

DeepSeek-Coder-V2: Breaking the Barrier of Closed-Source Models in Code Intelligence

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DeepSeek-AI

<https://github.com/deepseek-ai/DeepSeek-Coder-V2>

Abstract

We present DeepSeek-Coder-V2, an open-source Mixture-of-Experts (MoE) code language model that achieves performance comparable to GPT4-Turbo in code-specific tasks. Specifically, DeepSeek-Coder-V2 is further pre-trained from an intermediate checkpoint of DeepSeek-V2 with additional 6 trillion tokens. Through this continued pre-training, DeepSeek-Coder-V2 substantially enhances the coding and mathematical reasoning capabilities of DeepSeek-V2, while maintaining comparable performance in general language tasks. Compared to DeepSeek-Coder-33B, DeepSeek-Coder-V2 demonstrates significant advancements in various aspects of code-related tasks, as well as reasoning and general capabilities. Additionally, DeepSeek-Coder-V2 expands its support for programming languages from 86 to 338, while extending the context length from 16K to 128K. In standard benchmark evaluations, DeepSeek-Coder-V2 achieves superior performance compared to closed-source models such as GPT4-Turbo, Claude 3 Opus, and Gemini 1.5 Pro in coding and math benchmarks.

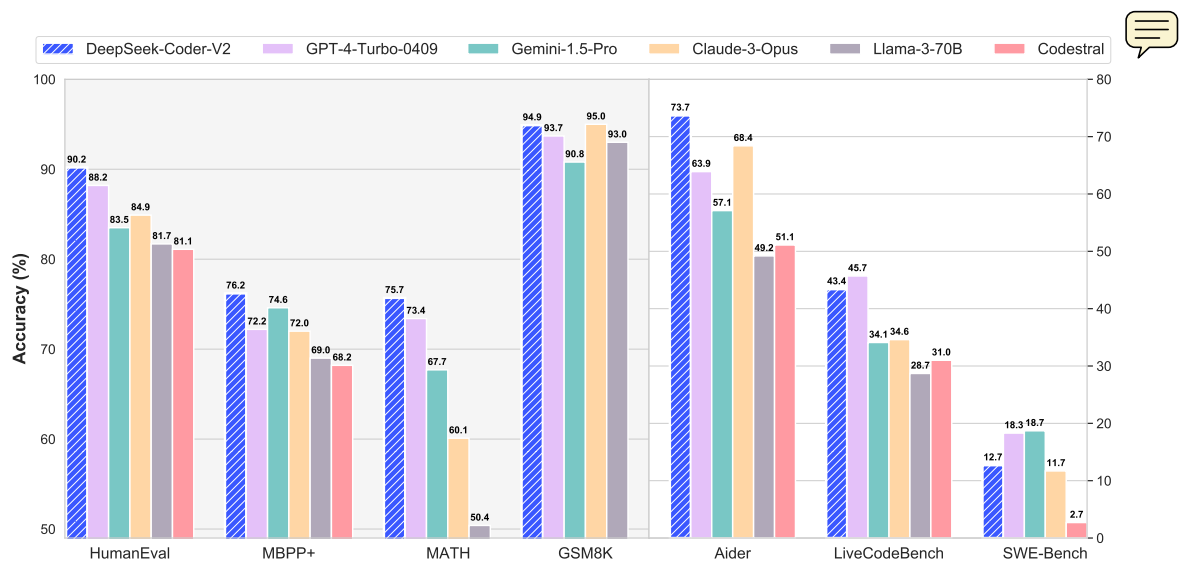


Figure 1 | The Performance of DeepSeek-Coder-V2 on math and code benchmarks.

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1. Introduction

The open-source community has made significant strides in advancing code intelligence through the development of open-source code models such as StarCoder (Li et al., 2023b; Lozhkov et al., 2024), CodeLlama (Roziere et al., 2023), DeepSeek-Coder (Guo et al., 2024), and Codestral (MistralAI, 2024). These models have steadily approached the performance levels of closed-source counterparts, contributing to the progress of code intelligence. However, there remains a discernible gap when comparing them to state-of-the-art closed-source models like GPT4-Turbo (OpenAI, 2023), Claude 3 Opus (Anthropic, 2024), and Gemini 1.5 Pro (Reid et al., 2024). To bridge this gap and further propel the development of open-source code models, we introduce the DeepSeek-Coder-V2 series. These models are built upon the foundation of DeepSeek-V2 (DeepSeek-AI, 2024) and are further pre-trained with an additional corpus with 6 trillion tokens.

In the pre-training phase, the dataset of DeepSeek-Coder-V2 is created with a composition of 60% source code, 10% math corpus, and 30% natural language corpus. The source code consists of 1,170B code-related tokens sourced from GitHub and CommonCrawl, using the same pipeline as DeepSeekMath (Shao et al., 2024). This corpus expands from 86 to 338 programming languages compared to the code corpus used to train DeepSeek-Coder. To demonstrate the effectiveness of the new code corpus, we conduct ablation studies with the 1B parameter model and observe improvements of 6.7% and 9.4% in accuracy across both HumanEval (from 30.5% to 37.2%) and MBPP (from 44.6% to 54.0%) benchmarks (Austin et al., 2021a; Chen et al., 2021), respectively. For the math corpus, we collect 221B math-related tokens sourced from CommonCrawl using the same pipeline, which approximately doubles the size of the 120B DeepSeekMath corpus (Shao et al., 2024), while for the natural language corpus, we directly sample from the training corpus in DeepSeek-V2. In total, DeepSeek-Coder-V2 has been exposed to 10.2T training tokens, where 4.2 trillion tokens originate from the DeepSeek V2 dataset, while the remaining 6 trillion tokens come from the DeepSeek-Coder-V2 dataset.

To accommodate longer code inputs and enhance applicability across various programming scenarios, we extend the context length from 16K to 128K tokens, allowing our models to handle more complex and extensive coding tasks. After continuous pre-training DeepSeek-V2 on this multi-source corpora, we find that DeepSeek-Coder-V2 significantly enhances the model’s capabilities in coding and mathematical reasoning while maintaining comparable general language performance.

In the alignment phase, we first construct an instruction training dataset that includes code and math data from DeepSeek-Coder (Guo et al., 2024) and DeepSeek-Math (Shao et al., 2024), as well as general instruction data from DeepSeek-V2 (DeepSeek-AI, 2024). This dataset is used to fine-tune the base model. Then, in the reinforcement learning phase, we employ Group Relative Policy Optimization (GRPO) algorithm to align its behavior with human preferences. Preference data is collected in the coding domain using compiler feedback and test cases, and a reward model is developed to guide the training of the policy model. This approach ensures that the model’s responses are optimized for correctness and human preference in coding tasks. To enable the model to support code completion after alignment, we also utilize Fill-In-Middle approach (Guo et al., 2024) during the fine-tuning of the base model with 16B parameters.

1.1. Contributions

In summary, our main contributions are:

- We introduce DeepSeek-Coder-V2 with 16B and 236B parameters based on the DeepSeek-

MoE framework, which has activation parameters of only 2.4B and 21B, efficiently supporting diverse computational and application needs. Additionally, DeepSeek-Coder-V2 supports 338 programming languages and a maximum context length of 128K tokens.

- We make the **first attempt to develop an open-source hundred-billion-parameter code model to advance the field of code intelligence**. Experimental results indicate that DeepSeek-Coder-V2 236B outperforms state-of-the-art closed-source models, such as GPT4-Turbo, Claude 3 Opus, and Gemini 1.5 Pro, in both coding and mathematics tasks.
- DeepSeek-Coder-V2 **models are released publicly under a permissive license, allowing for both research and unrestricted commercial use**.

