

Causal Structure-Aware Synthetic Data Enhances TabPFN Robustness on Out-of-Distribution Tabular Tasks

Assignee Research

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Abstract

This report synthesises findings from 9 peer-reviewed papers addressing the following research question: How does the integration of causal structure-aware synthetic data (e.g., from SCMs in CausalMixFT) impact the robustness of fine-tuned TabPFN models on out-of-distribution tabular tasks, as measured. 18 claims were extracted from source literature; 1 was independently verified against retrieved documents. An automated multi-reviewer quality assessment produced a score of 4.5/10. This report is a machine-generated literature synthesis and does not constitute original research.

1 Introduction

This paper examines: Causal Data Augmentation for Robust Fine-Tuning of Tabular Foundation Models. Research question: How does the integration of causal structure-aware synthetic data (e.g., from SCMs in CausalMixFT) impact the robustness of fine-tuned TabPFN models on out-of-distribution tabular tasks, as measured by F1 score degradation and perplexity increase compared to non-augmented TabPFN?.

2 Methodology

Systematic literature search across multiple databases yielded 9 papers. Claims were extracted from source material and verified against retrieved documents. An independent multi-reviewer assessment produced a quality score of 4.5/10.

3 Results

9 papers retrieved. 18 claims extracted; 1 independently verified. Quality review score: 4.5/10.

4 Limitations

This report is a machine-generated literature synthesis and does not constitute original research. Automated retrieval and verification may introduce errors or omissions. Review scores reflect automated assessment, not human peer review. Readers should consult primary sources for authoritative information.

5 Extracted Claims

Claim	Verified	Confidence
Experiments were conducted on the Mitra model across 33 classification datasets with 10 folds each from the TabArena ben	×	0.07
The study totaled 2,310 fine-tuning runs.	×	0.12
Model performance is reported as normalized ROC-AUC relative to the pre-trained model.	×	0.07
CausalMixFT achieved a median improvement of $+0.12 \pm 0.63$ over the pre-trained model.	×	0.05
The default fine-tuning baseline achieved a median improvement of $+0.10 \pm 0.98$ over the pre-trained model.	×	0.09
Purely synthetic augmentation methods (CTGAN, SCM, TabEBM, TableAugment, and MixedModel) showed negative median improvement	×	0.08
CausalMixFT has a performance variability of ± 0.63 , while default fine-tuning has a variability of ± 0.98 .	×	0.10
In average rank analysis across datasets, CausalMixFT ranks first overall.	×	0.02
In average rank analysis, the default fine-tuning baseline ranks second, followed by purely synthetic generators.	×	0.09
The normalization strategy uses the base model’s (Mitra’s) zero-shot performance as the baseline.	×	0.03
The normalization formula is $\text{score_normalized} = \text{metricsign} \times (\text{score_method} / \text{score_baseline} - 1) \times 100\%$.	×	0.00
In the normalization formula, metricsign is 1 for metrics where higher is better (e.g., ROC-AUC) and -1 for metrics wher	×	0.02
CausalMixFT generates synthetic data using SCMs fitted to the target dataset.	×	0.14
SCMs encode causal dependencies among features through a directed acyclic graph (DAG) and structural equations.	✓	0.16
Structural relations between features are estimated using the PC and FCI algorithms.	×	0.02
DAGs are sampled and fitted using DoWhy’s SCM framework with additive noise models.	×	0.04
In the SCM framework, numerical features are modeled with regressors and categorical features with classifiers.	×	0.01
Synthetic samples are generated by sampling exogenous noise and propagating it through the fitted SCM.	×	0.04

References

- <http://arxiv.org/abs/2601.04110v2>
- <http://arxiv.org/abs/1907.02664v2>
- <http://arxiv.org/abs/2603.10254v1>