RETRIEVAL OR GLOBAL CONTEXT UNDERSTANDING? ON MANY-SHOT IN-CONTEXT LEARNING FOR LONG-CONTEXT EVALUATION

Anonymous authors
Paper under double-blind review

ABSTRACT

Language models (LMs) have demonstrated an improved capacity to handle long-context information, yet existing long-context benchmarks primarily measure LMs' retrieval abilities with extended inputs, e.g., pinpointing a short phrase from long-form text. Therefore, they may fall short when evaluating models' global context understanding capacity, such as synthesizing and reasoning over content across input to generate the response. In this paper, we study *long-context language model (LCLM) evaluation* through *many-shot in-context learning (ICL)*. Concretely, we identify the skills each ICL task requires, and examine models' long-context capabilities on them. We ask the first question: *What types of ICL tasks benefit from additional demonstrations, and are these tasks effective at evaluating LCLMs?* We find that classification and summarization tasks show notable performance improvements with additional demonstrations, while translation and reasoning tasks do not exhibit clear trends. This suggests the classification tasks predominantly test models' retrieval skills. Next, we ask: *To what extent does each task require retrieval skills versus global context understanding from LCLMs?* We develop metrics to categorize ICL tasks into two groups: (i) **retrieval** tasks that require strong retrieval ability to pinpoint relevant examples, and (ii) **global context understanding** tasks that necessitate a deeper comprehension of the full input. We find that not all datasets can effectively evaluate these long-context capabilities. To address this gap, we introduce a new many-shot ICL benchmark, **MANY-ICLBENCH**, designed to characterize LCLMs' retrieval and global context understanding capabilities separately. We benchmark 11 open-weight LCLMs using MANYICLBENCH. We find that while state-of-the-art models demonstrate satisfactory performance up to 64k tokens in retrieval tasks, many models experience significant performance drops at only 16k tokens in global context understanding tasks.[1]

1 INTRODUCTION

Long-context language models (LCLMs) have revolutionized the way users interact with language models by extending the context size from 2K to 128K or even 1M tokens (Team et al., 2024a; GLM et al., 2024; Dubey et al., 2024), which unlock challenging applications, such as long- and multi-document summarization, multi-turn dialogue, and code repository comprehension. Despite the recent progress in building LCLMs, existing benchmarks primarily evaluate these models' retrieval capabilities (Liu et al., 2023; Hsieh et al., 2024). From synthetic tasks such as Needle-in-A-Haystack (Kamradt, 2023) and RULER benchmark (Hsieh et al., 2024) to real-world challenges like long-novel QA (Karpinska et al., 2024), the majority of benchmarks assess how well LCLMs retrieve specific pieces of information from extensive contexts. As a result, **evaluating models' global understanding of the full context remains lacking**.

To fill the gap, Li et al. (2024) introduce LongICLBench, which uses many-shot ICL classification tasks to evaluate models' long-context performance, arguing that these tasks require the comprehension of the entire input. A few other works have also explored many-shot ICL for long-context

[1]Data and code are available at `https://github.com/launchnlp/ManyICLBench`

models (Agarwal et al., 2024; Bertsch et al., 2024). Yet, they have mainly relied on classification tasks (Li et al., 2024; Bertsch et al., 2024), which are insufficient to distinguish which skills LCLMs require to perform well on many-shot ICL classification tasks. Recently, Agarwal et al. (2024) study non-classification ICL tasks but only on Gemini 1.5 Pro. In this work, we want to conduct a comprehensive study on many-shot ICL across a wide range of models, with a goal of identifying tasks that **benefit from additional demonstrations** and explore their utility in evaluating long-context models. Moreover, we seek to determine the extent to which these tasks rely on **retrieval versus global context understanding**.

RQ1: Which tasks benefit from many-shot ICL? First, we investigate ICL tasks that are used in prior work, including classification, summarization, and reasoning, under many-shot settings with context lengths from 1k to 128k (Agarwal et al., 2024). We find that classification and summarization tasks show *strong positive correlation between context lengths and model performance*. Our findings indicate that translation and reasoning tasks such as ARC (Clark et al., 2018) and FLORES-200 (NLLB Team, 2022) do not gain much performance with an increasing number of demonstrations. Science and symbolic reasoning tasks exhibit inconsistent trends between context lengths and model performance. This variance in performance is mainly attributed to the specific nature of tasks, where more demonstrations do not boost the models' task understanding. Interestingly, math tasks benefit from additional demonstrations only when step-by-step solutions are derived and using strong LCLMs.

RQ2: What skill does each task primarily measure? We then analyze the retrieval and global context understanding skills necessary for each ICL task. We use the ratio between the performance change of removing dissimilar examples and the change of removing similar examples. A high ratio means a more pronounced drop in performance upon removing similar examples, which indicates the task's heavy reliance on retrieval capabilities. Our analysis indicates that existing many-shot ICL *classification* tasks (Li et al., 2024) *predominantly assess retrieval abilities* rather than global context understanding. This leads us to categorize tasks into retrieval and non-retrieval groups.

Subsequently, we explore whether non-retrieval tasks genuinely benefit from additional demonstrations and assess models' global context understanding skills. By comparing the performance of models with unique demonstrations versus duplicated examples on non-retrieval tasks, we aim to determine if duplicating examples adversely affects performance compared to adding new examples. If this is the case, it signifies that unique demonstrations provide additional beneficial information, reinforcing the notion that these tasks require global context understanding. Using this method, we identify a subset of non-retrieval tasks that evaluate models' comprehension of global content.

Following the categorization, we propose a new many-shot ICL benchmark, **MANYICLBENCH**, designed for evaluating long-context models and advocate for the inclusion of many-shot ICL tasks as effective evaluation candidates. Importantly, on MANYICLBENCH, models are tested to either retrieve the most similar demonstrations or assimilate all demonstrations to enhance their understanding of the task (Lin & Lee, 2024; Bertsch et al., 2024). Therefore, MANYICLBENCH *evaluates both retrieval skills and global context understanding*, thus providing a holistic assessment of long-context models' capabilities.

In summary, we make the following contributions in this paper:

- Investigate whether ICL tasks benefit from additional demonstrations and assess their suitability for evaluating LCLMs with a context length up to 128k tokens.
- Develop methods to characterize the primary skills evaluated by ICL tasks, where we focus on distinguishing between retrieval capabilities and global context understanding.
- Construct a many-shot ICL benchmark, named MANYICLBENCH, designed for evaluating LCLMs on both retrieval and global context understanding, while excluding irrelevant datasets previously used in LCLM evaluation.
- Benchmark 11 widely-used state-of-the-art LCLMs on MANYICLBENCH to assess their performance comprehensively.

2 Related Work

2.1 Long-Context Language Models and Evaluation

As large language models grow in scale, there is an increasing demand for handling tasks that require extended contexts. Tasks such as long document summarization (Kryściński et al., 2022), conversations with long-context memory (Xu et al., 2021), and repository-level code completion (Zhang et al., 2023) have garnered significant interest. Advances in efficient attention mechanisms, such as flash attention (Dao et al., 2022) and grouped query attention (Ainslie et al., 2023), alongside the development of GPUs with larger memory capacities, have enabled LLMs to be trained on extended contexts. Techniques like position interpolation (Chen et al., 2023; Peng et al., 2023) and context compression (Chevalier et al., 2023; Mohtashami & Jaggi, 2023; Jiang et al., 2024) have further extended the context window size to up to 1 million tokens.

Despite these advancements, the NLP community still seeks a universal and effective method for evaluating long-context models. One prominent task is Needle-in-a-Haystack (Kamradt, 2023), which requires models to retrieve the most relevant document from a large set of documents. Currently, most evaluation benchmarks focus on synthetic tasks that primarily assess the retrieval capabilities of long-context models (Hsieh et al., 2024; Kamradt, 2023; Lee et al., 2024; Lei et al., 2024). Only a few benchmarks, such as Karpinska et al. (2024) and Zhang et al. (2024), emphasize the model's ability to comprehend the global context. For example, Karpinska et al. (2024) manually curated a set of challenging questions based on various novels to evaluate global context understanding. It is the first work to create a realistic long-context benchmark emphasizing retrieval and global context understanding skills.

2.2 Many-shot ICL with LCLMs

Because the context length of large language models expands, the number of demonstrations that can be utilized in ICL has also increased. Studies by Li et al. (2024), Bertsch et al. (2024), and Agarwal et al. (2024) have examined various properties of ICL under the many-shot setting. Bertsch et al. (2024) explore whether models are merely performing retrieval tasks or genuinely understanding the tasks during many-shot ICL classification. Similarly, Agarwal et al. (2024) analyzes the performance of tasks beyond classification in the many-shot context, using Gemini-Pro, and finds that additional demonstrations generally enhance task performance. Furthermore, Li et al. (2024) propose a long-context evaluation benchmark LongICLBench comprising many-shot ICL classification tasks, noting that current long-context models still face challenges in this area. None of the prior works has studied what skill each ICL task measures LCLMs for. LongICLBench mostly focuses on classification tasks, which may only evaluates the retrieval ability of LCLMs. Unlike previous studies, our work provides a more comprehensive analysis of many-shot ICL across a diverse set of tasks and multiple models. We introduce novel metrics to measure retrieval skills and the level of task understanding required for each task. We identify a set of ICL tasks suitable for evaluation and present a refined long-context evaluation benchmark with fine-grained categorization based on required retrieval skills and task understanding.

2.3 In-Context Learning

In-context learning (ICL) enables models to quickly recognize and perform tasks during inference by conditioning on a set of provided demonstrations (Brown et al., 2020). Many previous works have sought to understand the mechanisms behind in-context learning (ICL). Xie et al. (2022) suggests that models implicitly perform Bayesian inference during inference, retrieving relevant skills learned during pretraining. Additionally, Lin & Lee (2024) introduces the concept of a dual operating mode in ICL: task learning and task retrieval. With sufficient demonstrations, models can adapt to unseen tasks learned during pretraining, thereby enhancing performance as the number of demonstrations increases. To explore how many-shot ICL operates, Bertsch et al. (2024) modified the attention patterns by restricting attention among individual examples. Their findings suggest that performance improvements primarily arise from retrieving similar examples rather than comprehending the task. However, their experiment is limited to classification tasks. It may also be biased when comparing full attention and block attention, as block attention allows access to more demonstrations. Our work

Dataset	Task Category	Avg. Tokens / Shot	Max # of Shots	# of Tasks
BANKING77	Intent Classification	13.13	5386	1
GoEmotions	Emotion Classification	15.85	5480	1
DialogRE	Relation Classification	233.27	395	1
TREC	Question Classification	11.25	6272	1
CLINC150	Intent Classification	8.95	7252	1
MATH	Math reasoning	[185.52, 407.90]	[286, 653]	4
GSM8K	Math reasoning	55.78	784	1
BBH	Reasoning	[48.27, 243.01]	[406, 2660]	4
GPQA	MQ - Science	[183.55, 367.02]	[314, 580]	1
ARC	MQ - Science	[61.54, 61.54]	[1997, 2301]	2
XLSUM	New Summarization	621.32	220	1
FLORES-200	Translation	[63.63, 101.74]	[570, 1965]	3

Table 1: Dataset Information. GPT-4o tokenizer is used to calculate # of tokens. Max # of shots is the number of shots can be fitted into the 128k context window. For datasets that have multiple subtasks, we list the range for each value. We have 22 tasks in total.

tries to design better experiments to investigate during many-shot ICL what skill each task mainly requires from LCLMs.

3 Experiment Setting

To investigate many-shot ICL across various tasks and model sizes, we select 11 models ranging from 3.8B to 123B parameters. Our evaluation includes 12 datasets with 22 subtasks, spanning classification, summarization, reasoning, and translation domains. For each task, we randomly sample 200 data points from the test set, using the full test set if it contains fewer than 200 samples.

For each task, we construct prompts for different context window sizes by incrementally adding new demonstrations from the training set to the prompt of the shorter context window size and duplicate training examples if they are insufficient to fill the context window. To ensure a fair comparison, we randomize the order of demonstrations and consistently use the same set of examples across all context sizes. For simplicity, we apply greedy decoding across all models and conduct each experiment using three different random seeds. For the prompt construction, we only include demonstrations and provide minimal task instruction.

3.1 Datasets

We include five datasets for **classification** tasks: BANKING77, GoEmotions, DialogRE, TREC, and CLINC150. For the **summarization** task, we use XLSUM, and for **translation**, we use FLORES-200. Additionally, we incorporate four datasets for **reasoning** tasks: MATH, BBH, and GPQA, and ARC. More details about each dataset can be found in Table 1 and A.

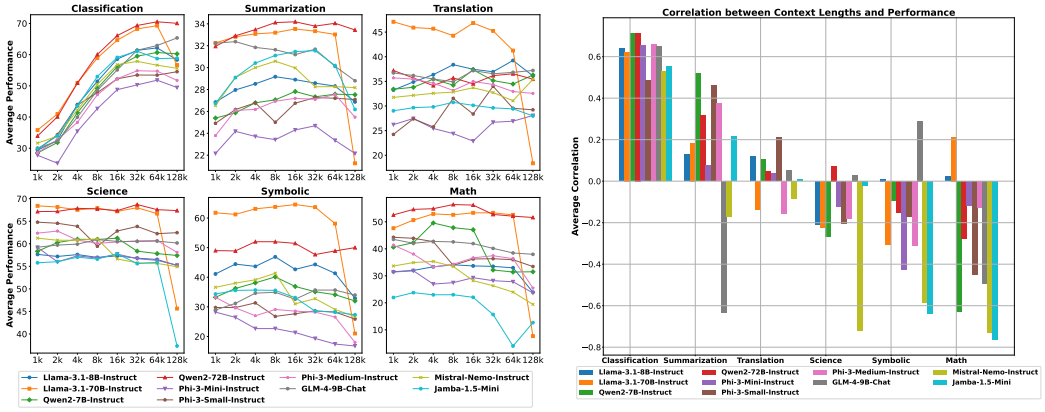
For the MATH, BBH, GPQA, and ARC tasks, we use accuracy as the evaluation metric. Macro F1-score is employed as the metric for all classification tasks. Rouge-L (Lin, 2004) is used for the XLSUM summarization task. ChrF (Popović, 2015) is applied for translation evaluation.

3.2 Models

The list of models we use in our experiment is: Llama-3.1 8B and 70B (Dubey et al., 2024), GLM-4-9B-Chat (GLM et al., 2024), Mistral Nemo (12B) and Large (123B) (Mistral AI, 2024), Qwen2 7B and 72B (Yang et al., 2024), Phi-3 mini (3.8B), small(7B), and medium(14B) (Abdin et al., 2024), and Jamba 1.5 Mini (12B/52B)(Team et al., 2024c), and Gemini-1.5-Pro (Team et al., 2024b).We only run Gemini-1-5-Pro on our benchmark. We use the instruction-tuned version of all the models. For models with more than 50B, we run the quantized version of the models, and in C, we show that the quantized version exhibits the same trend as the unquantized version with increasing context length.

4 WHICH TASKS BENEFIT FROM MORE EXAMPLES?

In this section, we explore the extent to which many-shot ICL enhances model performance across different task types. Previous work has either focused on only classification tasks (Bertsch et al., 2024) or studied only one specific model (Agarwal et al., 2024). In contrast, our analysis provides a comprehensive evaluation of many-shot ICL across both classification and generation tasks using ten open-weights LCLMs, excluding Mistral-Large in this section. We collect tasks from previous work (Bertsch et al., 2024; Agarwal et al., 2024; Li et al., 2024), categorize them into six types: classification, translation, summarization, math reasoning, science reasoning, and symbolic reasoning.[2] The results, illustrated in Figure 1, include aggregated model performance across task types and the correlation coefficients between context lengths and performance from 1k to 64k. We also plot models' performance on individual task in D.



(a) (b)

Figure 1: (a) Aggregated performance of models over datasets in different categories of tasks. (b) Average pearson correlation coefficient between context lengths (1k to 64k) and the corresponding performance.

Classification performance steadily improves with more shots: Figure 1a demonstrates a consistent performance increase across all models as more demonstrations are added for classification tasks. This trend indicates a strong positive correlation between context length and performance, which is illustrated in Fig 1b. Given that classification tasks often involve extensive label spaces, e.g., CLINC150 has 150 classes, additional demonstrations provide models with exposure to more classes and thus enhance their ability to perform accurately. This is consistent with prior research findings (Bertsch et al., 2024).

Subjective tasks do not benefit from more examples: The GoEmotions task, though being a classification problem, exhibits a fluctuating performance trend across all models with increasing shots in Figure 6. We attribute this inconsistency to the subjective nature of the task, where nuanced emotional categories may lead to low annotator agreement (Demszky et al., 2020). This variance in the annotated labels may results in a weaker correlation between context length and performance. This finding highlights a limitation in using ICL tasks with ambiguous ground truths to evaluate LCLMs, as their performance does not improve with more demonstrations.

Summarization shows gradual performance gains only: On summarization, most models exhibit a high correlation between context length and performance. However, there is a noticeable slowdown in the performance gains as the number of demonstrations increases. This suggests that while additional context may improve performance, it does so at a diminishing rate, particularly for smaller models like Llama-3.1-8B that struggle to leverage longer contexts effectively.

Models' performance fluctuates on translation tasks: As shown in Figure 7, the performance curves for all models across different languages differ. For the low-resource language, models show larger performance gap than those in the high-resource language, e.g., Spanish. In Chinese, mod-

[2]We exclude datasets that are noisy or not open access.

els become spikier than in other languages across different context sizes. In Figure 1a, translation tasks show a very flat curve, with no significant improvement as the number of demonstrations increases. This result contrasts with Agarwal et al. (2024), where the Gemini-1.5 Pro model demonstrated consistent performance improvements in Kurdish and Tamil translation tasks as the context size increased. We think the performance inconsistency is caused by the mismatched multilingual capability of models and different model sizes.