1.2. Summary of Evaluations and Metrics



- **Code:** Regarding code generation benchmark evaluation, DeepSeek-Coder-V2 demonstrates remarkable superiority over all open source models while exhibiting performance on par with the leading closed-source models, such as GPT4-Turbo, Claude 3 Opus, and Gemini 1.5 Pro. Notably, we achieve a **90.2%** score on HumanEval (Chen et al., 2021), a **76.2%** score on MBPP (Austin et al., 2021a) (establishing a new state-of-the-art result with EvalPlus evaluation pipeline), and a **43.4%** score on LiveCodeBench (Jain et al., 2024) (questions from Dec. 2023 to June. 2024). Additionally, DeepSeek-Coder-V2 is the first open-source model that surpasses a score of 10% on SWEBench (Jimenez et al., 2023).
- **Math:** DeepSeek-Coder-V2 exhibits strong mathematical reasoning abilities, rivaling top closed-source models such as GPT-4o, Gemini 1.5 Pro, and Claude 3 Opus on both elementary benchmarks like GSM8K (Cobbe et al., 2021) and advanced competition-level benchmarks including MATH (Hendrycks et al., 2021), AIME (MAA, 2024), and Math Odyssey (Netmind.AI, 2024). Notably, DeepSeek-Coder-V2 attains an accuracy of **75.7%** on the MATH benchmark, nearly matching the state-of-the-art accuracy of **76.6%** achieved by GPT-4o. Furthermore, it surpasses the performance of these closed-source models in the AIME 2024 competition.
- **Natural Language:** DeepSeek-Coder-V2 maintains comparable general language performance to DeepSeek-V2. For example, DeepSeek-Coder-V2 achieves 79.2% on MMLU with OpenAI simple-eval pipeline. Regarding subjective evaluation with GPT-4 as a judge, DeepSeek-Coder-V2 achieves **65.0** on arena-hard (Li et al., 2024), **8.77** on MT-bench (Zheng et al., 2023) and **7.84** on alignbench (Liu et al., 2023c). These scores are significantly better than other code-specific models, even comparable with general open source models.

2. Data Collection

The pre-training data for DeepSeek-Coder-V2 primarily consists of 60% source code, 10% math corpus, and 30% natural language corpus. **Since the natural language corpus is directly sampled from the training dataset of DeepSeek-V2, this section focuses on the collection, cleaning, and filtering processes of the code and math data.** Meanwhile, we further validate the quality of this data through comparative analysis experiments.

We collect public repositories created before November 2023 on GitHub. We first apply the **same filtering rules and near-deduplication as those used in the DeepSeek-Coder (Guo et al., 2024) to filter out lower-quality and duplicated source code.** To make the paper self-contained, we briefly describe the filtering rules. Firstly, we filter out files with an average line length exceeding 100 characters or a maximum line length surpassing 1000 characters. Additionally, we remove files with fewer than 25% alphabetic characters. Except for the XSLT programming language, we further filter out files where the string "`<?xml version=`" appears in the first 100

characters. For HTML files, we consider the ratio of visible text to HTML code. We retain files where the visible text constitutes at least 20% of the code and is no less than 100 characters. For JSON and YAML files, which typically contain more data, we only keep files that have a character count ranging from 50 to 5000 characters. This effectively removes most data-heavy files. By applying these filtering rules and near-deduplication, we obtain 821B code encompassing 338 programming languages and 185B code-related text, such as markdown and issues. The list of supported programming languages can be found in the Appendix A. We use the same tokenizer as DeepSeekV2, detailed in (DeepSeek-AI, 2024).

To collect code-related and math-related web texts from Common Crawl, we follow the same pipeline as DeepSeekMath (Shao et al., 2024). Specifically, we select coding forums such as StackOverflow¹, library sites such as PyTorch documentation², and mathematics website such as StackExchange³ as our initial seed corpus. Using this seed corpus, we train a fastText model (Joulin et al., 2016) to recall more coding-related and math-related web pages. Since tokenization for languages like Chinese cannot be done through spaces, we use the Byte Pair Encoding (BPE) tokenizer from DeepSeek-V2, which significantly improves the recall accuracy of fastText. For each domain, we calculate the percentage of web pages collected in the first iteration. Domains with over 10% of web pages collected are classified as code-related or math-related. We then annotate the URLs associated with code-related or math-related content within these identified domains. Uncollected web pages linked to these URLs are added to the seed corpus. After three iterations of data collection, we gather 70 billion code-related tokens and 221B math-related tokens from web pages. To further collect high-quality source code from GitHub, we also apply the same pipeline on GitHub with two iterations of data collection and collect 94B source code. The initial seed corpus is constructed by manually collecting high-quality source code, such as those containing detailed descriptions. Finally, the new code corpus consists of 1,170B code-related tokens sourced from GitHub and CommonCrawl.

To demonstrate the effectiveness of the new code corpus, we conducted ablation studies (see Table 1) using a 1B parameter model, comparing it with the corpus used to train DeepSeek-Coder. Pre-training the 1B model on the new code corpus using 1T tokens resulted in improvements of 5.5% and 4.4% in accuracy on the HumanEval (from 30.5% to 36.0%) and MBPP (from 44.6% to 49.0%) benchmarks, respectively. Further training the 1B model with 2T tokens led to additional improvements, with HumanEval and MBPP scores rising to 37.2% and 54.0%, respectively. Therefore, the new code corpus is superior to the code corpus used to train DeepSeek-Coder.

Model	Tokens	Python	C++	Java	PHP	TS	C#	Bash	JS	Avg	MBPP
DeepSeek-Coder-1B	1T	30.5%	28.0%	31.7%	23.0%	30.8%	31.7%	9.5%	28.6%	26.7%	44.6%
DeepSeek-Coder-V2-1B	1T	36.0%	34.8%	31.7%	27.3%	37.7%	34.2%	6.3%	38.5%	31.2%	49.0%
DeepSeek-Coder-V2-1B	2T	37.2%	39.1%	32.3%	31.7%	34.6%	36.7%	12.0%	32.9%	32.0%	54.0%

Table 1 | Performance of 1B base model between DeepSeek-Coder and DeepSeek-Coder-V2.

3. Training Policy

3.1. Training Strategy

We use two training objectives for DeepSeek-Coder-v2 16B: Next-Token-Prediction and Fill-In-Middle (FIM) (Bavarian et al., 2022; Guo et al., 2024; Li et al., 2023b). For DeepSeek-Coder-v2

¹<https://stackoverflow.com>

²<https://pytorch.org/docs>

³<https://math.stackexchange.com>

236B, we only utilize the Next-Token-Prediction objective. Here we give a brief introduction of the FIM training policy. We adopt the FIM training approach for the development of DeepSeek-Coder-v2-16B, leveraging the PSM (Prefix, Suffix, Middle) mode. This method structures the content reconstruction in the sequence: Prefix, Suffix, and Middle, as illustrated below:

$$\langle \text{fim_begin} \mid \rangle_{f_{pre}} \langle \text{fim_hole} \mid \rangle_{f_{suf}} \langle \text{fim_end} \mid \rangle_{f_{middle}} \langle \text{eos_token} \mid \rangle$$

This structure is applied at the document level as part of the pre-packing process. The FIM is utilized at a rate of 0.5, consistent with the PSM framework, to enhance the training efficacy and model performance.

3.2. Model Architecture

Our architecture aligns with that of DeepSeekV2 (DeepSeek-AI, 2024). The hyperparameters settings, 16B and 236B, correspond to those used in DeepSeek-V2-Lite and DeepSeek-V2, respectively. Notably, we encountered instability during training and spikes in gradient values, which we attributed to the exponential normalization technique. To address this, we reverted to the conventional normalization method.

3.3. Training Hyper-Parameters

Consistent with the DeepSeek V2 methodology (DeepSeek-AI, 2024), we utilize the AdamW optimizer (Loshchilov and Hutter, 2019), configured with $\beta_1 = 0.9$, $\beta_2 = 0.95$, and a weight decay of 0.1. Batch sizes and learning rates are adjusted according to DeepSeek-V2 specifications. For learning rate scheduling, we employ a cosine decay strategy, starting with 2000 warm-up steps and gradually reducing the learning rate to 10% of its initial value.

Both DeepSeek-Coder-V2 and DeepSeek-Coder-V2-Lite are trained using the same methodology. To maintain robust natural language understanding capabilities in DeepSeek-Coder-V2, we continue the pre-training process from an intermediate checkpoint of DeepSeek-V2. The intermediate checkpoint was initially trained on 4.2T tokens. Consequently, DeepSeek-Coder-V2 has been exposed to a total of 10.2T high-quality tokens during the pre-training phase.

Model	DeepSeek-Coder-V2-Lite	DeepSeek-Coder-V2
# Total Parameters (#TP)	16B	236B
# Active Parameters (#AP)	2.4B	21B
Pre-training Tokens	4.2T+6T	4.2T+6T
LR Scheduler	Cosine	Cosine
FIM	Enable	Disable

Table 2 | Training Setting of DeepSeek-Coder-V2.

