Enhancing Retrieval-Augmented Generation with Dehallucinating Parallel Context Extension

Zexiong Ma [1 †] **Shengnan An** [2 †] **Zeqi Lin** [3] **Yanzhen Zou** [1] **Jian-Guang Lou** [3] **Bing Xie** [1]

Abstract

Parallel context extension (PCE) is a line of research attempting to effectively integrate parallel (unordered) contexts, while it still suffers from in-context hallucinations when adapted to RAG scenarios. In this paper, we propose **DePaC** (**De**hallucinating **Pa**rallel **C**ontext Extension), which alleviates the in-context hallucination problem with **context-aware negative training** and **information-calibrated aggregation**. DePaC is designed to alleviate two types of in-context hallucination: **fact fabrication** (i.e., LLMs present claims that are not supported by the contexts) and **fact omission** (i.e., LLMs fail to present claims that can be supported by the contexts). Specifically, (1) for fact fabrication, we apply the context-aware negative training that fine-tunes the LLMs with negative supervisions, thus explicitly guiding the LLMs to refuse to answer when contexts are not related to questions; (2) for fact omission, we propose the information-calibrated aggregation which prioritizes context windows with higher information increment from their contexts.

1. Introduction

Retrieval-augmented generation (RAG) (Lewis et al., 2020; Gao et al., 2023) is nowadays a prevalent paradigm for incorporating large language models (LLMs) (OpenAI, 2023; Touvron et al., 2023; Jiang et al., 2023a) with outside knowledge. Parallel Context Extension (PCE) (Hao et al., 2022; Ratner et al., 2023; Su et al., 2024) is a line of research attempting to effectively integrating parallel contexts through an aggregation function. PCE is highly compatible with RAG scenarios, as the candidate retrieved documents of RAG are independ of each other.

However, existing PCE approaches still face two types of in-context hallucination issues (Ji et al., 2023; Rawte et al., 2023; Yang et al., 2023): **fact fabrication** and **fact omission.** (1) **fact fabrication** occurs when the model presents fabricated claims that are inconsistent with the contextual facts. (2) **fact omission** refers to windows lacking useful information may disproportionately affect the aggregation function, leading it to omit critical information present in other windows. This will make LLMs fail to present claims that can be supported by the contexts.

In this paper, we propose DePaC to alleviate the hallucination issue of parallel context extension on RAG. DePaC contains two parts: **NegTrain** (Context-aware **Neg**ative **Train**ing) to address fact fabrication and **ICA** (**I**nformation-**C**alibrated **A**ggregation) to address fact omission. (1) **NegTrain** guides the LLMs to refuse to answer when contexts are not related to the question. (2) **ICA** prioritizes context windows with higher information increment from their contexts. Specifically, we utilize Kullback-Leibler (Kullback & Leibler, 1951) divergence to measure the information increment of with-document compared to non-document. This approach enhances DePaC's capability to identify useful information within parallel windows.

2. Background: Parallel Context Extension (PCE)

The core idea of PCE involves aggregating information from multiple context windows into a unified representation space. Such a representation aggregation can be formalized on either the probability distributions of output tokens (Su et al., 2024), or the internal hidden states in attention layers (Hao et al., 2022; Ratner et al., 2023). Su et al. (2024) claimed the above two formalizations have similar practical performances. In this work, we adopt the formalization in (Su et al., 2024) that takes the aggregation of output distributions.

Given an question $\mathcal{Q}$, a set of retrieved documents $\mathcal{D} = \{d_1, d_2, ..., d_n\}$, and a language model with parameters θ, PCE first computes the output distribution of each context

[†]Work done during the internship at Microsoft. [1]School of Computer Science, Peking University [2]Xi'an Jiaotong University [3]Microsoft. Correspondence to: Zeqi Lin <Zeqi.Lin@microsoft.com>, Bing Xie <xiebing@pku.edu.cn>.

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window,

$$\mathbf{p_{i,j}} = p_\theta(\,\cdot \mid d_j \oplus \mathcal{Q} \oplus \mathcal{A}_{1:i-1}), \tag{1}$$

where $\mathbf{p_{i,j}}$ is the probability distribution of the i-th token for output $\mathcal{A}$ based on the d_j document, and $\oplus$ represents the concatenation of sequences. Subsequently, these individual distributions are aggregated into a single distribution,

$$\mathbf{p_i} = \mathrm{AGG}(\mathbf{p_{i,1}},\ \mathbf{p_{i,2}},\ ...,\ \mathbf{p_{i,n}}), \tag{2}$$

where $\mathrm{AGG}(\cdot)$ represents the aggregation method. Finally, the output token $\mathcal{A}_i$ will be sampled based on the aggregated distribution $\mathbf{p_i}$,

$$\mathcal{A}_i \sim \hat{\mathbf{p}}_\mathbf{i}, \quad \hat{\mathbf{p}}_\mathbf{i} = \mathbf{p_i} - \alpha \cdot \mathbf{p_{i,c}}, \tag{3}$$

$$\mathbf{p_{i,c}} = p_\theta(\,\cdot \mid \mathcal{Q} \oplus \mathcal{A}_{1:i-1}), \tag{4}$$

where the $\hat{\mathbf{p}}_\mathbf{i}$ is the calibrated distribution to facilitate generation. We set $\alpha = 0.2$ following Su et al. (2024).

The effectiveness of the PCE paradigm is significantly influenced by the design of the aggregation method $\mathrm{AGG}(\cdot)$. Here, we discuss two aggregation methods used in existing studies.

Average Aggregation (Hao et al., 2022; Ratner et al., 2023). The aggregated distribution is computed as the average of n individual distributions,

$$\mathbf{p_i} = \frac{1}{n}\sum_{j=1}^{n} \mathbf{p_{i,j}}. \tag{5}$$

In practice, the size of the retrieved document set $\mathcal{D}$ can be large, potentially containing only a few relevant documents. Average aggregation treats each context window with equal importance, makes it unable to seek critical information when applied to RAG.

Lowest-Uncertainty Aggregation (Su et al., 2024). This method selects the individual distribution with the lowest uncertainty as the aggregation result,

$$\mathbf{p_i} = \arg\min_{\mathbf{p_{i,j}}} H(\mathbf{p_{i,j}}), \tag{6}$$

$$H(\mathbf{p_{i,j}}) = -\mathbf{p_{i,j}}(\log \mathbf{p_{i,j}})^T. \tag{7}$$

Lowest-uncertainty aggregation addresses the limitations of average aggregation by filtering out high-uncertainty windows. However, it remains a sub-optimal solution as it still suffers from the two types of hallucinations illustrated in Figure 9 and 10.

3. Dehallucinating Parallel Context Extension (DePaC)

As shown in Figure 1, we propose two methods to alleviate the fact fabrication and fact omission hallucinations of PCE for RAG scenarios. First, we introduce **Context-aware Negative Training** to enable the model to refuse to answer questions when the relevant information is missing in the context, thereby mitigating fact fabrication. Then, we propose **Information-Calibrated Aggregation** to measure the information increment given by the document, preventing the model from fact omission.

Context-aware Negative Training (NegTrain). We introduce context-aware negative training to alleviate fact fabrication, which explicitly train the backbone model to determine whether a question is answerable based on the provided document.

