Causally Quantifying the Effect of Test Set Contamination on Generative Benchmarks

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Abstract

As large language models (LLMs) are pretrained on ever-expanding web-scale data, test set contamination has become a critical concern for accurately assessing the capabilities of LLMs. While significant research has quantified the amount and the impact of test set contamination on discriminative (i.e., scoring-based) benchmarks like multiple-choice question-answering, comparatively little research has studied the impact of test set contamination on generative (i.e., sampling-based) evaluations such as coding or mathematical problem solving. As the field shifts more towards generative evaluations, understanding what effect (if any) test set contamination has on generative evaluations becomes all the more important. To causally quantify the effect that test set contamination has on assessed capabilities, we pretrained language models, sweeping the number of replicas of benchmark test data in the pretraining corpora. We make four discoveries: (1) performance increases with contamination and model size, consistent with discriminative evaluations, (2) higher sampling temperature mitigates the effects of contamination, (3) longer solutions require more contamination to reach the same level of performance, and (4) generative performance is tightly coupled with test set memorization, but modulated by sampling temperature. As the field shifts to generative benchmarks to assess reasoning, our work reveals that factors like sampling temperature and solution length introduce novel complexities to data contamination, demanding a more sophisticated approach to model evaluation.

1 Introduction

Test set contamination – the inclusion of benchmarks in pretraining data – has emerged as a critical threat to the trustworthy evaluation of language models (Sainz et al., 2023; Schaeffer, 2023; Xu et al., 2024a; Deng et al., 2024a; Reuel et al., 2025). Evaluation aims to measure generalization on tasks the model has never seen, yet web-scale pretraining makes such contamination increasingly likely (Brown et al., 2020; Du et al., 2022; Wei et al., 2022; Chowdhery et al., 2022; Touvron et al., 2023).

Prior work has sought to quantify how training on benchmarks affects model evaluation scores through statistical and causal approaches. Statistical approaches aim to quantify the influence of test set contamination on evaluation performance by modifying the test set, for example, by reordering, rephrasing, or replicating benchmark problems, e.g., (Oren et al., 2023; Ni et al., 2025; Shi et al., 2024; Golchin & Surdeanu, 2023, 2024; Roberts et al., 2024; Wang et al., 2025; Zhang et al., 2024a). Causal approaches intentionally contaminate pretraining corpora to quantify how a particular dose of contamination translates into improved performance, e.g., (Magar & Schwartz, 2022; Jiang et al., 2024; Oren et al., 2023; Yao et al., 2024; Wang et al., 2025; Kocyigit et al., 2025; Bordt et al., 2025).

While both are useful, increasing model capabilities and the advent of reasoning models (OpenAI et al., 2024; DeepMind et al., 2025; Xu et al., 2025) have shifted the field from discriminative

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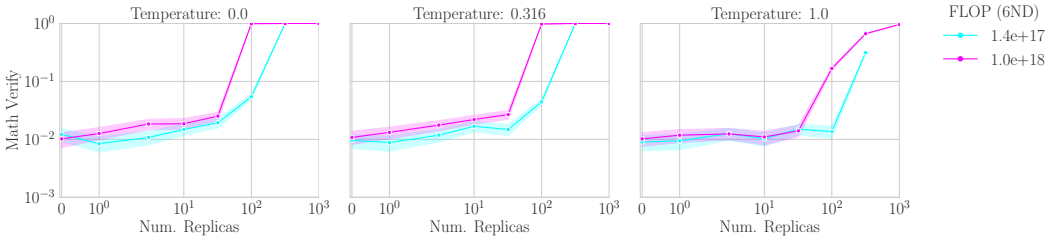

