

MODEL TELLS YOU WHAT TO DISCARD: ADAPTIVE KV CACHE COMPRESSION FOR LLMs

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ABSTRACT

In this study, we introduce adaptive KV cache compression, a plug-and-play method that reduces the memory footprint of generative inference for Large Language Models (LLMs). Different from the conventional KV cache that retains key and value vectors for all context tokens, we conduct targeted profiling to discern the intrinsic structure of attention modules. Based on the recognized structure, we then construct the KV cache in an adaptive manner: evicting long-range contexts on attention heads emphasizing local contexts, discarding non-special tokens on attention heads centered on special tokens, and only employing the standard KV cache for attention heads that broadly attend to all tokens. Moreover, with the lightweight attention profiling used to guide the construction of the adaptive KV cache, FastGen can be deployed without resource-intensive fine-tuning or re-training. In our experiments across various asks, FastGen demonstrates substantial reduction on GPU memory consumption with negligible generation quality loss. We will release our code and the compatible CUDA kernel for reproducibility.

1 INTRODUCTION

Based on the Transformer architecture, autoregressive language models have attracted extensive attention (OpenAI, 2023; Touvron et al., 2023b). Along with the increase of model size, these models present significant challenges in terms of computational complexity and GPU memory consumption (Shazeer et al., 2017). Since these models achieve remarkable success across diverse applications, there is a pressing need for serving these models in an economically feasible manner.

The generative inference of LLMs usually involves using the *KV Cache* mechanism to enhance the generation speed. KV cache stores previously computed Key/Value vectors in attention calculation and reuses those values for the current token generation. As such, it avoids recalculations of previous tokens at each token generation step at the cost of extra memory consumption. Despite being a prominent technique, the memory consumption of KV cache increases rapidly as the model size and generation length increase, drastically increasing the pressure of on-device memory.

When memory usage exceeds GPU capacity, the generative inference of LLMs typically resort to offloading (Aminabadi et al., 2022; Sheng et al., 2023). While these methods help mitigate the pressure on the scarce GPU memory from using KV cache, offloading KV cache to CPU/NVMe can still add non-trivial overhead to generative inference performance due to the limited PCIe bandwidth between the GPU and CPU on many devices. Therefore, it becomes a crucial task to reduce the memory footprint of KV cache without costly retraining or fine-tuning.

Our study starts from the observation (Figure 1) that there are abundant structures observed in attention modules (Michel et al., 2019; Voita et al., 2019; Clark et al., 2019; Wang et al., 2020; Child et al., 2019), and not all attention modules need to attend to all tokens (Liu et al., 2023b; Zhang et al., 2023; Liu et al., 2023a). Intuitively, harvesting such structures and compressing cached vectors could substantially reduce memory consumption and accelerate text generation.

Based on this intuition, we propose FastGen to *accelerate the generative inference by adaptively compressing the KV cache on the fly*. First, we employ an efficient profiling algorithm to recognize the structural patterns for attention modules. Under the guidance of this profiling, we then construct the KV cache for various modules adaptively. With this diagnose-before-compress approach, FastGen effectively reduces the memory footprint of KV cache while preserving the model quality.

Algorithm 1: FastGen–Prompt Encoding.

Input: Feasible Policy Set (\mathcal{C}), Prompt
Output: Adaptive KV Cache

- 1 **for** Attention Head H_i in LLM **do**
- 2 $K^i, Q^i, V^i \leftarrow H_i(\text{Prompt})$
- 3 $A^i \leftarrow \text{softmax}(Q^i K^{iT})$
- 4 $C^i \leftarrow$ apply Equation 1 to A^i
 /* C^i : optimal policy */
- 5 $K_{C^i}^i, V_{C^i}^i \leftarrow f(K^i, V^i, C^i)$
- 6 $\hat{K}^i, \hat{V}^i \leftarrow K_{C^i}^i V_{C^i}^i$
- 7 **return** $\{C^i, \hat{K}^i, \hat{V}^i\}$

Algorithm 2: FastGen–Token Generation.