Math tasks benefit from additional demonstrations, particularly for stronger models: In math reasoning tasks, only the Llama-3.1 and Qwen2 model families show significant performance improvements with additional demonstrations. Notably, Qwen2 performance plateaus at 16k length, while Llama-3.1 continues to improve until 64k. The models with larger parameter sizes tend to exhibit more consistent performance gains, supporting findings from Agarwal et al. (2024) who have demonstrated that Gemini 1.5 Pro improves on math tasks with more examples.

Inconsistent trends in science and symbolic tasks: For science and symbolic reasoning tasks, the performance trends are less predictable, with some models displaying minimal changes when seeing additional examples, while others benefit. *This variability suggests that not all tasks lend themselves to the advantages of many-shot ICL equally*.

Ideally, for every task, additional demonstrations should either improve performance or, at the very least, not harm it. A model with robust long-context capabilities should exhibit a non-decreasing performance trend as the context length increases. Given the inconsistent performance on non-classification tasks and even decreasing performance on some reasoning tasks, in the next two sections, we further investigate what aspects these datasets evaluate and identify a set of tasks useful for evaluating important skills of LCMLs.

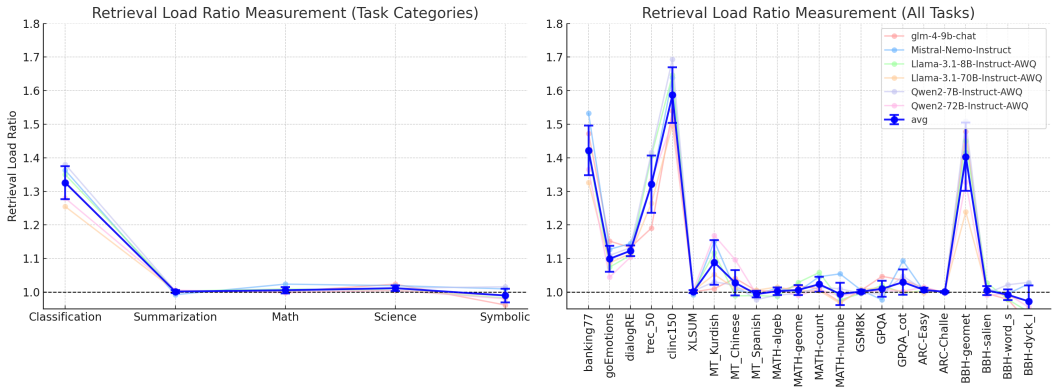


Figure 2: Retrieval Load Ratio on different categories of tasks from 1k to 64k tokens. The ratio of 1 indicates models are not doing retrieval during ICL. Classification is the only category of tasks that has a very high ratio, which means classification tasks requires models retrieval skill during ICL. The rest of tasks is close to 1, and models' performance on these tasks do not rely on retrieving similar examples.

5 Task Categorization: Retrieval vs. Global Context Understanding

To understand what skill each ICL task primarily requires from LCLMs, in this section, we first measure the **retrieval load** of each task and divide them into *retrieval* vs. *non-retrieval* tasks (5.1). Among non-retrieval tasks, we then conduct experiments to identify tasks that truly benefit from additional demonstrations and measure the model's global context understanding skill.(5.2)

5.1 Retrieval Tasks

To identify retrieval tasks, we propose a simple metric, **retrieval load ratio**, to assess whether tasks predominantly rely on models to retrieve relevant examples during many-shot ICL. We consider

retrieval load as the retrieval skill required by LCLMs to solve a ICL task. Concretely, for each ICL task, we create two variants of the original demonstrations at each context size ranging from 1k to 64k by removing the 10% most similar and the 10% least similar examples. The model's performance on these variants is then evaluated, and we have $score_{most}$ for removing similar examples and $score_{least}$ for removing dissimilar examples. Here we use BM25 retriever to calculate the similarity. We then average the ratios between $score_{least}$ and $score_{most}$ from 1k to 64k lengths as:

$$\text{Retrieval Load Ratio} = \frac{1}{7}\sum_{l=1k}^{64k}(\frac{score_{least}}{score_{most}})_l \tag{1}$$

Intuitively, if a model predominantly relies on retrieval for a task, removing most similar examples will result in a more pronounced performance drop compared to removing dissimilar ones, which causes the ratio to be larger than 1. Conversely, if there is minimal difference between the two, it means the model does not retrieve similar examples to perform the task, and the ratio will be close to 1.

Classification tasks requires high retrieval load: As shown in Figure 2, *all classification tasks exhibit high retrieval load ratio across the six models*. The BBH geometric shapes task also shows a high retrieval raio, indicating that tasks like BANKING77, CLINC150, and TREC50 demand strong retrieval capabilities from the models. Tasks such as GoEmotions and dialogRE have relatively lower retrieval ratios, suggesting they require moderate retrieval skills. Among the symbolic tasks, BBH-geometric_shapes is the only reasoning task that has a high retrieval load ratio. This task involves determining the geometric shape given a full SVG path element, making it similar to a classification task. The high retrieval load ratio of classification tasks can possibly explain the largest positive correlation between performance and context lengths, as displayed in Fig 1b.

Tasks with low retrieval load: All the non-classification tasks have a low retrieval load ratio. In Figure 1, models show inconsistent correlations on performance and context lengths for different non-retrieval tasks. This inconsistency may be attributed to the incapability of the LCLMs or the nature of the tasks, which we will investigate more in the next section.

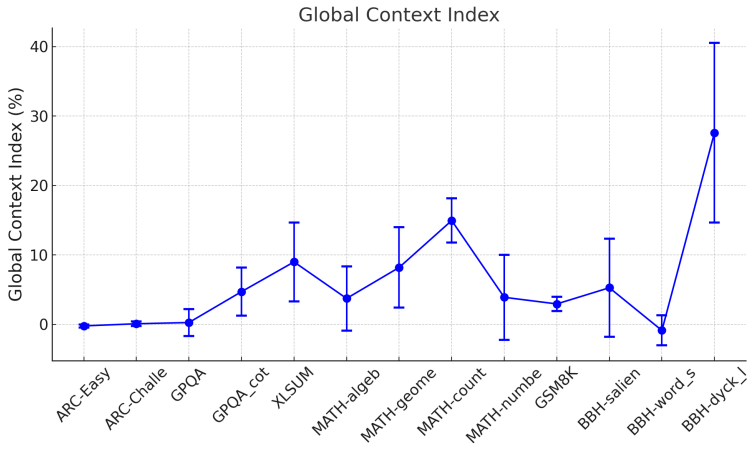


Figure 3: Global context index is the average % difference between adding duplicated vs. unique examples from 2k to 16k context for non-retrieval tasks. 0% means duplicating does not harm the model's performance. Easy tasks such as ARC and word sorting do not benefit from additional information. When a task is too difficult, e.g., GPQA, the model cannot effectively learn all demonstrations unless explanations are provided.

5.2 Global Context Understanding Tasks

In this section, we investigate whether non-retrieval tasks truly benefit from additional demonstrations and whether models use all the demonstrations to understand the task during ICL. We exclude

the translation tasks from this set of experiments due to inconsistent tokenization for different languages and mismatched multilingual capability of models.

Global Context Index: We propose another metric, **global context index**, to measure the global context understanding skill required by a task. Specifically, for each non-retrieval task, we have two variants of demonstrations, which both start with the same demonstrations used in the 1k context-length experiment. From 2k to 16k, the unique variant will keep adding unique demonstrations to the prompt, whereas the duplicate variants will repeat the same demonstrations in the 1k length. We denote the performance of the unique variant $score_{unique}$ and the performance of duplicate variant $score_{duplicate}$. Then, we average the percentage difference between $score_{unique}$ and $score_{duplicate}$ from 2k to 16k lengths as:

$$\text{Global Context Index} = \frac{1}{4}\sum_{l=2k}^{16k}(\frac{score_{unique} - score_{duplicate}}{score_{unique}})_l \tag{2}$$

If duplicating examples results in worse performance on a non-retrieval task than adding unique examples, the global context index will be positive and suggests that the model benefits more from unique demonstrations. This means that performance improvements come from learning from diverse examples rather than simply picking up on formatting patterns or relying on spurious correlations between in-domain tokens and predictions. Since non-retrieval tasks typically do not rely on retrieving similar examples, we can conclude that the performance gain on these tasks is likely due to the models' improved global context understanding when more demonstrations are available.

We use Llama-3.1-70B for the experiment because it is best at using additional demonstrations out of all models we have tested so far, e.g., it shows a high positive correlation between context lengths and performance in Fig 1b. Then, we only conduct the experiment up to 16k to minimize the impact of the model's long context capability.

Global context understanding tasks: In Figure 3, tasks such as the math problems and summarization, Dyck languages, translation error detection from BBH, and GPQA with explanations all have worse performance with duplicated demonstrations. This means that *they necessitate a greater degree of global context understanding rather than relying on the retrieval of relevant examples*. These tasks are often complex reasoning challenges, for which models may lack pretraining skills to solve perfectly, underscoring the need for additional demonstrations or deeper task comprehension.

ICL Tasks that are not suitable for LCLM evaluation: In Figure 3, ARC-Easy, ARC-Challenge, GPQA, the BBH word sorting tasks are indifferent to duplicating examples. This indicates that these tasks do not benefit from additional demonstrations. Most of these tasks assess the intrinsic abilities of the models reasoning with their parametric knowledge, thus a few demonstrations suffice. Adding more demonstrations may introduce distractions rather than improve performance. Interestingly, GPQA with "chain-of-thoughts" benefit from additional examples. We suspect that without these solution steps, GPQA is too challenging for the model to understand even after seeing many demonstrations with answers only.

6 MANYICLBENCH: A MANY-SHOT ICL BENCHMARK TO MEASURE RETRIEVAL SKILL AND GLOBAL CONTEXT UNDERSTANDING

In this section, we present a new long-context benchmark MANYICLBENCH, designed to evaluate LCLMs' retrieval skills and global context understanding capabilities using the ICL setup. Based on the results from Section 5, we group tasks into two types:

• **5 Retrieval Tasks**: BANKING77, dialogRE, TREC50, CLINC150, and the geometric shape task from BBH.

• **9 Global Context Understanding Tasks**: all math tasks, summarization task, GPQA with explanations, translation error detection, and dyck language task from BBH.

Evaluation results of popular LCLMs are summarized in Table 2.

Most models struggle at retrieving examples after 32k length: Up to a context length of 16k, *all models demonstrate a steady performance increase, indicating effective retrieval from shorter contexts*. However, performance begins to decline after reaching 32k tokens, particularly for the Mistral

Retrieval Tasks	1k	2k	4k	8k	16k	32k	64k	128k	AVG.	AVG.L.
GLM-4-9b-Chat	31.63	34.99	46.37	57.27	63.61	68.34	72.16	72.93	55.91	71.14
Mistral-Nemo-Instruct	33.44	35.45	48.17	57.95	65.38	65.49	63.61	61.73	53.90	63.61
Mistral-Large-Instruct-AWQ	49.15	51.23	60.78	71.95	77.10	79.45	77.77	61.89	**66.16**	73.04
Llama-3.1-8B-Instruct-AWQ	32.13	34.63	45.76	57.39	66.18	70.02	70.55	65.85	55.31	68.81
Llama-3.1-70B-Instruct-AWQ	38.75	42.87	53.98	66.07	73.12	76.56	78.48	65.56	61.92	73.53
Qwen2-7B-Instruct-AWQ	30.18	34.03	44.40	54.85	62.92	65.91	66.94	66.38	53.20	66.41
Qwen2-72B-Instruct-AWQ	36.41	41.89	54.24	65.33	73.39	76.53	77.51	77.47	62.85	**77.17**
Phi-3-Mini-Instruct	30.27	30.90	38.09	48.14	53.58	57.29	56.83	48.72	45.48	54.28
Phi-3-Medium-Instruct	31.73	33.55	39.10	49.83	58.29	61.17	60.63	45.32	47.45	55.70
Phi-3-Small-Instruct	31.48	36.27	46.20	54.34	59.63	59.73	60.20	48.97	49.60	56.30
Jamba-1.5-Mini	32.10	36.91	48.61	60.29	66.05	68.33	66.02	65.17	55.44	66.51
Gemini-1.5-Pro	36.40	47.31	58.01	65.49	71.43	74.22	72.43	72.42	62.21	73.03
Global Context Understanding Tasks	**1k**	**2k**	**4k**	**8k**	**16k**	**32k**	**64k**	**128k**	**AVG.**	**AVG.L.**
GLM-4-9b-Chat	36.79	36.23	38.30	39.30	37.60	37.94	36.53	35.45	37.27	36.64
Mistral-Nemo-Instruct	33.94	34.88	34.92	34.72	28.22	28.64	26.28	23.23	30.60	26.05
Mistral-Large-Instruct-AWQ	57.09	56.30	56.21	56.12	56.43	53.33	42.98	13.10	48.94	36.47
Llama-3.1-8B-Instruct-AWQ	31.31	32.79	33.02	34.50	34.25	35.22	33.71	27.88	32.84	32.27
Llama-3.1-70B-Instruct-AWQ	45.53	47.60	48.39	49.08	49.64	49.83	47.74	13.88	43.99	37.23
Qwen2-7B-Instruct-AWQ	37.75	39.47	43.86	44.55	42.83	35.17	33.00	32.70	38.67	33.62
Qwen2-72B-Instruct-AWQ	47.38	49.03	50.32	50.69	50.78	48.56	48.18	48.68	49.20	48.47
Phi-3-Mini-Instruct	29.86	29.20	26.61	26.95	27.65	26.34	25.54	23.08	26.90	24.98
Phi-3-Medium-Instruct	37.74	37.15	31.49	32.02	33.04	33.19	33.06	24.56	32.78	30.27
Phi-3-Small-Instruct	38.40	38.40	38.35	31.69	34.04	34.59	33.74	32.46	35.21	33.60
Jamba-1.5-Mini	27.86	29.04	28.93	28.86	27.86	24.92	23.12	22.42	26.63	23.48
Gemini-1.5-Pro	58.26	60.88	61.30	65.20	65.05	65.12	62.38	63.61	**66.20**	**66.92**

Table 2: Model performance on retrieval and global context understanding tasks. AVG. is the average model performance of all context lengths. AVG.L. is the average model performance of 32k, 64k and 128k. Red indicates performance improvement compared to 1k. Blue indicates performance downgrade compared to 1k. A darker color means higher improvement or downgrade. **BOLD** number means the largest number of a column. Many models start downgrading their performance after 32k on retrieval tasks. On global context understanding tasks, many models start struggling even before 16k.

family and Jamba models. After 64k, the Llama 3.1 family and the mini and medium versions of Phi-3 exhibit a notable downgrade in performance. In contrast, the Qwen-2 family maintains robust performance, with minimal degradation from 64k to 128k. Remarkably, only GLM-4 continues to improve in retrieval performance beyond 64k, indicating its impressive retrieval capabilities within a very long context window. Interestingly, larger models like Mistral-Large and Llama-3.1-70B exhibit the most significant performance losses as context length increases, suggesting that size alone does not ensure superior long-context retrieval ability.

Challenges in global context understanding tasks: Global context understanding tasks prove to be more challenging, with *many models struggling even at short context lengths like 2k or 4k*. Only the Llama 3.1 family, Qwen2 family, and GLM-4 models effectively leverage many demonstrations up to 16k. At 32k, only the Llama 3.1 models sustain performance. As context length extends from 32k to 128k, all models experience performance degradation, highlighting that current architectures still struggle to grasp global context and utilize demonstrations effectively. Notably, Qwen2-72B and GLM-4 are the only models that do not experience significant performance drops in this category.

The paradox of model size: Despite the common assumption that larger models possess greater capabilities, our findings illustrate that larger models can experience more substantial performance losses compared to smaller models if not trained adequately on long-context data. For instance, Mistral-Large (123B) shows optimal performance from 1k to 32k but experiences a dramatic drop beyond 32k, which is worse than Phi-3-Mini (3.8B). A similar trend is observed with Llama-3.1-70B at 128k. Both underscore the importance of targeted training for long-context tasks.

Llama 3.1 performance and training limitations: The Llama 3.1 models initially capitalize on additional demonstrations effectively up to 64k but suffer significant performance declines at 128k. This pattern aligns with trends observed in other long-context evaluation benchmarks (Hsieh et al., 2024). We suspect that these performance drops are linked to insufficient training with long-context data during the supervised fine-tuning (SFT) stage. According to Table 7 in (Dubey et al., 2024), the average token count for long-context datasets is around 38k, indicating limited exposure for models to effectively learn from data points at 128k lengths.

Qwen2 and GLM-4 show relatively robust capabilities on both tasks: The Qwen2-72B model consistently maintains performance across both retrieval and global context understanding tasks, demonstrating its adaptability for longer contexts. Trained on data with up to 32k tokens, Qwen2 models employ modified RoPE frequency and training-free positional interpolation methods to handle longer contexts. However, the Qwen2 family models drop their performance from 16k to 32k in the global context of understanding tasks but maintain their performance after 32k. This raises the question of whether the training-free length extension methods enable models to use additional demonstrations or merely maintain their performance in the short context length and ignore additional examples during many-shot ICL. Meanwhile, GLM-4-chat also shows a relatively robust performance at a longer context size and is the only model to experience a performance increase from 64k to 128k on retrieval tasks. GLM-4's training methodology closely mirrors that of Llama 3.1 models, with adjustments to the RoPE base and continuous training on long-context data. The difference is, during SFT, GLM-4-9B follows LongAlign (Bai et al., 2024), which determines the length distribution of the long-context SFT data carefully. GLM-4-9B also goes through the RLHF stage with both short and long data.