Given an RAG example with a question $\mathcal{Q}$, a ground-truth answer $\mathcal{A}$, and a retrieved document d_j, we fine-tune the backbone model θ according to the following loss function,

$$\mathrm{Loss}(\mathcal{Q}, \mathcal{A}_{1:m}, d_j) = \tag{8}$$
$$\begin{cases} \mathrm{CE}[p_\theta(\,\cdot \mid d_j \oplus \mathcal{Q}),\ \mathcal{A}_{1:m}], & \text{related}(\mathcal{Q}, d_j), \\ \mathrm{CE}[p_\theta(\,\cdot \mid d_j \oplus \mathcal{Q} \oplus \mathcal{A}_{1:i}),\ t_d], & \text{else}, \end{cases}$$

where $\mathrm{CE}[\cdot]$ represents the cross-entropy loss, t_d is a predefined **rejection token**, m refers to the sequence length of the ground-truth answer, $\mathcal{A}_{1:m}$ refers to the complete ground-truth answer with all tokens, $\mathcal{A}_{1:i}$ refers to the partial ground-truth answer with the first i tokens. As shown in Figure 1(1), to prevent DePaC from generating rejection token only at the beginning of the answer, we also include the positive answer clauses as input. After context-aware negative training, we use t_d to explicitly judge the usefulness of each context window. We set t_d as the `UNK` token to minimize interference with normal tokens during training.

Information-Calibrated Aggregation (ICA). As discussed in Section 2, merely measuring the uncertainty of the final output distribution can be heavily influenced by fact omission hallucination. We propose to measure the changes of uncertainty from the non-document output distribution to the with-document output distribution, reflecting the information increment provided by the retrieved document.

Specifically, we apply the Kullback-Leibler (KL) divergence to measure the information increment,

$$\Delta(\mathbf{p_{i,j}}, \mathbf{p_{i,c}}) = \mathrm{D_{KL}}(\mathbf{p_{i,j}} \,||\, \mathbf{p_{i,c}}), \tag{9}$$

$$\mathbf{p_{i,c}} = p_\theta(\,\cdot \mid \mathcal{Q} \oplus \mathcal{A}_{1:i-1}), \tag{10}$$

where $\mathbf{p_{i,c}}$ is the non-document output distribution.

Finally, we integrate the above two methods as two penalty terms to inject into Equation 6,

$$\mathbf{p_i} = \tag{11}$$
$$\arg\min_{\mathbf{p_{i,j}}} C(\mathbf{p_{i,j}}, \mathbf{p_{i,c}}) - \gamma \cdot \mathbb{I}(\arg\max_k \mathbf{p_{i,j}}^k = t_d),$$

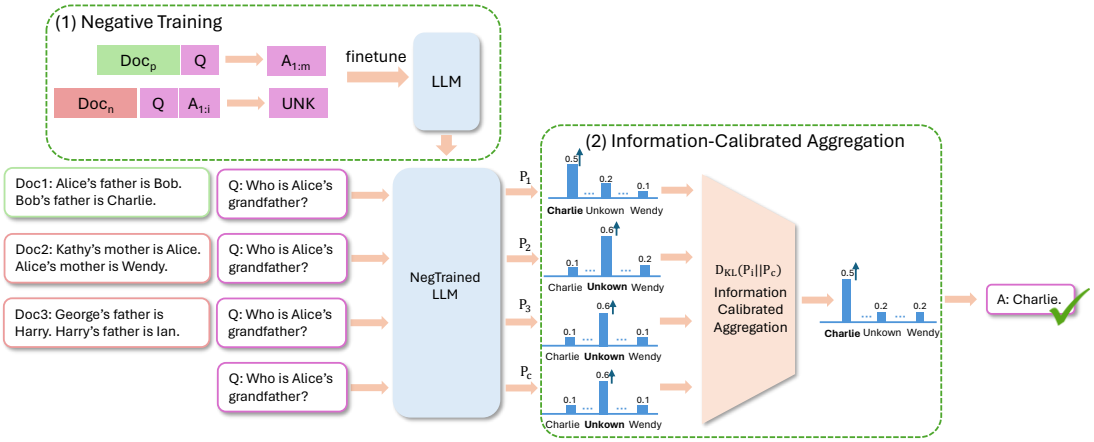

Figure 1: DePaC consists of two key components: (1) a context-aware negative training technique to alleviate fact fabrication, and (2) an information-calibrated aggregation method to alleviate fact omission.

$$C(\mathbf{p_{i,j}}, \mathbf{p_{i,c}}) = H(\mathbf{p_{i,j}}) - \beta \cdot \Delta(\mathbf{p_{i,j}}, \mathbf{p_{i,c}}), \tag{12}$$

where $\mathbb{I}[\cdot]$ represents the indicator function, $\mathbf{p_{i,j}}^k$ is the output probability on k-th token in the vocabulary, and $\beta > 0$ and $\gamma > 0$ are hyper-parameters. Equation 11 and 12 mean that the selected context window should have low uncertainty and high information increment, and should not be aligned to the rejection token. Finally, the output token $\mathcal{A}_i$ will be sampled based on the aggregated distribution $\mathbf{p_i}$.

4. Experiments

4.1. Tasks

Information seeking. Based on the given question, the model is required to seek for some textual pieces within the contexts. The information seeking tasks include: Function name retrieve **(FuncNR)** (An et al., 2024), Entity label retrieve **(EntLR)** (An et al., 2024), Multi-values Needle-in-a-Haystack **(MVIH)** (Hsieh et al., 2024), TensorHub APIBench**(Tens)** (Patil et al., 2023), TorchHub APIBench**(Torc)** (Patil et al., 2023), and Huggingface APIBench**(Hugg)** (Patil et al., 2023). Appendix D shows the detailed description of information seeking tasks.

Document-based question-answering (DocQA). Given a document-specific question, we provide the model several candidate documents, containing one ground-truth document and other unrelated documents. The DocQA tasks include: **Qasper** (Dasigi et al., 2021), **MultifieldQA (MulQA)** (Bai et al., 2023), **NarrativeQA (NarQA)** (Kočiskỳ et al., 2018). Appendix E shows the detailed description of DocQA tasks.

4.2. Baselines

We compare DePaC with four baselines: **Vanilla**, **AVP** (Hao et al., 2022; Ratner et al., 2023), **NBCE** (Su et al., 2024) and **CLeHe** (Qiu et al.). The detailed description of baselines is shown in Appendix F.

4.3. Models

We conduct experiments on three open-source language models: Mistral-7B (Jiang et al., 2023a), Llama3-8B (Grattafiori et al., 2024) and Phi3-3.8B (Abdin et al., 2024). And we use Mistral-7B (Jiang et al., 2023a) as the default backbone model for the ablation study and analysis.

4.4. Results and Analysis

DePaC consistently achieves promising performances across nine tasks. As shown in Table 1, DePaC achieves better performance than baselines across six information seeking tasks and three DocQA tasks. Since the baselines do not require additional training, we also compare solely ICA (DePaC w/o NegTrain) with them in Table 1. The results indicate that using ICA alone outperforms the baselines, and combining ICA with NegTrain further improves performance. The results also show that AVP performs much worse than vanilla. This is because AVP averages the logits across parallel windows, giving equal weight to each window's contribution to the final answer. This makes it underform for RAG scenarios, where it is crucial for the model to identify and focus on the most relevant information from the context.

Both information-calibrated aggregation and context-aware negative training are essential for DePaC performance. We compare DePaC with two ablation setting: (1)

Table 1: Comparison of DePaC with baselines across three models and nine tasks.