Figure 1: **Causally Quantifying the Effect of Test Set Contamination on Generative Benchmarks.** We pretrained language models of increasing size, while sweeping the number of generative benchmark replicas included in the pretraining corpora. We specifically chose MATH (Hendrycks et al., 2021b) as our generative benchmark of interest; Math Verify is the fraction of problems for which the model generates solutions verified to be mathematically equivalent to the benchmark's boxed answers. Math Verify scores increase with the amount of contamination (i.e., the number of test set replicas) as well as with model scale. Consistent with discriminative evaluations, larger models require fewer replicas of the test set to reach ceiling performance. Left to Right: Higher sampling temperature mitigates the effects of contamination. Shaded regions represent 95% confidence intervals.

benchmarks to generative benchmarks, and research on test set contamination has lagged behind. Previous investigations on contamination focused on *discriminative* (i.e., scoring-based) benchmarks like classification or multiple-choice question-answering (MCQA), but newer evaluations prioritize *generative* (i.e., sampling-based) benchmarks like coding, mathematical problem solving or agentic tasks. For example, prior papers that intentionally contaminated pretraining corpora focused overwhelmingly on discriminative benchmarks: Magar & Schwartz (2022) used SST-2 (Socher et al., 2013) (classification). Jiang et al. (2024) used SST-2 (classification), MMLU (Hendrycks et al., 2021a) (MCQA), SQuAD (Rajpurkar et al., 2016) (MCQA), and CNN/Daily Mail (fill-in-the-middle) (Nallapati et al., 2016). Oren et al. (2023) used 7 MCQA benchmarks and 1 mathematical problem solving benchmark (GSM8K) (Cobbe et al., 2021), Yao et al. (2024) used 3 MCQA benchmarks while Bordt et al. (2025) used 7 MCQA benchmarks.

Whether test set contamination has the same effect on generative and discriminative evaluations is unclear a priori. Discriminative evaluations require the model to place higher probability mass on the correct choice than on a small number of alternative incorrect choices (Gao et al., 2024; Schaeffer et al., 2025b), and candidate choices are often only a couple of tokens long. In comparison, generative evaluations introduce more axes of choice into evaluation (i.e., how tokens are sampled and how the model is prompted) and require the model to produce tens to thousands of tokens, e.g., (Jimenez et al., 2024). While a sufficiently large model trained on a generative benchmark for an infinite number of epochs would almost certainly memorize its content (Carlini et al., 2023), it is currently unclear how much performance improves after a finite number of exposures; perhaps exponentially many repetitions are necessary to memorize such long sequences.

In this work, we quantify the effect that causally contaminating pretraining corpora with generative reasoning benchmarks has, focusing specifically on MATH (Hendrycks et al., 2021b). We find that: (1) performance increases with contamination and model size, consistent with discriminative evaluations, (2) higher sampling temperature might reduce the effects of contamination, (3) longer solutions require more contamination to reach the same level of performance, and (4) generative performance is tightly coupled with test set memorization, but is modulated by higher sampling temperatures.

2 Experimental Setup

Benchmark For our generative benchmark of interest, we chose MATH (Hendrycks et al., 2021b); its test set contains approximately 1.5M tokens.

Pretraining We pretrained Qwen 3 (Yang et al., 2025a) transformer-based (Vaswani et al., 2017) causal language models from initialization. In this work, we consider two model sizes, 34M and 93M parameters, as our 344M and 1.44B parameter models are still pretraining at the time of this