Input: Adaptive KV cache ($\{C^i, \hat{K}^i, \hat{V}^i\}$)
Output: Generated Text

- 1 $z_0 \leftarrow$ last prompt token
- 2 **for** $j \in \{1, \dots, \text{Max Generate Length}\}$ **do**
- 3 **for** Attention Head H_i in LLM **do**
- 4 $K^i, Q^i, V^i \leftarrow H_i(z_{j-1}, \hat{K}^i, \hat{V}^i)$
- 5 $K_{C^i}^i, V_{C^i}^i \leftarrow f(K^i, V^i, C^i)$
- 6 $\hat{K}^i, \hat{V}^i \leftarrow K_{C^i}^i, V_{C^i}^i$
- 7 $z_j \leftarrow$ sample from LLM prediction
- 8 **return** $\{z_j\}$

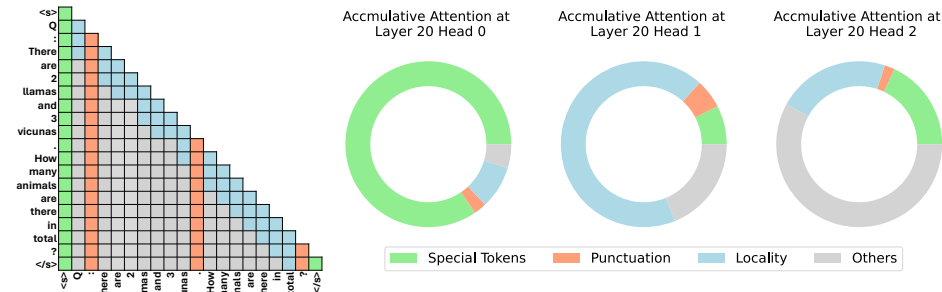


Figure 1: Different attention heads usually have different structures. Left: Four common attention structures (more details are elaborated in Section 3 and Section 4). Right: Attention map compositions of three attention heads that are in the same layer.

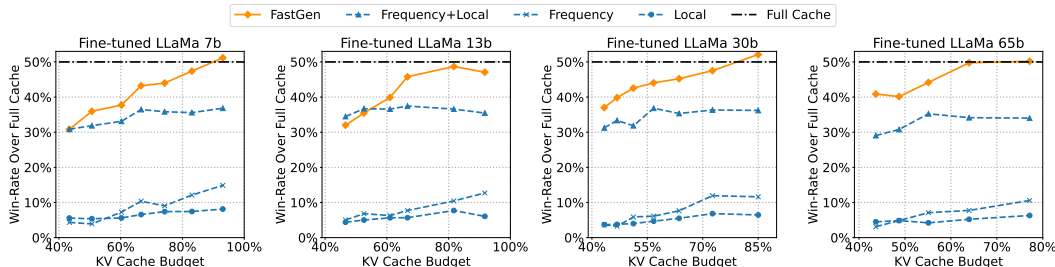


Figure 2: Performance of Adaptive KV Cache (FastGen) and Fixed KV Cache (Frequency, Local, and Frequency+Local; Zhang et al., 2023 and Liu et al., 2023a) on AlpacaEval.

In our study, FastGen recognizes five fundamental attention structures and applies them correspondingly. Specifically, some attention modules mostly attend to local contexts, for which we construct a KV cache that evicts long-range contexts; some primarily attend to specific tokens/punctuations, for which we create a KV cache that retains only special tokens/punctuations; some have attention maps that are column-wise sparse, for which we discard the least frequently attended tokens; and some broadly attend to all tokens, for which we employ the standard KV cache and store all tokens.

In this way, FastGen is able to compress the KV cache while retaining the original functionality of attention modules. Remarkably, FastGen does not require any fine-tuning and can be applied in a plug-and-play manner. This is a big advantage of FastGen, because the training cost on extra-large models (Brown et al., 2020), can hardly be affordable for many research labs or practitioners.

We evaluate FastGen on LLaMa (Touvron et al., 2023b) with a suite of major benchmarks covering generative tasks in math, code, knowledge, and common sense reasoning. FastGen effectively performs KV cache compression with negligible generation quality loss (i.e., recover over 95% of attention scores with 35% cache compressed). Notably, as to the 30b model in Figure 2, FastGen (50% cache compressed) surpasses all fixed KV compression methods (15% cache compressed).

2 RELATED WORK

Token Dropping and KV Cache Compression. Many efforts have been made to improve the model efficiency for LLMs. For recurrent neural networks, one method is to skip multiple tokens at a given time step (Campos et al., 2017; Seo et al., 2017; Hansen et al., 2019). Since Transformer models quickly attracted lots of attention, Goyal et al. (2020) proposes to eliminate redundant words in BERT (Devlin et al., 2019) based on their attention scores, while Dai et al. (2020) compresses the input sequence by adding pooling layers to the encoding modules of the transformer architecture. Recently, Huang et al. (2022) adds a token selection task to the original BERT model that learns to select performance-crucial tokens, and Kim et al. (2022) designs a learnable threshold to detect unimportant tokens to prune. Meanwhile, many efforts have been made to explore the possibility of compressing the hidden state of tokens rather than explicitly reducing the sequence length (Guan et al., 2022; Sun et al., 2022; Zhou et al., 2020).