Model	Method	FuncNR	EntLR	MVIH	Tens	Torc	Hugg	Qasper	MulQA	NarQA	Avg
Mistral-7B	Vanilla (Jiang et al., 2023a)	25.4	44.1	21.9	37.1	14.5	1.4	15.0	39.7	10.2	23.3
	AVP (Hao et al., 2022)	2.3	0.3	0.3	38.8	3.2	0.2	6.7	16.7	8.6	8.6
	NBCE (Su et al., 2024)	36.2	83.1	27.9	43.3	3.8	1.3	11.7	31.0	15.9	28.2
	CLeHe (Qiu et al.)	38.4	82.6	28.4	43.6	4.2	3.2	13.4	30.8	15.8	28.9
	DePaC (ours)	**72.8**	**87.4**	**41.6**	**44.8**	**16.7**	**7.5**	**17.3**	**40.7**	**16.4**	**38.4**
	ICA (DePaC w/o NegTrain)	69.7	85.1	35.9	44.2	14.5	6.2	16.2	40.1	16.1	36.4
	DePaC w/o ICA	64.9	72.6	32.8	44.1	15.0	6.6	15.2	39.8	15.7	34.1
Llama3-8B	Vanilla (Grattafiori et al., 2024)	24.3	42.3	22.3	34.6	12.6	1.6	7.2	9.6	6.4	17.9
	AVP (Hao et al., 2022)	2.1	0.4	0.2	36.9	2.9	0.4	6.9	17.3	8.2	8.4
	NBCE (Su et al., 2024)	32.8	84.2	24.8	40.3	6.5	2.1	9.9	15.6	13.9	25.6
	CLeHe (Qiu et al.)	37.2	84.0	26.2	41.7	13.3	2.7	11.5	19.6	**14.3**	27.8
	DePaC (ours)	**69.5**	**86.6**	**40.2**	**43.9**	**17.4**	**8.2**	**17.6**	**41.0**	14.1	**37.6**
	ICA (DePaC w/o NegTrain)	64.8	85.0	33.8	43.2	15.2	6.8	16.4	40.3	14.0	35.5
	DePaC w/o ICA	64.2	84.9	34.8	42.4	14.9	7.1	15.8	40.4	13.8	35.4
Phi3-3.8B	Vanilla (Abdin et al., 2024)	29.7	43.5	21.2	35.7	12.3	1.3	13.2	30.2	11.3	22.0
	AVP (Hao et al., 2022)	3.4	0.3	0.5	37.9	2.3	0.7	6.3	15.9	9.4	8.5
	NBCE (Su et al., 2024)	45.4	80.3	28.3	42.2	8.6	2.2	13.8	32.5	14.7	29.8
	CLeHe (Qiu et al.)	42.2	81.2	27.6	43.6	10.1	3.8	13.1	33.1	**15.7**	30.0
	DePaC (ours)	**71.4**	**87.0**	**43.2**	**45.3**	**15.5**	**7.2**	**17.5**	**39.1**	15.3	**37.9**
	ICA (DePaC w/o NegTrain)	68.6	85.2	36.3	44.5	14.0	6.1	16.5	37.9	15.1	36.0
	DePaC w/o ICA	67.9	83.4	35.3	43.6	13.8	4.9	15.3	36.2	14.9	35.0

DePaC w/o NegTrain. We reconstruct a **Pos**itive **Train**ing **(PosTrain)** dataset composed solely of positive samples, with the sample size as NegTrain dataset, and finetune with PosTrain dataset. (2) **DePaC w/o ICA.** We only replace the information-calibrated aggregation function of DePaC with lowest-uncertainty aggregation. We conducte ablation study on the six information seeking datasets. As shown in Table 1, the ablation results indicate that both parts of DePaC are essential for its performance.

5. Related Work

Retrieval-Augmented Generation (RAG) for LLM. To address hallucination issue of LLM, Retrieval-augmented generation (Lewis et al., 2020; Gao et al., 2023; Cheng et al., 2024; Asai et al., 2023) has been applied in many fields, including question answering (Zhang et al., 2024), code generation (Zhou et al., 2022; Ma et al., 2024) and recommendation (Zeng et al., 2024). The performance of RAG is limited by the effectiveness of retriever and the information utilization capability of LLM. Some work focus on enhancing the retriever's capabilities (Wang et al., 2023; Lewis et al., 2020). Shi et al. (2024) compresses the retrieved information for LLM. Some work proposes iterative RAG (Jiang et al., 2023b; Shao et al., 2023; Cheng et al., 2024) to help the model progressively utilize document information. Some work (Asai et al., 2023; Dhuliawala et al., 2023; Feng et al., 2024) utilizes prompt engineer to aggregate information from multiple documents.

LLM with Parallel Context Extension (PCE). Recent research has proposed some PCE approaches to aggregate multiple context windows into a unified representation space, extending context length of LLM. Some research (Hao et al., 2022; Ratner et al., 2023; Li et al., 2024) aggregates by average aggregation mechanisms. Su et al. (2024) proposes NBCE to aggregates by lowest-uncertainty aggregation mechanisms. Beyond parallel context extension for existing LLM, Yen et al. (2024) also proposes encoder-decoder architecture to implement parallel context.

6. Conclusion

In this paper, we propose DePaC to address two types of in-context hallucination issues of parallel context extension on RAG. DePaC consists of two key components: (1) a context-aware negative training technique to mitigate fact fabrication, and (2) an information-calibrated aggregation method to address fact omission issue. Both experiments on information seeking and DocQA tasks show the effectiveness of DePaC.

Impact Statement

This paper presents work whose goal is to advance the field of Machine Learning. There are many potential societal consequences of our work, none which we feel must be specifically highlighted here.

References

Abdin, M., Aneja, J., Awadalla, H., Awadallah, A., Awan, A. A., Bach, N., Bahree, A., Bakhtiari, A., Bao, J., Behl, H., et al. Phi-3 technical report: A highly capable language model locally on your phone. arXiv preprint arXiv:2404.14219, 2024.

An, S., Ma, Z., Lin, Z., Zheng, N., and Lou, J.-G. Make your llm fully utilize the context, 2024.

Asai, A., Wu, Z., Wang, Y., Sil, A., and Hajishirzi, H. Self-rag: Learning to retrieve, generate, and critique through self-reflection. arXiv preprint arXiv:2310.11511, 2023.

Bai, Y., Lv, X., Zhang, J., Lyu, H., Tang, J., Huang, Z., Du, Z., Liu, X., Zeng, A., Hou, L., et al. Longbench: A bilingual, multitask benchmark for long context understanding. arXiv preprint arXiv:2308.14508, 2023.

Bashlovkina, V., Kuang, Z., Matthews, R., Clifford, E., Jun, Y., Cohen, W. W., and Baumgartner, S. Trusted source alignment in large language models. arXiv preprint arXiv:2311.06697, 2023.

Chen, J., Lin, H., Han, X., and Sun, L. Benchmarking large language models in retrieval-augmented generation. In Proceedings of the AAAI Conference on Artificial Intelligence, volume 38, pp. 17754–17762, 2024.

Cheng, X., Luo, D., Chen, X., Liu, L., Zhao, D., and Yan, R. Lift yourself up: Retrieval-augmented text generation with self-memory. Advances in Neural Information Processing Systems, 36, 2024.