Gemini-1.5-Pro shows a very robust long context capability: Similar to other open-weight models on retrieval tasks, Gemini-1.5-Pro begins to show performance degradation beyond 32k. However, it is one of only three models (alongside Qwen-2-72B and GLM-Chat-9B) that demonstrate impressive retrieval capabilities beyond 64k and maintain performance at 128k. On global context understanding tasks, Gemini-1.5-Pro significantly outperforms other open-weight models, showcasing its ability to grasp the global context and effectively utilize all the demonstrations.

Future directions can be investigating the optimal length distribution of both pre-training and SFT long-context data, as well as studying the effects of continual training on long-context data and the implementation of training-free length extension methods.

7 Conclusion

We investigated many-shot in-context learning (ICL) across various tasks using different open-weight models, assessing their suitability for evaluating long-context language models (LCLMs). Our findings indicate that classification and summarization tasks consistently benefit from additional demonstrations, while other tasks do not. To identify a set of tasks suitable for long-context evaluation, we introduced the concept of retrieval load ratio to assess the retrieval demands of different tasks. This analysis revealed that classification tasks predominantly rely on the model's retrieval capabilities. For non-retrieval tasks, we conducted duplication experiments to differentiate global context understanding tasks from those that introduce noise. Based on these insights, we categorized tasks into two distinct groups: retrieval tasks and global context understanding tasks. Furthermore, we introduced a novel many-shot ICL benchmark, **ManyICLBench**, designed to evaluate both retrieval and global context understanding skills of LCLMs. Benchmarking open-weight LCLMs on ManyICLBench revealed that most models struggle with global context understanding tasks at lengths below 16k tokens. In contrast, performance on retrieval tasks tends to decline after 32k tokens.

References

Marah Abdin, Jyoti Aneja, Hany Awadalla, Ahmed Awadallah, Ammar Ahmad Awan, Nguyen Bach, Amit Bahree, Arash Bakhtiari, Jianmin Bao, Harkirat Behl, Alon Benhaim, Misha Bilenko, Johan Bjorck, Sébastien Bubeck, Martin Cai, Qin Cai, Vishrav Chaudhary, Dong Chen, Dongdong Chen, Weizhu Chen, Yen-Chun Chen, Yi-Ling Chen, Hao Cheng, Parul Chopra, Xiyang Dai, Matthew Dixon, Ronen Eldan, Victor Fragoso, Jianfeng Gao, Mei Gao, Min Gao, Amit Garg, Allie Del Giorno, Abhishek Goswami, Suriya Gunasekar, Emman Haider, Junheng Hao, Russell J. Hewett, Wenxiang Hu, Jamie Huynh, Dan Iter, Sam Ade Jacobs, Mojan Javaheripi, Xin Jin, Nikos Karampatziakis, Piero Kauffmann, Mahoud Khademi, Dongwoo Kim, Young Jin Kim, Lev Kurilenko, James R. Lee, Yin Tat Lee, Yuanzhi Li, Yunsheng Li, Chen Liang, Lars Liden, Xihui Lin, Zeqi Lin, Ce Liu, Liyuan Liu, Mengchen Liu, Weishung Liu, Xiaodong Liu, Chong Luo, Piyush Madan, Ali Mahmoudzadeh, David Majercak, Matt Mazzola, Caio César Teodoro Mendes, Arindam Mitra, Hardik Modi, Anh Nguyen, Brandon Norick, Barun Patra, Daniel Perez-Becker, Thomas Portet, Reid Pryzant, Heyang Qin, Marko Radmilac, Liliang Ren, Gustavo

de Rosa, Corby Rosset, Sambudha Roy, Olatunji Ruwase, Olli Saarikivi, Amin Saied, Adil Salim, Michael Santacroce, Shital Shah, Ning Shang, Hiteshi Sharma, Yelong Shen, Swadheen Shukla, Xia Song, Masahiro Tanaka, Andrea Tupini, Praneetha Vaddamanu, Chunyu Wang, Guanhua Wang, Lijuan Wang, Shuohang Wang, Xin Wang, Yu Wang, Rachel Ward, Wen Wen, Philipp Witte, Haiping Wu, Xiaoxia Wu, Michael Wyatt, Bin Xiao, Can Xu, Jiahang Xu, Weijian Xu, Jilong Xue, Sonali Yadav, Fan Yang, Jianwei Yang, Yifan Yang, Ziyi Yang, Donghan Yu, Lu Yuan, Chenruidong Zhang, Cyril Zhang, Jianwen Zhang, Li Lyna Zhang, Yi Zhang, Yue Zhang, Yunan Zhang, and Xiren Zhou. Phi-3 technical report: A highly capable language model locally on your phone, 2024. URL https://arxiv.org/abs/2404.14219.

Rishabh Agarwal, Avi Singh, Lei M. Zhang, Bernd Bohnet, Luis Rosias, Stephanie Chan, Biao Zhang, Ankesh Anand, Zaheer Abbas, Azade Nova, John D. Co-Reyes, Eric Chu, Feryal Behbahani, Aleksandra Faust, and Hugo Larochelle. Many-shot in-context learning, 2024. URL https://arxiv.org/abs/2404.11018.

Joshua Ainslie, James Lee-Thorp, Michiel de Jong, Yury Zemlyanskiy, Federico Lebrón, and Sumit Sanghai. Gqa: Training generalized multi-query transformer models from multi-head checkpoints, 2023. URL https://arxiv.org/abs/2305.13245.

Yushi Bai, Xin Lv, Jiajie Zhang, Yuze He, Ji Qi, Lei Hou, Jie Tang, Yuxiao Dong, and Juanzi Li. Longalign: A recipe for long context alignment of large language models, 2024. URL https://arxiv.org/abs/2401.18058.

Amanda Bertsch, Maor Ivgi, Uri Alon, Jonathan Berant, Matthew R. Gormley, and Graham Neubig. In-context learning with long-context models: An in-depth exploration, 2024. URL https://arxiv.org/abs/2405.00200.

Tom B. Brown, Benjamin Mann, Nick Ryder, Melanie Subbiah, Jared 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 M. Ziegler, Jeffrey Wu, Clemens Winter, Christopher Hesse, Mark Chen, Eric Sigler, Mateusz Litwin, Scott Gray, Benjamin Chess, Jack Clark, Christopher Berner, Sam McCandlish, Alec Radford, Ilya Sutskever, and Dario Amodei. Language models are few-shot learners, 2020. URL https://arxiv.org/abs/2005.14165.

Iñigo Casanueva, Tadas Temčinas, Daniela Gerz, Matthew Henderson, and Ivan Vulić. Efficient intent detection with dual sentence encoders, 2020. URL https://arxiv.org/abs/2003.04807.

Shouyuan Chen, Sherman Wong, Liangjian Chen, and Yuandong Tian. Extending context window of large language models via positional interpolation, 2023. URL https://arxiv.org/abs/2306.15595.

Alexis Chevalier, Alexander Wettig, Anirudh Ajith, and Danqi Chen. Adapting language models to compress contexts, 2023. URL https://arxiv.org/abs/2305.14788.

Peter Clark, Isaac Cowhey, Oren Etzioni, Tushar Khot, Ashish Sabharwal, Carissa Schoenick, and Oyvind Tafjord. Think you have solved question answering? try arc, the ai2 reasoning challenge. *arXiv:1803.05457v1*, 2018.

Tri Dao, Daniel Y. Fu, Stefano Ermon, Atri Rudra, and Christopher Ré. Flashattention: Fast and memory-efficient exact attention with io-awareness, 2022. URL https://arxiv.org/abs/2205.14135.

Dorottya Demszky, Dana Movshovitz-Attias, Jeongwoo Ko, Alan Cowen, Gaurav Nemade, and Sujith Ravi. Goemotions: A dataset of fine-grained emotions, 2020. URL https://arxiv.org/abs/2005.00547.

Yiran Ding, Li Lyna Zhang, Chengruidong Zhang, Yuanyuan Xu, Ning Shang, Jiahang Xu, Fan Yang, and Mao Yang. Longrope: Extending llm context window beyond 2 million tokens, 2024. URL https://arxiv.org/abs/2402.13753.

Abhimanyu Dubey, Abhinav Jauhri, Abhinav Pandey, Abhishek Kadian, Ahmad Al-Dahle, Aiesha Letman, Akhil Mathur, Alan Schelten, Amy Yang, Angela Fan, Anirudh Goyal, Anthony Hartshorn, Aobo Yang, Archi Mitra, Archie Sravankumar, Artem Korenev, Arthur Hinsvark, Arun Rao, Aston Zhang, Aurelien Rodriguez, Austen Gregerson, Ava Spataru, Baptiste Roziere, Bethany Biron, Binh Tang, Bobbie Chern, Charlotte Caucheteux, Chaya Nayak, Chloe Bi, Chris Marra, Chris McConnell, Christian Keller, Christophe Touret, Chunyang Wu, Corinne Wong, Cristian Canton Ferrer, Cyrus Nikolaidis, Damien Allonsius, Daniel Song, Danielle Pintz, Danny Livshits, David Esiobu, Dhruv Choudhary, Dhruv Mahajan, Diego Garcia-Olano, Diego Perino, Dieuwke Hupkes, Egor Lakomkin, Ehab AlBadawy, Elina Lobanova, Emily Dinan, Eric Michael Smith, Filip Radenovic, Frank Zhang, Gabriel Synnaeve, Gabrielle Lee, Georgia Lewis Anderson, Graeme Nail, Gregoire Mialon, Guan Pang, Guillem Cucurell, Hailey Nguyen, Hannah Korevaar, Hu Xu, Hugo Touvron, Iliyan Zarov, Imanol Arrieta Ibarra, Isabel Kloumann, Ishan Misra, Ivan Evtimov, Jade Copet, Jaewon Lee, Jan Geffert, Jana Vranes, Jason Park, Jay Mahadeokar, Jeet Shah, Jelmer van der Linde, Jennifer Billock, Jenny Hong, Jenya Lee, Jeremy Fu, Jianfeng Chi, Jianyu Huang, Jiawen Liu, Jie Wang, Jiecao Yu, Joanna Bitton, Joe Spisak, Jongsoo Park, Joseph Rocca, Joshua Johnstun, Joshua Saxe, Junteng Jia, Kalyan Vasuden Alwala, Kartikeya Upasani, Kate Plawiak, Ke Li, Kenneth Heafield, Kevin Stone, Khalid El-Arini, Krithika Iyer, Kshitiz Malik, Kuenley Chiu, Kunal Bhalla, Lauren Rantala-Yeary, Laurens van der Maaten, Lawrence Chen, Liang Tan, Liz Jenkins, Louis Martin, Lovish Madaan, Lubo Malo, Lukas Blecher, Lukas Landzaat, Luke de Oliveira, Madeline Muzzi, Mahesh Pasupuleti, Mannat Singh, Manohar Paluri, Marcin Kardas, Mathew Oldham, Mathieu Rita, Maya Pavlova, Melanie Kambadur, Mike Lewis, Min Si, Mitesh Kumar Singh, Mona Hassan, Naman Goyal, Narjes Torabi, Nikolay Bashlykov, Nikolay Bogoychev, Niladri Chatterji, Olivier Duchenne, Onur Çelebi, Patrick Alrassy, Pengchuan Zhang, Pengwei Li, Petar Vasic, Peter Weng, Prajjwal Bhargava, Pratik Dubal, Praveen Krishnan, Punit Singh Koura, Puxin Xu, Qing He, Qingxiao Dong, Ragavan Srinivasan, Raj Ganapathy, Ramon Calderer, Ricardo Silveira Cabral, Robert Stojnic, Roberta Raileanu, Rohit Girdhar, Rohit Patel, Romain Sauvestre, Ronnie Polidoro, Roshan Sumbaly, Ross Taylor, Ruan Silva, Rui Hou, Rui Wang, Saghar Hosseini, Sahana Chennabasappa, Sanjay Singh, Sean Bell, Seohyun Sonia Kim, Sergey Edunov, Shaoliang Nie, Sharan Narang, Sharath Raparthy, Sheng Shen, Shengye Wan, Shruti Bhosale, Shun Zhang, Simon Vandenhende, Soumya Batra, Spencer Whitman, Sten Sootla, Stephane Collot, Suchin Gururangan, Sydney Borodinsky, Tamar Herman, Tara Fowler, Tarek Sheasha, Thomas Georgiou, Thomas Scialom, Tobias Speckbacher, Todor Mihaylov, Tong Xiao, Ujjwal Karn, Vedanuj Goswami, Vibhor Gupta, Vignesh Ramanathan, Viktor Kerkez, Vincent Gonguet, Virginie Do, Vish Vogeti, Vladan Petrovic, Weiwei Chu, Wenhan Xiong, Wenyin Fu, Whitney Meers, Xavier Martinet, Xiaodong Wang, Xiaoqing Ellen Tan, Xinfeng Xie, Xuchao Jia, Xuewei Wang, Yaelle Goldschlag, Yashesh Gaur, Yasmine Babaei, Yi Wen, Yiwen Song, Yuchen Zhang, Yue Li, Yuning Mao, Zacharie Delpierre Coudert, Zheng Yan, Zhengxing Chen, Zoe Papakipos, Aaditya Singh, Aaron Grattafiori, Abha Jain, Adam Kelsey, Adam Shajnfeld, Adithya Gangidi, Adolfo Victoria, Ahuva Goldstand, Ajay Menon, Ajay Sharma, Alex Boesenberg, Alex Vaughan, Alexei Baevski, Allie Feinstein, Amanda Kallet, Amit Sangani, Anam Yunus, Andrei Lupu, Andres Alvarado, Andrew Caples, Andrew Gu, Andrew Ho, Andrew Poulton, Andrew Ryan, Ankit Ramchandani, Annie Franco, Aparajita Saraf, Arkabandhu Chowdhury, Ashley Gabriel, Ashwin Bharambe, Assaf Eisenman, Azadeh Yazdan, Beau James, Ben Maurer, Benjamin Leonhardi, Bernie Huang, Beth Loyd, Beto De Paola, Bhargavi Paranjape, Bing Liu, Bo Wu, Boyu Ni, Braden Hancock, Bram Wasti, Brandon Spence, Brani Stojkovic, Brian Gamido, Britt Montalvo, Carl Parker, Carly Burton, Catalina Mejia, Changhan Wang, Changkyu Kim, Chao Zhou, Chester Hu, Ching-Hsiang Chu, Chris Cai, Chris Tindal, Christoph Feichtenhofer, Damon Civin, Dana Beaty, Daniel Kreymer, Daniel Li, Danny Wyatt, David Adkins, David Xu, Davide Testuggine, Delia David, Devi Parikh, Diana Liskovich, Didem Foss, Dingkang Wang, Duc Le, Dustin Holland, Edward Dowling, Eissa Jamil, Elaine Montgomery, Eleonora Presani, Emily Hahn, Emily Wood, Erik Brinkman, Esteban Arcaute, Evan Dunbar, Evan Smothers, Fei Sun, Felix Kreuk, Feng Tian, Firat Ozgenel, Francesco Caggioni, Francisco Guzmán, Frank Kanayet, Frank Seide, Gabriela Medina Florez, Gabriella Schwarz, Gada Badeer, Georgia Swee, Gil Halpern, Govind Thattai, Grant Herman, Grigory Sizov, Guangyi, Zhang, Guna Lakshminarayanan, Hamid Shojanazeri, Han Zou, Hannah Wang, Hanwen Zha, Haroun Habeeb, Harrison Rudolph, Helen Suk, Henry Aspegren, Hunter Goldman, Ibrahim Damlaj, Igor Molybog, Igor Tufanov, Irina-Elena Veliche, Itai Gat, Jake Weissman, James Geboski, James Kohli, Japhet Asher, Jean-Baptiste Gaya, Jeff Marcus, Jeff Tang, Jennifer Chan, Jenny Zhen, Jeremy Reizenstein, Jeremy Teboul, Jessica Zhong, Jian Jin, Jingyi Yang, Joe

Cummings, Jon Carvill, Jon Shepard, Jonathan McPhie, Jonathan Torres, Josh Ginsburg, Junjie Wang, Kai Wu, Kam Hou U, Karan Saxena, Karthik Prasad, Kartikay Khandelwal, Katayoun Zand, Kathy Matosich, Kaushik Veeraraghavan, Kelly Michelena, Keqian Li, Kun Huang, Kunal Chawla, Kushal Lakhotia, Kyle Huang, Lailin Chen, Lakshya Garg, Lavender A, Leandro Silva, Lee Bell, Lei Zhang, Liangpeng Guo, Licheng Yu, Liron Moshkovich, Luca Wehrstedt, Madian Khabsa, Manav Avalani, Manish Bhatt, Maria Tsimpoukelli, Martynas Mankus, Matan Hasson, Matthew Lennie, Matthias Reso, Maxim Groshev, Maxim Naumov, Maya Lathi, Meghan Keneally, Michael L. Seltzer, Michal Valko, Michelle Restrepo, Mihir Patel, Mik Vyatskov, Mikayel Samvelyan, Mike Clark, Mike Macey, Mike Wang, Miquel Jubert Hermoso, Mo Metanat, Mohammad Rastegari, Munish Bansal, Nandhini Santhanam, Natascha Parks, Natasha White, Navyata Bawa, Nayan Singhal, Nick Egebo, Nicolas Usunier, Nikolay Pavlovich Laptev, Ning Dong, Ning Zhang, Norman Cheng, Oleg Chernoguz, Olivia Hart, Omkar Salpekar, Ozlem Kalinli, Parkin Kent, Parth Parekh, Paul Saab, Pavan Balaji, Pedro Rittner, Philip Bontrager, Pierre Roux, Piotr Dollar, Polina Zvyagina, Prashant Ratanchandani, Pritish Yuvraj, Qian Liang, Rachad Alao, Rachel Rodriguez, Rafi Ayub, Raghotham Murthy, Raghu Nayani, Rahul Mitra, Raymond Li, Rebekkah Hogan, Robin Battey, Rocky Wang, Rohan Maheswari, Russ Howes, Ruty Rinott, Sai Jayesh Bondu, Samyak Datta, Sara Chugh, Sara Hunt, Sargun Dhillon, Sasha Sidorov, Satadru Pan, Saurabh Verma, Seiji Yamamoto, Sharadh Ramaswamy, Shaun Lindsay, Shaun Lindsay, Sheng Feng, Shenghao Lin, Shengxin Cindy Zha, Shiva Shankar, Shuqiang Zhang, Shuqiang Zhang, Sinong Wang, Sneha Agarwal, Soji Sajuyigbe, Soumith Chintala, Stephanie Max, Stephen Chen, Steve Kehoe, Steve Satterfield, Sudarshan Govindaprasad, Sumit Gupta, Sungmin Cho, Sunny Virk, Suraj Subramanian, Sy Choudhury, Sydney Goldman, Tal Remez, Tamar Glaser, Tamara Best, Thilo Kohler, Thomas Robinson, Tianhe Li, Tianjun Zhang, Tim Matthews, Timothy Chou, Tzook Shaked, Varun Vontimitta, Victoria Ajayi, Victoria Montanez, Vijai Mohan, Vinay Satish Kumar, Vishal Mangla, Vítor Albiero, Vlad Ionescu, Vlad Poenaru, Vlad Tiberiu Mihailescu, Vladimir Ivanov, Wei Li, Wenchen Wang, Wenwen Jiang, Wes Bouaziz, Will Constable, Xiaocheng Tang, Xiaofang Wang, Xiaojian Wu, Xiaolan Wang, Xide Xia, Xilun Wu, Xinbo Gao, Yanjun Chen, Ye Hu, Ye Jia, Ye Qi, Yenda Li, Yilin Zhang, Ying Zhang, Yossi Adi, Youngjin Nam, Yu, Wang, Yuchen Hao, Yundi Qian, Yuzi He, Zach Rait, Zachary DeVito, Zef Rosnbrick, Zhaoduo Wen, Zhenyu Yang, and Zhiwei Zhao. The llama 3 herd of models, 2024. URL https://arxiv.org/abs/2407.21783.