Nevertheless, these methods can only be applied to non-autoregressive models and typically require an additional re-training phase, making them less suitable for large LLMs like ChatGPT and LLaMa. Recognizing this gap, researchers started examining the potential of pruning tokens within the KV cache of autoregressive LLMs. Mu et al. (2023) learns to compress the prompts into a few special tokens to reduce memory pressure during caching. However, the token prediction requires training and could be an expensive overhead during inference. Meanwhile, several concurrent methods propose to leverage accumulated attention score as the criteria to identify important tokens in the KV cache (Sheng et al., 2023; Zhang et al., 2023; Liu et al., 2023a). Our work, instead of investigating a specific eviction policy, aims to synergistically coordinate diverse eviction policies, adapting them to align more closely with model-specific attributes.

Underlying Structure of Attention. Inspired by the success of Transformer, extensive studies have been conducted to explore the underlying mechanism of different self-attention heads. Voita et al. (2019) analyzed the self-attention heads in BERT (Devlin et al., 2019) using LRF (Bach et al., 2015) and characterized them into interpretable roles, one of which is attending adjacent tokens all the time. Michel et al. (2019) demonstrated that even heads in the same layer could have different impact on the performance while the importance of each head change across tasks. Clark et al. (2019) and Kovaleva et al. (2019) identified the patterns that some heads primarily attend to separator tokens, adjacent tokens and a combination of these. We observe consistent patterns in decoder-only models, despite previous studies are mainly done on encoder models. Our work shares similar spirits with these studies but focus on characterizing the KV cache of different attention heads.

3 ADAPTIVE KV CACHE COMPRESSION

Here, we start by introducing the problem formulation and then proceed to present attention profiling method and adaptive KV cache compression.

3.1 GENERATIVE INFERENCE OF AUTOREGRESSIVE LLMs

Typical generative inference involves two stages, prompt encoding and token generation.

Prompt Encoding. The first step for generative inference is to let LLMs encode prompt inputs. For autoregressive transformers, when generating the i -th token, the attention module will reference information from all the preceding $i - 1$ tokens. To convey such contextual information, the attention module processes both key and value vectors of the preceding $i - 1$ tokens. To circumvent redundant KV vectors computations when generating succeeding tokens, all key and value vectors are retained once encoded, collectively termed as the KV cache.

Token Generation. Once prompt encoding finished, LLMs conduct incremental token generation. At each generation step, the model only needs to encode the newly generated tokens from the last step. Furthermore, after a new token being generated, its associated key and value vectors are appended to the current KV cache. Consequently, the KV cache’s size experiences a linear surge in tandem with the generation of additional tokens.

3.2 FASTGEN FRAMEWORK

As highlighted in Section 2, various efforts have sought to compress the KV cache to minimize memory usage and boost generation speed. Yet, these methods often overlook the intricate attention structure in LLMs. As detailed in Section 4, attention heads in these models often function distinctively, indicating the need for tailoring compression strategies to each attention head.

With these insights, we introduce FastGen: a dual-phase algorithm for crafting an adaptive KV cache. During the prompt encoding phase, model profiling is conducted to discern the behavior of various attention heads, thereby choosing the most appropriate compression strategies for each head. Then, in the token generation phase, rather than indiscriminately appending new key/value vectors, we strategically manage the KV cache in alignment with the selected compression strategies.

We will first introduce our profiling method, and then proceed to discuss compression strategies.

3.3 MODEL PROFILING

In our study, we propose to conduct model profiling based on the result of prompt encoding. Specifically, for a compression policy C , we mark the corresponding KV cache compression as $\mathbf{K}_C, \mathbf{V}_C = f(\mathbf{K}, \mathbf{V}, C)$, where \mathbf{K}_C and \mathbf{V}_C are the compressed KV cache. Then, for attention map $\mathbf{A} = \text{softmax}(\mathbf{Q}\mathbf{K}^T)$, we pick the optimal policy that can recover \mathbf{A} by a recover ratio T with the minimum memory cost:

$$C^* = \arg \min_{C \in \mathcal{C}} \text{CacheMemoryCost}(C) \quad \text{s.t.} \quad |\mathbf{A} - \text{softmax}(\mathbf{Q}\mathbf{K}_C^T)| \leq 1 - T, \quad (1)$$

where \mathcal{C} is the set of all feasible compression policies, $\text{CacheMemoryCost}(C)$ is the target KV cache budget of the compression policy C , and T is a predefined hyper-parameter representing how much we want the policy to recover \mathbf{A} . As discussed in Section 5, FastGen is able to recover over 95% percent of attention map with over 40% compression ratio for a 65B model. The final algorithm for prompt encoding is outlined as Algorithm 1.

