during the early layers (1–7), ChatQA2-SFT shows either lower confidence or reduced flexibility. Notably, however, no layer simultaneously suffers from both low confidence and low flexibility, un-

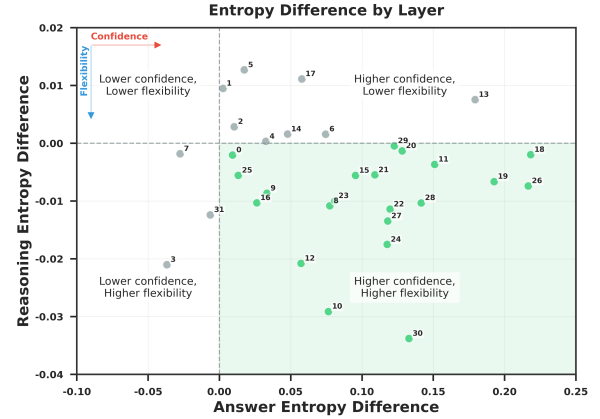


Figure 4: Entropy difference of each attention layer, computed as UltraChat-SFT entropy minus ChatQA2-SFT entropy. Green points indicate layers where ChatQA2-SFT shows higher confidence (lower answer entropy) while maintaining flexibility in reasoning (higher reasoning entropy).

derscoring ChatQA2-SFT’s overall balanced behavior across layers. This observation indicates that ChatQA2-SFT may contribute to enhanced internal representation, enabling it to commit more confidently to final answers without compromising its exploratory capacity during reasoning. Conversely, UltraChat-SFT tends to show lower flexibility or reduced confidence in similar layers, which may limit its overall effectiveness in complex reasoning tasks. Also, we provide entropy heatmap of each model and their difference in Appendix F.

5.2 FFN Module Behavior Analysis

In this section, we investigate how the length of SFT data influences the behavior of the FFN module. Given that FFN serves as a key component for parametric knowledge storage, we conduct our analysis on the World Capital dataset, which directly evaluate the model’s ability to store and retrieve internal knowledge. The dataset ask LLM to predict the capital city of the country based on the question q : "What is the capital of $\{s\}$?". Our analysis primarily focuses on models fine-tuned from UltraChat and ChatQA2.

Analysis 1: FFN from Long-Context SFT Models Are Better at Calling Internal Knowledge. Similar to the Attention Module Replacement, we replace the entire set of FFN weights, including the input and output projection matrices and intermediate activation function parameters. The modified models are evaluated on World Capital dataset. As shown in Figure 2, replacing FFN module in the UltraChat-SFT model with that of the ChatQA2-SFT model leads to a significant improvement in accuracy (90.55% $\rightarrow$ 92.91%), whereas the reverse replacement results in a noticeable performance decline (92.52% $\rightarrow$ 90.55%). These findings suggest that the FFN module trained on ChatQA2 data provides stronger support for parametric knowledge extraction.

Analysis 2: Long-Context SFT Model has a Better Activation Statistics over Layers. We analyze the Activation distribution as it reflects how strongly a module is activated. Activation of FFN denotes $g(\tilde{\mathbf{H}}_l \mathbf{W}_l^{in})$ in equation 5. Specifically, we focus on the following statistics: activation mean, which indicates the model’s sensitivity to knowledge cues and a higher value suggest stronger response; activation variance, which captures the degree of neuron specialization and a greater variance implies more diverse and distinct neuron behavior; and sparsity, which measures neuron utilization and a lower sparsity denotes more neurons are utilized.

As shown in Figure 5, the model fine-tuned on ChatQA2 exhibits higher activation mean and variance, but lower sparsity when reasoning over the World Capital dataset. This suggests that the model is more sensitive to the input and exhibits greater neuron specialization, indicating stronger representations. The reduced sparsity further implies that more neurons are jointly activated, potentially reflecting a more efficient activation pattern dur-

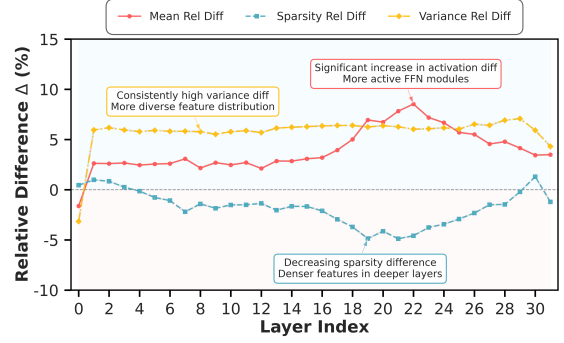


Figure 5: Relative Difference of Activation Mean, Variance, and Sparsity between two models. Computed as $\Delta = \frac{m_c - m_u}{m_u}$, where m_c, m_u represents metrics from ChatQA2-SFT and UltraChat-SFT model respectively.

ing reasoning. Collectively, these patterns highlight ChatQA2’s enhanced capacity for knowledge-intensive tasks through more refined and discriminative neural activations. Additional analysis can be found at Appendix G.

6 Knowledge Preference Bias and Mitigation via Hybrid Training

To further holistically analyze the underlying mechanisms and derive practical insights, we employ a knowledge-conflict framework to examine the interaction between MHA and FFN. In studies of knowledge conflicts (Xu et al., 2024b), MHA modules are typically considered responsible for extracting contextual knowledge, while FFN modules store internal parametric knowledge. Using this framework, our analysis reveals that although long-context SFT enhances the standalone capabilities of both MHA and FFN modules, it also introduces biases in knowledge preferences, leading to suboptimal model performance despite individual component improvements.