Team GLM, :, Aohan Zeng, Bin Xu, Bowen Wang, Chenhui Zhang, Da Yin, Dan Zhang, Diego Rojas, Guanyu Feng, Hanlin Zhao, Hanyu Lai, Hao Yu, Hongning Wang, Jiadai Sun, Jiajie Zhang, Jiale Cheng, Jiayi Gui, Jie Tang, Jing Zhang, Jingyu Sun, Juanzi Li, Lei Zhao, Lindong Wu, Lucen Zhong, Mingdao Liu, Minlie Huang, Peng Zhang, Qinkai Zheng, Rui Lu, Shuaiqi Duan, Shudan Zhang, Shulin Cao, Shuxun Yang, Weng Lam Tam, Wenyi Zhao, Xiao Liu, Xiao Xia, Xiaohan Zhang, Xiaotao Gu, Xin Lv, Xinghan Liu, Xinyi Liu, Xinyue Yang, Xixuan Song, Xunkai Zhang, Yifan An, Yifan Xu, Yilin Niu, Yuantao Yang, Yueyan Li, Yushi Bai, Yuxiao Dong, Zehan Qi, Zhaoyu Wang, Zhen Yang, Zhengxiao Du, Zhenyu Hou, and Zihan Wang. Chatglm: A family of large language models from glm-130b to glm-4 all tools, 2024. URL https://arxiv.org/abs/2406.12793.

Tahmid Hasan, Abhik Bhattacharjee, Md. Saiful Islam, Kazi Mubasshir, Yuan-Fang Li, Yong-Bin Kang, M. Sohel Rahman, and Rifat Shahriyar. XL-sum: Large-scale multilingual abstractive summarization for 44 languages. In *Findings of the Association for Computational Linguistics: ACL-IJCNLP 2021*, pp. 4693–4703, Online, August 2021. Association for Computational Linguistics. URL https://aclanthology.org/2021.findings-acl.413.

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. *NeurIPS*, 2021.

Eduard Hovy, Laurie Gerber, Ulf Hermjakob, Chin-Yew Lin, and Deepak Ravichandran. Toward semantics-based answer pinpointing. In *Proceedings of the First International Conference on Human Language Technology Research*, 2001. URL https://www.aclweb.org/anthology/H01-1069.

Cheng-Ping Hsieh, Simeng Sun, Samuel Kriman, Shantanu Acharya, Dima Rekesh, Fei Jia, Yang Zhang, and Boris Ginsburg. Ruler: What's the real context size of your long-context language models?, 2024. URL https://arxiv.org/abs/2404.06654.

Huiqiang Jiang, Qianhui Wu, Xufang Luo, Dongsheng Li, Chin-Yew Lin, Yuqing Yang, and Lili Qiu. Longllmlingua: Accelerating and enhancing llms in long context scenarios via prompt compression, 2024. URL https://arxiv.org/abs/2310.06839.

Gregory Kamradt. Needle in a haystack - pressure testing llms, 2023. URL https://github.com/gkamradt/LLMTest_NeedleInAHaystack/tree/main.

Marzena Karpinska, Katherine Thai, Kyle Lo, Tanya Goyal, and Mohit Iyyer. One thousand and one pairs: A "novel" challenge for long-context language models, 2024. URL https://arxiv.org/abs/2406.16264.

Wojciech Kryściński, Nazneen Rajani, Divyansh Agarwal, Caiming Xiong, and Dragomir Radev. Booksum: A collection of datasets for long-form narrative summarization, 2022. URL https://arxiv.org/abs/2105.08209.

Stefan Larson, Anish Mahendran, Joseph J. Peper, Christopher Clarke, Andrew Lee, Parker Hill, Jonathan K. Kummerfeld, Kevin Leach, Michael A. Laurenzano, Lingjia Tang, and Jason Mars. An evaluation dataset for intent classification and out-of-scope prediction. In Kentaro Inui, Jing Jiang, Vincent Ng, and Xiaojun Wan (eds.), *Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing and the 9th International Joint Conference on Natural Language Processing (EMNLP-IJCNLP)*, pp. 1311–1316, Hong Kong, China, November 2019. Association for Computational Linguistics. doi: 10.18653/v1/D19-1131. URL https://aclanthology.org/D19-1131.

Jinhyuk Lee, Anthony Chen, Zhuyun Dai, Dheeru Dua, Devendra Singh Sachan, Michael Boratko, Yi Luan, Sébastien M. R. Arnold, Vincent Perot, Siddharth Dalmia, Hexiang Hu, Xudong Lin, Panupong Pasupat, Aida Amini, Jeremy R. Cole, Sebastian Riedel, Iftekhar Naim, Ming-Wei Chang, and Kelvin Guu. Can long-context language models subsume retrieval, rag, sql, and more?, 2024. URL https://arxiv.org/abs/2406.13121.

Fangyu Lei, Qian Liu, Yiming Huang, Shizhu He, Jun Zhao, and Kang Liu. S3eval: A synthetic, scalable, systematic evaluation suite for large language models, 2024. URL https://arxiv.org/abs/2310.15147.

Tianle Li, Ge Zhang, Quy Duc Do, Xiang Yue, and Wenhu Chen. Long-context llms struggle with long in-context learning, 2024. URL https://arxiv.org/abs/2404.02060.

Xin Li and Dan Roth. Learning question classifiers. In *COLING 2002: The 19th International Conference on Computational Linguistics*, 2002. URL https://www.aclweb.org/anthology/C02-1150.

Chin-Yew Lin. ROUGE: A package for automatic evaluation of summaries. In *Text Summarization Branches Out*, pp. 74–81, Barcelona, Spain, July 2004. Association for Computational Linguistics. URL https://aclanthology.org/W04-1013.

Ziqian Lin and Kangwook Lee. Dual operating modes of in-context learning, 2024. URL https://arxiv.org/abs/2402.18819.

Nelson F. Liu, Kevin Lin, John Hewitt, Ashwin Paranjape, Michele Bevilacqua, Fabio Petroni, and Percy Liang. Lost in the middle: How language models use long contexts, 2023. URL https://arxiv.org/abs/2307.03172.

Mistral AI. Mistral nemo. https://mistral.ai/news/mistral-nemo/, 2024. Accessed: 6 September 2024.

Amirkeivan Mohtashami and Martin Jaggi. Landmark attention: Random-access infinite context length for transformers, 2023. URL https://arxiv.org/abs/2305.16300.

James Cross Onur Çelebi Maha Elbayad Kenneth Heafield Kevin Heffernan Elahe Kalbassi Janice Lam Daniel Licht Jean Maillard Anna Sun Skyler Wang Guillaume Wenzek Al Youngblood Bapi Akula Loic Barrault Gabriel Mejia Gonzalez Prangthip Hansanti John Hoffman Semarley Jarrett Kaushik Ram Sadagopan Dirk Rowe Shannon Spruit Chau Tran Pierre Andrews Necip

Fazil Ayan Shruti Bhosale Sergey Edunov Angela Fan Cynthia Gao Vedanuj Goswami Francisco Guzmán Philipp Koehn Alexandre Mourachko Christophe Ropers Safiyyah Saleem Holger Schwenk Jeff Wang NLLB Team, Marta R. Costa-jussà. No language left behind: Scaling human-centered machine translation. 2022.

Bowen Peng, Jeffrey Quesnelle, Honglu Fan, and Enrico Shippole. Yarn: Efficient context window extension of large language models, 2023. URL https://arxiv.org/abs/2309.00071.

Maja Popović. chrF: character n-gram F-score for automatic MT evaluation. In Ondřej Bojar, Rajan Chatterjee, Christian Federmann, Barry Haddow, Chris Hokamp, Matthias Huck, Varvara Logacheva, and Pavel Pecina (eds.), *Proceedings of the Tenth Workshop on Statistical Machine Translation*, pp. 392–395, Lisbon, Portugal, September 2015. Association for Computational Linguistics. doi: 10.18653/v1/W15-3049. URL https://aclanthology.org/W15-3049.

Rafael Rafailov, Archit Sharma, Eric Mitchell, Stefano Ermon, Christopher D. Manning, and Chelsea Finn. Direct preference optimization: Your language model is secretly a reward model, 2024. URL https://arxiv.org/abs/2305.18290.

Nils Reimers and Iryna Gurevych. Sentence-bert: Sentence embeddings using siamese bert-networks. In *Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing*. Association for Computational Linguistics, 11 2019. URL https://arxiv.org/abs/1908.10084.

David Rein, Betty Li Hou, Asa Cooper Stickland, Jackson Petty, Richard Yuanzhe Pang, Julien Dirani, Julian Michael, and Samuel R. Bowman. Gpqa: A graduate-level google-proof qa benchmark, 2023.

Aarohi Srivastava, Abhinav Rastogi, Abhishek Rao, Abu Awal Md Shoeb, Abubakar Abid, Adam Fisch, Adam R Brown, Adam Santoro, Aditya Gupta, Adrià Garriga-Alonso, et al. Beyond the imitation game: Quantifying and extrapolating the capabilities of language models. *arXiv preprint arXiv:2206.04615*, 2022.

Mirac Suzgun, Nathan Scales, Nathanael Schärli, Sebastian Gehrmann, Yi Tay, Hyung Won Chung, Aakanksha Chowdhery, Quoc V Le, Ed H Chi, Denny Zhou, , and Jason Wei. Challenging big-bench tasks and whether chain-of-thought can solve them. *arXiv preprint arXiv:2210.09261*, 2022.

Gemini Team, Rohan Anil, Sebastian Borgeaud, Jean-Baptiste Alayrac, Jiahui Yu, Radu Soricut, Johan Schalkwyk, Andrew M. Dai, Anja Hauth, Katie Millican, David Silver, Melvin Johnson, Ioannis Antonoglou, Julian Schrittwieser, Amelia Glaese, Jilin Chen, Emily Pitler, Timothy Lillicrap, Angeliki Lazaridou, Orhan Firat, James Molloy, Michael Isard, Paul R. Barham, Tom Hennigan, Benjamin Lee, Fabio Viola, Malcolm Reynolds, Yuanzhong Xu, Ryan Doherty, Eli Collins, Clemens Meyer, Eliza Rutherford, Erica Moreira, Kareem Ayoub, Megha Goel, Jack Krawczyk, Cosmo Du, Ed Chi, Heng-Tze Cheng, Eric Ni, Purvi Shah, Patrick Kane, Betty Chan, Manaal Faruqui, Aliaksei Severyn, Hanzhao Lin, YaGuang Li, Yong Cheng, Abe Ittycheriah, Mahdis Mahdieh, Mia Chen, Pei Sun, Dustin Tran, Sumit Bagri, Balaji Lakshminarayanan, Jeremiah Liu, Andras Orban, Fabian Güra, Hao Zhou, Xinying Song, Aurelien Boffy, Harish Ganapathy, Steven Zheng, HyunJeong Choe, Ágoston Weisz, Tao Zhu, Yifeng Lu, Siddharth Gopal, Jarrod Kahn, Maciej Kula, Jeff Pitman, Rushin Shah, Emanuel Taropa, Majd Al Merey, Martin Baeuml, Zhifeng Chen, Laurent El Shafey, Yujing Zhang, Olcan Sercinoglu, George Tucker, Enrique Piqueras, Maxim Krikun, Iain Barr, Nikolay Savinov, Ivo Danihelka, Becca Roelofs, Anaïs White, Anders Andreassen, Tamara von Glehn, Lakshman Yagati, Mehran Kazemi, Lucas Gonzalez, Misha Khalman, Jakub Sygnowski, Alexandre Frechette, Charlotte Smith, Laura Culp, Lev Proleev, Yi Luan, Xi Chen, James Lottes, Nathan Schucher, Federico Lebron, Alban Rrustemi, Natalie Clay, Phil Crone, Tomas Kocisky, Jeffrey Zhao, Bartek Perz, Dian Yu, Heidi Howard, Adam Bloniarz, Jack W. Rae, Han Lu, Laurent Sifre, Marcello Maggioni, Fred Alcober, Dan Garrette, Megan Barnes, Shantanu Thakoor, Jacob Austin, Gabriel Barth-Maron, William Wong, Rishabh Joshi, Rahma Chaabouni, Deeni Fatiha, Arun Ahuja, Gaurav Singh Tomar, Evan Senter, Martin Chadwick, Ilya Kornakov, Nithya Attaluri, Iñaki Iturrate, Ruibo Liu, Yunxuan Li, Sarah Cogan, Jeremy Chen, Chao Jia, Chenjie Gu, Qiao Zhang, Jordan Grimstad, Ale Jakse Hartman, Xavier Garcia, Thanumalayan Sankaranarayana Pillai, Jacob Devlin, Michael Laskin, Diego