3.4. Long Context Extension

Following DeepSeek-V2, we extend the context length of DeepSeek-Coder-V2 to 128K using Yarn (Peng et al., 2023). The hyper-parameters of YARN are the same as DeepSeek-V2: the scale s to 40, α to 1, β to 32. We further continue training the model using two stages to enhance its capability for handling long contexts. In the first stage, we utilize a sequence length of 32K and a batch size of 1152 for 1000 steps. In the second stage, we train the model for an additional 1000 steps, employing a sequence length of 128K and a batch size of 288 sequences.

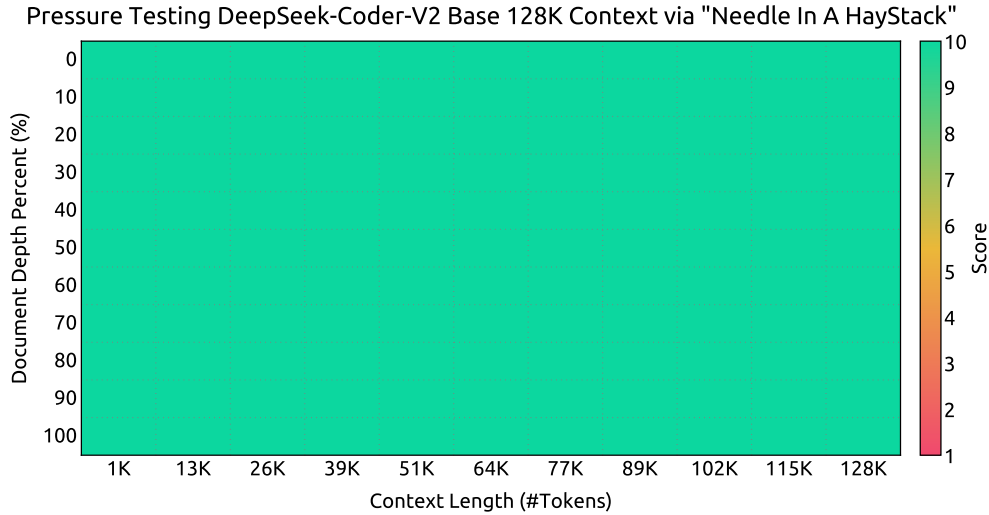


Figure 2 | Evaluation results on the “Needle In A Haystack” (NIAH) tests. DeepSeek-Coder-V2 performs well across all context window lengths up to 128K.

It should be noted here we upsample long context data ratio during long context extension. As shown in Figure 2, the results on the “Needle In A Haystack” (NIAH) tests indicate that DeepSeek-Coder-V2 performs well across all context window lengths up to 128K.

3.5. Alignment

3.5.1. Supervised Fine-Tuning

To build DeepSeek-Coder-V2 Chat, we construct the instruction training dataset mixed with code and math data. We first collect 20k code-related instruction data and 30k math related data from DeepSeek-Coder and DeepSeek-Math. To maintain the general ability, we also sample several data from the instruction data of DeepSeek-V2. Finally, we use a instruction dataset of 300M tokens. For training, we use a cosine schedule with 100 warm-up steps and an initial learning rate $5e^{-6}$. We also use a batch size of 1M tokens and 1B tokens in total.

3.5.2. Reinforcement Learning

We further employ Reinforcement Learning (RL) techniques to fully simulate the capabilities of DeepSeek-Coder-V2, which is proven to be quite effective.

Prompts Considerable effort was spent collecting prompts related to code and math from various sources, and each code prompt comes with corresponding test cases. After filtering the prompts, there are approximately 40k data in total.

Reward Modeling Reward models play crucial roles in the RL training. In terms of mathematical preference data, we obtain them using the ground-truth labels. In terms of code preference data, although the code compiler itself can already provide 0-1 feedback (whether the code pass all test cases or not), some code prompts may have a limited number of test cases, and do not provide full coverage, and hence directly using 0-1 feedback from the compiler may be noisy and sub-optimal. Therefore, we still decide to train a reward model on the data provided by the compiler, and use the reward model to provide signal during RL training, which is more robust

and has better generalization ability, in comparison with raw compiler signal. As illustrated in Figure 3 in our in-house test sets (Leetcode and Leetcode-zh), using a reward model to provide RL training signal clearly outperforms using raw compiler signal. Hence, we use reward model signal rather than compiler signal in all subsequent experiments.

Reinforcement Learning Algorithm We employ Group Relative Policy Optimization (GRPO) Shao et al. (2024) as our RL algorithm, which is the same as what DeepSeek-V2 uses. Notably, GRPO is proven to be quite effective and has less cost compared with PPO, since there is no need to maintain an additional critic model.

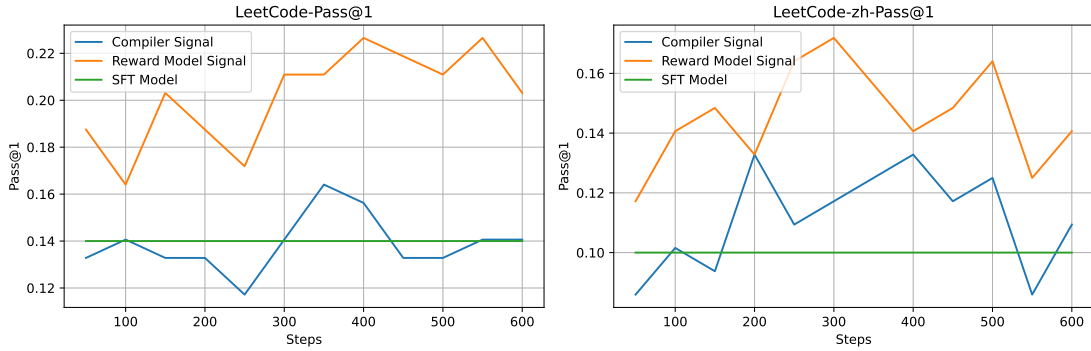


Figure 3 | Performances of Different Methods

4. Experimental Results

In this section, we evaluate DeepSeek-Coder-V2 on three types of tasks, including coding, mathematics, and general natural language. We compare DeepSeek-Coder-V2 with the previous state-of-the-art large language models.

- **CodeLlama** (Roziere et al., 2023) consists of a series of code language models based on Llama2 (Touvron et al., 2023), and continue pre-training on datasets ranging from 500 to 1000 billion code tokens. These models are available in four sizes: 7B, 13B, 34B, and 70B.
- **StarCoder** (Lozhkov et al., 2024) is a publicly accessible model with 15 billion parameters. It is specifically trained on a meticulously curated subset of the Stack dataset (Kocetkov et al., 2022), covering 86 programming languages.
- **StarCoder2** (Lozhkov et al., 2024) consists of 3B, 7B, and 15B parameters models trained on 3.3 to 4.3 trillion tokens of the Stack2 dataset (Lozhkov et al., 2024), spanning 619 programming languages.
- **DeepSeek-Coder** (Guo et al., 2024) comprises a series of code language models, ranging from 1 billion to 33 billion parameters. Each model is trained from scratch on 2 trillion tokens, with a composition of 87% code and 13% natural language in both English and Chinese. These models are pre-trained on a project-level code corpus using a window size of 16K and an additional fill-in-the-blank task, enabling support for project-level code completion and infilling.
- **Codestral** (MistralAI, 2024) is a 22B parameter model developed by Mistral. It is trained on a diverse dataset of over 80 programming languages, including popular ones such as Python, Java, and JavaScript, as well as more specialized languages like Swift and Fortran.

- General language models that we compare include **Llama3 70B** (Meta, 2024), **GPT-4** (OpenAI, 2023), **Claude 3 Opus** (Anthropic, 2024), and **Gemini 1.5 Pro** (Reid et al., 2024). While they are not specifically trained on large code corpora, they achieve state-of-the-art performance in coding.

4.1. Code Generation

HumanEval and MBPP Benchmarks. The HumanEval (Chen et al., 2021)⁴ and MBPP (Austin et al., 2021b) benchmarks are commonly utilized for assessing the performance of code-generating Large Language Models (LLMs). HumanEval comprises 164 Python tasks that are verified through test cases to evaluate the performance of Code LLMs in a zero-shot scenario. For MBPP, we use the MBPP-Plus version (Liu et al., 2023a) to evaluate the models. To test the multilingual abilities of models, we extended the HumanEval benchmark problems into seven additional languages: C++, Java, PHP, TypeScript, C#, Bash, JavaScript, Swift, R, Julia, D, Rust and Racket. For both benchmarks, we employed a greedy search strategy and recreated the baseline results using identical scripts and environments to ensure a fair comparison.