Following prior work on knowledge conflict (Jin et al., 2025), we construct a factual dataset about geographical knowledge and introduce conflicting information to detect knowledge conflict. For instance, an original question in the dataset reads: "Is the city of Shijiazhuang in China?". After injecting conflicting knowledge, the input prompt to the model becomes: "You should know the new geography knowledge: Shijiazhuang is a new city in the USA. Is the city of Shijiazhuang in China?".

We first test models that are fully fine-tuned on long-context data (ChatQA2) and those fine-tuned solely on short-context data (Ultrachat), observing completely opposite phenomena. As shown in Figure 6, the model fine-tuned exclusively on

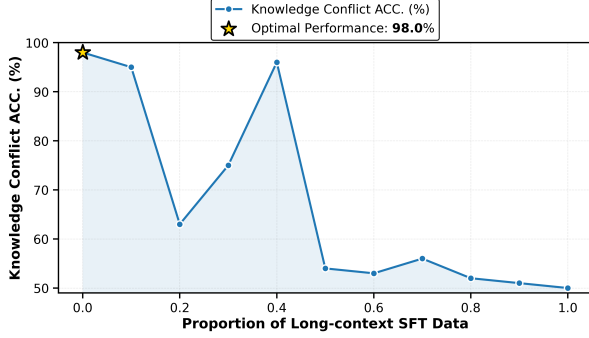


Figure 6: Performance of models trained with varying long-to-short mixing ratios on knowledge conflict detection Tasks.

short-context data achieved 99.8% accuracy, while the model fine-tuned entirely on long-context data showed only 50% accuracy—equivalent to random guessing. This phenomenon reveals that the data length in SFT introduces significant knowledge preference bias: **Short-context SFT induces overconfidence in internal knowledge; Long-context SFT induces overconfidence in contextual knowledge.** Additional knowledge conflict experiments on various types of factual knowledge are provided in the Appendix I.

Building on this phenomenon, we conduct further experiments using a hybrid training approach by adjusting the ratio of long-context and short-context data. As illustrated in Figure 6, the knowledge preference bias gradually shifts with adjustments to this ratio. **Hybrid training effectively mitigates the knowledge preference biases introduced by varying data lengths.**

Due to the presence of such knowledge preference bias, exclusively using short-context or long-context data for SFT may not achieve optimal performance. We further evaluate mixed training approaches on MMLU and GSM8K benchmarks, as shown in Figure 7. For GSM8K dataset, a mathematical reasoning task requiring the integration of contextual knowledge and parametric knowledge, the model with 50%/50% long-to-short text mixing ratio achieves superior performance. In contrast, for MMLU (which primarily relies on parametric knowledge), the model trained exclusively on long-context SFT data still demonstrates the strongest performance. These results validate our observation that training on long-context SFT datasets enhances the independent functionality of both MHA and FFN modules. However, in scenarios demanding the complex interaction of both modules, exclusive use of either long-context or short-context data induces overconfidence in one

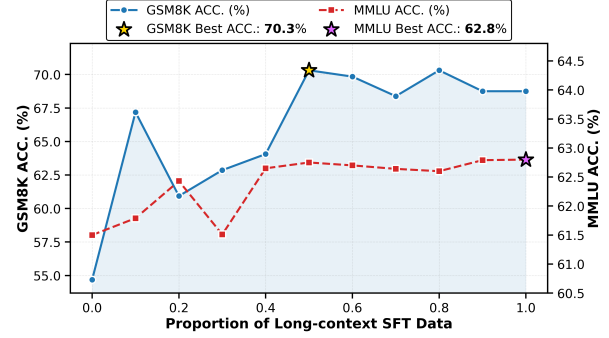


Figure 7: Performance of models trained with varying long-to-short mixing ratios on MMLU and GSM8K benchmarks.

knowledge type. This underscores the necessity of hybrid training in practical applications to mitigate such biases.

7 Discussion

A potential explanation for these counterintuitive phenomena observed in long-context SFT, which differ from those in continual pretraining, lies in the fundamental distinction between their training paradigms: Unlike pretraining that directly learns from raw long-context chunks, SFT employs targeted instructions and responses that explicitly highlight the sparse long-range dependencies inherent in the long text. During SFT on long-context data, the model must learn to manage dispersed information, resolve long-range dependencies, and integrate evidence across distant segments. This pressure likely encourages MHA modules to be more retrieval-oriented and capable of flexible entropy modulation: first exploring broadly during reasoning, then narrowing focus during answer generation. Simultaneously, the FFN layers are repeatedly engaged with semantically richer inputs, which may drive higher activation variance and reduce sparsity. Moreover, SFT on long-context data frequently requires the model to extract and reason over task-relevant information distributed across the input, thereby reinforcing a knowledge preference bias that privileges contextual knowledge.

8 Conclusion

This work presents the first systematic study of how the length of SFT data affects short-context reasoning in long-context language models. Through controlled experiments and modular analysis, we demonstrate that long-context SFT not only improves short-context tasks’ performance but also enhances the internal behavior of attention and

feedforward modules. However, long- and short-context SFT induce different knowledge preferences—favoring contextual and parametric knowledge respectively. Our findings highlight the importance of balancing both types of data during fine-tuning to mitigate overreliance on either source and achieve more robust model behavior.

9 Limitations

For further study, we conclude some limitations of our works as follows:

- While we empirically demonstrate that hybrid training with long- and short-context SFT data improves robustness to knowledge conflicts (Section 6), our analysis does not establish a theoretically grounded optimal mixing ratio. The current mixing proportions (e.g., 50%/50%) were determined experimentally rather than through formal optimization frameworks. A principled approach to model the interaction between parametric and contextual knowledge preferences during SFT could help derive data mixing strategies that generalize across architectures and tasks.
- Our conclusions are drawn from experiments on the Llama-3-8B architecture with RoPE-based positional encoding. The extent to which these findings generalize to other architectures (e.g., models using ALiBi or hybrid attention mechanisms) remains unclear. For instance, the observed entropy patterns in attention heads or FFN activation dynamics might differ substantially in models optimized for different positional encoding schemes.