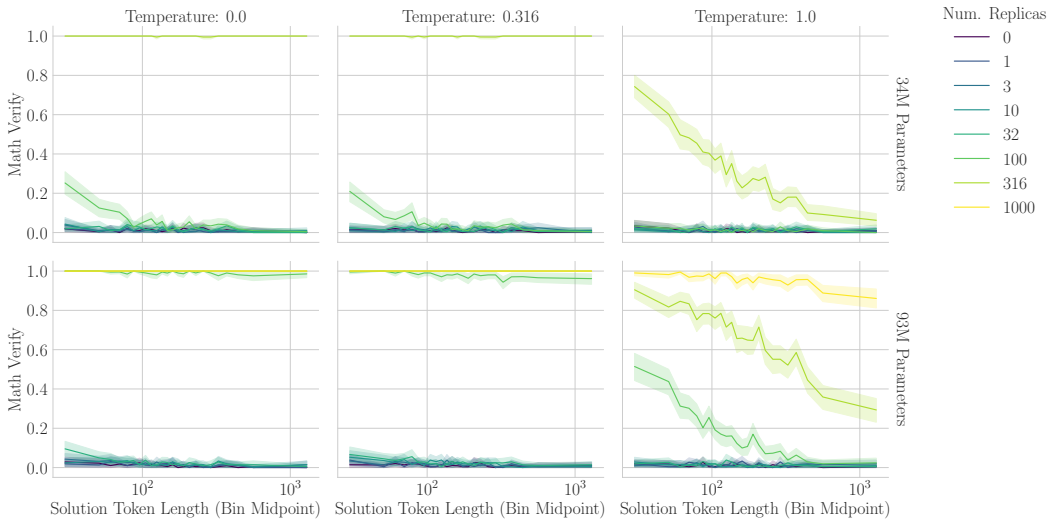

Figure 2: **Model Performance Declines with Increasing Solution Token Length.** Math Verify scores depend primarily on model size and the number of benchmark replicas. However, scores clearly decrease as a function of the number of tokens in the solution, and higher temperature amplifies this effect (right). Shaded regions represent 95% confidence intervals.

submission. For each model size, we created multiple pretraining corpora by concatenating FineWeb-Edu (Penedo et al., 2024) with a different number of replicas of the benchmark test set from 0 (uncontaminated) through $1, 3, 10, 32, 100, 316, 1000$. For our benchmark of interest, we chose the MATH (Hendrycks et al., 2021b) test set, containing approximately 1.5M tokens. Each model was pretrained for 20 tokens per parameter, following compute-optimal scaling (Hoffmann et al., 2022). Pretraining compute was calculated using the common approximation $C \approx 6\,N\,D$ (Kaplan et al., 2020; Porian et al., 2024), where N is the number of parameters and D is the number of tokens.

Evaluating We evaluated our models using EleutherAI's Language Model Evaluation Harness (Gao et al., 2024), which reports the "math verify" score: the fraction of problems for which the model generates solutions that are verified to be mathematically equivalent to the benchmark's boxed answers. Along the way, we discovered an error with how the Harness computes Math Verify scores on MATH, and worked with its maintainers to fix the error; this suggests to us that any research reporting MATH scores from the past 1+ years may have egregiously incorrect values. We used basic (i.e., temperature-only) sampling (Schaeffer et al., 2025a) and report scores for three different sampling temperatures: 0 (greedy), 0.316 and 1.00.

3 Results

In this section, we report how model performance (i.e., Math Verify score) changes as a function of model size, number of test set replicas, and generative evaluation sampling temperature.

Finding #1: Performance Increases with Contamination and Model Size Consistent with discriminative evaluations, we find that increasing the number of replicas of the benchmark in the pretraining corpus increases Math Verify scores, as does increasing the model size (Fig 1). We observe a non-linear relationship between the number of test set replicas and model performance: For low levels of contamination (≤ 10 replicas), the impact on performance is minimal, with Math Verify scores remaining close to the baseline (0 replicas) performance; at around 100 replicas, a notable inflection point occurs, where performance sharply increases across all temperatures; at the highest level of contamination (316 replicas), the model achieves near-perfect performance, particularly at lower temperatures. Although we currently have only two model sizes, the trend suggests that while minor contamination may not significantly affect evaluation of tiny models, minor contamination of larger models can lead to severe overestimation of model capabilities.