de Las Casas, Dasha Valter, Connie Tao, Lorenzo Blanco, Adrià Puigdomènech Badia, David Reitter, Mianna Chen, Jenny Brennan, Clara Rivera, Sergey Brin, Shariq Iqbal, Gabriela Surita, Jane Labanowski, Abhi Rao, Stephanie Winkler, Emilio Parisotto, Yiming Gu, Kate Olszewska, Ravi Addanki, Antoine Miech, Annie Louis, Denis Teplyashin, Geoff Brown, Elliot Catt, Jan Balaguer, Jackie Xiang, Pidong Wang, Zoe Ashwood, Anton Briukhov, Albert Webson, Sanjay Ganapathy, Smit Sanghavi, Ajay Kannan, Ming-Wei Chang, Axel Stjerngren, Josip Djolonga, Yuting Sun, Ankur Bapna, Matthew Aitchison, Pedram Pejman, Henryk Michalewski, Tianhe Yu, Cindy Wang, Juliette Love, Junwhan Ahn, Dawn Bloxwich, Kehang Han, Peter Humphreys, Thibault Sellam, James Bradbury, Varun Godbole, Sina Samangooei, Bogdan Damoc, Alex Kaskasoli, Sébastien M. R. Arnold, Vijay Vasudevan, Shubham Agrawal, Jason Riesa, Dmitry Lepikhin, Richard Tanburn, Srivatsan Srinivasan, Hyeontaek Lim, Sarah Hodkinson, Pranav Shyam, Johan Ferret, Steven Hand, Ankush Garg, Tom Le Paine, Jian Li, Yujia Li, Minh Giang, Alexander Neitz, Zaheer Abbas, Sarah York, Machel Reid, Elizabeth Cole, Aakanksha Chowdhery, Dipanjan Das, Dominika Rogozińska, Vitaliy Nikolaev, Pablo Sprechmann, Zachary Nado, Lukas Zilka, Flavien Prost, Luheng He, Marianne Monteiro, Gaurav Mishra, Chris Welty, Josh Newlan, Dawei Jia, Miltiadis Allamanis, Clara Huiyi Hu, Raoul de Liedekerke, Justin Gilmer, Carl Saroufim, Shruti Rijhwani, Shaobo Hou, Disha Shrivastava, Anirudh Baddepudi, Alex Goldin, Adnan Ozturel, Albin Cassirer, Yunhan Xu, Daniel Sohn, Devendra Sachan, Reinald Kim Amplayo, Craig Swanson, Dessie Petrova, Shashi Narayan, Arthur Guez, Siddhartha Brahma, Jessica Landon, Miteyan Patel, Ruizhe Zhao, Kevin Villela, Luyu Wang, Wenhao Jia, Matthew Rahtz, Mai Giménez, Legg Yeung, James Keeling, Petko Georgiev, Diana Mincu, Boxi Wu, Salem Haykal, Rachel Saputro, Kiran Vodrahalli, James Qin, Zeynep Cankara, Abhanshu Sharma, Nick Fernando, Will Hawkins, Behnam Neyshabur, Solomon Kim, Adrian Hutter, Priyanka Agrawal, Alex Castro-Ros, George van den Driessche, Tao Wang, Fan Yang, Shuo yiin Chang, Paul Komarek, Ross McIlroy, Mario Lučić, Guodong Zhang, Wael Farhan, Michael Sharman, Paul Natsev, Paul Michel, Yamini Bansal, Siyuan Qiao, Kris Cao, Siamak Shakeri, Christina Butterfield, Justin Chung, Paul Kishan Rubenstein, Shivani Agrawal, Arthur Mensch, Kedar Soparkar, Karel Lenc, Timothy Chung, Aedan Pope, Loren Maggiore, Jackie Kay, Priya Jhakra, Shibo Wang, Joshua Maynez, Mary Phuong, Taylor Tobin, Andrea Tacchetti, Maja Trebacz, Kevin Robinson, Yash Katariya, Sebastian Riedel, Paige Bailey, Kefan Xiao, Nimesh Ghelani, Lora Aroyo, Ambrose Slone, Neil Houlsby, Xuehan Xiong, Zhen Yang, Elena Gribovskaya, Jonas Adler, Mateo Wirth, Lisa Lee, Music Li, Thais Kagohara, Jay Pavagadhi, Sophie Bridgers, Anna Bortsova, Sanjay Ghemawat, Zafarali Ahmed, Tianqi Liu, Richard Powell, Vijay Bolina, Mariko Iinuma, Polina Zablotskaia, James Besley, Da-Woon Chung, Timothy Dozat, Ramona Comanescu, Xiance Si, Jeremy Greer, Guolong Su, Martin Polacek, Raphaël Lopez Kaufman, Simon Tokumine, Hexiang Hu, Elena Buchatskaya, Yingjie Miao, Mohamed Elhawaty, Aditya Siddhant, Nenad Tomasev, Jinwei Xing, Christina Greer, Helen Miller, Shereen Ashraf, Aurko Roy, Zizhao Zhang, Ada Ma, Angelos Filos, Milos Besta, Rory Blevins, Ted Klimenko, Chih-Kuan Yeh, Soravit Changpinyo, Jiaqi Mu, Oscar Chang, Mantas Pajarskas, Carrie Muir, Vered Cohen, Charline Le Lan, Krishna Haridasan, Amit Marathe, Steven Hansen, Sholto Douglas, Rajkumar Samuel, Mingqiu Wang, Sophia Austin, Chang Lan, Jiepu Jiang, Justin Chiu, Jaime Alonso Lorenzo, Lars Lowe Sjösund, Sébastien Cevey, Zach Gleicher, Thi Avrahami, Anudhyan Boral, Hansa Srinivasan, Vittorio Selo, Rhys May, Konstantinos Aisopos, Léonard Hussenot, Livio Baldini Soares, Kate Baumli, Michael B. Chang, Adrià Recasens, Ben Caine, Alexander Pritzel, Filip Pavetic, Fabio Pardo, Anita Gergely, Justin Frye, Vinay Ramasesh, Dan Horgan, Kartikeya Badola, Nora Kassner, Subhrajit Roy, Ethan Dyer, Víctor Campos Campos, Alex Tomala, Yunhao Tang, Dalia El Badawy, Elspeth White, Basil Mustafa, Oran Lang, Abhishek Jindal, Sharad Vikram, Zhitao Gong, Sergi Caelles, Ross Hemsley, Gregory Thornton, Fangxiaoyu Feng, Wojciech Stokowiec, Ce Zheng, Phoebe Thacker, Çağlar Ünlü, Zhishuai Zhang, Mohammad Saleh, James Svensson, Max Bileschi, Piyush Patil, Ankesh Anand, Roman Ring, Katerina Tsihlas, Arpi Vezer, Marco Selvi, Toby Shevlane, Mikel Rodriguez, Tom Kwiatkowski, Samira Daruki, Keran Rong, Allan Dafoe, Nicholas FitzGerald, Keren Gu-Lemberg, Mina Khan, Lisa Anne Hendricks, Marie Pellat, Vladimir Feinberg, James Cobon-Kerr, Tara Sainath, Maribeth Rauh, Sayed Hadi Hashemi, Richard Ives, Yana Hasson, Eric Noland, Yuan Cao, Nathan Byrd, Le Hou, Qingze Wang, Thibault Sottiaux, Michela Paganini, Jean-Baptiste Lespiau, Alexandre Moufarek, Samer Hassan, Kaushik Shivakumar, Joost van Amersfoort, Amol Mandhane, Pratik Joshi, Anirudh Goyal, Matthew Tung, Andrew Brock, Hannah Sheahan, Vedant Misra, Cheng Li, Nemanja Rakićević, Mostafa Dehghani, Fangyu Liu, Sid Mittal, Junhyuk Oh, Seb Noury, Eren Sezener, Fantine Huot, Matthew Lamm, Nicola De Cao, Charlie Chen, Sidharth Mudgal, Romina Stella, Kevin Brooks,

Gautam Vasudevan, Chenxi Liu, Mainak Chain, Nivedita Melinkeri, Aaron Cohen, Venus Wang, Kristie Seymore, Sergey Zubkov, Rahul Goel, Summer Yue, Sai Krishnakumaran, Brian Albert, Nate Hurley, Motoki Sano, Anhad Mohananey, Jonah Joughin, Egor Filonov, Tomasz Kepa, Yomna Eldawy, Jiawern Lim, Rahul Rishi, Shirin Badiezadegan, Taylor Bos, Jerry Chang, Sanil Jain, Sri Gayatri Sundara Padmanabhan, Subha Puttagunta, Kalpesh Krishna, Leslie Baker, Norbert Kalb, Vamsi Bedapudi, Adam Kurzrok, Shuntong Lei, Anthony Yu, Oren Litvin, Xiang Zhou, Zhichun Wu, Sam Sobell, Andrea Siciliano, Alan Papir, Robby Neale, Jonas Bragagnolo, Tej Toor, Tina Chen, Valentin Anklin, Feiran Wang, Richie Feng, Milad Gholami, Kevin Ling, Lijuan Liu, Jules Walter, Hamid Moghaddam, Arun Kishore, Jakub Adamek, Tyler Mercado, Jonathan Mallinson, Siddhinita Wandekar, Stephen Cagle, Eran Ofek, Guillermo Garrido, Clemens Lombriser, Maksim Mukha, Botu Sun, Hafeezul Rahman Mohammad, Josip Matak, Yadi Qian, Vikas Peswani, Pawel Janus, Quan Yuan, Leif Schelin, Oana David, Ankur Garg, Yifan He, Oleksii Duzhyi, Anton Älgmyr, Timothée Lottaz, Qi Li, Vikas Yadav, Luyao Xu, Alex Chinien, Rakesh Shivanna, Aleksandr Chuklin, Josie Li, Carrie Spadine, Travis Wolfe, Kareem Mohamed, Subhabrata Das, Zihang Dai, Kyle He, Daniel von Dincklage, Shyam Upadhyay, Akanksha Maurya, Luyan Chi, Sebastian Krause, Khalid Salama, Pam G Rabinovitch, Pavan Kumar Reddy M, Aarush Selvan, Mikhail Dektiarev, Golnaz Ghiasi, Erdem Guven, Himanshu Gupta, Boyi Liu, Deepak Sharma, Idan Heimlich Shtacher, Shachi Paul, Oscar Akerlund, François-Xavier Aubet, Terry Huang, Chen Zhu, Eric Zhu, Elico Teixeira, Matthew Fritze, Francesco Bertolini, Liana-Eleonora Marinescu, Martin Bölle, Dominik Paulus, Khyatti Gupta, Tejasi Latkar, Max Chang, Jason Sanders, Roopa Wilson, Xuewei Wu, Yi-Xuan Tan, Lam Nguyen Thiet, Tulsee Doshi, Sid Lall, Swaroop Mishra, Wanming Chen, Thang Luong, Seth Benjamin, Jasmine Lee, Ewa Andrejczuk, Dominik Rabiej, Vipul Ranjan, Krzysztof Styrc, Pengcheng Yin, Jon Simon, Malcolm Rose Harriott, Mudit Bansal, Alexei Robsky, Geoff Bacon, David Greene, Daniil Mirylenka, Chen Zhou, Obaid Sarvana, Abhimanyu Goyal, Samuel Andermatt, Patrick Siegler, Ben Horn, Assaf Israel, Francesco Pongetti, Chih-Wei "Louis" Chen, Marco Selvatici, Pedro Silva, Kathie Wang, Jackson Tolins, Kelvin Guu, Roey Yogev, Xiaochen Cai, Alessandro Agostini, Maulik Shah, Hung Nguyen, Noah Ó Donnaile, Sébastien Pereira, Linda Friso, Adam Stambler, Adam Kurzrok, Chenkai Kuang, Yan Romanikhin, Mark Geller, ZJ Yan, Kane Jang, Cheng-Chun Lee, Wojciech Fica, Eric Malmi, Qijun Tan, Dan Banica, Daniel Balle, Ryan Pham, Yanping Huang, Diana Avram, Hongzhi Shi, Jasjot Singh, Chris Hidey, Niharika Ahuja, Pranab Saxena, Dan Dooley, Srividya Pranavi Potharaju, Eileen O'Neill, Anand Gokulchandran, Ryan Foley, Kai Zhao, Mike Dusenberry, Yuan Liu, Pulkit Mehta, Ragha Kotikalapudi, Chalence Safranek-Shrader, Andrew Goodman, Joshua Kessinger, Eran Globen, Prateek Kolhar, Chris Gorgolewski, Ali Ibrahim, Yang Song, Ali Eichenbaum, Thomas Brovelli, Sahitya Potluri, Preethi Lahoti, Cip Baetu, Ali Ghorbani, Charles Chen, Andy Crawford, Shalini Pal, Mukund Sridhar, Petru Gurita, Asier Mujika, Igor Petrovski, Pierre-Louis Cedoz, Chenmei Li, Shiyuan Chen, Niccolò Dal Santo, Siddharth Goyal, Jitesh Punjabi, Karthik Kappaganthu, Chester Kwak, Pallavi LV, Sarmishta Velury, Himadri Choudhury, Jamie Hall, Premal Shah, Ricardo Figueira, Matt Thomas, Minjie Lu, Ting Zhou, Chintu Kumar, Thomas Jurdi, Sharat Chikkerur, Yenai Ma, Adams Yu, Soo Kwak, Victor Ähdel, Sujeevan Rajayogam, Travis Choma, Fei Liu, Aditya Barua, Colin Ji, Ji Ho Park, Vincent Hellendoorn, Alex Bailey, Taylan Bilal, Huanjie Zhou, Mehrdad Khatir, Charles Sutton, Wojciech Rzadkowski, Fiona Macintosh, Konstantin Shagin, Paul Medina, Chen Liang, Jinjing Zhou, Pararth Shah, Yingying Bi, Attila Dankovics, Shipra Banga, Sabine Lehmann, Marissa Bredesen, Zifan Lin, John Eric Hoffmann, Jonathan Lai, Raynald Chung, Kai Yang, Nihal Balani, Arthur Bražinskas, Andrei Sozanschi, Matthew Hayes, Héctor Fernández Alcalde, Peter Makarov, Will Chen, Antonio Stella, Liselotte Snijders, Michael Mandl, Ante Kärrman, Paweł Nowak, Xinyi Wu, Alex Dyck, Krishnan Vaidyanathan, Raghavender R, Jessica Mallet, Mitch Rudominer, Eric Johnston, Sushil Mittal, Akhil Udathu, Janara Christensen, Vishal Verma, Zach Irving, Andreas Santucci, Gamaleldin Elsayed, Elnaz Davoodi, Marin Georgiev, Ian Tenney, Nan Hua, Geoffrey Cideron, Edouard Leurent, Mahmoud Alnahlawi, Ionut Georgescu, Nan Wei, Ivy Zheng, Dylan Scandinaro, Heinrich Jiang, Jasper Snoek, Mukund Sundararajan, Xuezhi Wang, Zack Ontiveros, Itay Karo, Jeremy Cole, Vinu Rajashekhar, Lara Tumeh, Eyal Ben-David, Rishub Jain, Jonathan Uesato, Romina Datta, Oskar Bunyan, Shimu Wu, John Zhang, Piotr Stanczyk, Ye Zhang, David Steiner, Subhajit Naskar, Michael Azzam, Matthew Johnson, Adam Paszke, Chung-Cheng Chiu, Jaume Sanchez Elias, Afroz Mohiuddin, Faizan Muhammad, Jin Miao, Andrew Lee, Nino Vieillard, Jane Park, Jiageng Zhang, Jeff Stanway, Drew Garmon, Abhijit Karmarkar, Zhe Dong, Jong Lee, Aviral Kumar, Luowei Zhou, Jonathan Evens, William Isaac, Geoffrey Irving, Edward Loper, Michael Fink, Isha Arkatkar, Nanxin Chen, Izhak Shafran, Ivan Petrychenko, Zhe Chen, John-

son Jia, Anselm Levskaya, Zhenkai Zhu, Peter Grabowski, Yu Mao, Alberto Magni, Kaisheng Yao, Javier Snaider, Norman Casagrande, Evan Palmer, Paul Suganthan, Alfonso Castaño, Irene Giannoumis, Wooyeol Kim, Mikołaj Rybiński, Ashwin Sreevatsa, Jennifer Prendki, David Soergel, Adrian Goedeckemeyer, Willi Gierke, Mohsen Jafari, Meenu Gaba, Jeremy Wiesner, Diana Gage Wright, Yawen Wei, Harsha Vashisht, Yana Kulizhskaya, Jay Hoover, Maigo Le, Lu Li, Chimezie Iwuanyanwu, Lu Liu, Kevin Ramirez, Andrey Khorlin, Albert Cui, Tian LIN, Marcus Wu, Ricardo Aguilar, Keith Pallo, Abhishek Chakladar, Ginger Perng, Elena Allica Abellan, Mingyang Zhang, Ishita Dasgupta, Nate Kushman, Ivo Penchev, Alena Repina, Xihui Wu, Tom van der Weide, Priya Ponnapalli, Caroline Kaplan, Jiri Simsa, Shuangfeng Li, Olivier Dousse, Fan Yang, Jeff Piper, Nathan Ie, Rama Pasumarthi, Nathan Lintz, Anitha Vijayakumar, Daniel Andor, Pedro Valenzuela, Minnie Lui, Cosmin Paduraru, Daiyi Peng, Katherine Lee, Shuyuan Zhang, Somer Greene, Duc Dung Nguyen, Paula Kurylowicz, Cassidy Hardin, Lucas Dixon, Lili Janzer, Kiam Choo, Ziqiang Feng, Biao Zhang, Achintya Singhal, Dayou Du, Dan McKinnon, Natasha Antropova, Tolga Bolukbasi, Orgad Keller, David Reid, Daniel Finchelstein, Maria Abi Raad, Remi Crocker, Peter Hawkins, Robert Dadashi, Colin Gaffney, Ken Franko, Anna Bulanova, Rémi Leblond, Shirley Chung, Harry Askham, Luis C. Cobo, Kelvin Xu, Felix Fischer, Jun Xu, Christina Sorokin, Chris Alberti, Chu-Cheng Lin, Colin Evans, Alek Dimitriev, Hannah Forbes, Dylan Banarse, Zora Tung, Mark Omernick, Colton Bishop, Rachel Sterneck, Rohan Jain, Jiawei Xia, Ehsan Amid, Francesco Piccinno, Xingyu Wang, Praseem Banzal, Daniel J. Mankowitz, Alex Polozov, Victoria Krakovna, Sasha Brown, MohammadHossein Bateni, Dennis Duan, Vlad Firoiu, Meghana Thotakuri, Tom Natan, Matthieu Geist, Ser tan Girgin, Hui Li, Jiayu Ye, Ofir Roval, Reiko Tojo, Michael Kwong, James Lee-Thorp, Christopher Yew, Danila Sinopalnikov, Sabela Ramos, John Mellor, Abhishek Sharma, Kathy Wu, David Miller, Nicolas Sonnerat, Denis Vnukov, Rory Greig, Jennifer Beattie, Emily Caveness, Libin Bai, Julian Eisenschlos, Alex Korchemniy, Tomy Tsai, Mimi Jasarevic, Weize Kong, Phuong Dao, Zeyu Zheng, Frederick Liu, Fan Yang, Rui Zhu, Tian Huey Teh, Jason Sanmiya, Evgeny Gladchenko, Nejc Trdin, Daniel Toyama, Evan Rosen, Sasan Tavakkol, Linting Xue, Chen Elkind, Oliver Woodman, John Carpenter, George Papamakarios, Rupert Kemp, Sushant Kafle, Tanya Grunina, Rishika Sinha, Alice Talbert, Diane Wu, Denese Owusu-Afriyie, Cosmo Du, Chloe Thornton, Jordi Pont-Tuset, Pradyumna Narayana, Jing Li, Saaber Fatehi, John Wieting, Omar Ajmeri, Benigno Uria, Yeongil Ko, Laura Knight, Amélie Héliou, Ning Niu, Shane Gu, Chenxi Pang, Yeqing Li, Nir Levine, Ariel Stolovich, Rebeca Santamaria-Fernandez, Sonam Goenka, Wenny Yustalim, Robin Strudel, Ali Elqursh, Charlie Deck, Hyo Lee, Zonglin Li, Kyle Levin, Raphael Hoffmann, Dan Holtmann-Rice, Olivier Bachem, Sho Arora, Christy Koh, Soheil Hassas Yeganeh, Siim Põder, Mukarram Tariq, Yanhua Sun, Lucian Ionita, Mojtaba Seyedhosseini, Pouya Tafti, Zhiyu Liu, Anmol Gulati, Jasmine Liu, Xinyu Ye, Bart Chrzaszcz, Lily Wang, Nikhil Sethi, Tianrun Li, Ben Brown, Shreya Singh, Wei Fan, Aaron Parisi, Joe Stanton, Vinod Koverkathu, Christopher A. Choquette-Choo, Yunjie Li, TJ Lu, Abe Ittycheriah, Prakash Shroff, Mani Varadarajan, Sanaz Bahargam, Rob Willoughby, David Gaddy, Guillaume Desjardins, Marco Cornero, Brona Robenek, Bhavishya Mittal, Ben Albrecht, Ashish Shenoy, Fedor Moiseev, Henrik Jacobsson, Alireza Ghaffarkhah, Morgane Rivière, Alanna Walton, Clément Crepy, Alicia Parrish, Zongwei Zhou, Clement Farabet, Carey Radebaugh, Praveen Srinivasan, Claudia van der Salm, Andreas Fidjeland, Salvatore Scellato, Eri Latorre-Chimoto, Hanna Klimczak-Plucińska, David Bridson, Dario de Cesare, Tom Hudson, Piermaria Mendolicchio, Lexi Walker, Alex Morris, Matthew Mauger, Alexey Guseynov, Alison Reid, Seth Odoom, Lucia Loher, Victor Cotruta, Madhavi Yenugula, Dominik Grewe, Anastasia Petrushkina, Tom Duerig, Antonio Sanchez, Steve Yadlowsky, Amy Shen, Amir Globerson, Lynette Webb, Sahil Dua, Dong Li, Surya Bhupatiraju, Dan Hurt, Haroon Qureshi, Ananth Agarwal, Tomer Shani, Matan Eyal, Anuj Khare, Shreyas Rammohan Belle, Lei Wang, Chetan Tekur, Mihir Sanjay Kale, Jinliang Wei, Ruoxin Sang, Brennan Saeta, Tyler Liechty, Yi Sun, Yao Zhao, Stephan Lee, Pandu Nayak, Doug Fritz, Manish Reddy Vuyyuru, John Aslanides, Nidhi Vyas, Martin Wicke, Xiao Ma, Evgenii Eltyshev, Nina Martin, Hardie Cate, James Manyika, Keyvan Amiri, Yelin Kim, Xi Xiong, Kai Kang, Florian Luisier, Nilesh Tripuraneni, David Madras, Mandy Guo, Austin Waters, Oliver Wang, Joshua Ainslie, Jason Baldridge, Han Zhang, Garima Pruthi, Jakob Bauer, Feng Yang, Riham Mansour, Jason Gelman, Yang Xu, George Polovets, Ji Liu, Honglong Cai, Warren Chen, XiangHai Sheng, Emily Xue, Sherjil Ozair, Christof Angermueller, Xiaowei Li, Anoop Sinha, Weiren Wang, Julia Wiesinger, Emmanouil Koukoumidis, Yuan Tian, Anand Iyer, Madhu Gurumurthy, Mark Goldenson, Parashar Shah, MK Blake, Hongkun Yu, Anthony Urbanowicz, Jennimaria Palomaki, Chrisantha Fernando, Ken Durden, Harsh Mehta, Nikola Momchev, Elahe Rahimtoroghi, Maria