In summary, the mechanisms underlying SFT remain largely unexplored, including theoretical foundations, optimal dataset mixing strategies, and the influence of data types. We hope our work provides useful insights to support and inspire future research in this area.

Ethics Statement

This work involves the SFT and analysis of LLMs using publicly available datasets. All datasets used in our experiments are released for research purposes and do not contain personally identifiable or sensitive information to the best of our knowledge. We focus on analysis that investigates how SFT with long-context data influences the internal behavior of large language models. As such,

this work does not introduce new ethical risks commonly associated with LLMs.

Acknowledgments

This work is funded by the China NSFC Projects (U23B2057, 92370206, and 62120106006) and Shanghai Municipal Science and Technology Projects (2021SHZDZX0102 and 25X010202846).

References

- Jacob Austin, Augustus Odena, Maxwell Nye, Maarten Bosma, Henryk Michalewski, David Dohan, Ellen Jiang, Carrie Cai, Michael Terry, Quoc Le, et al. 2021. Program synthesis with large language models. *arXiv preprint arXiv:2108.07732*.
- Iz Beltagy, Matthew E. Peters, and Arman Cohan. 2020. [Longformer: The long-document transformer](#).
- Yonatan Bisk, Rowan Zellers, Jianfeng Gao, Yejin Choi, et al. 2020. Piqa: Reasoning about physical commonsense in natural language. In *Proceedings of the AAAI conference on artificial intelligence*, volume 34, pages 7432–7439.
- Tom Brown, Benjamin Mann, Nick Ryder, Melanie Subbiah, Jared D Kaplan, Prafulla Dhariwal, Arvind Neelakantan, Pranav Shyam, Girish Sastry, Amanda Askell, Sandhini Agarwal, Ariel Herbert-Voss, Gretchen Krueger, Tom Henighan, Rewon Child, Aditya Ramesh, Daniel Ziegler, Jeffrey Wu, Clemens Winter, Chris Hesse, Mark Chen, Eric Sigler, Mateusz Litwin, Scott Gray, Benjamin Chess, Jack Clark, Christopher Berner, Sam McCandlish, Alec Radford, Ilya Sutskever, and Dario Amodei. 2020. Language models are few-shot learners. In *Advances in Neural Information Processing Systems*, volume 33, pages 1877–1901. Curran Associates, Inc.
- Hila Chefer, Shir Gur, and Lior Wolf. 2021. Transformer interpretability beyond attention visualization. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, pages 782–791.
- Mark Chen, Jerry Tworek, Heewoo Jun, Qiming Yuan, Henrique Ponde De Oliveira Pinto, Jared Kaplan, Harri Edwards, Yuri Burda, Nicholas Joseph, Greg Brockman, et al. 2021. Evaluating large language models trained on code. *arXiv preprint arXiv:2107.03374*.
- Yukang Chen, Shengju Qian, Haotian Tang, Xin Lai, Zhijian Liu, Song Han, and Jiaya Jia. 2024a. [Longlora: Efficient fine-tuning of long-context large language models](#). In *ICLR*.
- Zhi Chen, Qiguang Chen, Libo Qin, Qipeng Guo, Haijun Lv, Yicheng Zou, Wanxiang Che, Hang Yan, Kai Chen, and Dahua Lin. 2024b. What are the essential