Intrinsically, our method assumes that, for all attention heads, the structure of the attention map is stable at different positions, i.e., it is sufficient to use only the encoded prompt for picking the proper compression policy. It is worth mentioning that, existing literature has provided theoretical justification for using only the encoded prompts to capture attention structures for the full contexts (Zhang et al., 2023; Liu et al., 2023a). In our study, we also have provided empirical verification for this assumption (elaborated in Section 4).

3.4 KV CACHE COMPRESSION POLICIES

As discussed in Section 4, we observe that a large number of attention heads closely followed certain patterns. Correspondingly, besides the conventional full KV cache, we consider four fundamental KV cache compression policies in our study. While our research mainly utilizes these four fundamental KV cache compression policies, FastGen’s design accommodates an expansion to incorporate numerous other strategies. The four foundational policies are:

- **Special Tokens.** This policy would only keep special tokens like the begin-of-the-sentence token $\langle s \rangle$, the instruction token [INST], etc. Formally, we refer to this policy as C_{special} .
- **Punctuation.** This policy would exclusively preserve punctuation tokens like “.”, “:”, “?”, etc. We refer to this policy as C_{punct} .
- **Locality** This policy would evict long-range contexts, i.e., once the relative distance between the context token and the current token exceeds a threshold, the KV cache of the context token will be evicted. The length budget of local context over the current sequence length is controlled by a ratio r_l . We refer to this policy as C_{local} .
- **Frequency (Heavy Hitter)** This policy was proposed in multiple studies (Sheng et al., 2023; Zhang et al., 2023; Liu et al., 2023a). It monitors the cumulative sum of attention scores, essentially operating like a least-frequently-used cache by equating this sum to a token’s frequency. The length budget of frequent tokens over the current sequence length is controlled by a ratio r_f . We refer to this policy as C_{frequent} .

Naive Strategy Combination. In practice, we noticed that it is necessary to combine those above-mentioned strategies. However, the total number of the resulting hybrid policy grows at a combinatorial speed. In our study, we employed a naive strategy to construct hybrid-policies. Specifically, together with the naive full KV cache (no compression), we consider the following feasible compression policy set:

$$\mathcal{C} = \{C_{\text{special}}, C_{\text{special+punct.}}, C_{\text{special+punct.+frequent}}, C_{\text{special+punct.+frequent+local}}, C_{\text{full}}\}, \quad (2)$$

where the sum of two compression strategies is to compute the union of their compressed KV cache.

Here we prioritize combining other strategies with C_{special} for two reasons: 1) We observe high attention scores are usually allocated towards C_{special} in Section 4, indicating that C_{special} are crucial for attention map recovery; 2) the compressed cache of C_{special} consumes limited memory since there are usually less than 5 special tokens in a sentence. In other words, it brings little-to-no extra memory consumption by always including C_{special} . Similarly, we set $C_{\text{punct.}}$ as our second priority due to the limited number of punctuations in a sentence. More discussions on the strategy priorities are included in Section 5.3. The final algorithm for token generation is outlined as Algorithm 2.

4 DIVERSITY AND STABILITY OF ATTENTION STRUCTURES

In this section, we present empirical verifications on our intuition that KV cache compression can and should be conducted adaptively. Specifically, we aim to first demonstrate that different attention heads typically possess distinct structures; and then, to show that these attention head structures remain relatively consistent. For this purpose, we analyze the attention scores of LLaMa 65B using random samples from GSM8k (Cobbe et al., 2021) as our case study.

4.1 HEAD DISTINCTIVE ATTENTION STRUCTURE

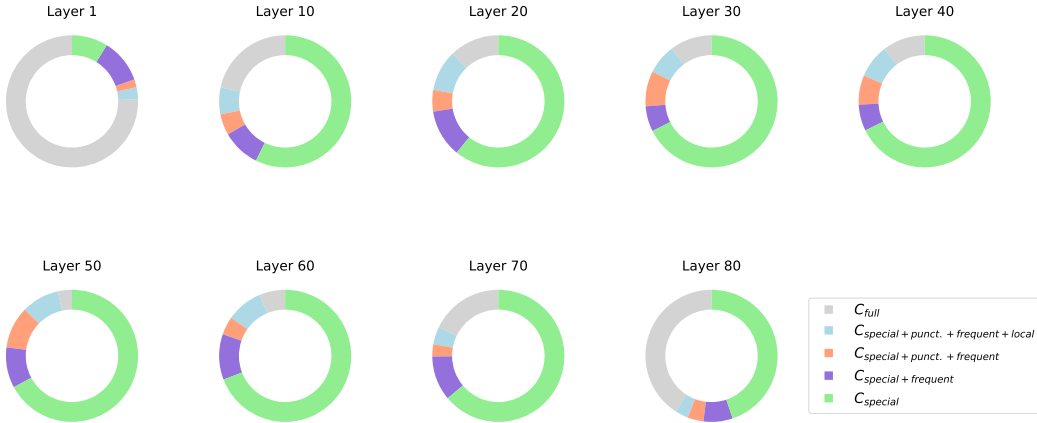


Figure 3: Attention Profiling Result Distribution across different layers.