Dao, T. FlashAttention-2: Faster attention with better parallelism and work partitioning. 2023.

Dasigi, P., Lo, K., Beltagy, I., Cohan, A., Smith, N. A., and Gardner, M. A dataset of information-seeking questions and answers anchored in research papers. In Proceedings of the 2021 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, pp. 4599–4610, 2021.

Dhuliawala, S., Komeili, M., Xu, J., Raileanu, R., Li, X., Celikyilmaz, A., and Weston, J. Chain-of-verification reduces hallucination in large language models. arXiv preprint arXiv:2309.11495, 2023.

Fabbri, A., Li, I., She, T., Li, S., and Radev, D. Multi-news: A large-scale multi-document summarization dataset and abstractive hierarchical model. In Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics, pp. 1074. Association for Computational Linguistics, 2019.

Feng, S., Shi, W., Wang, Y., Ding, W., Balachandran, V., and Tsvetkov, Y. Don't hallucinate, abstain: Identifying llm knowledge gaps via multi-llm collaboration. arXiv preprint arXiv:2402.00367, 2024.

Gao, Y., Xiong, Y., Gao, X., Jia, K., Pan, J., Bi, Y., Dai, Y., Sun, J., and Wang, H. Retrieval-augmented generation for large language models: A survey. arXiv preprint arXiv:2312.10997, 2023.

Ghoshal, B. and Tucker, A. On calibrated model uncertainty in deep learning. arXiv preprint arXiv:2206.07795, 2022.

Grattafiori, A., Dubey, A., Jauhri, A., Pandey, A., Kadian, A., Al-Dahle, A., Letman, A., Mathur, A., Schelten, A., Vaughan, A., et al. The llama 3 herd of models. arXiv preprint arXiv:2407.21783, 2024.

Hao, Y., Sun, Y., Dong, L., Han, Z., Gu, Y., and Wei, F. Structured prompting: Scaling in-context learning to 1,000 examples. arXiv preprint arXiv:2212.06713, 2022.

Ho, X., Duong Nguyen, A.-K., Sugawara, S., and Aizawa, A. Constructing a multi-hop QA dataset for comprehensive evaluation of reasoning steps. In Scott, D., Bel, N., and Zong, C. (eds.), Proceedings of the 28th International Conference on Computational Linguistics, pp. 6609–6625, Barcelona, Spain (Online), December 2020. International Committee on Computational Linguistics. doi: 10.18653/v1/2020.coling-main.580. URL https://aclanthology.org/2020.coling-main.580/.

Hsieh, C.-P., Sun, S., Kriman, S., Acharya, S., Rekesh, D., Jia, F., and Ginsburg, B. Ruler: What's the real context size of your long-context language models?, 2024.

Huang, L., Cao, S., Parulian, N., Ji, H., and Wang, L. Efficient attentions for long document summarization. In 2021 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, NAACL-HLT 2021, pp. 1419–1436. Association for Computational Linguistics (ACL), 2021.

Ji, Z., Lee, N., Frieske, R., Yu, T., Su, D., Xu, Y., Ishii, E., Bang, Y. J., Madotto, A., and Fung, P. Survey of hallucination in natural language generation. ACM Computing Surveys, 55(12):1–38, 2023.

Jiang, A. Q., Sablayrolles, A., Mensch, A., Bamford, C., Chaplot, D. S., Casas, D. d. l., Bressand, F., Lengyel, G., Lample, G., Saulnier, L., et al. Mistral 7b. arXiv preprint arXiv:2310.06825, 2023a.

Jiang, Z., Xu, F. F., Gao, L., Sun, Z., Liu, Q., Dwivedi-Yu, J., Yang, Y., Callan, J., and Neubig, G. Active retrieval augmented generation. arXiv preprint arXiv:2305.06983, 2023b.

Joshi, M., Choi, E., Weld, D. S., and Zettlemoyer, L. Triviaqa: A large scale distantly supervised challenge dataset for reading comprehension. arXiv preprint arXiv:1705.03551, 2017.

Kočiskỳ, T., Schwarz, J., Blunsom, P., Dyer, C., Hermann, K. M., Melis, G., and Grefenstette, E. The narrativeqa reading comprehension challenge. Transactions of the Association for Computational Linguistics, 6:317–328, 2018.

Kullback, S. and Leibler, R. A. On Information and Sufficiency. The Annals of Mathematical Statistics, 22(1): 79 – 86, 1951. doi: 10.1214/aoms/1177729694. URL https://doi.org/10.1214/aoms/1177729694.

Kwiatkowski, T., Palomaki, J., Redfield, O., Collins, M., Parikh, A., Alberti, C., Epstein, D., Polosukhin, I., Devlin, J., Lee, K., et al. Natural questions: a benchmark for question answering research. Transactions of the Association for Computational Linguistics, 7:453–466, 2019.

Lewis, P., Perez, E., Piktus, A., Petroni, F., Karpukhin, V., Goyal, N., Küttler, H., Lewis, M., Yih, W.-t., Rocktäschel, T., et al. Retrieval-augmented generation for knowledge-intensive nlp tasks. Advances in Neural Information Processing Systems, 33:9459–9474, 2020.

Li, R., Zi, Y., Muennighoff, N., Kocetkov, D., Mou, C., Marone, M., Akiki, C., Jia, L., Chim, J., Liu, Q., et al. Starcoder: may the source be with you! Transactions on Machine Learning Research, 2023.

Li, X., Nguyen, X.-P., Joty, S., and Bing, L. Paraicl: Towards robust parallel in-context learning. arXiv preprint arXiv:2404.00570, 2024.

Ma, Z., An, S., Xie, B., and Lin, Z. Compositional api recommendation for library-oriented code generation. arXiv preprint arXiv:2402.19431, 2024.

OpenAI. Gpt-4 technical report, 2023.

Patil, S. G., Zhang, T., Wang, X., and Gonzalez, J. E. Gorilla: Large language model connected with massive apis. arXiv preprint arXiv:2305.15334, 2023.

Qiu, Z., Ou, Z., Wu, B., Li, J., Liu, A., and King, I. Entropy-based decoding for retrieval-augmented large language models. In MINT: Foundation Model Interventions.

Raffel, C., Shazeer, N., Roberts, A., Lee, K., Narang, S., Matena, M., Zhou, Y., Li, W., and Liu, P. J. Exploring the limits of transfer learning with a unified text-to-text transformer. Journal of machine learning research, 21 (140):1–67, 2020.

Ratner, N., Levine, Y., Belinkov, Y., Ram, O., Magar, I., Abend, O., Karpas, E., Shashua, A., Leyton-Brown, K., and Shoham, Y. Parallel context windows for large language models. In Proceedings of the 61st Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers), pp. 6383–6402, 2023.

Rawte, V., Sheth, A., and Das, A. A survey of hallucination in large foundation models. arXiv preprint arXiv:2309.05922, 2023.

Shao, Z., Gong, Y., Shen, Y., Huang, M., Duan, N., and Chen, W. Enhancing retrieval-augmented large language models with iterative retrieval-generation synergy. arXiv preprint arXiv:2305.15294, 2023.

Shi, K., Sun, X., Li, Q., and Xu, G. Compressing long context for enhancing rag with amr-based concept distillation. arXiv preprint arXiv:2405.03085, 2024.

