How Does Code Pretraining Affect Language Model Task Performance?

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1 Introduction

Large language models (LLMs) are increasingly pretrained on corpora containing both natural language text and programming source code (see, e.g., Gemini Team et al. 2024; OpenAI et al. 2024; Anthropic AI 2024; Groeneveld et al. 2024). While code pretraining straightforwardly improves performance on code-related tasks, its impact in other domains is less clear. Fu and Khot (2022) speculated that code pretraining may be partly responsible for the concomitant rise in reasoning performance in large language models. Observational studies have lent credence to this hypothesis (Yang et al., 2024; Mueller et al., 2024; Kim et al., 2024), but establishing a causal relationship between code pretraining and non-code downstream task performance is frustrated by the lack of experimental studies which control for relevant hyperparameters to directly compare the utility of training on source code.

Here we do just this, constructing pretraining datasets which parametrically vary the amount of data coming from natural-language and source-code sources. We then pretrain families of identical models on these datasets and measure their performance on three compositional generalization tasks (COGS, Kim and Linzen 2020; COGS-vf, Qiu et al. 2022; and English Passivization, Mueller et al. 2024) and on BigBench (Srivastava et al., 2023) against the amount of code seen during pretraining.

We find that code pretraining can significantly improve model performance on some downstream tasks, though other tasks are harmed. Code pretraining strongly benefits compositional generalization in COGS and COGS-vf, where outputs have strict formal syntactic constraints; and on arithmetic tasks from BigBench. Conversely code pretraining can harm compositional generalization in purely natural-language domains like English Passivization, and is harmful for some tasks in BigBench which rely on linguistic- or world-knowledge. In aggregate, we find that code pretraining is helpful on average for BigBench tasks.

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2 Related Work

Fu and Khot (2022) speculated that code pretraining is partially responsible for the improvement in reasoning capabilities between the `-001` and `-002` series of GPT-3(.5) of models. Several observational studies have argued code-pretrained models outperform non-code-pretrained models in several domains including reasoning (Yang et al., 2024), syntax-aware generalization in in-context learning (Mueller et al., 2024), and entity tracking (Kim et al., 2024), though Coda-Forno et al. (2024) find code pretraining does not improve performance on tasks motivated by cognitive psychology.

Several experimental studies on the impact of code pretraining have also been conducted. Ma et al. (2024) argues that code pretraining is beneficial for performance on logical reasoning and chain-of-thought capabilities, while Longpre et al. (2024) find that removing code from pretraining corpora is harmful for performance on question answering in a number of different domains; both experimental designs, however, do not fully control for data volume as an experimental hyperparameter (and consequently, any other hyperparameters which are influenced by volume) which prevents the establishment of a clear causal impact.

3 Methodology

To establish the causal impact of code pretraining, we construct datasets which mix language and code sequences. The ingredients for our datasets are the English portion of the Colossal Cleaned Common Crawl (C4; Raffel et al. 2023) and a cleaned corpus of source code from GitHub. Each dataset is parameterized by a single value $m \in [0, 1]$ denoting the percentage of code data in each mixture.

We consider two different experimental setups. In the *competitive* setting, each dataset has the same number of total tokens; increasing the number of code tokens then amounts to reducing the number of language tokens. This setup provides the clearest way to study the impact of code volume in pretraining since it directly controls for all other factors; however, for high values of m the interpretability of results may be skewed by the fact that models will have seen very little language, and so may not be able to adequately understand the tasks themselves.

To remedy this, our second *additive* setting holds constant the number of language tokens across datasets, and additional code tokens are added on top such that the total code-to-language ratio is m. This setting ensures that all models have an equal chance to learn from language, but at the cost of controlling for data volume. To address this, we also pretrain models on equal-volume language-only baselines to compare a counterfactual scenario in which models were simply trained for additional time on non-code data.

On these datasets we pretrain 374 M-parameter decoder-only transformer language models with a base data volume of 132 B tokens (total volume in the competitive setting, language volume in additive). We evaluate models in two ways: first, we fine-tune models on the training portions of three compositional generalization datasets (COGS, COGS-vf, and English Passivization) and then measure performance via full-sequence generalization accuracy on the generalization splits of each. Second, we measure zero-shot performance on BigBench tasks. For each setting and code mixture we pretraining 5 models from different random seeds and report mean performance across these models for each evaluation. Using these independent trials, we calculate lines-of-best-fit between performance and code mixture and compare slopes ($\hat{\beta}$) between tasks.

4 Results

In a controlled setup, code pretraining does have a meaningful impact on non-code downstream task performance. On compositional generalization tasks whose output has a formal structure, like COGS and COGS-vf, code pretraining significantly improves model performance in both competitive and additive settings. Code pretraining likewise

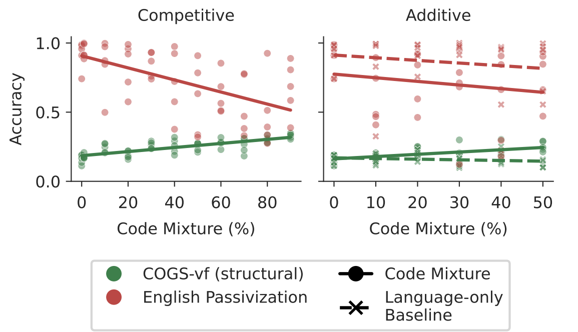

Figure 1: Code pretraining aids compositional generalization on the structural split of COGS-vf ($\hat{\beta} = 0.147$ competitive, 0.165 additive) but harms performance on English Passivization ($\hat{\beta} = -0.436$ competitive, -0.263 additive). Points show performance of a single model (=random seed).

improves performance on the BigBench arithmetic tasks. Conversely, we find cases where code pretraining can harm performance: on the English Passivization compositional generalization task, where models produce natural-language outputs, increased code exposure is harmful in both settings; similar patterns emerge on several BigBench tasks, including common morpheme identification, implicature judgement, and general world knowledge.

To quantify the impact of code pretraining in aggregate across BigBench tasks, we consider a null hypothesis that any correlation between task performance and code pretraining could arise from chance. We construct a counterfactual sample by shuffling the code mixture values and recomputing lines-of-best-fit for all BigBench tasks. We then conduct a 10 K-trial two-sided permutation test measuring the difference in mean, variance and upper- and lower-quartile ranges between our treatment and control samples. At a significance level of $\alpha = 0.05$, the differences of variance and upper-quartile range are significant. In particular, we find a positive difference in upper-quartile range (and no difference in lower-quartile range), showing that code pretraining results in stronger increases in performance for the best-performing tasks without harming the least-performing tasks more than would otherwise be expected.

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