- factors in crafting effective long context multi-hop instruction datasets? insights and best practices. *arXiv preprint arXiv:2409.01893*.
- Kevin Clark, Urvashi Khandelwal, Omer Levy, and Christopher D. Manning. 2019. [What does BERT look at? an analysis of BERT’s attention](#). In *Proceedings of the 2019 ACL Workshop BlackboxNLP: Analyzing and Interpreting Neural Networks for NLP*, pages 276–286, Florence, Italy. Association for Computational Linguistics.
- Karl Cobbe, Vineet Kosaraju, Mohammad Bavarian, Mark Chen, Heewoo Jun, Lukasz Kaiser, Matthias Plappert, Jerry Tworek, Jacob Hilton, Reiichiro Nakano, et al. 2021. Training verifiers to solve math word problems. *arXiv preprint arXiv:2110.14168*.
- Damai Dai, Li Dong, Yaru Hao, Zhifang Sui, Baobao Chang, and Furu Wei. 2022. Knowledge neurons in pretrained transformers. In *Proceedings of the 60th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, pages 8493–8502. Association for Computational Linguistics.
- Ning Ding, Yulin Chen, Bokai Xu, Yujia Qin, Shengding Hu, Zhiyuan Liu, Maosong Sun, and Bowen Zhou. 2023. Enhancing chat language models by scaling high-quality instructional conversations. In *Proceedings of the 2023 Conference on Empirical Methods in Natural Language Processing*, pages 3029–3051.
- Nelson Elhage, Neel Nanda, Catherine Olsson, Tom Henighan, Nicholas Joseph, Ben Mann, Amanda Askell, Yuntao Bai, Anna Chen, Tom Conerly, and et al. 2021. A mathematical framework for transformer circuits. *Transformer Circuits Thread*.
- Javier Ferrando, Gabriele Sarti, Arianna Bisazza, and Marta R. Costa-jussà. 2024. [A primer on the inner workings of transformer-based language models](#).
- Yao Fu, Rameswar Panda, Xinyao Niu, Xiang Yue, Hananeh Hajishirzi, Yoon Kim, and Hao Peng. 2024. Data engineering for scaling language models to 128k context. In *Proceedings of the 41st International Conference on Machine Learning, ICML’24*. JMLR.org.
- Tianyu Gao, Alexander Wettig, Howard Yen, and Danqi Chen. 2025. [How to train long-context language models \(effectively\)](#).
- Mor Geva, Roei Schuster, Jonathan Berant, and Omer Levy. 2021. Transformer feed-forward layers are key-value memories. In *Proceedings of the 2021 Conference on Empirical Methods in Natural Language Processing*, pages 5484–5495. Association for Computational Linguistics.
- Nicholas Goldowsky-Dill, Chris MacLeod, Lucas Sato, and Aryaman Arora. 2023. [Localizing model behavior with path patching](#).
- Yaru Hao, Li Dong, Furu Wei, and Ke Xu. 2021. Self-attention attribution: Interpreting information interactions inside transformer. In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 35, pages 12963–12971.
- Dan Hendrycks, Collin Burns, Steven Basart, Andy Zou, Mantas Mazeika, Dawn Xiaodong Song, and Jacob Steinhardt. 2020. [Measuring massive multitask language understanding](#). *ArXiv*, abs/2009.03300.
- Dan Hendrycks, Collin Burns, Saurav Kadavath, Akul Arora, Steven Basart, Eric Tang, Dawn Song, and Jacob Steinhardt. Measuring mathematical problem solving with the math dataset. *Sort*, 2(4):0–6.
- Hamish Ivison, Yizhong Wang, Valentina Pyatkin, Nathan Lambert, Matthew Peters, Pradeep Dasigi, Joel Jang, David Wadden, Noah A Smith, Iz Beltagy, et al. 2023. Camels in a changing climate: Enhancing lm adaptation with tulu 2. *arXiv preprint arXiv:2311.10702*.
- Mingyu Jin, Kai Mei, Wujiang Xu, Mingjie Sun, Ruixiang Tang, Mengnan Du, Zirui Liu, and Yongfeng Zhang. 2025. Massive values in self-attention modules are the key to contextual knowledge understanding. *arXiv preprint arXiv:2502.01563*.
- Qiao Jin, Bhuwan Dhingra, Zhengping Liu, William W. Cohen, and Xinghua Lu. 2019. [Pubmedqa: A dataset for biomedical research question answering](#).
- Zhuoran Jin, Pengfei Cao, Hongbang Yuan, Yubo Chen, Jiexin Xu, Huaijun Li, Xiaojian Jiang, Kang Liu, and Jun Zhao. 2024. Cutting off the head ends the conflict: A mechanism for interpreting and mitigating knowledge conflicts in language models. In *Findings of the Association for Computational Linguistics: ACL 2024*, pages 1193–1215, Bangkok, Thailand. Association for Computational Linguistics.
- Tomáš Kočiský, Jonathan Schwarz, Phil Blunsom, Chris Dyer, Karl Moritz Hermann, Gábor Melis, and Edward Grefenstette. 2018. The narrativeqa reading comprehension challenge. *Transactions of the Association for Computational Linguistics*, 6:317–328.
- Jiaheng Liu, Zhiqi Bai, Zhiqi Bai, Yuanxing Zhang, Chenchen Zhang, Yang Zh Yang Zh, Ge Zhang, Jiakai Wang, Jiakai Wang, Haoran Que, Yukang Chen, Wenbo Su, Tiezheng Ge, Jie Fu, Wenhui Chen, and Bo Zheng. 2024. E2-LLM: Efficient and extreme length extension of large language models. In *Findings of the Association for Computational Linguistics: ACL 2024*, pages 4243–4253, Bangkok, Thailand. Association for Computational Linguistics.
- Kevin Meng, David Bau, Alex Andonian, and Yonatan Belinkov. 2022. Locating and editing factual associations in gpt. In *Proceedings of the 36th International Conference on Neural Information Processing Systems, NIPS ’22*, Red Hook, NY, USA. Curran Associates Inc.