Su, J., Ahmed, M., Ao, L., Zhu, M., Liu, Y., et al. Naive bayes-based context extension for large language models. arXiv preprint arXiv:2403.17552, 2024.

Touvron, H., Martin, L., Stone, K., Albert, P., Almahairi, A., Babaei, Y., Bashlykov, N., Batra, S., Bhargava, P., Bhosale, S., et al. Llama 2: Open foundation and fine-tuned chat models. arXiv preprint arXiv:2307.09288, 2023.

Wang, L., Yang, N., Huang, X., Yang, L., Majumder, R., and Wei, F. Improving text embeddings with large language models. arXiv preprint arXiv:2401.00368, 2023.

Wei, J., Wang, X., Schuurmans, D., Bosma, M., Xia, F., Chi, E., Le, Q. V., Zhou, D., et al. Chain-of-thought prompting elicits reasoning in large language models. Advances in neural information processing systems, 35:24824–24837, 2022.

Weng, L. Extrinsic hallucinations in llms, 2024. URL https://lilianweng.github.io/posts/2024-07-07-hallucination/.

Yang, K., Liu, X., Men, K., Zeng, A., Dong, Y., and Tang, J. Revisiting parallel context windows: A frustratingly simple alternative and chain-of-thought deterioration. arXiv preprint arXiv:2305.15262, 2023.

Yang, Z., Qi, P., Zhang, S., Bengio, Y., Cohen, W., Salakhutdinov, R., and Manning, C. D. Hotpotqa: A dataset for diverse, explainable multi-hop question answering. In Proceedings of the 2018 Conference on Empirical Methods in Natural Language Processing, pp. 2369–2380, 2018.

Yen, H., Gao, T., and Chen, D. Long-context language modeling with parallel context encoding. arXiv preprint arXiv:2402.16617, 2024.

Zeng, H., Yue, Z., Jiang, Q., and Wang, D. Federated recommendation via hybrid retrieval augmented generation. arXiv preprint arXiv:2403.04256, 2024.

Zhang, T., Patil, S. G., Jain, N., Shen, S., Zaharia, M., Stoica, I., and Gonzalez, J. E. Raft: Adapting language model to domain specific rag. arXiv preprint arXiv:2403.10131, 2024.

Zhong, M., Yin, D., Yu, T., Zaidi, A., Mutuma, M., Jha, R., Hassan, A., Celikyilmaz, A., Liu, Y., Qiu, X., et al. Qmsum: A new benchmark for query-based multi-domain meeting summarization. In Proceedings of the 2021 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, pp. 5905–5921, 2021.

Zhou, S., Alon, U., Xu, F. F., Wang, Z., Jiang, Z., and Neubig, G. Docprompting: Generating code by retrieving the docs. arXiv preprint arXiv:2207.05987, 2022.

A. Complexity Analysis

Considering that RAG scenarios have high expectations for execution efficiency and previous PCE-style work lacked analysis of the execution efficiency, we present the inference complexity of DePaC compared with vanilla inference approach. Figure 2 shows the attention pattern and execution time comparison between DePaC and vanilla inference. As the length of the question is much smaller than the length of the document, the complexity of processing the question is ignored. Given a LLM with m layers, we assume that the context consists of k documents, each with n tokens.

Vanilla complexity. Vanilla inference directly concatenates the k documents as the input to LLM, with a sequence length of kn. The attention of each layer is calculated by $\text{Attention}(Q, K, V) = \text{softmax}\left(QK^T\right)V$, where $Q, K, V \in \mathbb{R}^{(kn)\times d}$ is the query, key and value matrix. The complexity of QK^T is $\mathcal{O}((kn)^2 \cdot d)$. So the complexity of $Attention(Q, K, V)$ for m layers is $\mathcal{O}(k^2 \cdot n^2 \cdot d \cdot m)$.

DePaC complexity. In DePaC, k documents are inputted to LLM in parallel, the sequence length for each input is n. This is akin to k times $Attention(Q, K, V)$ computations, but with smaller $Q, K, V \in \mathbb{R}^{n\times d}$, so the complexity of $Attention(Q, K, V)$ for m layers is $\mathcal{O}(k \cdot n^2 \cdot d \cdot m)$.

The complexity of Vanilla increases quadratically with k, while DePaC's complexity grows linearly. Figure 2 shows the average execution time of DePaC and vanilla inference approach with different context length, DePaC has faster inference speed than vanilla approach. Moreover, DePaC can place all documents in a single batch for parallel processing, further enhancing DePaC's inference speed.

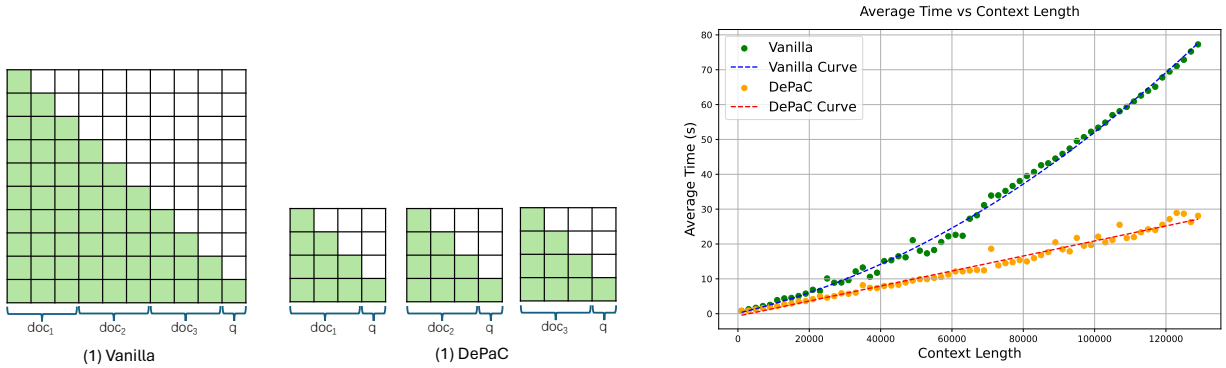

Figure 2: Attention pattern and execution time comparison between DePaC and vanilla inference. The execution time of DePaC increases linearly with context length, while vanilla's complexity grows quadratically.

B. More Formula Details

The Kullback-Leibler (KL) divergence for discrete probability distributions $\mathbf{P_1}$ and $\mathbf{P_2}$ is defined as:

$$\mathrm{D_{KL}}(\mathbf{P_1} \,||\, \mathbf{P_2}) = \sum_i \mathbf{P_1}(i) \log \frac{\mathbf{P_1}(i)}{\mathbf{P_2}(i)} \tag{13}$$

The cross-entropy loss function is defined as:

$$\begin{aligned} &\mathrm{CE}[p_\theta(\,\cdot \mid d_j \oplus \mathcal{Q}),\ \mathcal{A}] = \\ &-\sum_{i=1}^{n} \log p_\theta(\mathcal{A}_i \mid d_j \oplus \mathcal{Q} \oplus \mathcal{A}_{1:i-1}) \end{aligned} \tag{14}$$

where $\mathcal{A}_i$ is the i-th token in g round-truth answers, n is the sequence length of ground-truth. $p_\theta(\mathcal{A}_i | d_j \oplus \mathcal{Q} \oplus \mathcal{A}_{1:i-1})$ is the probability of generating $\mathcal{A}_i$ given the input $d_j \oplus \mathcal{Q} \oplus \mathcal{A}_{1:i-1}$.