	#TP	#AP	Python	Java	C++	C#	TS	JS	PHP	Bash
Closed-Source Models										
Gemini-1.5-Pro	-	-	83.5%	81.0%	78.3%	75.3%	77.4%	80.8%	74.5%	39.9%
Claude-3-Opus	-	-	84.2%	78.5%	81.4%	74.7%	76.1%	75.8%	78.3%	48.7%
GPT-4-1106	-	-	87.8%	82.3%	78.9%	80.4%	81.8%	80.1%	77.6%	55.7%
GPT-4-Turbo-0409	-	-	88.2%	81.7%	78.3%	79.1%	79.3%	80.8%	78.9%	55.1%
GPT-4o-0513	-	-	91.0%	80.4%	87.0%	82.9%	86.2%	87.6%	79.5%	53.8%
Open-Source Models										
Codestral	22B	22B	78.1%	71.5%	71.4%	77.2%	72.3%	73.9%	69.6%	47.5%
DS-Coder-instruct	33B	33B	79.3%	73.4%	68.9%	74.1%	67.9%	73.9%	72.7%	43.0%
Llama3-Instruct	70B	70B	81.1%	67.7%	64.0%	69.6%	69.8%	70.2%	65.8%	36.1%
DS-Coder-V2-Lite-Instruct	16B	2.4B	81.1%	76.6%	75.8%	76.6%	80.5%	77.6%	74.5%	43.0%
DS-Coder-V2-Instruct	236B	21B	90.2%	82.3%	84.8%	82.3%	83.0%	84.5%	79.5%	52.5%
	#TP	#AP	Swift	R	Julia	D	Rust	Racket	MBPP+	Average
Closed-Source Models										
Gemini-1.5-Pro	-	-	66.5%	53.4%	71.7%	55.8%	73.1%	48.4%	74.6%	68.9%
Claude-3-Opus	-	-	63.9%	55.9%	76.1%	60.3%	71.2%	64.6%	72.0%	70.8%
GPT-4-1106	-	-	62.7%	57.8%	69.2%	60.9%	78.8%	64.0%	69.3%	72.5%
GPT-4-Turbo-0409	-	-	63.9%	56.5%	69.8%	61.5%	78.8%	63.4%	72.2%	72.3%
GPT-4o-0513	-	-	75.9%	65.2%	78.0%	60.9%	80.1%	64.6%	73.5%	76.4%
Open-Source Models										
Codestral	22B	22B	63.3%	49.7%	67.9%	32.1%	67.3%	37.3%	68.2%	63.2%
DS-Coder-instruct	33B	33B	61.4%	44.7%	53.5%	31.4%	68.6%	46.0%	70.1%	61.9%
Llama3-Instruct	70B	70B	55.1%	46.0%	62.9%	48.1%	58.3%	46.0%	68.8%	60.6%
DS-Coder-V2-Lite-Instruct	16B	2.4B	64.6%	47.8%	67.3%	45.5%	62.2%	41.6%	68.8%	65.6%
DS-Coder-V2-Instruct	236B	21B	72.2%	64.0%	72.3%	64.1%	78.2%	63.4%	76.2%	75.3%

Table 3 | Performance Metrics for Various Models on HumanEval and MBPP Benchmarks

Table 3 provides an extensive overview of the performance metrics for various models across multiple programming languages on the HumanEval and MBPP+ Benchmarks. The DeepSeek-Coder-V2-Instruct demonstrates exceptional performance, securing the second-highest average

⁴We use the template "Please complete the python function below. The final complete version of your function must be returned within a code block. Here is the unfinished function:\n ``python\n{problem_description}\n\n" to build the instruction prompt.

score of 75.3%. This performance is notable as it breaks the dominance typically seen from closed-source models, standing out as a leading open-source contender. It is surpassed only by GPT-4o, which leads with an average score of 76.4%. DeepSeek-Coder-V2-Instruct shows top-tier results across a variety of languages, including the highest scores in Java and PHP, and strong performances in Python, C++, C#, TypeScript, and JavaScript, underscoring its robustness and versatility in handling diverse coding challenges.

Furthermore, the DeepSeek-Coder-V2-Lite-Instruct also performs impressively, surpassing the larger 33B model. With a considerable margin in average performance (65.6% vs. 61.9%), it highlights the effectiveness of the 16B model in delivering competitive results despite its smaller size. This underscores the model’s efficiency and the advancements in model architecture and training methodologies that allow it to outperform larger counterparts.

Competitive Programming. To further validate the model’s capability in real-world competitive programming problems, we utilize the LiveCodeBench (Jain et al., 2024) and USACO benchmark (Shi et al., 2024) to estimate the effectiveness of DeepSeek-Coder-V2. LiveCodeBench is a meticulous and contamination-free assessment of Large Language Models (LLMs) for code generation, systematically gathering novel challenges over time from three prominent competitive programming platforms: LeetCode, AtCoder, and CodeForces. Since the cut-off of the training data is before November 2023, we use the subset (1201-0601) of Livecodebench. USACO benchmark contains 307 problems from the USA Computing Olympiad, along with high-quality unit tests, reference code, and official analyses for each problem.

Model	#TP	#AP	LiveCodeBench				USACO
			Easy (82)	Medium (87)	Hard (57)	Overall (226)	
Closed-Source Models							
Gemini-1.5-Pro	-	-	74.9%	16.8%	1.8%	34.1%	4.9%
Claude-3-Opus	-	-	77.2%	16.7%	0.7%	34.6%	7.8%
GPT-4-1106	-	-	78.4%	20.2%	3.5%	37.1%	11.1%
GPT-4-Turbo-0409	-	-	84.1%	35.4%	6.1%	45.7%	12.3%
GPT-4o-0513	-	-	87.4%	27.5%	4.9%	43.4%	18.8%
Open-Source Models							
Codestral	22B	22B	66.5%	17.7%	0.2%	31.0%	4.6%
DS-Coder-instruct	33B	33B	51.6%	9.7%	0.4%	22.5%	4.2%
Llama3-Instruct	70B	70B	62.4%	14.4%	2.1%	28.7%	3.3%
DS-Coder-V2-Lite-Instruct	16B	2.4B	58.5%	8.0%	0.0%	24.3%	6.5%
DS-Coder-V2-Instruct	236B	21B	84.1%	29.9%	5.3%	43.4%	12.1%

Table 4 | Performance on the LiveCodeBench (LCB) and USACO benchmarks.

Table 4 showcases the performance of various language models on the two benchmarks. Notably, DeepSeek-Coder-V2-Instruct delivers a standout performance, tying for the highest score among large models at 43.4%, on par with GPT-4o. This exceptional result places it second overall, just behind GPT-4-Turbo-0409, which leads with an overall performance of 45.7%. DeepSeek-Coder-V2-Instruct’s impressive ability to handle complex coding challenges firmly establishes it as a top contender, closely trailing the leading GPT-4-Turbo variant.

4.2. Code Completion

4.2.1. Repository-Level Code Completion Evaluation

We use RepoBench (Liu et al., 2023b) to evaluate the capabilities of currently available open-source code models with sizes below 35B in repository-level code completion tasks. This dataset is constructed from a diverse set of real-world, open-sourced, permissively licensed repositories in two popular programming languages: Python and Java. Notably, the latest version (v1.1) of RepoBench sources its data from GitHub repositories created between October 6th and December 31st, 2023, while our pre-training data includes code created before November 2023. To ensure this dataset was not present in our pre-training data and avoid data leakage, we only use data from December 2023.

Our evaluation includes five context length levels—2k, 4k, 8k, 12k, and 16k tokens—across three settings: cross-file-first, cross-file-random, and in-file. We use greedy search for all models under evaluation. The models were constrained to generate a maximum of 64 new tokens per prompt, and the first non-empty and non-comment line of the output was selected as the prediction. The maximum token length for prompts was set to 15,800 by truncating excess cross-file context. We report the average exact match for the different context length levels.