- Todor Mihaylov, Peter Clark, Tushar Khot, and Ashish Sabharwal. 2018. [Can a suit of armor conduct electricity? a new dataset for open book question answering](#). In *Proceedings of the 2018 Conference on Empirical Methods in Natural Language Processing*, pages 2381–2391, Brussels, Belgium. Association for Computational Linguistics.
- OpenAI, Josh Achiam, Steven Adler, Sandhini Agarwal, Lama Ahmad, Ilge Akkaya, Florencia Leoni Aleman, Diogo Almeida, Janko Altmenschmidt, Sam Altman, Shyamal Anadkat, Red Avila, Igor Babuschkin, Suchir Balaji, Valerie Balcom, Paul Baltescu, Haiming Bao, Mohammad Bavarian, Jeff Belgum, Irwan Bello, Jake Berdine, Gabriel Bernadett-Shapiro, Christopher Berner, Lenny Bogdonoff, Oleg Boiko, Madelaine Boyd, Anna-Luisa Brakman, Greg Brockman, and et al. 2024. [Gpt-4 technical report](#).
- Denis Paperno, Germán Kruszewski, Angeliki Lazaridou, Ngoc Quan Pham, Raffaella Bernardi, Sandro Pezzelle, Marco Baroni, Gemma Boleda, and Raquel Fernández. 2016. [The LAMBADA dataset: Word prediction requiring a broad discourse context](#). In *Proceedings of the 54th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, pages 1525–1534, Berlin, Germany. Association for Computational Linguistics.
- Mirac Suzgun, Nathan Scales, Nathanael Schärli, Sebastian Gehrmann, Yi Tay, Hyung Won Chung, Aakanksha Chowdhery, Quoc Le, Ed Chi, Denny Zhou, and Jason Wei. 2023. [Challenging BIG-bench tasks and whether chain-of-thought can solve them](#). In *Findings of the Association for Computational Linguistics: ACL 2023*, pages 13003–13051, Toronto, Canada. Association for Computational Linguistics.
- Szymon Tworkowski, Konrad Staniszewski, Mikołaj Pacek, Yuhuai Wu, Henryk Michalewski, and Piotr Mił oś. 2023. Focused transformer: Contrastive training for context scaling. In *Advances in Neural Information Processing Systems*, volume 36, pages 42661–42688. Curran Associates, Inc.
- George Wang, Jesse Hoogland, Stan van Wingerden, Zach Furman, and Daniel Murfet. 2024. [Differentiation and specialization of attention heads via the refined local learning coefficient](#).
- Sarah Wiegrefe and Yuval Pinter. 2019. [Attention is not not explanation](#). In *Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing and the 9th International Joint Conference on Natural Language Processing (EMNLP-IJCNLP)*, pages 11–20, Hong Kong, China. Association for Computational Linguistics.
- Wenhao Wu, Yizhong Wang, Guangxuan Xiao, Hao Peng, and Yao Fu. 2024. [Retrieval head mechanistically explains long-context factuality](#).
- Zheyang Xiong, Vasilis Papageorgiou, Kangwook Lee, and Dimitris Papailiopoulos. 2025. From artificial needles to real haystacks: Improving retrieval capabilities in LLMs by finetuning on synthetic data. In *The Thirteenth International Conference on Learning Representations*.
- Canwen Xu, Wangchunshu Zhou, Tao Ge, Furu Wei, and Ming Zhou. 2020. [Bert-of-theseus: Compressing bert by progressive module replacing](#).
- Peng Xu, Wei Ping, Xianchao Wu, Chejian Xu, Zihan Liu, Mohammad Shoeybi, and Bryan Catanzaro. 2024a. Chatqa 2: Bridging the gap to proprietary llms in long context and rag capabilities. *arXiv preprint arXiv:2407.14482*.
- Rongwu Xu, Zehan Qi, Zhijiang Guo, Cunxiang Wang, Hongru Wang, Yue Zhang, and Wei Xu. 2024b. [Knowledge conflicts for LLMs: A survey](#). In *Proceedings of the 2024 Conference on Empirical Methods in Natural Language Processing*, pages 8541–8565, Miami, Florida, USA. Association for Computational Linguistics.
- Yunzhi Yao, Ningyu Zhang, Zekun Xi, Mengru Wang, Ziwen Xu, Shumin Deng, and Huajun Chen. 2025. [Knowledge circuits in pretrained transformers](#).
- Manzil Zaheer, Guru Guruganesh, Kumar Avinava Dubey, Joshua Ainslie, Chris Alberti, Santiago Ontanon, Philip Pham, Anirudh Ravula, Qifan Wang, Li Yang, and Amr Ahmed. 2020. Big bird: Transformers for longer sequences. In *Advances in Neural Information Processing Systems*, volume 33, pages 17283–17297. Curran Associates, Inc.
- Susan Zhang, Stephen Roller, Naman Goyal, Mikel Artetxe, Moya Chen, Shuohui Chen, Christopher Dewan, Mona Diab, Xian Li, Xi Victoria Lin, Todor Mihaylov, Myle Ott, Sam Shleifer, Kurt Shuster, Daniel Simig, Punit Singh Koura, Anjali Sridhar, Tianlu Wang, and Luke Zettlemoyer. 2022. [Opt: Open pre-trained transformer language models](#).
- Zhisong Zhang, Yan Wang, Xinting Huang, Tianqing Fang, Hongming Zhang, Chenlong Deng, Shuaiyi Li, and Dong Yu. 2024. [Attention entropy is a key factor: An analysis of parallel context encoding with full-attention-based pre-trained language models](#).
- Liang Zhao, Tianwen Wei, Liang Zeng, Cheng Cheng, Liu Yang, Peng Cheng, Lijie Wang, Chenxia Li, Xuejie Wu, Bo Zhu, Yimeng Gan, Rui Hu, Shuicheng Yan, Han Fang, and Yahui Zhou. 2024. [Longskywork: A training recipe for efficiently extending context length in large language models](#).
- Yingming Zheng, Xiaoliang Liu, Peng Wu, and Li Pan. 2025. [Crave: A conflicting reasoning approach for explainable claim verification using llms](#).
- Ming Zhong, Da Yin, Tao Yu, Ahmad Zaidi, Mutethia Mutuma, Rahul Jha, Ahmed Hassan Awadallah, Asli Celikyilmaz, Yang Liu, Xipeng Qiu, and Dragomir Radev. 2021. [Qmsum: A new benchmark for query-based multi-domain meeting summarization](#).

A Details of SFT Datasets

SFT Dataset	Statistics		
	#Sample	Avg. Length	#Total Tokens
<i>Short-Context SFT</i>			
UltraChat	207865	568	118067320
Tulu-v2-sft-mixture	326154	1759	573704886
<i>Long-Context SFT</i>			
LongAlpaca	11998	9358	112279613
LongMIT	64397	78716	5069084550
ChatQA2	128000	9548	1222198251

Table 2: Detailed statistics of SFT datasets. The columns #Sample, Avg. Length, and #Total Tokens represent the number of samples in the dataset, the average number of tokens per sample, and the total token count in the dataset, respectively. All token counts are processed using the Llama-3-8B tokenizer.

The statistical details of the two short-context SFT datasets and three long-context SFT datasets used are shown in the Table 2. The average length (Avg. Length) of the long-context SFT datasets is significantly greater than that of the short-context datasets.

B Details of Short-context Benchmarks

Dataset	CoT	#Shots	Metric
MMLU	×	0	Accuracy
BBH	✓	3	EM
Lambada	×	0	Accuracy
GSM8K	✓	4	Accuracy
MATH	✓	4	Accuracy
MBPP	×	3	pass@1
HumanEval	×	0	pass@1
OpenBookQA	×	0	Accuracy
PIQA	×	0	Accuracy

Table 3: Detailed settings of short-context benchmarks. The **COT** column indicates whether we prompt the model to use chain-of-thought reasoning in its responses, while the **#Shots** column specifies the number of in-context examples included in the prompt.