C. DePaC Simplified Form

Notice that one implicate constraint in Equation 11 is $\gamma \gg C(\mathbf{p_{i,j}}, \mathbf{p_{i,c}})$ as we hope to directly filter out irrelevant context windows. To simplify this constraint for implementation, we rewrite Equation 11 as the product of two terms and modify Equation 12 to make sure $\hat{C}(\mathbf{p_{i,j}}, \mathbf{p_{i,c}}) \geq 0$,

$$\mathbf{p_i} = \arg\max_{\mathbf{p_{i,j}}} \hat{C}(\mathbf{p_{i,j}}, \mathbf{p_{i,c}}) \cdot \mathbb{I}(\arg\max_k \mathbf{p_{i,j}}^k = t_d), \tag{15}$$

$$\hat{C}(\mathbf{p_{i,j}}, \mathbf{p_{i,c}}) = \max_k \mathbf{p_{i,j}}^k + \beta \cdot \Delta(\mathbf{p_{i,j}}, \mathbf{p_{i,c}}), \tag{16}$$

where we use $\max_k \mathbf{p_{i,j}}^k$ to estimate the output certainty, and $\beta > 0$ is hyper-parameter. For the output of deep learning models, a higher $\max_k \mathbf{p_{i,j}}^k$ always indicates a higher certainty in practice (Ghoshal & Tucker, 2022). We set $\beta = 0.2$ by default and analyze the choice of β in Appendix G.

Implementation Details Following previous work (An et al., 2024), we use the C4 (Raffel et al., 2020) corpus to construct our context-aware negative training dataset. For a segment of text from C4, we first split it into text fragments with a maximum length of 4k tokens. We first sample a fragment serves as oracle document, and use GPT-4-Turbo to generate questions and answers based on the oracle document as positive training data. Then we sample unrelated fragment serves as distractor document to construct context-aware negative training data based on the positive ones. To prevent the model from overfitting on t_d, we control t_d occurrence to match the average frequency of the 2,000 most frequent tokens in NegTrain. Finally, we construct 19K samples for context-aware negative training. We fine-tune three open-source models (introduce in Section 4.3) using 8x80G A100 GPUs, set the global batch size as 128 and trained for two epochs. We use Flash Attention-2 (Dao, 2023) to enhance the training speed. The entire training process takes about 4 hours.

D. Information Seeking Task Details

Below shows the detailed description of information seeking tasks:

- **Function name retrieve (FuncNR)** (An et al., 2024). The contexts in FuncNR contain a large number of Python functions, all of which are sampled from the training data of Starcoder (Li et al., 2023). The questions in FuncNR ask for retrieving the function names based on the given code snippets. We extend the original context length in An et al. (2024) from 32K to 128K.
- **Entity label retrieve (EntLR)** (An et al., 2024). The contexts in EntLR contain a large number of entities, all of which are sampled from Wikidata. Each entity is a triplet in the form of (id, label, description). The questions in EntLR ask for retrieving the labels corresponding to the given entity ids from the contexts. We extend the original context length in An et al. (2024) from 32K to 128K.
- **Multi-values Needle-in-a-Haystack (MVIH)** (Hsieh et al., 2024). The contexts in MVIH contain multiple values for a certain key, along with other unrelated text pieces. The questions in MVIH require the model to seek for all the associated values for the given key.
- **APIBench** (Patil et al., 2023). The contexts in APIBench consist of many real-world APIs, each of which includes an API name, an API call and an API description. The questions in APIBench require to retrieve the API calls based on the given development requirements. Due to the ambiguity in the requirements, APIBench serves as the most challenging evaluation task for information seeking. We take three sub-tasks from APIBench for evaluations: **TensorHub (Tens)**, **TorchHub (Torc)**, and **Huggingface (Hugg)**. In each sub-task, we regard all the candidate APIs as the contexts.

E. DocQA Task Details

Below shows the detailed description of DocQA tasks:

- **Qasper** (Dasigi et al., 2021). The documents in Qasper are academic research papers and the questions in Qasper are written by NLP practitioners. Specifically, after reading only the title and abstract of each paper, the annotators are required to ask an in-depth question which need the information from the full text to get a comprehensive answer.

- **MultifieldQA** (Bai et al., 2023). The MultifieldQA task aims to test long-document understanding of the model on across diverse fields. The contexts in MultifieldQA are collected from various data sources, including legal documents, government reports, encyclopedias, and academic papers.
- **NarrativeQA** (Kočiskỳ et al., 2018). The NarrativeQA task evaluates how well the model understands the entire long books or movie scripts. Answering the questions in NarrativeQA requires the understanding of the underlying narratives in the given document.

F. Baseline Details

Below shows the detailed description of baselines:

- **Vanilla** refers to directly using the vanilla inference approach for a context-limited model (Bai et al., 2023), i.e., concatenating all candidate contexts into input sequence and applying the middle truncation strategy to meet the maximum context length of the model.
- **AVP** (Hao et al., 2022; Ratner et al., 2023) takes the average aggregation (defined in Equation 5) to aggregate the parallel context windows.
- **CLeHe** (Qiu et al.) ensemble the logits of multiple windows to aggregate the parallel context windows.
- **NBCE** (Su et al., 2024) employs the lowest-uncertainty aggregation (defined in Equation 6) to aggregate the parallel context windows.

G. Hyperparameter Settings

We conducted β ablation study on the EntLR dataset. The result in Figure 3 indicates that $\beta \in [0.2, 0.3]$ achieves better trade-off between information entropy and KL divergence. We set $\beta = 0.2$ in our experiments.

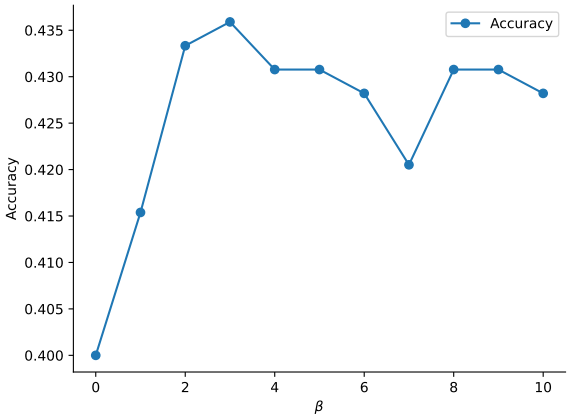

Figure 3: DePaC performance with different $beta$

H. Analysis on NegTrain

Context-aware Negative training can improve the ability of refusing to answer questions with unrelated documents. We constructed an additional 4.4K positive samples (PosEval) and negative samples (NegEval), using the same data construction method as NegTrain, but with different seed documents. PosEval represents the situation that documents are related to the question, while NegEval represents the opposite. We compare the rejection token t_d prediction loss on PosEval and NegEval datasets with different NegTrain steps. Figure 4 shows that NegTrain can increase the probability difference between refusing to answer questions with unrelated document and related document.