Georgaki, Amit Raul, Sebastian Ruder, Morgan Redshaw, Jinhyuk Lee, Denny Zhou, Komal Jalan, Dinghua Li, Blake Hechtman, Parker Schuh, Milad Nasr, Kieran Milan, Vladimir Mikulik, Juliana Franco, Tim Green, Nam Nguyen, Joe Kelley, Aroma Mahendru, Andrea Hu, Joshua Howland, Ben Vargas, Jeffrey Hui, Kshitij Bansal, Vikram Rao, Rakesh Ghiya, Emma Wang, Ke Ye, Jean Michel Sarr, Melanie Moranski Preston, Madeleine Elish, Steve Li, Aakash Kaku, Jigar Gupta, Ice Pasupat, Da-Cheng Juan, Milan Someswar, Tejvi M., Xinyun Chen, Aida Amini, Alex Fabrikant, Eric Chu, Xuanyi Dong, Amruta Muthal, Senaka Buthpitiya, Sarthak Jauhari, Nan Hua, Urvashi Khandelwal, Ayal Hitron, Jie Ren, Larissa Rinaldi, Shahar Drath, Avigail Dabush, Nan-Jiang Jiang, Harshal Godhia, Uli Sachs, Anthony Chen, Yicheng Fan, Hagai Taitelbaum, Hila Noga, Zhuyun Dai, James Wang, Chen Liang, Jenny Hamer, Chun-Sung Ferng, Chenel Elkind, Aviel Atias, Paulina Lee, Vít Listík, Mathias Carlen, Jan van de Kerkhof, Marcin Pikus, Krunoslav Zaher, Paul Müller, Sasha Zykova, Richard Stefanec, Vitaly Gatsko, Christoph Hirnschall, Ashwin Sethi, Xingyu Federico Xu, Chetan Ahuja, Beth Tsai, Anca Stefanoiu, Bo Feng, Keshav Dhandhania, Manish Katyal, Akshay Gupta, Atharva Parulekar, Divya Pitta, Jing Zhao, Vivaan Bhatia, Yashodha Bhavnani, Omar Alhadlaq, Xiaolin Li, Peter Danenberg, Dennis Tu, Alex Pine, Vera Filippova, Abhipso Ghosh, Ben Limonchik, Bhargava Urala, Chaitanya Krishna Lanka, Derik Clive, Yi Sun, Edward Li, Hao Wu, Kevin Hongtongsak, Ianna Li, Kalind Thakkar, Kuanysh Omarov, Kushal Majmundar, Michael Alverson, Michael Kucharski, Mohak Patel, Mudit Jain, Maksim Zabelin, Paolo Pelagatti, Rohan Kohli, Saurabh Kumar, Joseph Kim, Swetha Sankar, Vineet Shah, Lakshmi Ramachandruni, Xiangkai Zeng, Ben Bariach, Laura Weidinger, Tu Vu, Alek Andreev, Antoine He, Kevin Hui, Sheleem Kashem, Amar Subramanya, Sissie Hsiao, Demis Hassabis, Koray Kavukcuoglu, Adam Sadovsky, Quoc Le, Trevor Strohman, Yonghui Wu, Slav Petrov, Jeffrey Dean, and Oriol Vinyals. Gemini: A family of highly capable multimodal models, 2024a. URL https://arxiv.org/abs/2312.11805.

Gemini Team, Petko Georgiev, Ving Ian Lei, Ryan Burnell, Libin Bai, Anmol Gulati, Garrett Tanzer, Damien Vincent, Zhufeng Pan, Shibo Wang, Soroosh Mariooryad, Yifan Ding, Xinyang Geng, Fred Alcober, Roy Frostig, Mark Omernick, Lexi Walker, Cosmin Paduraru, Christina Sorokin, Andrea Tacchetti, Colin Gaffney, Samira Daruki, Olcan Sercinoglu, Zach Gleicher, Juliette Love, Paul Voigtlaender, Rohan Jain, Gabriela Surita, Kareem Mohamed, Rory Blevins, Junwhan Ahn, Tao Zhu, Kornraphop Kawintiranon, Orhan Firat, Yiming Gu, Yujing Zhang, Matthew Rahtz, Manaal Faruqui, Natalie Clay, Justin Gilmer, JD Co-Reyes, Ivo Penchev, Rui Zhu, Nobuyuki Morioka, Kevin Hui, Krishna Haridasan, Victor Campos, Mahdis Mahdieh, Mandy Guo, Samer Hassan, Kevin Kilgour, Arpi Vezer, Heng-Tze Cheng, Raoul de Liedekerke, Siddharth Goyal, Paul Barham, DJ Strouse, Seb Noury, Jonas Adler, Mukund Sundararajan, Sharad Vikram, Dmitry Lepikhin, Michela Paganini, Xavier Garcia, Fan Yang, Dasha Valter, Maja Trebacz, Kiran Vodrahalli, Chulayuth Asawaroengchai, Roman Ring, Norbert Kalb, Livio Baldini Soares, Siddhartha Brahma, David Steiner, Tianhe Yu, Fabian Mentzer, Antoine He, Lucas Gonzalez, Bibo Xu, Raphael Lopez Kaufman, Laurent El Shafey, Junhyuk Oh, Tom Hennigan, George van den Driessche, Seth Odoom, Mario Lucic, Becca Roelofs, Sid Lall, Amit Marathe, Betty Chan, Santiago Ontanon, Luheng He, Denis Teplyashin, Jonathan Lai, Phil Crone, Bogdan Damoc, Lewis Ho, Sebastian Riedel, Karel Lenc, Chih-Kuan Yeh, Aakanksha Chowdhery, Yang Xu, Mehran Kazemi, Ehsan Amid, Anastasia Petrushkina, Kevin Swersky, Ali Khodaei, Gowoon Chen, Chris Larkin, Mario Pinto, Geng Yan, Adria Puigdomenech Badia, Piyush Patil, Steven Hansen, Dave Orr, Sebastien M. R. Arnold, Jordan Grimstad, Andrew Dai, Sholto Douglas, Rishika Sinha, Vikas Yadav, Xi Chen, Elena Gribovskaya, Jacob Austin, Jeffrey Zhao, Kaushal Patel, Paul Komarek, Sophia Austin, Sebastian Borgeaud, Linda Friso, Abhimanyu Goyal, Ben Caine, Kris Cao, Da-Woon Chung, Matthew Lamm, Gabe Barth-Maron, Thais Kagohara, Kate Olszewska, Mia Chen, Kaushik Shivakumar, Rishabh Agarwal, Harshal Godhia, Ravi Rajwar, Javier Snaider, Xerxes Dotiwalla, Yuan Liu, Aditya Barua, Victor Ungureanu, Yuan Zhang, Bat-Orgil Batsaikhan, Mateo Wirth, James Qin, Ivo Danihelka, Tulsee Doshi, Martin Chadwick, Jilin Chen, Sanil Jain, Quoc Le, Arjun Kar, Madhu Gurumurthy, Cheng Li, Ruoxin Sang, Fangyu Liu, Lampros Lamprou, Rich Munoz, Nathan Lintz, Harsh Mehta, Heidi Howard, Malcolm Reynolds, Lora Aroyo, Quan Wang, Lorenzo Blanco, Albin Cassirer, Jordan Griffith, Dipanjan Das, Stephan Lee, Jakub Sygnowski, Zach Fisher, James Besley, Richard Powell, Zafarali Ahmed, Dominik Paulus, David Reitter, Zalan Borsos, Rishabh Joshi, Aedan Pope, Steven Hand, Vittorio Selo, Vihan Jain, Nikhil Sethi, Megha Goel, Takaki Makino, Rhys May, Zhen Yang, Johan Schalkwyk, Christina Butterfield, Anja Hauth, Alex Goldin, Will Hawkins, Evan Senter, Sergey Brin, Oliver Woodman, Marvin Ritter, Eric Noland, Minh Giang, Vijay Bolina, Lisa Lee, Tim Blyth, Ian Mackinnon, Machel

Reid, Obaid Sarvana, David Silver, Alexander Chen, Lily Wang, Loren Maggiore, Oscar Chang, Nithya Attaluri, Gregory Thornton, Chung-Cheng Chiu, Oskar Bunyan, Nir Levine, Timothy Chung, Evgenii Eltyshev, Xiance Si, Timothy Lillicrap, Demetra Brady, Vaibhav Aggarwal, Boxi Wu, Yuanzhong Xu, Ross McIlroy, Kartikeya Badola, Paramjit Sandhu, Erica Moreira, Wojciech Stokowiec, Ross Hemsley, Dong Li, Alex Tudor, Pranav Shyam, Elahe Rahimtoroghi, Salem Haykal, Pablo Sprechmann, Xiang Zhou, Diana Mincu, Yujia Li, Ravi Addanki, Kalpesh Krishna, Xiao Wu, Alexandre Frechette, Matan Eyal, Allan Dafoe, Dave Lacey, Jay Whang, Thi Avrahami, Ye Zhang, Emanuel Taropa, Hanzhao Lin, Daniel Toyama, Eliza Rutherford, Motoki Sano, HyunJeong Choe, Alex Tomala, Chalence Safranek-Shrader, Nora Kassner, Mantas Pajarskas, Matt Harvey, Sean Sechrist, Meire Fortunato, Christina Lyu, Gamaleldin Elsayed, Chenkai Kuang, James Lottes, Eric Chu, Chao Jia, Chih-Wei Chen, Peter Humphreys, Kate Baumli, Connie Tao, Rajkumar Samuel, Cicero Nogueira dos Santos, Anders Andreassen, Nemanja Rakićević, Dominik Grewe, Aviral Kumar, Stephanie Winkler, Jonathan Caton, Andrew Brock, Sid Dalmia, Hannah Sheahan, Iain Barr, Yingjie Miao, Paul Natsev, Jacob Devlin, Feryal Behbahani, Flavien Prost, Yanhua Sun, Artiom Myaskovsky, Thanumalayan Sankaranarayana Pillai, Dan Hurt, Angeliki Lazaridou, Xi Xiong, Ce Zheng, Fabio Pardo, Xiaowei Li, Dan Horgan, Joe Stanton, Moran Ambar, Fei Xia, Alejandro Lince, Mingqiu Wang, Basil Mustafa, Albert Webson, Hyo Lee, Rohan Anil, Martin Wicke, Timothy Dozat, Abhishek Sinha, Enrique Piqueras, Elahe Dabir, Shyam Upadhyay, Anudhyan Boral, Lisa Anne Hendricks, Corey Fry, Josip Djolonga, Yi Su, Jake Walker, Jane Labanowski, Ronny Huang, Vedant Misra, Jeremy Chen, RJ Skerry-Ryan, Avi Singh, Shruti Rijhwani, Dian Yu, Alex Castro-Ros, Beer Changpinyo, Romina Datta, Sumit Bagri, Arnar Mar Hrafnkelsson, Marcello Maggioni, Daniel Zheng, Yury Sulsky, Shaobo Hou, Tom Le Paine, Antoine Yang, Jason Riesa, Dominika Rogozinska, Dror Marcus, Dalia El Badawy, Qiao Zhang, Luyu Wang, Helen Miller, Jeremy Greer, Lars Lowe Sjos, Azade Nova, Heiga Zen, Rahma Chaabouni, Mihaela Rosca, Jiepu Jiang, Charlie Chen, Ruibo Liu, Tara Sainath, Maxim Krikun, Alex Polozov, Jean-Baptiste Lespiau, Josh Newlan, Zeyncep Cankara, Soo Kwak, Yunhan Xu, Phil Chen, Andy Coenen, Clemens Meyer, Katerina Tsihlas, Ada Ma, Juraj Gottweis, Jinwei Xing, Chenjie Gu, Jin Miao, Christian Frank, Zeynep Cankara, Sanjay Ganapathy, Ishita Dasgupta, Steph Hughes-Fitt, Heng Chen, David Reid, Keran Rong, Hongmin Fan, Joost van Amersfoort, Vincent Zhuang, Aaron Cohen, Shixiang Shane Gu, Anhad Mohananey, Anastasija Ilic, Taylor Tobin, John Wieting, Anna Bortsova, Phoebe Thacker, Emma Wang, Emily Caveness, Justin Chiu, Eren Sezener, Alex Kaskasoli, Steven Baker, Katie Millican, Mohamed Elhawaty, Kostas Aisopos, Carl Lebsack, Nathan Byrd, Hanjun Dai, Wenhao Jia, Matthew Wiethoff, Elnaz Davoodi, Albert Weston, Lakshman Yagati, Arun Ahuja, Isabel Gao, Golan Pundak, Susan Zhang, Michael Azzam, Khe Chai Sim, Sergi Caelles, James Keeling, Abhanshu Sharma, Andy Swing, YaGuang Li, Chenxi Liu, Carrie Grimes Bostock, Yamini Bansal, Zachary Nado, Ankesh Anand, Josh Lipschultz, Abhijit Karmarkar, Lev Proleev, Abe Ittycheriah, Soheil Hassas Yeganeh, George Polovets, Aleksandra Faust, Jiao Sun, Alban Rrustemi, Pen Li, Rakesh Shivanna, Jeremiah Liu, Chris Welty, Federico Lebron, Anirudh Baddepudi, Sebastian Krause, Emilio Parisotto, Radu Soricut, Zheng Xu, Dawn Bloxwich, Melvin Johnson, Behnam Neyshabur, Justin Mao-Jones, Renshen Wang, Vinay Ramasesh, Zaheer Abbas, Arthur Guez, Constant Segal, Duc Dung Nguyen, James Svensson, Le Hou, Sarah York, Kieran Milan, Sophie Bridgers, Wiktor Gworek, Marco Tagliasacchi, James Lee-Thorp, Michael Chang, Alexey Guseynov, Ale Jakse Hartman, Michael Kwong, Ruizhe Zhao, Sheleem Kashem, Elizabeth Cole, Antoine Miech, Richard Tanburn, Mary Phuong, Filip Pavetic, Sebastien Cevey, Ramona Comanescu, Richard Ives, Sherry Yang, Cosmo Du, Bo Li, Zizhao Zhang, Mariko Iinuma, Clara Huiyi Hu, Aurko Roy, Shaan Bijwadia, Zhenkai Zhu, Danilo Martins, Rachel Saputro, Anita Gergely, Steven Zheng, Dawei Jia, Ioannis Antonoglou, Adam Sadovsky, Shane Gu, Yingying Bi, Alek Andreev, Sina Samangooei, Mina Khan, Tomas Kocisky, Angelos Filos, Chintu Kumar, Colton Bishop, Adams Yu, Sarah Hodkinson, Sid Mittal, Premal Shah, Alexandre Moufarek, Yong Cheng, Adam Bloniarz, Jaehoon Lee, Pedram Pejman, Paul Michel, Stephen Spencer, Vladimir Feinberg, Xuehan Xiong, Nikolay Savinov, Charlotte Smith, Siamak Shakeri, Dustin Tran, Mary Chesus, Bernd Bohnet, George Tucker, Tamara von Glehn, Carrie Muir, Yiran Mao, Hideto Kazawa, Ambrose Slone, Kedar Soparkar, Disha Shrivastava, James Cobon-Kerr, Michael Sharman, Jay Pavagadhi, Carlos Araya, Karolis Misiunas, Nimesh Ghelani, Michael Laskin, David Barker, Qiujia Li, Anton Briukhov, Neil Houlsby, Mia Glaese, Balaji Lakshminarayanan, Nathan Schucher, Yunhao Tang, Eli Collins, Hyeontaek Lim, Fangxiaoyu Feng, Adria Recasens, Guangda Lai, Alberto Magni, Nicola De Cao, Aditya Siddhant, Zoe Ashwood, Jordi Orbay, Mostafa Dehghani, Jenny Brennan, Yifan He, Kelvin Xu, Yang Gao, Carl Saroufim, James Molloy, Xinyi Wu, Seb Arnold,