Setting. We apply our proposed profiling method (with a recover threshold of 0.95) and compute the distribution of profiling results for $\{1, 10, 20, 30, 40, 50, 60, 70, 80\}$ layers. The resulting distribution is visualized in Figure As in Figure 3.

Observation. As in Figure 3, attention heads in different layers have vastly different structures. Specifically, for the initial and final layers, they have more attention heads assigned to the full KV cache, indicating more attention heads of these layers broadly attend to all tokens. Meanwhile, for middle layers, the attention map focuses more on special tokens, indicating most attention heads of these layers primarily attend to special tokens (i.e., the accumulated attention score on special tokens is higher than 0.95 for these attention heads). As in Figure 1, we also provide a case study

to illustrate the structure of different attention heads in the same layer, which demonstrates that the attention structure differs across different layers and different heads.

Correspondingly, it is suboptimal to follow the same pattern and apply the same KV cache to all layers without adaptation. Also, it could be beneficial to first diagnose the cache of each attention head before deciding how to construct the cache. We’ll further discuss the benefit of this diagnose-to-compress strategy in the experiment section.

4.2 PROFILE TENDS TO BE CONSISTENT IN ONE SEQUENCE

The previous section demonstrates the great potential for constructing an adaptive KV cache in accordance with the structure of different attention heads. Here, we aim to demonstrate that, it is sufficient to leverage only the user-provided prompts and conduct one-shot profiling, as outlined in Section 3.3. Specifically, we aim to illustrate that user-provided prompts share the same attention structure in the generation process.

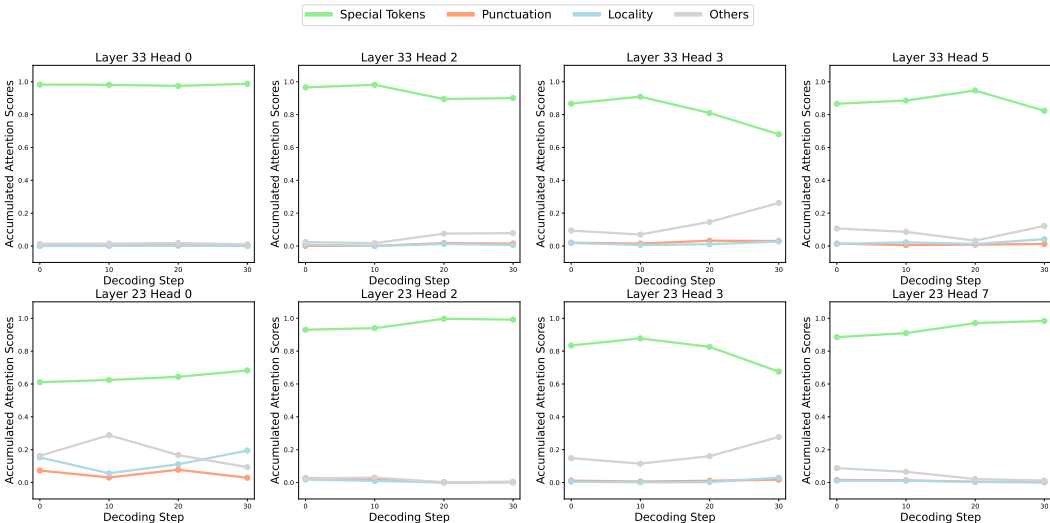


Figure 4: Accumulated Attention Score at 1st (prompt encoding), 10th, 20th, 30th decoding steps.

Setting. Following Figure 1, we compute the accumulated attention score for attention heads in different layers of LLaMa 65B at multiple decoding steps (i.e., 1st, 10th, 20th, 30th). We visualized the resulting accumulated score in Figure 4.

Observation. Despite some fluctuations in the exact accumulated attention scores across time steps, the pattern of the attention maps remains relatively stable. For example, Layer 33 Head 0 and Layer 23 Head 2 almost only attend to the special token, while the locality and punctuation plays an important role in Layer 23 Head 0. As to Layer 23 Head 3, more than 10 percent of the attention score is allocated to the Others portion, making it suitable for the uncompressed KV cache C_{full} .