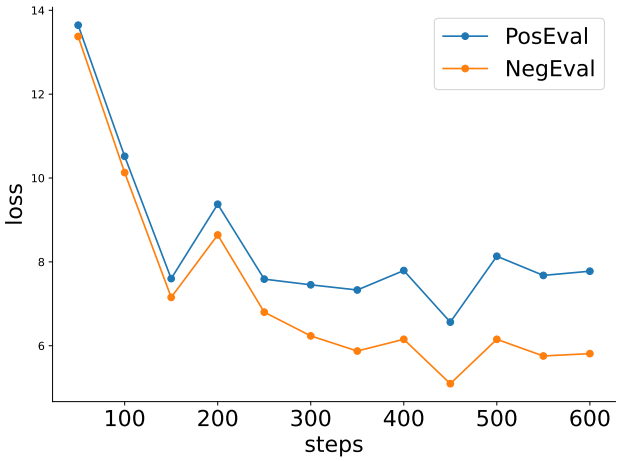

Figure 4: Rejection token prediction loss on PosEval and NegEval over context-aware negative training steps.

Table 2: Comparison results between DePaC and aggregation approaches for RAG.

Method	NaturalQuestions	TriviaQA	RGB
SelfRAG (Asai et al., 2023)	28.67	74.33	75.33
CoVe (Dhuliawala et al., 2023)	26.67	68.67	76.33
COMPETE (Feng et al., 2024)	22.67	69.00	74.00
DePaC (ours)	**33.67**	**88.33**	**94.33**

I. More Evaluation Results

DePaC performs better than aggregation approaches for RAG. We also compare DePaC with previous aggregation approaches specific to RAG (Asai et al., 2023) or can be applied to RAG (Dhuliawala et al., 2023; Feng et al., 2024), the results in Table 2 show that DePaC outperforms other aggregation approaches on different datasets (Kwiatkowski et al., 2019; Joshi et al., 2017; Chen et al., 2024).

DePaC maintains promising performance with candidate documents number increases. On DocQA tasks, as the number of documents increases, more redundant information in the context. As shown in Table 3 DePaC still achieves promising performance. DePaC's performance with k=20 even surpasses NBCE with k=5 (23.9 vs. 19.5), further demonstrating DePaC's capability to identify key information from redundant context.

DePaC also outperforms baselinse on summarization tasks. We also compare DePac on Mistral-7B with baselines on summarization tasks (GovReport (Huang et al., 2021), QMSum (Zhong et al., 2021), and MultiNews (Fabbri et al., 2019)), which better assess the ability of LLMs to integrate information across entire documents. The results in Table 4 demonstrate that DePaC consistently outperforms the baselines on these summarization tasks.

DePaC significantly alleviates fact fabrication and fact omission hallucinations. We analyze the proportion of hallucinations produced by different approaches on three information seeking tasks (FuncNR, EntLR and MVIH). As shown in Figure 5 and Figure 6, DePaC significantly reduces the occurrence of both types of hallucinations. DePaC even completely avoids fact omission on EntLR and fact fabrication on MVIH. The detailed hallucination evaluation setup is shown in Appendix J.

DePaC with CoT maintains performance advantage on multi-hop DocQA. We evaluate on 2WikimQA (Ho et al., 2020) and HotPotQA (Yang et al., 2018) datasets using Mistral-7B. The results in Table 5 show that DePaC still maintains its performance advantage on multi-hop QA datasets. We make the prompt for multi-hop QA datasets end with *"Let's think*

Table 3: DocQA results with different candidate document numbers.

Method	Qasper			MulQA			NarQA		
	k=5	k=10	k=20	k=5	k=10	k=20	k=5	k=10	k=20
Vanilla (Jiang et al., 2023a)	15.0	13.3	8.6	39.7	33.4	31.6	10.2	9.1	9.6
AVP (Hao et al., 2022)	6.7	6.6	6.7	16.7	15.3	15.4	8.6	8.5	8.3
NBCE (Su et al., 2024)	11.7	9.9	9.8	31.0	29.0	26.9	15.9	15.8	15.1
CLeHe (Qiu et al.)	13.4	10.3	10.1	30.8	28.8	26.2	15.8	15.5	14.9
DePaC (ours)	**17.3**	**16.0**	**14.8**	**40.7**	**40.6**	**40.9**	**16.4**	**16.3**	**16.0**

Table 4: Comparison results on summarization tasks.

Method	GovReport	QMSum	MultiNews
Vanilla (Jiang et al., 2023a)	12.4	14.8	17.5
NBCE (Su et al., 2024)	22.3	19.6	21.3
CLeHe (Qiu et al.)	22.2	20.4	21.7
DePaC (ours)	**29.1**	**25.7**	**28.4**

step by step, ", this Chain-of-Thought (CoT) prompt (Wei et al., 2022) helps DePaC first seeks useful information across different contexts before generate the final answer. Figure 7 shows a multi-hop example, where DePaC perform context window switching and successfully locate relevant information spread across multiple documents.

J. Hallucination Definition and Evaluation Setup

Previous work (Weng, 2024) categorizes hallucination into two types: (1) **extrinsic hallucination**, where the output of LLM is not grounded by the pre-training dataset or external world knowledge. (2) **in-context hallucination**, where the output of the model is inconsistent with the source content in context. In this work we focus on two types of in-context hallucination: (1) **fact fabrication**, where LLMs present claims that are not supported by the contexts. (2) **fact omission**, where LLMs fail to present claims that are supported by the contexts. Figure 9 shows an example for fact fabrication, and Figure 10 shows an example for fact omission.

We done in-context hallucination evaluation on three information seeking tasks (FuncNR, EntLR and MVIH), as they are evaluated by exact-match score, makes them easier to analyze than QA tasks. Since these tasks have clear answers in the document and all incorrect outputs are hallucinations, we manually analyzed the data to define 27 fact omission phrases (shown in Figure 8), counted the incorrect outputs that appeared with these phrases as fact omission, and classified other errors as fact fabrication.

K. Window Number Analysis

To analyze DePaC's performance with different numbers of windows, we conduct experiments on the FuncNR dataset, keeping the total number of candidate functions constant while varying the number of windows into which the context is divided. The results in Figure 11 show that as the number of windows increases (form 4 to 128), DePaC's information-seeking ability improves; however, when the number of windows becomes too large (larger than 256), there may be a slight performance decline. All DePaC with split-window outperforms the single-window, further validating the effectiveness of DePaC with parallel context windows.

L. Effectiveness of NegTrain

As shown in Table 6, to further show the effectiveness of NegTrain, we compare NegTrain-Llama2-13B with SlefRAG-Llama2-13B (Asai et al., 2023) (which enhance model's ability of abstaining irrelevant information from context) on

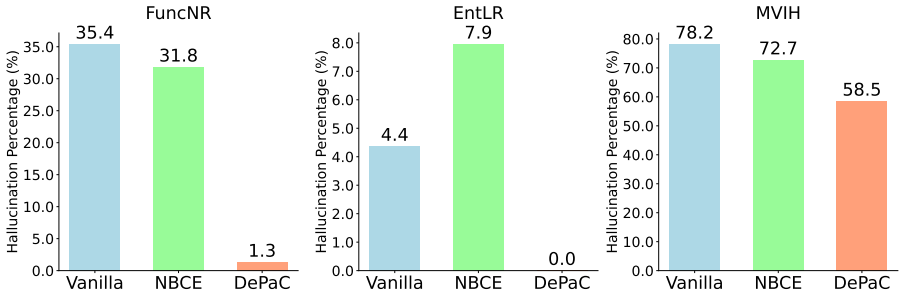

Figure 5: Fact Omission percentage in responses for the information seeking tasks.