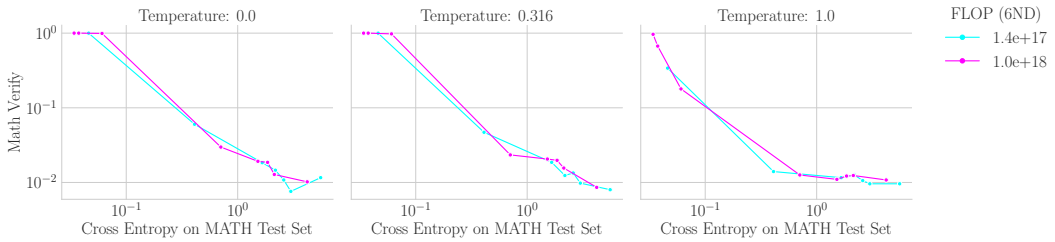

Figure 3: **Generative Performance is Tightly Coupled with Test Set Memorization, but is Modulated by Sampling Temperature.** As the number of test set replicas in the pretraining data increases, the cross-entropy loss decreases, leading to a sharp increase in the Math Verify score. This indicates that improved generative performance is tightly coupled with the model's memorization of the test set, as measured by cross-entropy. Notably, a higher sampling temperature increases the curvature of this relationship (right), resulting in a less abrupt performance increase as cross-entropy decreases. Shaded regions represent 95% confidence intervals.

Finding #2: Higher Sampling Temperature Might Mitigate the Effects of Contamination Math Verify Scores do not change substantially between zero-temperature and low temperature sampling (0.316) (Fig. 1, left and center). At higher temperature (1.0), Math Verify scores are reduced relative to lower temperatures (0 and 0.316). Interestingly, higher temperature sampling reduces the gap between highly contaminated models and uncontaminated models, suggesting that higher temperatures might mitigate the effect of contamination. This relationship between temperature and extraction is not always monotonic; other work has found that the optimal temperature for extracting memorized text can vary and is co-dependent on other details like the sampling algorithm (Hayes et al., 2025).

Finding #3: Longer Solutions Require More Contamination To Reach the Same Performance To understand how the length of the solution affects model performance, we bin problems based on solution token length and compute the average Math Verify score per bin. While model performance depends primarily on model size and number of test set replicas, scores decrease with the token length of the solution (Fig 2). Higher temperature additionally amplifies this effect. We currently do not have sufficient data to mathematically describe the relationships, but we intend to pursue this in future work once our larger models finish pretraining. Prior work on memorization corroborates this claim, as Jiang et al. (2025) and Lu et al. (2024) find that longer memorized sequences are the higher repeated ones, although to the best of our knowledge, this has not been studied causally in prior work.

Finding #4: Generative Performance is Tightly Coupled with Test Set Memorization, but Is Modulated by Sampling Temperature We find a strong negative correlation between a model's Math Verify score and its cross-entropy loss on the MATH test set (Fig. 3). As we increase the number of benchmark replicas in the pretraining data, the model's cross-entropy on the test set decreases, which in turn is associated with a sharp, non-linear increase in its generative performance. This tight coupling suggests that the performance gains are a direct consequence of memorization, with cross-entropy on the test set serving as a quantitative proxy for this effect. This effect is moderated by sampling temperature; higher temperatures increase the curvature of the relationship, resulting in a less abrupt performance increase as the model better memorizes the test set (Fig. 3, right).

4 Discussion

Our findings deliver a crucial caution as the field increasingly turns to generative benchmarks to evaluate advanced reasoning. We causally demonstrate that performance gains on these benchmarks are not necessarily evidence of improved reasoning, but are tightly coupled with test set memorization. This relationship, however, is not straightforward. Unlike in discriminative tasks, the effects of contamination are modulated by new factors unique to generative evaluation: higher sampling temperatures can mitigate or mask the impact of contamination, while longer solutions require more contaminating repetitions to achieve the same inflated performance. These complexities introduce a significant risk of severely overestimating model capabilities.

Related Work Due to space limitations, we defer related work to Appendix A.