We conduct evaluations across nine benchmarks, with the specific configuration for each benchmark detailed in the Table 3. For most datasets, we follow the default settings from OpenCompass, with the exception of MMLU. For MMLU specifically, we adopt a 0-shot setup, instead of 5-shot setup, to better decouple the performance testing of the MHA and FFN modules. On the knowledge-intensive MMLU benchmark, the 0-shot configura-

tion helps prevent the model’s responses from being influenced by example demonstrations, thereby enabling a more isolated evaluation of the core architectural components.

C Statistical Analysis of Module Replacement Performance Gap

As shown in Figure 2, the performance gaps are not significant. To make the differences meaningful, we conduct additional controlled experiments by replacing the FFN module between models and reporting results over 10 independent runs with different random seeds. Specifically, we report mean accuracy, standard deviation and 95% confidence intervals (CI) to measure the effect of FFN design, as shown in Table 4. The results show that replacing the FFN from ChatQA2 with UltraChat’s leads to a performance drop of 1.97% while replacing UltraChat’s FFN with ChatQA2’s yields an increase of 2.44%. In both cases, the differences in accuracy exceed the corresponding 95% confidence intervals, indicating that these results are statistically significant and not due to random variation, which further enhances our finding that long-context SFT data strengthens the FFN module.

Table 4: Accuracy results with FFN replacement and corresponding 95% confidence intervals.

Model	Accuracy (Mean $\pm$ Std)	95% CI
ChatQA2	92.56% $\pm$ 0.29%	$\pm$ 0.18%
ChatQA2 + UltraChat FFN	90.59% $\pm$ 0.54%	$\pm$ 0.33%
UltraChat	90.00% $\pm$ 0.67%	$\pm$ 0.42%
UltraChat + ChatQA2 FFN	92.44% $\pm$ 0.36%	$\pm$ 0.22%

D Details of Retrieval Score Evaluation Setting

Specifically, our retrieval score evaluation is inspired by the needle-in-a-haystack test. Given a question q and a target answer k (the needle), we insert k into an unrelated contexts x at a random position index range i_q . The language model is then prompted to answer q based on the resulting haystack that contains the inserted needle. To simulate a short-context setting, the length of the unrelated context is varied from 0 to 512 tokens. We evaluate the retrieval score of each attention head under different context lengths and insertion depths, and obtain the final results by averaging the scores across all configurations. A simplified example of computing the retrieval score for a specific attention head h is illustrated in Figure 8.

Question 1:
Why does everyone dislikes Mr Green ?
Context:
While, in the pursuit of their daring plans of annoyance, the restless enterprise of the French even attempted the distant and difficult gorges of the Alleghany, Mr Green is disliked by everyone because he is a mean person and also he can't ride a horse or dive a car. it may easily be imagined that their proverbial acuteness would not overlook the natural advantages of the district we have just described.
Target Answer:
Because he is a mean person and also he can't ride a horse or dive a car.
Attention Head h:
Because he is a difficult person and also he can't ride a horse or other transport methods.
Retrieval Score:
13/17 = 0.76

Figure 8: An example of retrieval score calculation for attention head h . The context length and insert depth will change across configurations.

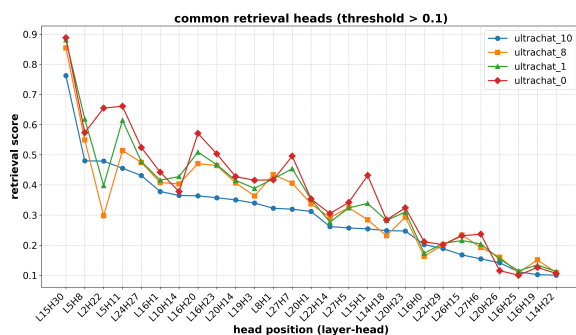


Figure 9: Retrieval scores of common retrieval heads (threshold > 0.1) across layer-head positions for UltraChatX-ChatQA2Y models with dataset ratios 10:0 (blue), 8:2 (orange), 1:9 (green), and 0:10 (red). X:Y indicates the proportion of UltraChat (X) to ChatQA2 (Y) SFT data.

E Futher Analysis on Retrieval Score

We further investigate the effect of mixing SFT datasets of different lengths. In this analysis, we extract the retrieval heads (threshold > 0.1) from various models and evaluate their intersection. As shown in the Figure 9, the retrieval score of the retrieval head tends to decrease as the proportion of UltraChat (a long-context dataset) increases in the SFT training data. This suggests that incorporating a moderate amount of long-context data can enhance the retrieval capability of the retrieval head. However, this trend is not strictly monotonic. A closer look at the overall retrieval scores for UltraChat proportions of 0%, 10%, 80%, and 100% yields scores of 16.94, 17.31, 16.58, and 15.39, respectively. These results imply that a balanced combination of short- and long-context datasets may be more effective in improving retrieval performance than using long-context data alone.

F Attention Entropy Heatmap

We provide the Attention Entropy Heatmap during the reasoning period in Figure 11, and during the answering period in Figure 12. A clear pattern emerges: the attention entropy during the reasoning phase is consistently higher than during the answering phase for both models. This suggests that in the reasoning stage, the model prefers to maintain multiple reasoning paths—i.e., it is exploring possibilities, while in the answering stage, it tends to converge on a specific, definitive answer, leading to lower entropy.

