# A Comparative Study of Preprocessing Methods for Bias Mitigation in Fair Machine Learning Systems

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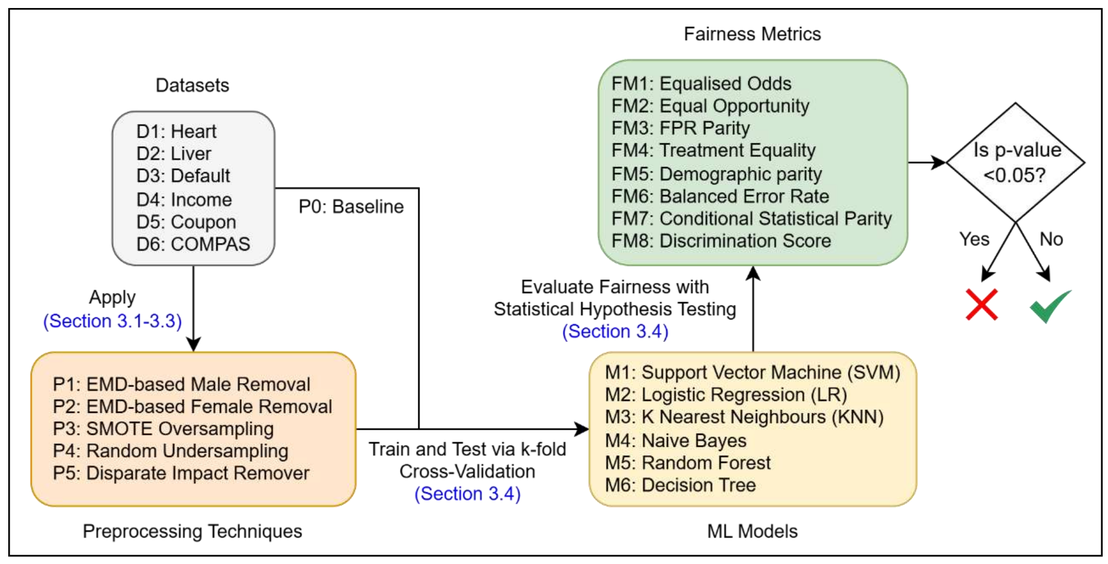
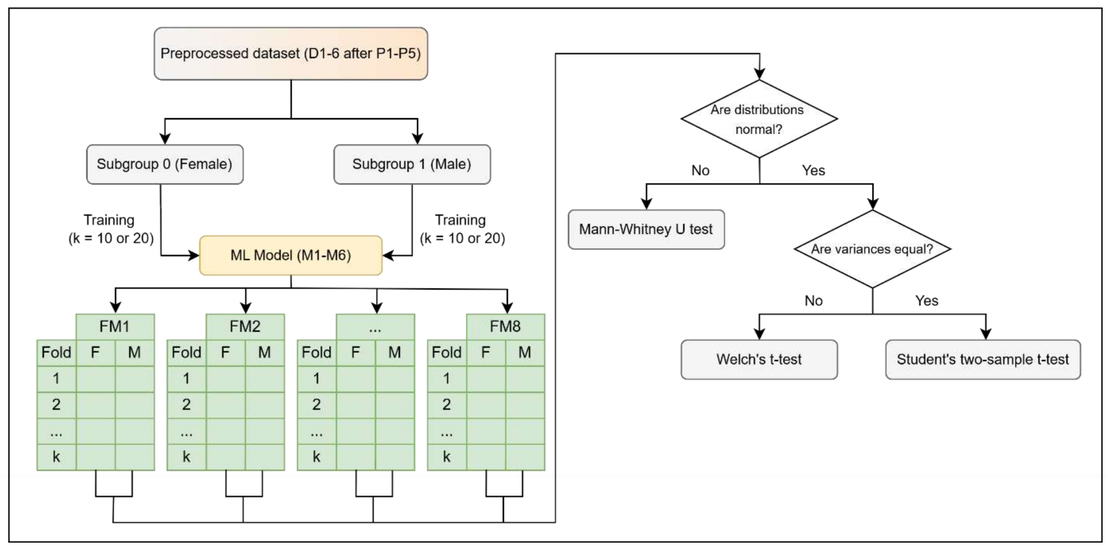
## 1. Introduction