Model	#TP	#AP	Python						Java					
			2k	4k	8k	12k	16k	Avg	2k	4k	8k	12k	16k	Avg
StarCoder2-Base	15B	15B	35.7%	36.7%	34.6%	27.4%	25.1%	32.1%	46.2%	45.0%	39.8%	30.5%	30.7%	38.7%
CodeLlama-Base	7B	7B	32.0%	34.4%	35.3%	33.3%	32.2%	33.5%	43.1%	42.1%	40.4%	37.0%	40.3%	40.6%
CodeLlama-Base	13B	13B	33.0%	36.5%	37.0%	34.6%	35.0%	35.2%	43.5%	44.8%	40.7%	38.6%	41.1%	41.8%
CodeLlama-Base	34B	34B	35.3%	37.5%	39.5%	34.9%	35.6%	36.6%	45.9%	45.4%	42.5%	41.0%	41.2%	43.3%
DS-Coder-Base	6.7B	6.7B	36.1%	37.5%	38.2%	34.0%	35.0%	36.2%	46.8%	46.4%	42.9%	38.8%	40.8%	43.3%
DS-Coder-Base	33B	33B	39.7%	40.1%	40.0%	36.9%	38.5%	39.1%	47.9%	47.7%	43.3%	40.9%	43.6%	44.8%
Codestral	22B	22B	42.1%	44.3%	46.6%	46.6%	51.5%	46.1%	48.3%	47.8%	46.0%	42.2%	43.9%	45.7%
DS-Coder-V2-Lite-Base	16B	2.4B	38.3%	38.6%	40.6%	38.3%	38.7%	38.9%	48.8%	45.7%	42.4%	38.1%	41.1%	43.3%

Table 5 | Performance of different models on December subset of RepoBench v1.1.

As shown in Table 5, the results indicate that the DeepSeek-Coder-V2-Lite-Base model, despite having only 2.4 billion active parameters, achieves code completion capabilities in Python comparable to the DeepSeek-Coder-Base 33B model and in Java comparable to the DeepSeek-Coder-Base 7B model. Compared to CodeStral, the DeepSeek-Coder-V2-Lite-Base model has only one-tenth of the active parameters of CodeStral, resulting in lower performance in code completion tasks. However, we believe that the smaller number of active parameters in DeepSeek-Coder-V2 makes it faster for code completion scenarios.

4.2.2. Fill-in-the-Middle Code Completion

DeepSeek-Coder-V2-Lite is trained with a unique approach that includes a 0.5 Fill-In-the-Middle (FIM) rate during their pre-training phase. This method allows the model to adeptly complete code by filling in blanks using the surrounding context, which includes both the preceding and following code segments. This ability is particularly advantageous for code completion tools. Several open-source models, such as SantaCoder (Allal et al., 2023), StarCoder (Li et al., 2023b), and CodeLlama (Roziere et al., 2023), also leverage similar capabilities and have established high standards in the domain of code generation and completion.

To evaluate the performance of DeepSeek-Coder-V2 models, we conducted a comparative analysis against leading models. The assessment was based on the Single-Line Infilling benchmarks, covering three different programming languages as described by Allal et al. (2023). The

main metric for this evaluation was the line exact match accuracy⁵

Model	#TP	#AP	python	java	javascript	Mean
StarCoder ⁶	16B	16B	71.5%	82.3%	83.0%	80.2%
CodeLlama-Base	7B	7B	58.6%	70.6%	70.7%	68.0%
CodeLlama-Base	13B	13B	60.7%	74.3%	78.5%	73.1%
DS-Coder-Base	1B	1B	74.1%	85.1%	82.9%	81.8%
DS-Coder-Base	7B	7B	79.8%	89.6%	86.3%	86.1%
DS-Coder-Base	33B	33B	80.5%	88.4%	86.6%	86.4%
Codestral	22B	22B	77.2%	83.2%	85.9%	83.0%
DS-Coder-V2-Lite-Base	16B	2.4B	80.0%	89.1%	87.2%	86.4%

Table 6 | Performance of different approaches on the FIM-Tasks.

The table presents the performance of various coding models on FIM (Fill-in-the-Middle) tasks across three programming languages: Python, Java, and JavaScript, with a Mean score indicating overall effectiveness. Among the compared models, **DeepSeek-Coder-V2-Lite-Base**, with a configuration of 2.4B active parameters, achieves outstanding results. It scores 80.0% in Python, 89.1% in Java, and 87.2% in JavaScript, leading to a top Mean score of 86.4%. This demonstrates the superior effectiveness of DeepSeek-Coder-V2-Lite-Base, particularly in handling FIM tasks across different programming languages, achieving comparable performance with other bigger models in the evaluation.

4.3. Code Fixing

To evaluate the bug-fixing capabilities of the model, we used the Defects4J⁷, SWE-bench (Jimenez et al., 2023), and Aider⁸ datasets for testing. Defects4J is a widely used dataset in the field of software engineering, specifically designed for the purpose of evaluating and testing program repair techniques. It consists of a collection of real-world software bugs from various open-source projects, including but not limited to Apache Commons, JFreeChart, and Closure Compiler. Each bug in the dataset is accompanied by test suites that can be used to validate the effectiveness of program repair tools. Since the original bugs in Defec4J may need modify several files in the repository resulting in a long context, we collect 238 bugs that only need to modify one method from this benchmark.

SWE-bench is a comprehensive benchmark designed to evaluate the performance of large language models in addressing real-world software issues sourced from GitHub. The benchmark presents a codebase alongside a specific issue, challenging the language model to generate a patch that effectively resolves the described problem. This rigorous evaluation framework ensures that the language model’s ability to understand and fix real-world software issues is thoroughly tested, providing a clear measure of its practical utility and effectiveness in software development tasks.

Aider’s code editing benchmark evaluates the LLM’s ability to modify Python source files, completing 133 distinct coding tasks. This benchmark not only tests the LLM’s coding skills but also checks its consistency in producing code edits according to the specifications in the prompt.

⁵We use the first generated line rather than the whole generated chunk, thus the result is slightly different with DeepSeek-Coder.

⁷<https://github.com/rjust/defects4j>

⁸<https://github.com/paul-gauthier/aider>

For DeepSeek-Coder-V2 models, we use *whole* format to evaluate.

Model	#TP	#AP	Defects4J	SWE-Bench	Aider
Closed-Source Models					
Gemini-1.5-Pro	-	-	18.6%	19.3%	57.1%
Claude-3-Opus	-	-	25.5%	11.7%	68.4%
GPT-4-1106	-	-	22.8%	22.7%	65.4%
GPT-4-Turbo-0409	-	-	24.3%	18.3%	63.9%
GPT-4o-0513	-	-	26.1%	26.7%	72.9%
Open-Source Models					
Codestral	22B	22B	17.8%	2.7%	51.1%
DS-Coder-Instruct	33B	33B	11.3%	0.0%	54.5%
Llama3-Instruct	70B	70B	16.2%	-	49.2%
DS-Coder-V2-Lite-Instruct	16B	2.4B	9.2%	0.0%	44.4%
DS-Coder-V2-Instruct	236B	21B	21.0%	12.7%	73.7%

Table 7 | Performances of different models on repair benchmarks. We do not evaluate Llama3-Instruct on SWE-Bench as it just supports 8K context length.

Table 7 outlines the performances of different language models on software repair benchmarks, including Defects4J, SWE-Bench, and Aider. Among open-source models, **DeepSeek-Coder-Instruct emerges as a standout, achieving the best performance within the open source models**. It scores 21% in Defects4J and 12.7% in SWE-Bench, closely approaching the results of leading closed-source models and demonstrating significant capability in handling longer code sequences. Notably, DeepSeek-Coder-V2-Instruct achieves the highest score of 73.7% in Aider, surpassing all other models listed, including closed-source counterparts. This superior performance highlights its efficiency and robustness in automated code repair tasks, positioning DeepSeek-Coder-V2-Instruct as the top open-source model and a formidable competitor to closed-source alternatives in the field.

4.4. Code Understanding and Reasoning

To assess the code reasoning capabilities of our models, we utilize the CRUXEval benchmark. This benchmark comprises 800 Python functions paired with corresponding input-output examples. It is divided into two distinct tasks: CRUXEval-I, which requires the large language model (LLM) to predict the output based on the given input, and CRUXEval-O, where the model must predict the input from the known output. This structure challenges the model’s ability to understand and reason through Python code in both forward and reverse directions. Table 8 presents the performance of various language models on the CruxEval benchmark, which assesses models on two metrics: CruxEval-I-COT and CruxEval-O-COT. Among the open-source models, **DeepSeek-Coder-V2-Instruct stands out significantly. It scores 70.0% on CruxEval-I-COT and 75.1% on CruxEval-O-COT**, showcasing its superior capability within the open-source domain. However, when compared to larger closed-source models, there is a performance gap. This performance gap may largely be attributed to the fact that DeepSeek-Coder-V2-Instruct operates with only 21 billion activation parameters, which is considerably fewer than those in larger, more advanced closed-source models like GPT-4o. This limitation in model complexity could restrict its learning and problem-solving capacities.