Solomon Chang, Julian Schrittwieser, Elena Buchatskaya, Soroush Radpour, Martin Polacek, Skye Giordano, Ankur Bapna, Simon Tokumine, Vincent Hellendoorn, Thibault Sottiaux, Sarah Cogan, Aliaksei Severyn, Mohammad Saleh, Shantanu Thakoor, Laurent Shefey, Siyuan Qiao, Meenu Gaba, Shuo yiin Chang, Craig Swanson, Biao Zhang, Benjamin Lee, Paul Kishan Rubenstein, Gan Song, Tom Kwiatkowski, Anna Koop, Ajay Kannan, David Kao, Parker Schuh, Axel Stjerngren, Golnaz Ghiasi, Gena Gibson, Luke Vilnis, Ye Yuan, Felipe Tiengo Ferreira, Aishwarya Kamath, Ted Klimenko, Ken Franko, Kefan Xiao, Indro Bhattacharya, Miteyan Patel, Rui Wang, Alex Morris, Robin Strudel, Vivek Sharma, Peter Choy, Sayed Hadi Hashemi, Jessica Landon, Mara Finkelstein, Priya Jhakra, Justin Frye, Megan Barnes, Matthew Mauger, Dennis Daun, Khuslen Baatarsukh, Matthew Tung, Wael Farhan, Henryk Michalewski, Fabio Viola, Felix de Chaumont Quitry, Charline Le Lan, Tom Hudson, Qingze Wang, Felix Fischer, Ivy Zheng, Elspeth White, Anca Dragan, Jean baptiste Alayrac, Eric Ni, Alexander Pritzel, Adam Iwanicki, Michael Isard, Anna Bulanova, Lukas Zilka, Ethan Dyer, Devendra Sachan, Srivatsan Srinivasan, Hannah Muckenhirn, Honglong Cai, Amol Mandhane, Mukarram Tariq, Jack W. Rae, Gary Wang, Kareem Ayoub, Nicholas FitzGerald, Yao Zhao, Woohyun Han, Chris Alberti, Dan Garrette, Kashyap Krishnakumar, Mai Gimenez, Anselm Levskaya, Daniel Sohn, Josip Matak, Inaki Iturrate, Michael B. Chang, Jackie Xiang, Yuan Cao, Nishant Ranka, Geoff Brown, Adrian Hutter, Vahab Mirrokni, Nanxin Chen, Kaisheng Yao, Zoltan Egyed, Francois Galilee, Tyler Liechty, Praveen Kallakuri, Evan Palmer, Sanjay Ghemawat, Jasmine Liu, David Tao, Chloe Thornton, Tim Green, Mimi Jasarevic, Sharon Lin, Victor Cotruta, Yi-Xuan Tan, Noah Fiedel, Hongkun Yu, Ed Chi, Alexander Neitz, Jens Heitkaemper, Anu Sinha, Denny Zhou, Yi Sun, Charbel Kaed, Brice Hulse, Swaroop Mishra, Maria Georgaki, Sneha Kudugunta, Clement Farabet, Izhak Shafran, Daniel Vlasic, Anton Tsitsulin, Rajagopal Ananthanarayanan, Alen Carin, Guolong Su, Pei Sun, Shashank V, Gabriel Carvajal, Josef Broder, Iulia Comsa, Alena Repina, William Wong, Warren Weilun Chen, Peter Hawkins, Egor Filonov, Lucia Loher, Christoph Hirnschall, Weiyi Wang, Jingchen Ye, Andrea Burns, Hardie Cate, Diana Gage Wright, Federico Piccinini, Lei Zhang, Chu-Cheng Lin, Ionel Gog, Yana Kulizhskaya, Ashwin Sreevatsa, Shuang Song, Luis C. Cobo, Anand Iyer, Chetan Tekur, Guillermo Garrido, Zhuyun Xiao, Rupert Kemp, Huaixiu Steven Zheng, Hui Li, Ananth Agarwal, Christel Ngani, Kati Goshvadi, Rebeca Santamaria-Fernandez, Wojciech Fica, Xinyun Chen, Chris Gorgolewski, Sean Sun, Roopal Garg, Xinyu Ye, S. M. Ali Eslami, Nan Hua, Jon Simon, Pratik Joshi, Yelin Kim, Ian Tenney, Sahitya Potluri, Lam Nguyen Thiet, Quan Yuan, Florian Luisier, Alexandra Chronopoulou, Salvatore Scellato, Praveen Srinivasan, Minmin Chen, Vinod Koverkathu, Valentin Dalibard, Yaming Xu, Brennan Saeta, Keith Anderson, Thibault Sellam, Nick Fernando, Fantine Huot, Junehyuk Jung, Mani Varadarajan, Michael Quinn, Amit Raul, Maigo Le, Ruslan Habalov, Jon Clark, Komal Jalan, Kalesha Bullard, Achintya Singhal, Thang Luong, Boyu Wang, Sujeevan Rajayogam, Julian Eisenschlos, Johnson Jia, Daniel Finchelstein, Alex Yakubovich, Daniel Balle, Michael Fink, Sameer Agarwal, Jing Li, Dj Dvijotham, Shalini Pal, Kai Kang, Jaclyn Konzelmann, Jennifer Beattie, Olivier Dousse, Diane Wu, Remi Crocker, Chen Elkind, Siddhartha Reddy Jonnalagadda, Jong Lee, Dan Holtmann-Rice, Krystal Kallarackal, Rosanne Liu, Denis Vnukov, Neera Vats, Luca Invernizzi, Mohsen Jafari, Huanjie Zhou, Lilly Taylor, Jennifer Prendki, Marcus Wu, Tom Eccles, Tianqi Liu, Kavya Kopparapu, Francoise Beaufays, Christof Angermueller, Andreea Marzoca, Shourya Sarcar, Hilal Dib, Jeff Stanway, Frank Perbet, Nejc Trdin, Rachel Sterneck, Andrey Khorlin, Dinghua Li, Xihui Wu, Sonam Goenka, David Madras, Sasha Goldshtein, Willi Gierke, Tong Zhou, Yaxin Liu, Yannie Liang, Anais White, Yunjie Li, Shreya Singh, Sanaz Bahargam, Mark Epstein, Sujoy Basu, Li Lao, Adnan Ozturel, Carl Crous, Alex Zhai, Han Lu, Zora Tung, Neeraj Gaur, Alanna Walton, Lucas Dixon, Ming Zhang, Amir Globerson, Grant Uy, Andrew Bolt, Olivia Wiles, Milad Nasr, Ilia Shumailov, Marco Selvi, Francesco Piccinno, Ricardo Aguilar, Sara McCarthy, Misha Khalman, Mrinal Shukla, Vlado Galic, John Carpenter, Kevin Villela, Haibin Zhang, Harry Richardson, James Martens, Matko Bosnjak, Shreyas Rammohan Belle, Jeff Seibert, Mahmoud Alnahlawi, Brian McWilliams, Sankalp Singh, Annie Louis, Wen Ding, Dan Popovici, Lenin Simicich, Laura Knight, Pulkit Mehta, Nishesh Gupta, Chongyang Shi, Saaber Fatehi, Jovana Mitrovic, Alex Grills, Joseph Pagadora, Dessie Petrova, Danielle Eisenbud, Zhishuai Zhang, Damion Yates, Bhavishya Mittal, Nilesh Tripuraneni, Yannis Assael, Thomas Brovelli, Prateek Jain, Mihajlo Velimirovic, Canfer Akbulut, Jiaqi Mu, Wolfgang Macherey, Ravin Kumar, Jun Xu, Haroon Qureshi, Gheorghe Comanici, Jeremy Wiesner, Zhitao Gong, Anton Ruddock, Matthias Bauer, Nick Felt, Anirudh GP, Anurag Arnab, Dustin Zelle, Jonas Rothfuss, Bill Rosgen, Ashish Shenoy, Bryan Seybold, Xinjian Li, Jayaram Mudigonda, Goker Erdogan, Jiawei Xia, Jiri Simsa, Andrea Michi, Yi Yao, Christopher Yew, Steven Kan, Isaac Caswell, Carey

Radebaugh, Andre Elisseeff, Pedro Valenzuela, Kay McKinney, Kim Paterson, Albert Cui, Eri Latorre-Chimoto, Solomon Kim, William Zeng, Ken Durden, Priya Ponnapalli, Tiberiu Sosea, Christopher A. Choquette-Choo, James Manyika, Brona Robenek, Harsha Vashisht, Sebastien Pereira, Hoi Lam, Marko Velic, Denese Owusu-Afriyie, Katherine Lee, Tolga Bolukbasi, Alicia Parrish, Shawn Lu, Jane Park, Balaji Venkatraman, Alice Talbert, Lambert Rosique, Yuchung Cheng, Andrei Sozanschi, Adam Paszke, Praveen Kumar, Jessica Austin, Lu Li, Khalid Salama, Wooyeol Kim, Nandita Dukkipati, Anthony Baryshnikov, Christos Kaplanis, XiangHai Sheng, Yuri Chervonyi, Caglar Unlu, Diego de Las Casas, Harry Askham, Kathryn Tunyasuvunakool, Felix Gimeno, Siim Poder, Chester Kwak, Matt Miecnikowski, Vahab Mirrokni, Alek Dimitriev, Aaron Parisi, Dangyi Liu, Tomy Tsai, Toby Shevlane, Christina Kouridi, Drew Garmon, Adrian Goedeckemeyer, Adam R. Brown, Anitha Vijayakumar, Ali Elqursh, Sadegh Jazayeri, Jin Huang, Sara Mc Carthy, Jay Hoover, Lucy Kim, Sandeep Kumar, Wei Chen, Courtney Biles, Garrett Bingham, Evan Rosen, Lisa Wang, Qijun Tan, David Engel, Francesco Pongetti, Dario de Cesare, Dongseong Hwang, Lily Yu, Jennifer Pullman, Srini Narayanan, Kyle Levin, Siddharth Gopal, Megan Li, Asaf Aharoni, Trieu Trinh, Jessica Lo, Norman Casagrande, Roopali Vij, Loic Matthey, Bramandia Ramadhana, Austin Matthews, CJ Carey, Matthew Johnson, Kremena Goranova, Rohin Shah, Shereen Ashraf, Kingshuk Dasgupta, Rasmus Larsen, Yicheng Wang, Manish Reddy Vuyyuru, Chong Jiang, Joana Ijazi, Kazuki Osawa, Celine Smith, Ramya Sree Boppana, Taylan Bilal, Yuma Koizumi, Ying Xu, Yasemin Altun, Nir Shabat, Ben Bariach, Alex Korchemniy, Kiam Choo, Olaf Ronneberger, Chimezie Iwuanyanwu, Shubin Zhao, David Soergel, Cho-Jui Hsieh, Irene Cai, Shariq Iqbal, Martin Sundermeyer, Zhe Chen, Elie Bursztein, Chaitanya Malaviya, Fadi Biadsy, Prakash Shroff, Inderjit Dhillon, Tejasi Latkar, Chris Dyer, Hannah Forbes, Massimo Nicosia, Vitaly Nikolaev, Somer Greene, Marin Georgiev, Pidong Wang, Nina Martin, Hanie Sedghi, John Zhang, Praseem Banzal, Doug Fritz, Vikram Rao, Xuezhi Wang, Jiageng Zhang, Viorica Patraucean, Dayou Du, Igor Mordatch, Ivan Jurin, Lewis Liu, Ayush Dubey, Abhi Mohan, Janek Nowakowski, Vlad-Doru Ion, Nan Wei, Reiko Tojo, Maria Abi Raad, Drew A. Hudson, Vaishakh Keshava, Shubham Agrawal, Kevin Ramirez, Zhichun Wu, Hoang Nguyen, Ji Liu, Madhavi Sewak, Bryce Petrini, DongHyun Choi, Ivan Philips, Ziyue Wang, Ioana Bica, Ankush Garg, Jarek Wilkiewicz, Priyanka Agrawal, Xiaowei Li, Danhao Guo, Emily Xue, Naseer Shaik, Andrew Leach, Sadh MNM Khan, Julia Wiesinger, Sammy Jerome, Abhishek Chakladar, Alek Wenjiao Wang, Tina Ornduff, Folake Abu, Alireza Ghaffarkhah, Marcus Wainwright, Mario Cortes, Frederick Liu, Joshua Maynez, Andreas Terzis, Pouya Samangouei, Riham Mansour, Tomasz Kepa, François-Xavier Aubet, Anton Algymr, Dan Banica, Agoston Weisz, Andras Orban, Alexandre Senges, Ewa Andrejczuk, Mark Geller, Niccolo Dal Santo, Valentin Anklin, Majd Al Merey, Martin Baeuml, Trevor Strohman, Junwen Bai, Slav Petrov, Yonghui Wu, Demis Hassabis, Koray Kavukcuoglu, Jeffrey Dean, and Oriol Vinyals. Gemini 1.5: Unlocking multimodal understanding across millions of tokens of context, 2024b. URL https://arxiv.org/abs/2403.05530.

Jamba Team, Barak Lenz, Alan Arazi, Amir Bergman, Avshalom Manevich, Barak Peleg, Ben Aviram, Chen Almagor, Clara Fridman, Dan Padnos, Daniel Gissin, Daniel Jannai, Dor Muhlgay, Dor Zimberg, Edden M Gerber, Elad Dolev, Eran Krakovsky, Erez Safahi, Erez Schwartz, Gal Cohen, Gal Shachaf, Haim Rozenblum, Hofit Bata, Ido Blass, Inbal Magar, Itay Dalmedigos, Jhonathan Osin, Julie Fadlon, Maria Rozman, Matan Danos, Michael Gokhman, Mor Zusman, Naama Gidron, Nir Ratner, Noam Gat, Noam Rozen, Oded Fried, Ohad Leshno, Omer Antverg, Omri Abend, Opher Lieber, Or Dagan, Orit Cohavi, Raz Alon, Ro'i Belson, Roi Cohen, Rom Gilad, Roman Glozman, Shahar Lev, Shaked Meirom, Tal Delbari, Tal Ness, Tomer Asida, Tom Ben Gal, Tom Braude, Uriya Pumerantz, Yehoshua Cohen, Yonatan Belinkov, Yuval Globerson, Yuval Peleg Levy, and Yoav Shoham. Jamba-1.5: Hybrid transformer-mamba models at scale, 2024c. URL https://arxiv.org/abs/2408.12570.

Sang Michael Xie, Aditi Raghunathan, Percy Liang, and Tengyu Ma. An explanation of in-context learning as implicit bayesian inference, 2022. URL https://arxiv.org/abs/2111.02080.

Jing Xu, Arthur Szlam, and Jason Weston. Beyond goldfish memory: Long-term open-domain conversation, 2021. URL https://arxiv.org/abs/2107.07567.

An Yang, Baosong Yang, Binyuan Hui, Bo Zheng, Bowen Yu, Chang Zhou, Chengpeng Li, Chengyuan Li, Dayiheng Liu, Fei Huang, Guanting Dong, Haoran Wei, Huan Lin, Jialong Tang,

Jialin Wang, Jian Yang, Jianhong Tu, Jianwei Zhang, Jianxin Ma, Jianxin Yang, Jin Xu, Jingren Zhou, Jinze Bai, Jinzheng He, Junyang Lin, Kai Dang, Keming Lu, Keqin Chen, Kexin Yang, Mei Li, Mingfeng Xue, Na Ni, Pei Zhang, Peng Wang, Ru Peng, Rui Men, Ruize Gao, Runji Lin, Shijie Wang, Shuai Bai, Sinan Tan, Tianhang Zhu, Tianhao Li, Tianyu Liu, Wenbin Ge, Xiaodong Deng, Xiaohuan Zhou, Xingzhang Ren, Xinyu Zhang, Xipin Wei, Xuancheng Ren, Xuejing Liu, Yang Fan, Yang Yao, Yichang Zhang, Yu Wan, Yunfei Chu, Yuqiong Liu, Zeyu Cui, Zhenru Zhang, Zhifang Guo, and Zhihao Fan. Qwen2 technical report, 2024. URL https://arxiv.org/abs/2407.10671.

Dian Yu, Kai Sun, Claire Cardie, and Dong Yu. Dialogue-based relation extraction. In Dan Jurafsky, Joyce Chai, Natalie Schluter, and Joel Tetreault (eds.), *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics*, pp. 4927–4940, Online, July 2020. Association for Computational Linguistics. doi: 10.18653/v1/2020.acl-main.444. URL https://aclanthology.org/2020.acl-main.444.

Fengji Zhang, Bei Chen, Yue Zhang, Jacky Keung, Jin Liu, Daoguang Zan, Yi Mao, Jian-Guang Lou, and Weizhu Chen. RepoCoder: Repository-level code completion through iterative retrieval and generation. In Houda Bouamor, Juan Pino, and Kalika Bali (eds.), *Proceedings of the 2023 Conference on Empirical Methods in Natural Language Processing*, pp. 2471–2484, Singapore, December 2023. Association for Computational Linguistics. doi: 10.18653/v1/2023.emnlp-main.151. URL https://aclanthology.org/2023.emnlp-main.151.

Xinrong Zhang, Yingfa Chen, Shengding Hu, Zihang Xu, Junhao Chen, Moo Khai Hao, Xu Han, Zhen Leng Thai, Shuo Wang, Zhiyuan Liu, and Maosong Sun. ∞bench: Extending long context evaluation beyond 100k tokens, 2024. URL https://arxiv.org/abs/2402.13718.