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A Related Work

Data Contamination and its Consequences Test set contamination, where benchmark data is included in pretraining corpora, is widely recognized as a threat to valid model evaluation, as it can lead to inflated performance metrics. Numerous survey and position papers have documented the various ways contamination can occur and have called for routine audits and transparent reporting for all benchmarks (Sainz et al., 2023, 2024; Deng et al., 2024a; Xu et al., 2024a; Reuel et al., 2025). Empirical studies of large web-scale datasets have confirmed significant overlap and duplication between training and test sets (Dodge et al., 2021). Research focused on ensuring benchmark integrity has identified multiple ways that language models might "cheat" on evaluations if contamination is not properly managed (Zhou et al., 2023; Dong et al., 2024). For instance, analyses of popular mathematics benchmarks have revealed signals of data leakage and potential overfitting (Zhang et al., 2024a). Ongoing community efforts and open-source audits continue to measure the extent of contamination across different models and datasets (Li et al., 2024). The risks extend beyond evaluation integrity; scaling studies indicate that poisoning risks increase with model size, as larger models learn harmful behaviors from minuscule amounts of poisoned data far more rapidly than smaller models, underscoring the necessity of robust data curation (Bowen et al., 2025). As a cautionary illustration, Schaeffer (2023) demonstrated that pretraining on the test set is a trivial path to strong benchmark performance, reinforcing the importance of rigorous decontamination and auditing.

Controlled Contamination During Pretraining A line of research directly investigates the causal effects of contamination by intentionally adding benchmark data to pretraining corpora and observing the results. Magar & Schwartz (2022) interleaved task-specific datasets into a general text corpus during pretraining, varying the duplication rate of the leaked examples. They differentiated between "memorization" (storing examples) and "exploitation" (using stored examples to boost test scores), finding that both model size and the number of repetitions increased exploitation. Jiang et al. (2024) pretrained models from scratch on corpora containing either only the inputs ("text-only") or the full input-output pairs ("ground-truth") of benchmark examples, sweeping the contamination frequency. They observed significant performance gains when ground-truth pairs were used and showed that simple n-gram-based detection methods could be bypassed by paraphrasing or partial data leaks. The problem also transcends language barriers; Yao et al. (2024) demonstrated a cross-lingual contamination channel where continuing to pretrain a model on non-English translations of English benchmarks led to material improvements on the original English tests, a form of contamination that string-matching would not detect. At a larger scale, Bordt et al. (2025) varied the repetition count of leaked examples, model size (up to 1.6B parameters), and the total training token budget, finding that performance scales predictably with size and repetition. They also showed that sufficiently long training on abundant unique data could mitigate or even reverse the effects of earlier contamination. In the context of machine translation, Kocyigit et al. (2025) injected source-target pairs into the pretraining data of 1B and 8B parameter models, quantifying significant overestimation in BLEU scores, with larger models and low-resource languages showing more pronounced effects. Together, these causal intervention studies provide clear evidence that language models memorize and leverage benchmark data when it is present during pretraining.

Repeated Data and Memorization Dynamics Closely related is the study of memorization dynamics, particularly how repeated data affects model behavior. Hernandez et al. (2022) trained models where a small portion of the data was repeated many times, observing strong double descent phenomena (Advani et al., 2020; Belkin et al., 2019; Adlam & Pennington, 2020; Bordelon et al., 2020; Schaeffer et al.) and showing that repeating just 0.1% of tokens 100 times could significantly degrade generalization. Studies tracking exact-sequence memorization have shown that larger models not only memorize more content and at a faster rate but also forget less over the course of training (Tirumala et al., 2022). Carlini et al. (2023) quantified log-linear relationships between verbatim generation and model size, data duplication count, and prompt length. Other work has explored the feasibility of *forecasting* whether a model will memorize a specific string, finding that accurate prediction is possible but may require a substantial portion of the target model's pretraining compute (Biderman et al., 2023). Beyond explicit repetition, Duan et al. (2025) discovered *latent memorization*, where memorized sequences that are not obvious at a final checkpoint can persist and be revealed later, posing privacy risks. Finally, memorization appears to be task-dependent: Wang et al. (2025) observed stronger memorization for knowledge-intensive QA, whereas machine

translation and mathematical reasoning demonstrated greater novelty. Memorization also interacts with logical reasoning; using dynamically generated puzzles, Xie et al. (2025) showed that models could be fine-tuned to perfectly memorize training examples yet failed on slight variations, even as their genuine reasoning abilities also improved, revealing a complex balance between the two.