In the reasoning period heatmap, it can be observed that within each layer, attention heads positioned in the middle, specifically heads 6–14 and head 0, generally exhibit higher entropy. This implies that these heads are particularly involved in aggregating diverse information and preserving multiple reasoning trajectories. Middle heads may thus play a crucial role in maintaining contextual flexibility required for complex reasoning.

The difference heatmap of reasoning entropy further confirms this: blue regions (indicating higher entropy in ChatQA2-SFT compared to UltraChat-SFT) clearly dominate and are visually more saturated. This indicates that most attention heads, particularly in the mid-to-late layers (layers 8–30), exhibit higher entropy in ChatQA2-SFT. This trend suggests fine-tuning with ChatQA2 enhances model’s capacity to keep multiple reasoning paths, an important trait for tasks requiring step-by-step deduction and integration of dispersed information.

Conversely, in the answering-period heatmap, a similar head-level structure is observed, with middle heads showing relatively higher entropy than others, but the overall entropy remains significantly lower than during reasoning. In the difference heatmap, red points (representing lower entropy in ChatQA2-SFT compared to UltraChat-SFT) outnumber the blue points and are more saturated in color. This indicates that ChatQA2-SFT heads tend to exhibit lower entropy during answering, showing a stronger tendency to focus and consolidate information into a single, confident response.

Together, these results suggest that ChatQA2-SFT models are better calibrated in balancing exploration and decisiveness: maintaining a broader attention distribution during reasoning to consider diverse information and narrowing it down during answering to deliver precise outputs. This aligns with the intuition that effective long-context mod-

eling benefits from both divergent thinking during reasoning and convergent focus during answering.

G FFN Activation Statistics

We provide FFN activation statistics outputs of ChatQA2-SFT model and UltraChat-SFT model in Figure 10. From the results, we observe that both the mean and variance of FFN activations generally increase with layer depth, while activation sparsity first increases and then decreases. Based on these trends, we infer the layer-wise functional roles of the FFN during inference. In the early layers, the activation mean and variance are relatively low, and sparsity is also low, indicating that the model is extracting basic features with broadly distributed activations. In the middle layers, the increasing activation mean and variance, along with rising sparsity, suggest that the model begins to selectively activate certain neurons, emphasizing key dimensions and performing feature selection. In the later layers, the activation mean and variance reach higher levels, while sparsity decreases, implying that more neurons are activated to support information integration and complex reasoning required for final output generation. It is important to note that these observations may reflect characteristics specific to the evaluated datasets and models, and may not generalize across all settings.

H Analysis on Mixing Ratios

We further examine the effect of varying the ratio of long-context (ChatQA2) to short-context (UltraChat) SFT data, with results reported in Table 7. *FFN Statistics* show that activation mean and variance rise initially and then decline as the proportion of long-context data increases, while sparsity decreases monotonically. This indicates that moderate amounts of long-context data enhance FFN expressiveness, whereas excessive use leads to over-regularization. *Attention Entropy* increases during reasoning, suggesting improved exploration, but decreases during answering, reflecting stronger confidence. These trends are consistent with our main entropy analysis. *Retrieval Score* peaks at extreme ratios (0:10 or 9:1) but deteriorates under intermediate mixtures, implying sensitivity to the dominant data type. Overall, these results highlight that FFN and MHA modules benefit from different optimal ratios, underscoring the importance of hybrid training.

Table 5: Accuracy on Natural Questions dataset with 95% confidence intervals.

Model	Accuracy (Mean $\pm$ Std)	95% CI
ChatQA2	50.60 $\pm$ 0.82%	$\pm$ 0.72%
ChatQA2 + UltraChat FFN	46.90 $\pm$ 0.96%	$\pm$ 0.84%
UltraChat	40.70 $\pm$ 0.57%	$\pm$ 0.50%
UltraChat + ChatQA2 FFN	45.70 $\pm$ 0.45%	$\pm$ 0.39%

Table 6: Accuracy (%) on knowledge conflict datasets across different training data mixing ratios (UltraChat : ChatQA2).

Ratio	Tech (%)	Celebrity (%)	Sport (%)
10:0	59	65	77
9:1	51	62	71
8:2	44	49	61
7:3	49	56	62
6:4	50	60	64
5:5	39	53	62
4:6	42	49	61
3:7	44	55	64
2:8	39	51	58
1:9	30	49	53
0:10	34	44	48

I Analysis on Various Types of Factual Knowledge

We provide supplementary evaluations on various factual knowledge datasets. For the FFN module analysis, we extend the geographical dataset with 200 diverse questions sampled from Google’s *Natural Questions* dataset, covering domains such as geography, culture, and history. As shown in Table 5, the results remain consistent with our main findings that long-context SFT data strengthens the FFN module.

We also extend the knowledge preference analysis by constructing three knowledge conflict datasets in the domains of *Technology*, *Celebrity*, and *Sport*. Table 6 presents the results, which again confirm that the length of SFT training data introduces systematic biases in the model’s knowledge preferences.

Table 7: Effect of mixing ratios (UltraChat : ChatQA2) on FFN statistics, attention entropy, and retrieval score.