- **Motivation:** ML models used in high-stakes domains can exhibit systematic bias against protected groups like gender or race.
- **Gap:** Prior studies on preprocessing-based bias mitigation often lack statistical validation and broad comparative evaluation.
- **Approach:** We compare instance removal, resampling, and feature transformation methods across multiple datasets, models, and fairness metrics using cross-validation and hypothesis testing.
- **Key contribution:** An automated, statistically grounded optimisation of Earth Mover's Distance (EMD)-based instance removal.
- **Findings:** Distribution-aware preprocessing achieves substantial fairness improvements, while preserving predictive performance.




## 2. Methodology

For code and relevant artefacts!

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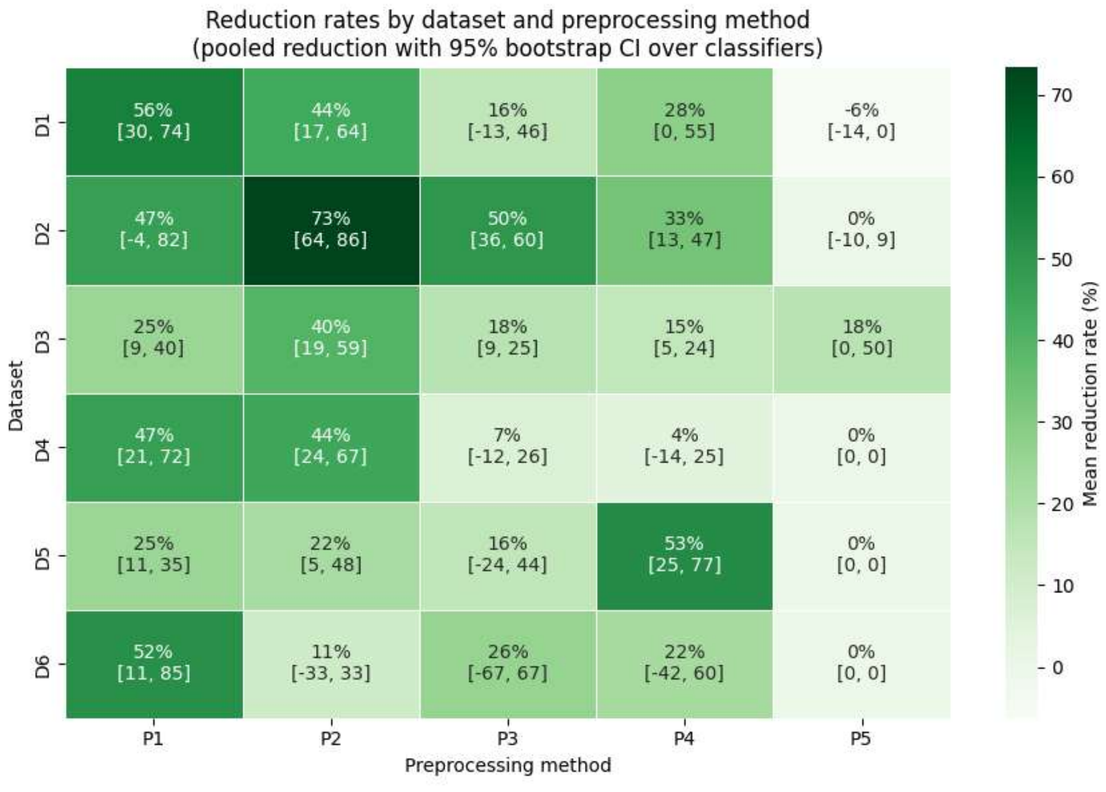
Fairness is evaluated within a cross-validated statistical framework that treats group disparities as inferential quantities rather than single-run estimates. For each dataset–model configuration, fairness violations are identified using appropriate parametric or non-parametric tests across multiple fairness definitions, enabling robust comparison of both the magnitude and stability of bias mitigation effects. Furthermore, the proposed EMD-based instance removal applies a systematic coarse-to-fine search to identify the minimal number and type of instances required to eliminate statistically significant distributional disparities.