Also, we observe that a large part of attention scores focuses on special tokens in all cases, which matches our intuition for conducting the naive strategy combinations in Section 3.4.

5 EXPERIMENT

We conduct comprehensive experiments to demonstrate the effectiveness of FastGen on memory footprint reduction and generation quality preserving. First, we report the trade-off between memory reduction and end-to-end generation quality in Section 5.1, and discuss the compression ratio of FastGen in Section 5.2. Finally, we present more discussions and ablation studies in Section 5.3.

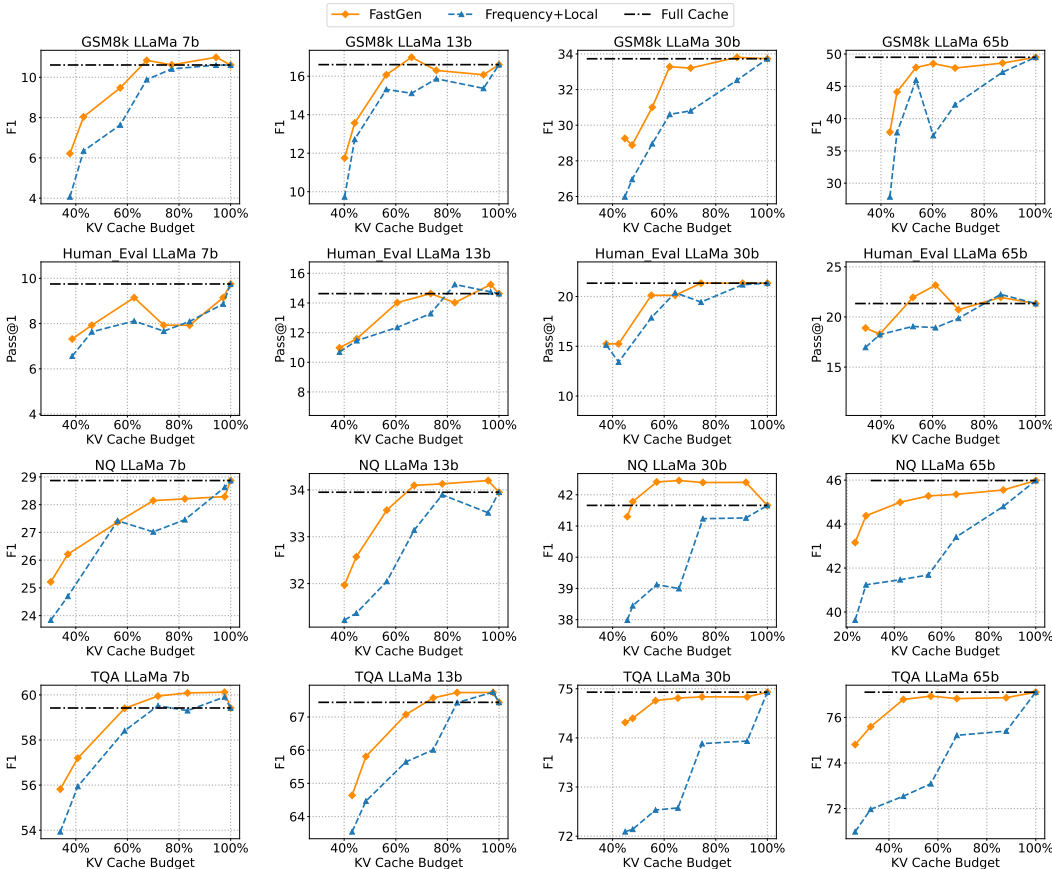


Figure 5: Performance of Adaptive KV Cache (FastGen) and Fixed KV Cache (Frequency+Local; Zhang et al., 2023 and Liu et al., 2023a) of LLaMa on GSM8k, Human Eval, NQ, and TQA.

5.1 TRADE-OFF BETWEEN PERFORMANCE AND MEMORY REDUCTION

Backbones. We conduct experiments with both LLaMa1 (Touvron et al., 2023a) and its fine-tuned variants, with model sizes ranging from 7B to 65B. For fine-tuned variants, we do not choose the open-sourced ChatLLaMa2 (Touvron et al., 2023b) model due to its grouped-query attention techniques. Instead, we base on the original multi-head attention architecture in this work and leave the integration of grouped-query attention as future work. To prepare a comparable instruction-following model for analysis, we fine-tuned the LLaMa1 model with open-sourced instruction-tuning datasets. Specifically, the fine-tuned variants are trained on LIMA¹ data (Zhou et al., 2023) and Open Assistant² (Köpf et al., 2023) data.