Model	#TP	#AP	CruxEval-I-COT	CruxEval-O-COT
Closed-Source Models				
Gemini-1.5-Pro	-	-	67.0%	77.5%
Claude-3-Opus	-	-	73.4%	82.0%
GPT-4-1106	-	-	75.5%	77.1%
GPT-4-Turbo-0409	-	-	75.7%	82.0%
GPT-4o-0513	-	-	77.4%	88.7%
Open-Source Models				
Codestral	22B	22B	48.0%	60.6%
DS-Coder-Instruct	33B	33B	47.3%	50.6%
Llama3-Instruct	70B	70B	61.1%	64.3%
DS-Coder-V2-Lite-Instruct	16B	2.4B	53.0%	52.9%
DS-Coder-V2-Instruct	236B	21B	70.0%	75.1%

Table 8 | Performance of different models on the CruxEval benchmark.

4.5. Mathematical Reasoning

To assess the mathematical reasoning capabilities of DeepSeekCoder-V2, we utilized the popular grade-school benchmark GSM8K (Cobbe et al., 2021), along with advanced competition-level benchmarks including MATH (Hendrycks et al., 2021), the American Invitational Mathematics Examination (AIME) 2024 (MAA, 2024), and Math Odyssey (Netmind.AI, 2024)⁹.

Model	#TP	#AP	GSM8K	MATH	AIME 2024	Math Odyssey
Closed-Source Models						
Gemini 1.5 Pro	-	-	90.8%	67.7%	2/30	45.0%
Claude-3-Opus	-	-	95.0%	60.1%	2/30	40.6%
GPT-4-1106	-	-	91.4%	64.3%	1/30	49.1%
GPT-4-Turbo-0409	-	-	93.7%	73.4%	3/30	46.8%
GPT-4o-0513	-	-	95.8%	76.6%	2/30	53.2%
Open-Source Models						
Llama3-Instruct	70B	70B	93.0%	50.4%	1/30	27.9%
DS-Coder-V2-Lite-Instruct	16B	2.4B	86.4%	61.8%	0/30	44.4%
DS-Coder-V2-Instruct	236B	21B	94.9%	75.7%	4/30	53.7%

Table 9 | Performance of different models on the mathematical reasoning. DeepSeek-Coder-V2-Instruct can achieve 5/30 on AIME 2024 with maj@64.

The results, presented in Table 9, were obtained using greedy decoding without the aid of tools or voting techniques, unless otherwise specified. DeepSeek-Coder-V2 achieved an accuracy of 75.7% on the MATH benchmark and 53.7% on Math Odyssey, comparable to the state-of-the-art GPT-4o. Additionally, DeepSeek-Coder-V2 solves more problems from AIME 2024 than the other models, demonstrating its strong mathematical reasoning capabilities.

⁹The performance of DeepSeek-Coder-V2 on the four mathematical benchmarks was obtained with zero-shot chain-of-thought prompting; each test question was concatenated with the instruction: "\nPlease reason step by step, and put your final answer within \boxed{}."

4.6. General Natural Language

As DeepSeek-Coder-V2 is built upon DeepSeek-V2, it inherits the strong natural language capability, even surpassing DeepSeek-V2 on reasoning-related benchmarks. We compare DeepSeek-Coder-V2 Instruct with DeepSeek-V2 Chat on standard benchmarks, which covers both English and Chinese benchmarks, including BigBench Hard (BBH) (Suzgun et al., 2022), MMLU (Hendrycks et al., 2020), ARC (Clark et al., 2018), TriviaQA (Joshi et al., 2017), NaturalQuestions (Kwiatkowski et al., 2019), AGIEval (Zhong et al., 2023), CLUEWSC (Xu et al., 2020), C-Eval (Huang et al., 2023), and CMMLU (Li et al., 2023a). Besides, we also evaluate the open-ended generation ability of models, including Arena-Hard (Li et al., 2024), AlpacaEval2.0 (Dubois et al., 2024), MT-Bench (Zheng et al., 2023), and Alignbench (Liu et al., 2023c). The evaluation pipeline and metrics are the same as in DeepSeek-V2, where the MMLU are evaluated using OpenAI simple-eval package <https://github.com/openai/simple-evals>.

	Benchmark (Metric)	# Shots	DeepSeek-V2-Lite Chat	DeepSeek-Coder-V2-Lite Instruct	DeepSeek-V2 Chat	DeepSeek-Coder-V2 Instruct
	# Active Params	-	2.4B	2.4B	21B	21B
	# Total Params	-	16B	16B	236B	236B
	# Training Tokens	-	5.7T	10.2T	8.1T	10.2T
English	BBH (EM)	3-shot	48.1	61.2	79.7	83.9
	MMLU (Acc.)	5-shot	55.7	60.1	78.1	79.2
	ARC-Easy (Acc.)	25-shot	86.1	88.9	98.1	97.4
	ARC-Challenge (Acc.)	25-shot	73.4	77.4	92.3	92.8
	TriviaQA (EM)	5-shot	65.2	59.5	86.7	82.3
	NaturalQuestions (EM)	5-shot	35.5	30.8	53.4	47.5
	AGIEval (Acc.)	0-shot	42.8	28.7	61.4	60.0
Chinese	CLUEWSC (EM)	5-shot	80.0	76.5	89.9	85.9
	C-Eval (Acc.)	5-shot	60.1	61.6	78.0	79.4
	CMMLU (Acc.)	5-shot	62.5	62.7	81.6	80.9
Open-ended	Arena-Hard	-	11.40	38.10	41.60	65.00
	AlpacaEval 2.0	-	16.85	17.74	38.90	36.92
	MT-Bench	-	7.37	7.81	8.97	8.77
	Alignbench	-	6.02	6.83	7.91	7.84

Table 10 | A Comparison of DeepSeek-Coder-V2 Instruct with DeepSeek-V2 Chat.

When comparing the performance of 16B models, it is evident that DeepSeek-Coder-V2-Lite-Instruct outperforms DeepSeek-V2-Lite-Chat in benchmarks like BBH and Arena-Hard. These benchmarks place a high demand on the model’s reasoning ability, which DeepSeek-Coder-V2-Lite-Instruct excels at. However, DeepSeek-Coder-V2-Lite Instruct falls behind in knowledge-intensive benchmarks like TriviaQA, primarily due to the relatively smaller amount of web data used during pre-training.

Moving on to 236B models, DeepSeek-Coder-V2 Instruct exhibits greater strength in reasoning benchmarks, particularly in Arena-Hard, which comprises a substantial proportion of code, math, and reasoning questions. On the other hand, DeepSeek-V2 Chat demonstrates slightly better results in benchmarks such as MT-bench (Zheng et al., 2023), AlpacaEval 2.0 (Dubois et al., 2024), and AlignBench (Liu et al., 2023c). This advantage can be attributed to the general-purpose alignment stage of DeepSeek-V2 Chat.

5. Conclusion



In this paper, we introduce DeepSeek-Coder-V2 to further advance the field of code intelligence, which is continually pre-trained from DeepSeek-V2 with 6 trillion tokens sourced from a high-quality and multi-source corpus. Through this continued pre-training, we find that DeepSeek-

Coder-V2 significantly enhances the model’s capabilities in coding and mathematical reasoning while maintaining comparable general language performance to DeepSeek-V2. Compared to DeepSeek-Coder, DeepSeek-Coder-V2 supports a significantly larger number of programming languages, increasing from 86 to 338, and extends the maximum context length from 16K to 128K tokens. Experimental results demonstrate that DeepSeek-Coder-V2 achieves performance comparable to state-of-the-art closed-source models such as GPT-4 Turbo, Claude 3 Opus, and Gemini 1.5 Pro in code and math-specific tasks.