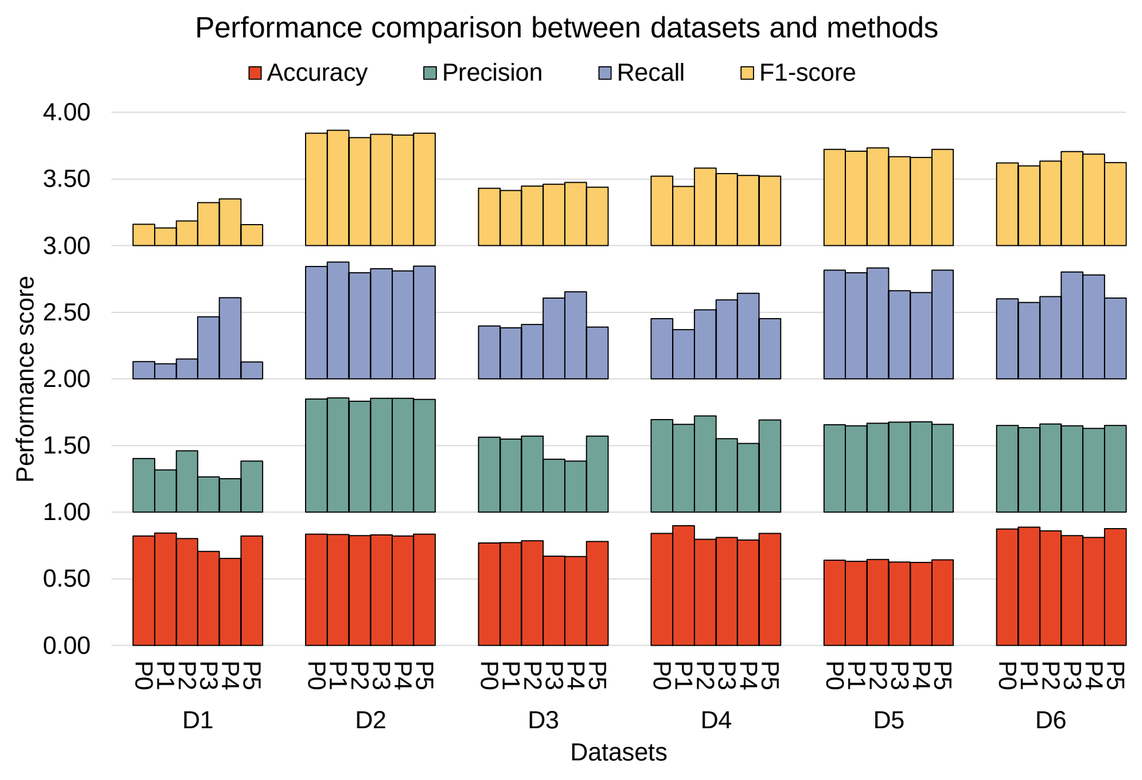
## 3. Fairness Results

EMD-based instance removal (P1, P2) reduces statistically significant fairness violations by approximately 40% on average, compared to around 25% for resampling methods (P3, P4) and 2% for feature transformation approach (P5).




## 4. Performance Results

Despite the fairness gains, EMD-based removal largely preserves predictive performance, whereas resampling methods introduce more noticeable trade-offs, including reduced accuracy but increased recall in several datasets.




## 5. Conclusion and Future Work

- Statistically grounded preprocessing, particularly optimised EMD-based instance removal, provides consistent and substantial reductions in fairness violations without sacrificing predictive performance.
- Future work will explore hybrid EMD strategies that jointly consider male (P1) and female (P2) instance removal to balance interventions across groups, as well as extensions to intersectional attributes and multi-class datasets.

## References

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