A DATASETS

BANKING77 (Casanueva et al., 2020) is an intent classification task in the banking domain. It has over 10k customer service queries labeled with 77 intents.

GoEmotions (Demszky et al., 2020) contains 58 Reddit comments labeled for 27 emotion categories or Neutral.

DialogRE (Yu et al., 2020) is a relation extraction dataset that is built based on transcripts of an American TV show Friends. It comprises 10,168 relation triples for 1,788 dialogues and 36 total relations types. We only focus on relation classification for this dataset.

TREC (Li & Roth, 2002; Hovy et al., 2001) is a question classification dataset with six coarse and 50 fine class labels. It contains 5,500 questions in the training set and 500 in the test set.

CLINC150 (Larson et al., 2019) is an intent classification dataset with 150 intents from 10 domains.

MATH (Hendrycks et al., 2021) is a dataset of 12,5000 challenging completion mathematics problems. Each problem has a full step-by-step solution. We use four subdomains from the dataset: algebra, geometry, counting and probability, and number theory.

GSM8K (Hendrycks et al., 2021) consists of 8.5K high quality grade school math problems created by human problem writers. These problems take between 2 and 8 steps to solve, and solutions primarily involve performing a sequence of elementary calculations using basic arithmetic operations (+ - / *) to reach the final answer.

BBH (Srivastava et al., 2022) is a subset of 23 challenging BIG-Bench tasks (Suzgun et al., 2022), which include task categories such as mathematics, commonsense reasoning, and question answering. We use four subtasks from BBH-Hard: geometric shape, salient translation error detection, word sorting, and dyck languages.

ARC (Clark et al., 2018) is a dataset of 7,787 genuine grade-school level, multiple-choice science questions. The dataset is partitioned into a Challenge Set and Easy Set, where the former contains only questions answered incorrectly by both a retrieval-based algorithm and a word co-occurrence algorithm.

GPQA (Rein et al., 2023) is a dataset of 448 multiple-choice questions with detailed explanations written by domain experts in biology, physics, and chemistry.

XLSUM (Hasan et al., 2021) is a summarization dataset that focuses on news articles from BBC. In this work, we focus only on English news articles.

FLORES-200 (NLLB Team, 2022) is a translation benchmark that contains many low-resource languages. We follow Agarwal et al. (2024) and choose the translation task from Tamil to English. Additionally, we also test models on Chinese and Spanish.

B MODELS

Llama-3.1 8B and 70B (Dubey et al., 2024): We use both the 8B and 70B Llama 3.1 Instruction models. These multilingual models are trained on a 128k context window using position interpolation. The models are further fine-tuned with synthetic long-text Supervised Fine-Tuning (SFT) data and also undergo Direct Preference Optimization (DPO) (Rafailov et al., 2024).

GLM-4-9B-Chat (GLM et al., 2024): This is a 9-billion-parameter multilingual model, also trained on a 128k context window with position interpolation. It is further fine-tuned with labeled long-text SFT data and undergoes a DPO stage.

Mistral Family (Mistral AI, 2024): We use both 12-billion-parameter and 123-billion-parameter multilingual models, trained on a 128k context window.

Qwen2 7B and 72B (Yang et al., 2024): These two models are trained with a context size of 32k tokens, and their context window is extended to 128k by YARN (Peng et al., 2023), a dynamic position interpolation technique.

Phi-3 (Abdin et al., 2024): We use the mini (3.8B), small (7B), and medium (14B) versions of Phi-3 models. They are trained with the context size of 4k tokens on high quality data, and LongRope (Ding et al., 2024) extends their context size to 128k.

Jamba-1.5-Mini (Team et al., 2024c): It's a hybrid SSM-Transformer model with 12B of active parameters and 52B of total parameters with a context size of 256k tokens.

Gemini-1.5-Pro: It is a commercial model introduced by Google and has a context size of 2 million tokens.

C QUANTIZATION VS. REGULAR

We compare the 4-bit quantized version and unquantized version of both Llama-3.1 8B and Llama-3.1-70B. In both Figure 4 and Figure 5, we can observe that the quantized version experiences a little performance drop but exhibits the same trend as the unquantized version with the increasing context length.

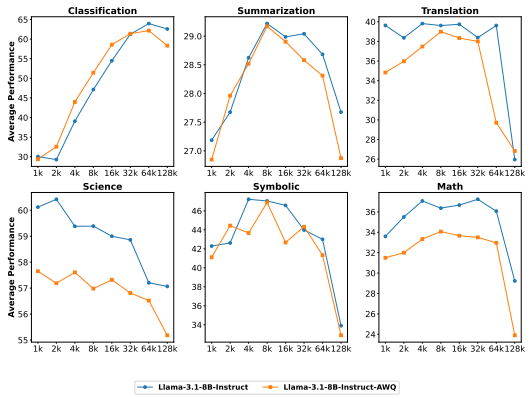


Figure 4: Comparison between Llama-3.1-8B and 4-bit quantized Llama-3.1-8B. There are some performance gaps between two models on translation, science, and math tasks, but with the increasing context size, the performance trend is the same for both models.

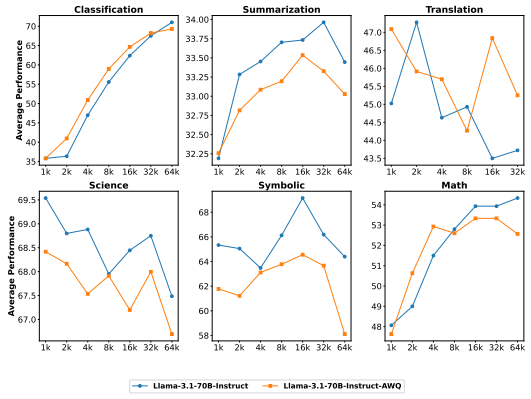


Figure 5: Comparison between Llama-3.1-70B and 4-bit quantized Llama-3.1-70B. Similar to the smaller model, the performance trends hold for both models except the translation tasks. In our benchmark, we exclude all the translation tasks because of the inconsistent multilingual ability of LCLMs.

D TASK PERFORMANCE

In this section, we present the models' performance on individual tasks and group them by the task categories: classification, translation, summarization, and reasoning.

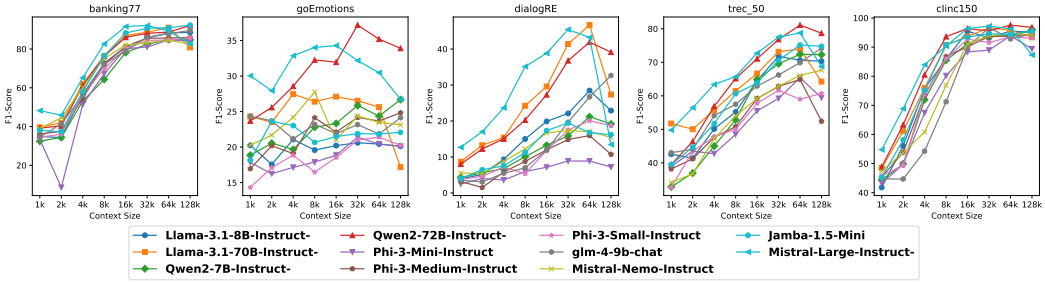


Figure 6: Models' performance on all classification tasks. All tasks except GoEmotions show a very consistent gain with increasing context size. We excluded GoEmotions from our benchmark because of the data's strong subjectivity.

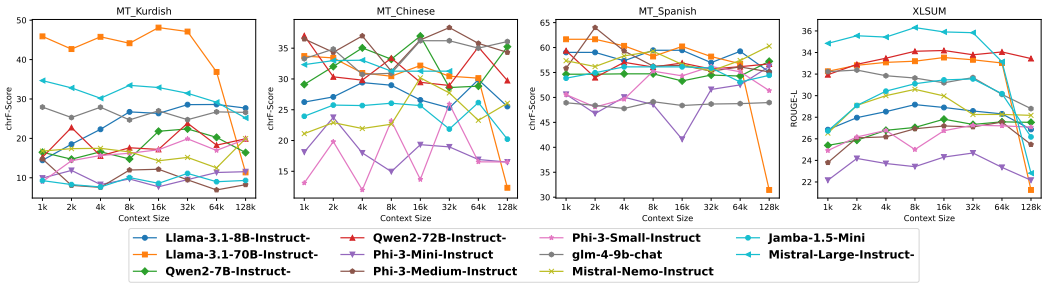


Figure 7: Models' performance on all translation tasks and the summarization task. For translation tasks, we do not observe a clear pattern among different languages and models, which can be caused by LCLMs' different multilingual abilities. We can see a slightly positive trend for the summarization task.

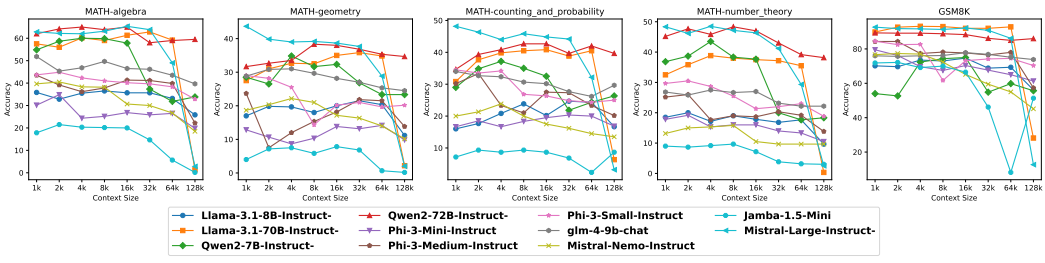


Figure 8: Models' performance on all math tasks. Overall, the larger and stronger models benefit more from the increasing context window size on math tasks.

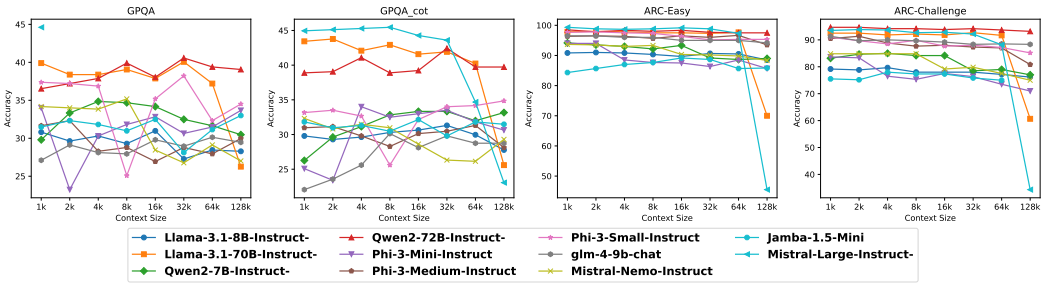


Figure 9: Models' performance on all science tasks. For the ARC task, the performance of all models stays the same across all context sizes. For GPQA, we can see larger and more robust LCLMs keep or increase their performance with the increasing context size.

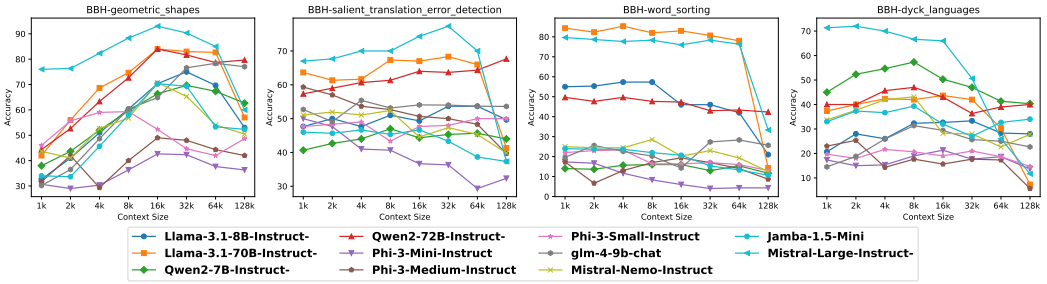


Figure 10: Models' performance on all symbolic tasks. For the geometric shape and translation error detection tasks, we can all model benefit from the increasing context length. We suspect the word sorting task may too easy for the models, so the lines are flat. For the dyck language task, the models experience performance gain up 16k context length but start downgrading afterward.

E Additional Retrieval Load Experiments

To ensure the performance downgrade is not caused by the absence of certain labels in the retrieval load experiment from Section 5, we replace similar examples with distant examples with the same labels. The new retrieval load ratio formula is $\frac{score_{original}}{score_{replace}}$. We use Llama-3.1 models and conduct this experiment from 1k to 64k with both BM25 and SBERT (Reimers & Gurevych, 2019) retrievers and exclude XLSUM.

BM25: The trend in Figure 2 matches the results of Figure 11. All the classification tasks downgrade performance more when similar examples are replaced. However, the degree of downgrade is less significant than removing similar examples.

SBERT: For SentenceTransformer, we use multi-qa-MiniLM-L6-cos-v1 as the base model. In addition to XLSUM, we exclude geometric shape, Dyck language, and dialogRE because the inputs of the first two tasks are mainly symbols and numbers, and the input of dialogRE is too long for the retriever to be effective. The trends observed from Figure 2 and Figure 11still hold in Figure 12. That is, all the classification tasks still have a higher ratio and the non-classification tasks have a ratio close to 1.

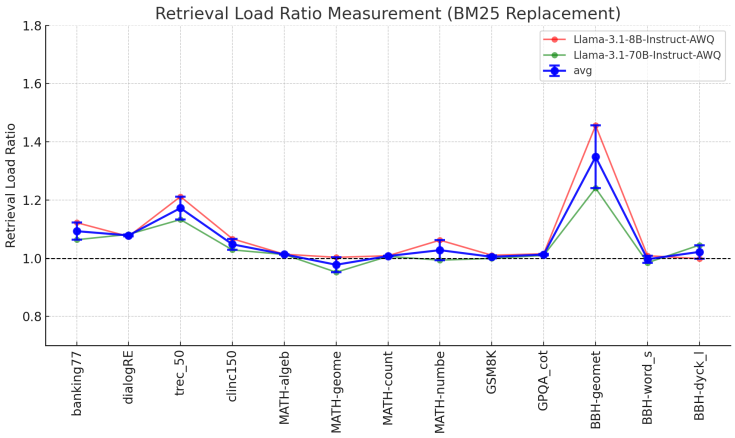


Figure 11: Retrieval Load Ratio under the replacement setting with BM25 on all tasks expect XL-SUM from 1k to 64k tokens. The ratio of 1 indicates models are not doing retrieval during ICL because similar demonstrations don't help models perform better. Similar to Figure 2, classification is the only category of tasks that has a higher ratio, which means classification tasks largely require model retrieval skills during ICL. The rest of the tasks is close to 1, and the models' performance on these tasks does not rely on retrieving similar examples.

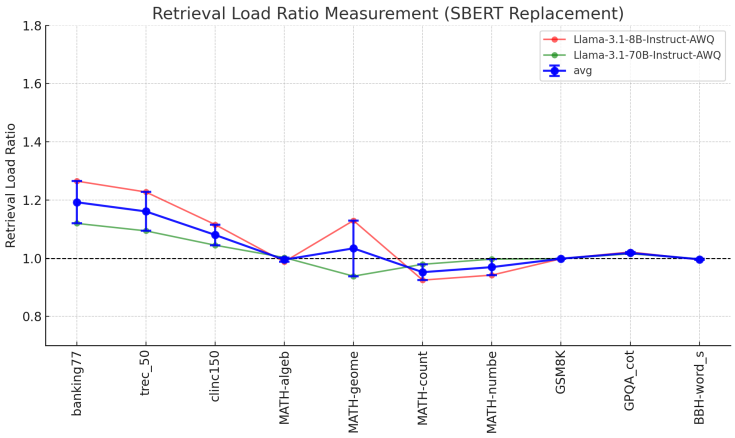


Figure 12: Retrieval Load Ratio under the replacement setting with SBERT on selective tasks from 1k to 64k tokens. A ratio of 1 signifies that models do not perform retrieval during in-context learning (ICL), as similar demonstrations do not enhance their performance. As shown in Figure 2, classification tasks are the only category with a higher retrieval load ratio, indicating a strong dependence on retrieval during ICL. In contrast, other tasks exhibit ratios close to 1, suggesting minimal reliance on retrieval, with models' performance largely unaffected by retrieval-based demonstrations.

F Additional Global Context Index Result

In Figure 13, We present the global context index for each non-retrieval task with input lengths of up to 64k, observing results consistent with those from the 16k input length setup.

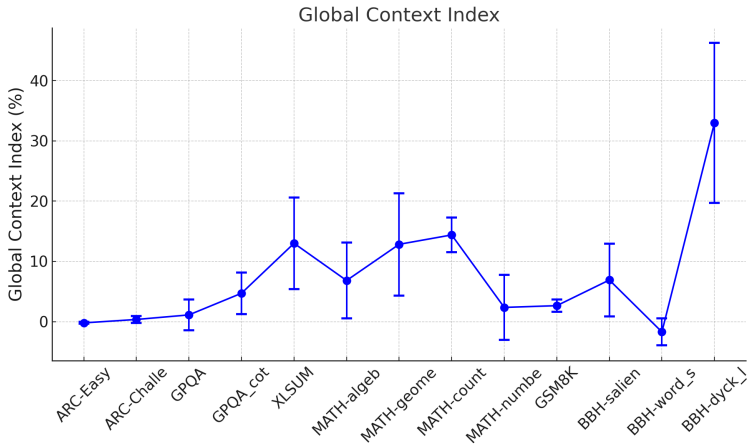


Figure 13: Global context index is the average % difference between adding duplicated vs. unique examples from 2k to 64k context for non-retrieval tasks. 0% means duplicating does not harm the model's performance. Easy tasks such as ARC and word sorting do not benefit from additional information. When a task is challenging, e.g., GPQA, the model cannot effectively learn all demonstrations unless explanations are provided.