Tasks. We use standard generation tasks to evaluate LLaMa and our fine-tuned LLaMa models. For LLaMa, we choose four different tasks, including Human Eval (Chen et al., 2021), GSM8k (Cobbe et al., 2021), NQ (Kwiatkowski et al., 2019) and TQA (Kembhavi et al., 2017) to evaluate model abilities on different domains (code, math, question answering and reading comprehension). Note that the four tasks all formulate each testing sample in a generative format, where answers are extracted after model generation finishes. This is crucial for a fair evaluation of model generation quality. For instruction finetuned LLaMa, we evaluate it on instruction tuning benchmark AlpacaEval (Li et al., 2023), which consists of 805 question prompts from diverse domains.

Experiment Setup. The evaluation of the LLaMa model follows the default setting and evaluation metrics on each benchmark. In particular, we calculate the F1 scores for GSM8k, NQ and TQA, and use the code execution Pass@1 rate on Human Eval. While best practices for comprehensively

¹<https://huggingface.co/datasets/GAIR/lima>.

²<https://huggingface.co/datasets/OpenAssistant/oasst1>.

evaluating an instruction-tuning model is an open research question, we follow previous work (Zhou et al., 2023; Touvron et al., 2023b) to use GPT4 as an evaluator for pair-wise comparison between two different model generations. For each prompt, we input the FastGen generations and generations from the same model with Full KV Cache as a pair, and ask GPT4 to judge which shows better quality. We then calculate the win rate of FastGen over Full Cache. Ideally, the win rate of a lossless method should be around 50%. Aside from full-cache models, we also include non-adaptive KV cache methods. Specifically, we apply C_{local} , C_{frequent} , and $C_{\text{local+frequent}}$ to all attention head without any adaptation, as baselines. It is worth mentioning that, $C_{\text{local+frequent}}$ is the same with the H2O method proposed in Zhang et al. (2023) and the Scissorhands method proposed in Liu et al. (2023a), and thus is a very strong baseline. We set $r_l = 0.3$, $r_f = 0.3$ in FastGen, and only change the recovery ratio T to control the pruned KV cache ratio. For generation, we use nucleus sampling (Holtzman et al., 2019) with temperature $T = 0.6$, $p = 0.9$. Experiments are conducted on 8 NVIDIA A100 80GB GPUs.

Main Results. In Figure 2 and Figure 5, we present the model quality trend with KV cache budget ranging from 30% to 100%. On the 30b model case, FastGen (50% cache compressed) surpasses all non-adaptive KV compression methods (15% cache compressed). Also, we can see FastGen achieves more KV cache reduction ratio as the model scales, with the same level of model quality preservation. For example, given a 45% win rate, FastGen can get as much as 44.9% pruned ratio on LLaMa-65B, compared to 16.9% pruned ratio on LLaMa-7B. In all settings, FastGen shows consistent and significant improvement over non-adaptive compression methods, despite they being single strategy or combinations. This observation verifies the benefits of adaptively constructing cache based on the specific attention structure of each head.

Model Size	KV Cache			T	Win rate
	Full	FastGen	Pruned ratio		
7B	32Gb	14Gb	56.6%	91%	30.8%
		20Gb	39.8%	95%	37.7%
		27Gb	16.9%	98%	47.4%
13B	63Gb	29Gb	53.4%	91%	32.0%
		38Gb	39.0%	95%	39.9%
		51Gb	18.3%	98%	48.7%
30B	158Gb	69Gb	56.7%	93%	37.0%
		81Gb	48.8%	95%	42.5%
		115Gb	27.4%	98%	47.5%
65B	320Gb	140Gb	56.3%	93%	40.9%
		176Gb	44.9%	95%	44.2%
		205Gb	36.0%	98%	49.8%

Table 1: Memory footprint reduction by FastGen. We compared the memory consumption between models with full KV cache, and models compressed by FastGen on fine-tuned LLaMa.

5.2 MEMORY FOOTPRINT REDUCTION ANALYSIS

In this section, we report the KV cache memory footprint reduction in Table 1. For all the evaluated 7B-65B models, we evaluate the memory consumption with a fixed batch size of 16, sequence length of 512, and model weights in fp16 format. We observe that our method is able to substantially reduce the KV cache memory footprint across all model sizes, with more significant reductions for larger models. Taking a win rate over 45% as no quality regression, FastGen can achieve $\sim 50\%$ memory reduction in LLaMa-65B, $\sim 30\%$ in LLaMa-30B, $\sim 20\%$ in LLaMa-13B and LLaMa-7B.

5.3 ABLATIONS

For all the ablations, we fix the targeted recovery ratio T as 0.98.