Detecting and Proving Contamination Another significant area of research focuses on detecting or proving test set contamination in existing models. Oren et al. (2023) and Ni et al. (2025) proposed statistical tests with provable control over false positives by testing if a benchmark's canonical ordering is statistically privileged over random shuffles. Shi et al. (2024) introduced Min-$k\%$-Prob to determine if a sequence likely appeared in pretraining using only black-box probabilities. Two related works from Golchin & Surdeanu (2023, 2024) frame detection as a multiple-choice "quiz" and use temporal information about model training windows versus benchmark release dates, a strategy also used by Roberts et al. (2024). Broader audits have aimed to quantify leakage and decontamination across a wide range of tasks and models (Xu et al., 2024b; Deng et al., 2024b; Li et al., 2024), while Yang et al. (2023) showed that rephrasing benchmark questions can often bypass n-gram filters. In the domain of code generation, Riddell et al. (2024) quantified contamination in popular coding benchmarks and connected the degree of overlap to performance differences. Matton et al. (2024) cataloged various channels for leakage and released a dataset (LBPP) to help mitigate these issues. Complementing these audits, Yang et al. (2025b) systematically tested fine-grained contamination scenarios in code intelligence across different model types, finding that paired contamination substantially affects LLMs under a pretraining-plus-inference paradigm but has limited effect under a pretrain–finetune–inference pipeline. Other work has also provided instruments for detecting the origins of chain-of-thought sequences (Li et al., 2025).

Preventing Test Set Contamination The growing concern over contamination has spurred the development of new methods for creating benchmarks. These include dynamically updated benchmarks (Jain et al., 2025; Xia et al., 2024; Zhang et al., 2025; Qian et al., 2024) and private or restricted-access benchmarks (Zhang et al., 2024a; Glazer et al., 2025). Recently, Nie et al. (2025) released a benchmark consisting of unsolved scientific questions, which, by its nature, prevents models from being trained on the correct solutions.

Retrieval- and Agent-Time Contamination As model evaluation evolves from static prompting to using tool-augmented agents, the risk of contamination expands. Han et al. (2025) introduced search-time contamination, where an agent retrieves benchmark questions and answers from the web during its evaluation process, which can artificially inflate its performance.

Membership Inference Attacks The field of Membership Inference Attacks (MIA) aims to determine if a specific data point was used to train a model, given only access to the model itself (Shokri et al., 2017). This is highly relevant to contamination, as detection can be viewed as an MIA problem. While the MIA literature is extensive in computer vision (Yeom et al., 2018; Salem et al., 2018; Sablayrolles et al., 2019; Jagielski et al., 2024), it has more recently been applied to language models (Carlini et al., 2021; Zarifzadeh et al., 2023; Shi et al., 2024; Mattern et al., 2023; Li et al., 2023). However, progress in sequence-level MIA for language models has been complicated by issues such as flawed evaluations (Meeus et al., 2024; Zhang et al., 2024b; Jiang et al., 2025). Duan et al. (2024) argue that membership can be inherently "blurry" for natural language. Das et al. (2024) and Meeus et al. (2024) report that existing MIA testbeds suffer from distribution shifts. Kong et al. (2023) refute MIAs with a theoretical attack, and Liu et al. (2025) and Mangaokar et al. (2025) demonstrate fundamental limitations and exploits of n-gram based methods. Due to these challenges, recent work explores strengthening the membership signal by using multiple correlated sequences as input (Maini et al., 2021; Kandpal et al., 2023; Maini et al., 2024), which aligns more closely with detecting contamination of an entire test set rather than a single example (Golchin & Surdeanu, 2023; Oren et al., 2023).