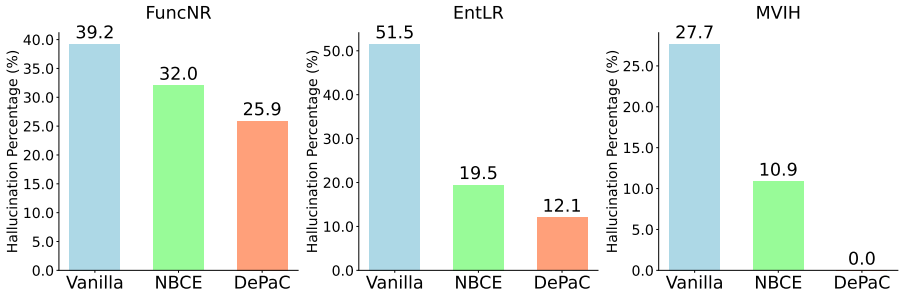

Figure 6: Fact Fabrication percentage in responses for the information seeking tasks.

FactCheckQA (Bashlovkina et al., 2023) benchmark (which requires LLM to answer the question based on the provided context). The results show that NegTrain outperforms SelfRAG and original Llama2 model on FactCheckQA dataset.

M. Limitations

Data generation cost. We rely on GPT-4-Turbo to generate our training data, which cost around 90$ for API calling. Future work should attempt to generate data using cheaper models without compromising data quality.

Training cost. Our training process consumes some computational resources, but it's a one-time effort. Given the advantages of our method in terms of inference efficiency and accuracy, we believe these offline costs are justified.

Table 5: Comparison results on multi-hop DocQA tasks.

Method	2WikimQA	HotPotQA
Vanilla (Jiang et al., 2023a)	19.04	12.01
NBCE (Su et al., 2024)	17.45	10.52
CLeHe (Qiu et al.)	18.32	14.64
DePaC (ours)	**29.72**	**30.95**

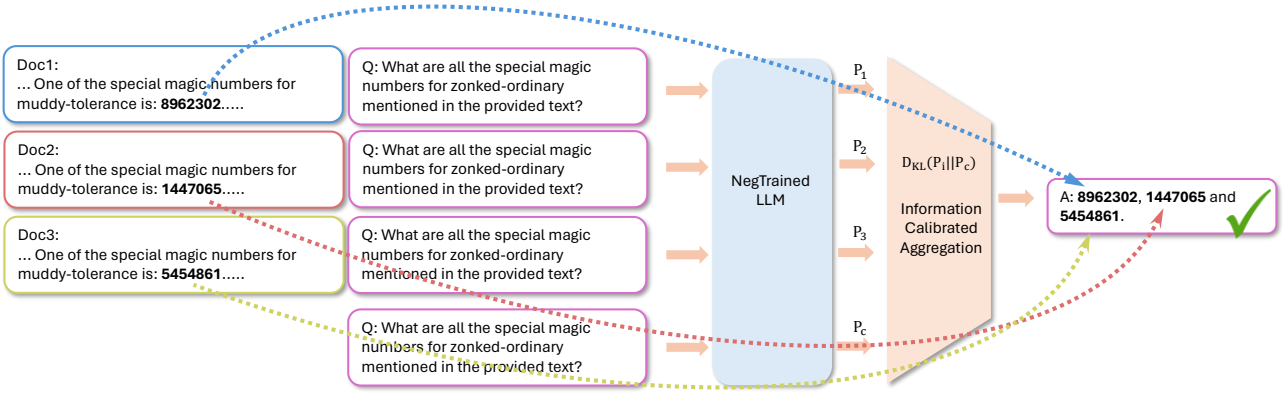

Figure 7: DePaC can switch context window for multi-hop questions.

Fact Omission Phrases

not provided, not mentioned, not given, not stated, not available, not included, not specified, not reported, not recorded, not found, not applicable, not clear, not known, not indicated, not listed, not present, not provided, not reported, not shown, not tested, not directly provided, not explicitly mentioned, not explicitly given, cannot be determined, not have a specific, not been mentioned, not contain, not include, not explicitly stated

Figure 8: Fact omission phrases.

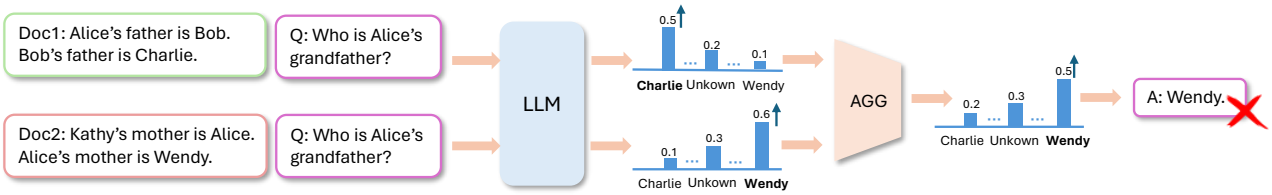

Figure 9: Fact fabrication example. Doc_2 is useless to answer the question. The higher confidence in *"Wendy"* on Doc_2 caused PCE to fabricate the answer "Alice's grandfather is Wendy."

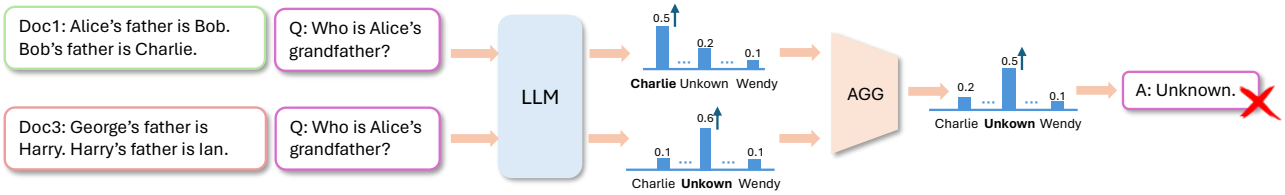

Figure 10: Fact omission example. Doc_3 is useless to answer the question. The higher confidence in "unknown" on Doc_3 caused PCE to omit the fact on Doc_1, resulting an incorrect final answer after aggregation.

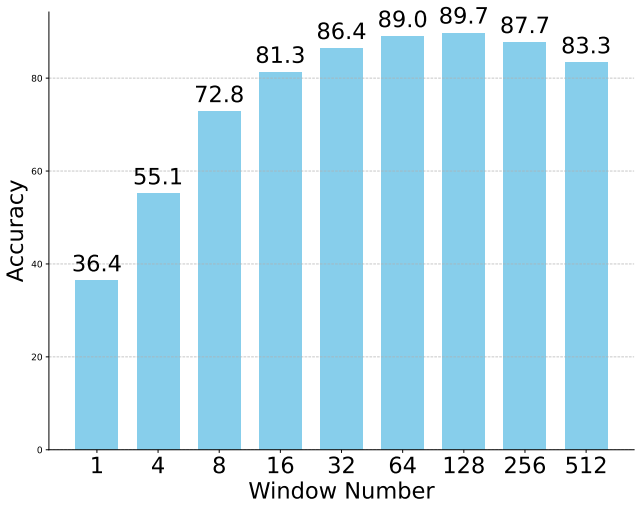

Figure 11: DePaC performance at different degrees of context window parallelism.

Table 6: FactCheckQA results.

Model	FactCheckQA
Llama2-13B-Chat (Touvron et al., 2023)	73
SlefRAG-Llama2-13B (Asai et al., 2023)	76.5
NegTrain-Llama2-13B	**78.5**