Although DeepSeek-Coder-V2 achieves impressive performance on standard benchmarks, we find that there is still a significant gap in instruction-following capabilities compared to current state-of-the-art models like GPT-4 Turbo. This gap leads to poor performance in complex scenarios and tasks such as those in SWEbench. Therefore, we believe that a code model needs not only strong coding abilities but also exceptional instruction-following capabilities to handle real-world complex programming scenarios. In the future, we will focus more on improving the model’s instruction-following capabilities to better handle real-world complex programming scenarios and enhance the productivity of the development process.

References

- L. B. Allal, R. Li, D. Kocetkov, C. Mou, C. Akiki, C. M. Ferrandis, N. Muennighoff, M. Mishra, A. Gu, M. Dey, et al. Santacoder: don’t reach for the stars! [arXiv preprint arXiv:2301.03988](#), 2023.
- A. Anthropic. The claude 3 model family: Opus, sonnet, haiku. [Claude-3 Model Card](#), 2024.
- J. Austin, A. Odena, M. Nye, M. Bosma, H. Michalewski, D. Dohan, E. Jiang, C. Cai, M. Terry, Q. Le, and C. Sutton. Program synthesis with large language models, 2021a.
- J. Austin, A. Odena, M. Nye, M. Bosma, H. Michalewski, D. Dohan, E. Jiang, C. Cai, M. Terry, Q. Le, et al. Program synthesis with large language models. [arXiv preprint arXiv:2108.07732](#), 2021b.
- M. Bavarian, H. Jun, N. Tezak, J. Schulman, C. McLeavey, J. Tworek, and M. Chen. Efficient training of language models to fill in the middle. [arXiv preprint arXiv:2207.14255](#), 2022.
- M. Chen, J. Tworek, H. Jun, Q. Yuan, H. P. d. O. Pinto, J. Kaplan, H. Edwards, Y. Burda, N. Joseph, G. Brockman, et al. Evaluating large language models trained on code. [arXiv preprint arXiv:2107.03374](#), 2021.
- P. Clark, I. Cowhey, O. Etzioni, T. Khot, A. Sabharwal, C. Schoenick, and O. Tafjord. Think you have solved question answering? try arc, the AI2 reasoning challenge. [CoRR](#), abs/1803.05457, 2018. URL <http://arxiv.org/abs/1803.05457>.
- K. Cobbe, V. Kosaraju, M. Bavarian, M. Chen, H. Jun, L. Kaiser, M. Plappert, J. Tworek, J. Hilton, R. Nakano, et al. Training verifiers to solve math word problems. [arXiv preprint arXiv:2110.14168](#), 2021.
- DeepSeek-AI. Deepseek-v2: A strong, economical, and efficient mixture-of-experts language model, 2024.
- Y. Dubois, B. Galambosi, P. Liang, and T. B. Hashimoto. Length-controlled alpacaEval: A simple way to debias automatic evaluators. [arXiv preprint arXiv:2404.04475](#), 2024.

- D. Guo, Q. Zhu, D. Yang, Z. Xie, K. Dong, W. Zhang, G. Chen, X. Bi, Y. Wu, Y. Li, et al. Deepseek-coder: When the large language model meets programming—the rise of code intelligence. arXiv preprint arXiv:2401.14196, 2024.
- D. Hendrycks, C. Burns, S. Basart, A. Zou, M. Mazeika, D. Song, and J. Steinhardt. Measuring massive multitask language understanding. arXiv preprint arXiv:2009.03300, 2020.
- D. Hendrycks, C. Burns, S. Kadavath, A. Arora, S. Basart, E. Tang, D. Song, and J. Steinhardt. Measuring mathematical problem solving with the math dataset. arXiv preprint arXiv:2103.03874, 2021.
- Y. Huang, Y. Bai, Z. Zhu, J. Zhang, J. Zhang, T. Su, J. Liu, C. Lv, Y. Zhang, J. Lei, et al. C-Eval: A multi-level multi-discipline chinese evaluation suite for foundation models. arXiv preprint arXiv:2305.08322, 2023.
- N. Jain, K. Han, A. Gu, W.-D. Li, F. Yan, T. Zhang, S. Wang, A. Solar-Lezama, K. Sen, and I. Stoica. Livecodebench: Holistic and contamination free evaluation of large language models for code, 2024.
- C. E. Jimenez, J. Yang, A. Wettig, S. Yao, K. Pei, O. Press, and K. Narasimhan. Swe-bench: Can language models resolve real-world github issues? arXiv preprint arXiv:2310.06770, 2023.
- M. Joshi, E. Choi, D. Weld, and L. Zettlemoyer. TriviaQA: A large scale distantly supervised challenge dataset for reading comprehension. In R. Barzilay and M.-Y. Kan, editors, Proceedings of the 55th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers), pages 1601–1611, Vancouver, Canada, July 2017. Association for Computational Linguistics. doi: 10.18653/v1/P17-1147. URL <https://aclanthology.org/P17-1147>.
- A. Joulin, E. Grave, P. Bojanowski, M. Douze, H. Jégou, and T. Mikolov. Fasttext. zip: Compressing text classification models. arXiv preprint arXiv:1612.03651, 2016.
- D. Kocetkov, R. Li, L. Jia, C. Mou, Y. Jernite, M. Mitchell, C. M. Ferrandis, S. Hughes, T. Wolf, D. Bahdanau, et al. The stack: 3 tb of permissively licensed source code. Transactions on Machine Learning Research, 2022.
- T. Kwiatkowski, J. Palomaki, O. Redfield, M. Collins, A. P. Parikh, C. Alberti, D. Epstein, I. Polosukhin, J. Devlin, K. Lee, K. Toutanova, L. Jones, M. Kelcey, M. Chang, A. M. Dai, J. Uszkoreit, Q. Le, and S. Petrov. Natural questions: a benchmark for question answering research. Trans. Assoc. Comput. Linguistics, 7:452–466, 2019. doi: 10.1162/tac1_a_00276. URL https://doi.org/10.1162/tac1_a_00276.
- H. Li, Y. Zhang, F. Koto, Y. Yang, H. Zhao, Y. Gong, N. Duan, and T. Baldwin. CMMLU: Measuring massive multitask language understanding in Chinese. arXiv preprint arXiv:2306.09212, 2023a.
- R. Li, L. B. Allal, Y. Zi, N. Muennighoff, D. Kocetkov, C. Mou, M. Marone, C. Akiki, J. Li, J. Chim, et al. Starcoder: may the source be with you! arXiv preprint arXiv:2305.06161, 2023b.
- T. Li, W.-L. Chiang, E. Frick, L. Dunlap, B. Zhu, J. E. Gonzalez, and I. Stoica. From live data to high-quality benchmarks: The arena-hard pipeline, April 2024. URL <https://lmsys.org/blog/2024-04-19-arena-hard/>.
- J. Liu, C. S. Xia, Y. Wang, and L. Zhang. Is your code generated by chatGPT really correct? rigorous evaluation of large language models for code generation. In Thirty-seventh Conference