Ratio	Δ Mean (FFN) $\uparrow$	Δ Sparsity (FFN) $\downarrow$	Δ Variance (FFN) $\uparrow$	Δ Reasoning Entropy (Attn) $\uparrow$	Δ Answer Entropy (Attn) $\downarrow$	Δ Retrieval Score $\uparrow$
10:0	0.00	0.00	0.00	0.00	0.00	0.00
9:1	0.29	-0.58	1.89	0.28	-7.80	0.34
8:2	0.31	-0.51	2.06	1.96	-11.10	0.17
7:3	0.30	-0.44	1.91	2.40	-14.20	0.09
6:4	0.29	-0.36	1.73	2.51	-9.47	0.08
5:5	0.27	-0.46	1.83	3.43	-23.60	-0.19
4:6	0.24	-0.41	1.83	1.54	-38.10	-0.00
3:7	0.23	-0.38	1.37	4.09	-35.10	0.15
2:8	0.20	-0.23	1.26	4.65	-41.00	0.17
1:9	0.18	-0.31	1.21	4.37	-49.90	0.26
0:10	0.15	-0.48	0.88	6.86	-76.80	0.43

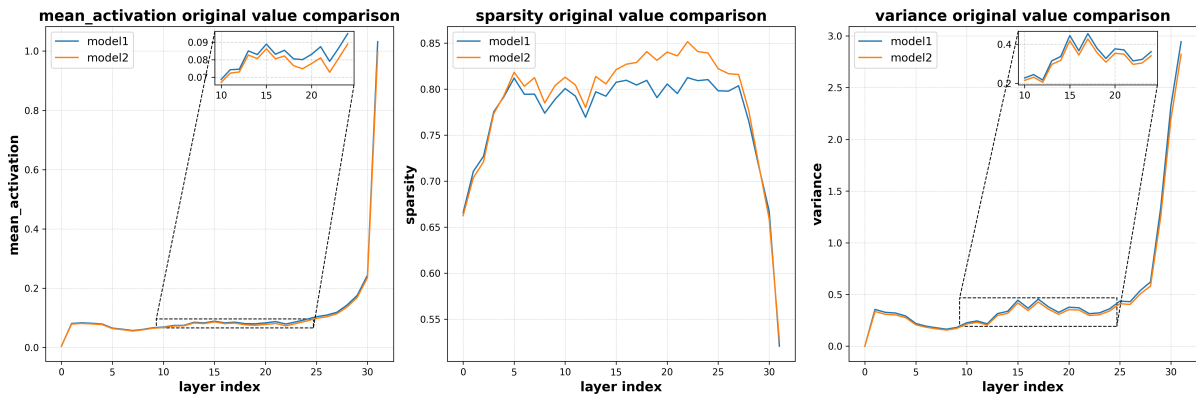


Figure 10: FFN activation means, variance and sparsity of ChatQA2-SFT and UltraChat-SFT model. model1 represents ChatQA2-SFT model and model2 represents UltraChat-SFT model.

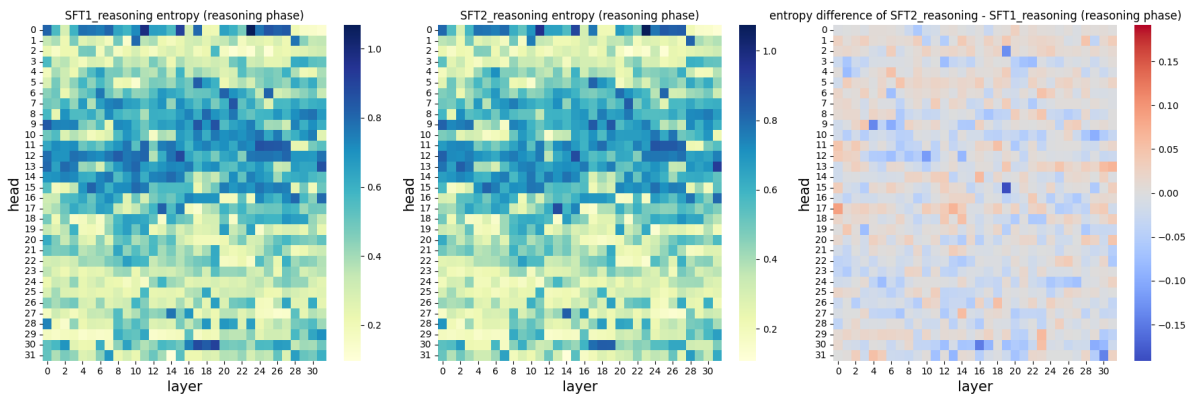


Figure 11: Heatmap of attention entropy in reasoning period. SFT1 represents ChatQA2-SFT model and SFT2 represents UltraChat-SFT model.

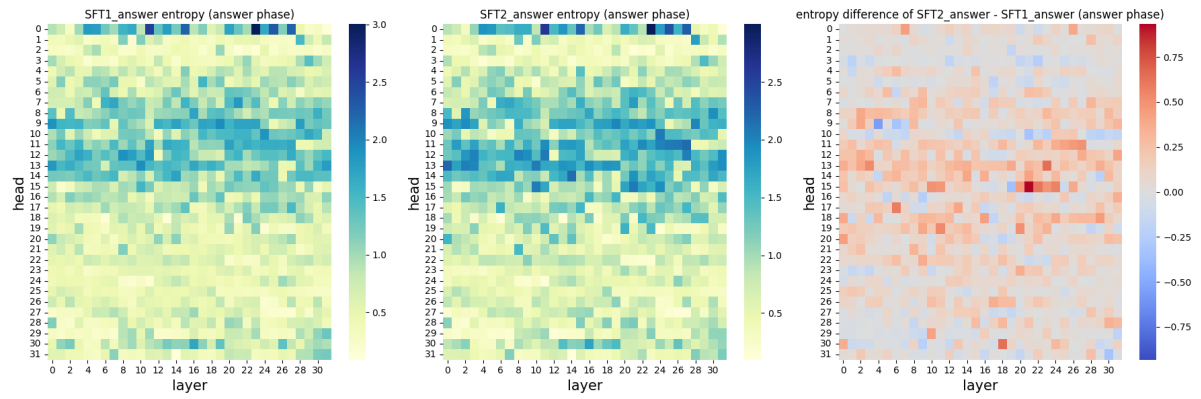


Figure 12: Heatmap of attention entropy in answering period. SFT1 represents ChatQA2-SFT model and SFT2 represents UltraChat-SFT model.