How one policy affect all the other policies? We study the complementary effects of each policy on the combination of all other policies in our framework. We watch changes in pruned KV cache and win rate while fixing the targeted recovery ratio T . We take the full policy set as our control set \mathcal{C} . For each ablation, we remove one of the policies from all policy combination in \mathcal{C} . We summarized the results in Table 2, which suggests the C_{frequent} and the C_{special} are the most important policies. Removing them will incur a 3.67% and a 2.11% win rate drop respectively. We

Feasible Policy Set	Pruned KV Ratio	Win Rate
\mathcal{C}	36.04%	49.75%
$\{C_{\text{punct.}}, C_{\text{punct.}+\text{frequent}}, C_{\text{punct.}+\text{frequent}+\text{local}}, C_{\text{full}}\}$	31.16%	47.64%
$\{C_{\text{special}}, C_{\text{special}+\text{frequent}}, C_{\text{special}+\text{frequent}+\text{local}}, C_{\text{full}}\}$	34.23%	49.56%
$\{C_{\text{special}}, C_{\text{special}+\text{punct.}}, C_{\text{special}+\text{punct.}+\text{frequent}}, C_{\text{full}}\}$	30.18%	49.06%
$\{C_{\text{special}}, C_{\text{special}+\text{punct.}}, C_{\text{special}+\text{punct.}+\text{local}}, C_{\text{full}}\}$	21.26%	46.08%

Table 2: Complementary effects of each policy. We display the win rate of each method over full cache setting. We evaluate the fine-tuned LLaMa 65B on AlpacaEval with the same parameters.

Cache Order	Pruned KV Ratio	Win Rate
$C_{\text{special}} \rightarrow C_{\text{punct.}} \rightarrow C_{\text{frequent}} \rightarrow C_{\text{local}}$	36.04%	49.75%
$C_{\text{special}} \rightarrow C_{\text{frequent}} \rightarrow C_{\text{local}} \rightarrow C_{\text{punct.}}$	36.40%	47.64%

Table 3: Policy order ablation on fine-tuned LLaMa 65B with AlpacaEval.

can also observe from the pruned cache ratio that C_{frequent} and C_{local} reduce more KV caches than the others. However, their standalone non-adaptive deployment yields suboptimal performance, as depicted in Figure 2, further verifying the importance of adapting different compression policies.

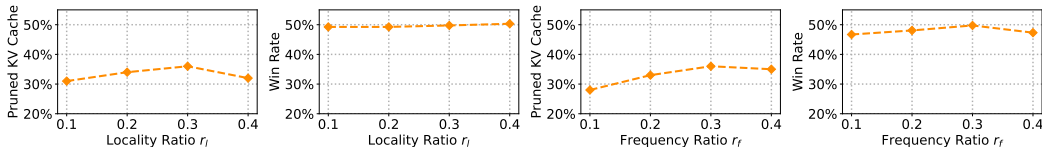


Figure 6: Hyper-parameter ablation on fine-tuned LLaMa 65B with AlpacaEval.

Which policy should we add first (and last)? As in Section 3.4, we leveraged a naive strategy to construct adaptive KV cache. Here, we examine how the order of introducing each policy would affect the performance. Similar to the previous study, we fix the targeted recovery ratio as 0.98, and allow any cache budget allocation until the constructed cache hit the recovery ratio. For simplicity, we make every examined order opt-in the C_{special} first, as it’s typically the most important tokens and of super-low memory cost, suggested by Figure 1. We summarized the results in Table 3. Our current order (as in Equation 2) achieves both the highest win-rates and pruned ratios. Meanwhile, using alternative orders may lead to a different trade-off between KV cache compression and generation quality. For example, using $C_{\text{frequent}} \rightarrow C_{\text{local}} \rightarrow C_{\text{punct.}}$ leads to improved KV cache compression ratio at the cost of generation quality.

Sensitivity Study. We analyze the sensitivity of FastGen against the hyper-parameters, as illustrated in Figure 6. We can observe that, altering these hyper-parameters would not have a large impact on the generation quality a lot. Specifically, the model maintains a winrate over 45% in all situations. Meanwhile, it may lead to a relative large change on the compression ratio. For example, changing the ratio for the frequency policy from 0.3 to 0.1 leads to more than 10% more KV cache. In our experiments, we set the ratio to 0.3 for both r_l and r_f .

6 CONCLUSION

In this work, we introduce FastGen, a novel method that improves the efficiency of large language models through lightweight attention profiling and adaptive key-value caching. Our approach enables more efficient deployment across diverse models and datasets without loss of generation quality. Further work includes combining FastGen with other optimization techniques like quantization and distillation. Meanwhile, another direction could be accommodating other efficient attention architecture, such as grouped-query attention. We hope our initial results will spur further developments in efficient and deployable LLM technologies.

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