- on Neural Information Processing Systems, 2023a. URL <https://openreview.net/forum?id=1qv610Cu7>
- T. Liu, C. Xu, and J. McAuley. Repobench: Benchmarking repository-level code auto-completion systems. In *The Twelfth International Conference on Learning Representations*, 2023b.
- X. Liu, X. Lei, S. Wang, Y. Huang, Z. Feng, B. Wen, J. Cheng, P. Ke, Y. Xu, W. L. Tam, X. Zhang, L. Sun, H. Wang, J. Zhang, M. Huang, Y. Dong, and J. Tang. Alignbench: Benchmarking chinese alignment of large language models. *CoRR*, abs/2311.18743, 2023c. doi: 10.48550/ARXIV.2311.18743. URL <https://doi.org/10.48550/arXiv.2311.18743>.
- I. Loshchilov and F. Hutter. Decoupled weight decay regularization, 2019.
- A. Lozhkov, R. Li, L. B. Allal, F. Cassano, J. Lamy-Poirier, N. Tazi, A. Tang, D. Pykhtar, J. Liu, Y. Wei, et al. Starcoder 2 and the stack v2: The next generation. *arXiv preprint arXiv:2402.19173*, 2024.
- MAA. American invitational mathematics examination - aime. *American Invitational Mathematics Examination - AIME 2024*, 2024. URL <https://maa.org/math-competitions/american-invitational-mathematics-examination-aime>.
- Meta. Introducing meta llama 3: The most capable openly available llm to date. <https://ai.meta.com/blog/meta-llama-3/>, April 2024.
- MistralAI. Codestral. <https://mistral.ai/news/codestral/>, 2024. Accessed: 2024-05-29.
- Netmind.AI. Odyssey-math. <https://github.com/protagolabs/odyssey-math/tree/main>, 2024. Accessed: April 22, 2024.
- OpenAI. Gpt-4 technical report, 2023.
- B. Peng, J. Quesnelle, H. Fan, and E. Shippole. Yarn: Efficient context window extension of large language models. *arXiv preprint arXiv:2309.00071*, 2023.
- M. Reid, N. Savinov, D. Teplyashin, D. Lepikhin, T. Lillicrap, J.-b. Alayrac, R. Soricut, A. Lazaridou, O. Firat, J. Schrittwieser, et al. Gemini 1.5: Unlocking multimodal understanding across millions of tokens of context. *arXiv preprint arXiv:2403.05530*, 2024.
- B. Roziere, J. Gehring, F. Gloeckle, S. Sootla, I. Gat, X. E. Tan, Y. Adi, J. Liu, T. Remez, J. Rapin, et al. Code llama: Open foundation models for code. *arXiv preprint arXiv:2308.12950*, 2023.
- Z. Shao, P. Wang, Q. Zhu, R. Xu, J. Song, M. Zhang, Y. Li, Y. Wu, and D. Guo. Deepseekmath: Pushing the limits of mathematical reasoning in open language models. *arXiv preprint arXiv:2402.03300*, 2024.
- Q. Shi, M. Tang, K. Narasimhan, and S. Yao. Can language models solve olympiad programming? *arXiv preprint arXiv:2404.10952*, 2024.
- M. Suzgun, N. Scales, N. Schärli, S. Gehrmann, Y. Tay, H. W. Chung, A. Chowdhery, Q. V. Le, E. H. Chi, D. Zhou, et al. Challenging big-bench tasks and whether chain-of-thought can solve them. *arXiv preprint arXiv:2210.09261*, 2022.
- H. Touvron, L. Martin, K. Stone, P. Albert, A. Almahairi, Y. Babaei, N. Bashlykov, S. Batra, P. Bhargava, S. Bhosale, et al. Llama 2: Open foundation and fine-tuned chat models. *arXiv preprint arXiv:2307.09288*, 2023.

- L. Xu, H. Hu, X. Zhang, L. Li, C. Cao, Y. Li, Y. Xu, K. Sun, D. Yu, C. Yu, Y. Tian, Q. Dong, W. Liu, B. Shi, Y. Cui, J. Li, J. Zeng, R. Wang, W. Xie, Y. Li, Y. Patterson, Z. Tian, Y. Zhang, H. Zhou, S. Liu, Z. Zhao, Q. Zhao, C. Yue, X. Zhang, Z. Yang, K. Richardson, and Z. Lan. CLUE: A chinese language understanding evaluation benchmark. In D. Scott, N. Bel, and C. Zong, editors, *Proceedings of the 28th International Conference on Computational Linguistics, COLING 2020, Barcelona, Spain (Online), December 8-13, 2020*, pages 4762–4772. International Committee on Computational Linguistics, 2020. doi: 10.18653/V1/2020.COLING-MAIN.419. URL <https://doi.org/10.18653/v1/2020.coling-main.419>.
- L. Zheng, W.-L. Chiang, Y. Sheng, S. Zhuang, Z. Wu, Y. Zhuang, Z. Lin, Z. Li, D. Li, E. P. Xing, H. Zhang, J. E. Gonzalez, and I. Stoica. Judging llm-as-a-judge with mt-bench and chatbot arena, 2023.
- W. Zhong, R. Cui, Y. Guo, Y. Liang, S. Lu, Y. Wang, A. Saied, W. Chen, and N. Duan. AGIEval: A human-centric benchmark for evaluating foundation models. *CoRR*, abs/2304.06364, 2023. doi: 10.48550/arXiv.2304.06364. URL <https://doi.org/10.48550/arXiv.2304.06364>.

A. Supported Programming Languages

ABAP, ActionScript, Ada, Agda, AGS Script, Alloy, AmbientTalk, AMD GPU, AMPL, ANSYS Parametric Design Language, ANTLR, Apache Configuration, APL, AppleScript, Arc, Arduino, ASP, AspectJ, Assembly, Asymptote, Augeas, AutoHotkey, AutoIt, AWK, BC, Berry, BitBake, BlitzBasic, BlitzMax, Bluespec, BNF, Boo, Boogie, Brainfuck, BrightScript, Bro, BST, C, C#, C2HS Haskell, CADL, CapDL, Ceylon, Chapel, Chuck, Cirru, Click, Clojure, CMake, COBOL, COBOLFree, CoffeeScript, ColdFusion CFC, Common Lisp, C++, Crystal, Csound, Csound Score, CSS, CUDA, Cypher, Cython, Darcs Patch, Dart, DASM16, Debian Control File, DeviceTree, Diff, DM, Docker, Dockerfile, Dylan, EBNF, eC, Eiffel, Elixir, Elm, ELPi, Emacs Lisp, EmberScript, Erlang, Execline, F#, Factor, Fancy, Fantom, Felix, Fennel, Fish, Flux, Fortran, Fortran Fixed Form, FoxPro, FreeFem, FreeMarker, F*, Futhark, G-Code, GAP, GAS, GDScript, Genshi, Gentoo Ebuild, Gentoo Eclass, Gettext Catalog, GLSL, Glyph, Gnuplot, Go, Gosu, Grace, Gradle, Grammatical Framework, GraphQL, Graphviz DOT, Groff, Groovy, Groovy Server Pages, GSQL, Handlebars, Haskell, Haxe, HCL, HLSL, HTML, HTML Django, HTML ERB, HTML PHP, HTTP, Hy, Idris, IGOR Pro, Inform 6 Template, Inno Setup, Io, Isabelle, J, Jade, JAGS, Jasmin, Java, Java Server Pages, JavaScript, JavaScript MozPreproc, JCL, JFlex, JSON, JSONiq, JSX, Julia, Jupyter Notebook, K, Kconfig, Koka, Kotlin, KRL, Lean, Less, Lex, LFE, Lighttpd Configuration File, LilyPond, Limbo, Linker Script, Liquid, Literate Agda, Literate CoffeeScript, LLVM, Logtalk, LSL, Lua, M4, Makefile, Mako, Mason, MATLAB, Maxima, Meson, Metal, MiniScript, Mirah, Mizar, Modelica, Modula-2, Monkey, MooCode, MoonScript, Mosel, MQL, MUF, MuPAD, NASM, NCL, NetLinx, Nginx Configuration File, Nimrod, Ninja, Nit, Nix, NSIS, Nu, NuSMV, Objdump, Objective-C, Objective-C++, OCaml, Octave, Odin, OMG Interface Definition Language, ooc, Opa, OpenCL, OpenEdge ABL, OpenSCAD, Ox, Oz, Papyrus, Parrot Internal Representation, Pascal, PAWN, PEG, Perl, Perl 6, PHP, Pike, PkgConfig, POD, Pony, POV-Ray, PowerShell, Praat, Processing, Propeller Spin, Protocol Buffer, Pug, Puppet, PureBasic, PureScript, Python, Q, QML, QVTO, R, Racket, Ragel in Ruby Host, RAML, RConsole, Rd, REALbasic, ReasonML, Red, RenderScript, Ren'Py, REXX, RHTML, Ride, Robot Framework, Rouge, Ruby, Rust, S, Sage, SARL, SAS, Sass, Scala, Scheme, Scilab, SCSS, Self, Shell, ShExC, Sieve, Silver, Singularity, Slim, Smali, Smarty, Smithy, SMT, Solidity, SourcePawn, SPARQL, SQF, SQL, Squirrel, Stan, Standard ML, Stata, Stylus, SuperCollider, Swift, SWIG, SystemVerilog, Tcl, Tcsh, Tea, Terminfo, TeX, Thrift, Transact-SQL, Treetop, Turing, Twig, TypeScript, TypoScript, Unity3D Asset, Uno, UnrealScript, UrWeb, USD, Vala, VBScript, VCL, Velocity, Verilog, VHDL, VimL, Visual Basic, Vue, WebAssembly, Web IDL, Whiley, X10, XBase, XC, XML, XML Lasso, XQuery, XS, XSLT, Xtend, Xtlang, YANG, Zeek, Zephir, Zig, Zimpl