

LOCAL CAUSAL DISCOVERY FOR STRUCTURAL EVIDENCE OF DIRECT DISCRIMINATION

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Efficient graph learning enables causal fairness analysis in complex decision systems

DETECTING DIRECT DISCRIMINATION == CAUSAL PARENT DISCOVERY

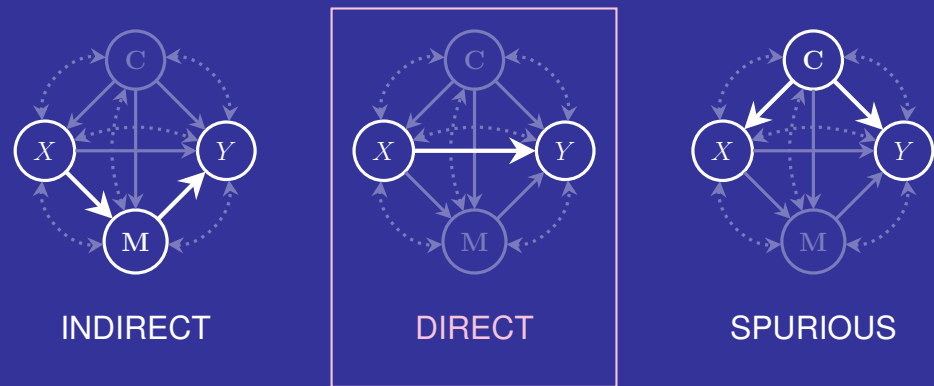


Fig. 1: The standard fairness model (SFM) with protected attribute X , outcome Y , confounders C , and mediators M [1]. Directed edges denote active paths. Bidirected edges denote latent confounding. **This work identifies direct mechanisms of unfairness in a data-driven way.**



LD3: CAUSAL PARENT DISCOVERY FOR FAIRNESS ANALYSIS

- **APPROACH.** We introduce LD3, a constraint-based discovery method that leverages the **causal partition taxonomy** proposed in [2] to label variables by their causal relation to the protected attribute X and outcome Y (Fig. 2), rather than learning the full graph. We assume that Y has no observed descendants and no unobserved parents (other latent variables are permitted).

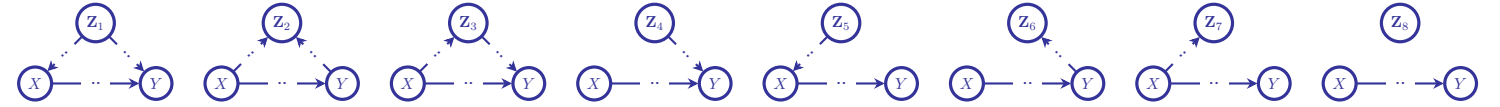


Fig. 2: The nodes of any DAG can be uniquely partitioned into 8 disjoint subsets defined by the paths shared with a pair $\{X, Y\}$ [2]. This applies to DAGs of any size; triple DAGs are for illustration only. Partition Z_1 generalizes the *confounder*, Z_2 the *collider*, Z_3 the *mediator*, etc.

- **COMPLEXITY.** LD3 discovers $parents(Y)$ in a **linear number of conditional independence tests** w.r.t. variable set size.
- **FAIRNESS CRITERIA.** LD3 results directly evaluate the **SDC** and can be used as a valid adjustment set for the **WCDE**:

Definition 1 (Structural direct criterion (SDC), Plečko and Bareinboim 2024). A structural causal model is fair w.r.t. direct discrimination if and only if the following evaluates to 0:

$$SDC = 1(X \in parents(Y)). \quad (1)$$

Definition 2 (Weighted controlled direct effect (WCDE), Pearl 2000). Let $M' \subseteq M$ denote mediators that are parents of Y . WCDE is nonzero if and only if $X \in parents(Y)$ (i.e., $SDC = 1$):

$$WCDE = \sum_{m'} (\mathbb{E}[Y | do(x, m')] - \mathbb{E}[Y | do(x^*, m')]) P(m'). \quad (2)$$

RESULTS

- **FASTER.** LD3 ran 46–5870× faster than baselines on real-world data.
- **MORE PLAUSIBLE RESULTS.** Parent sets predicted from real-world data aligned with expert knowledge better than baselines.
- **ENABLES EFFECT ESTIMATION.** LD3 returns a valid adjustment set for the WCDE under a new graphical criterion.

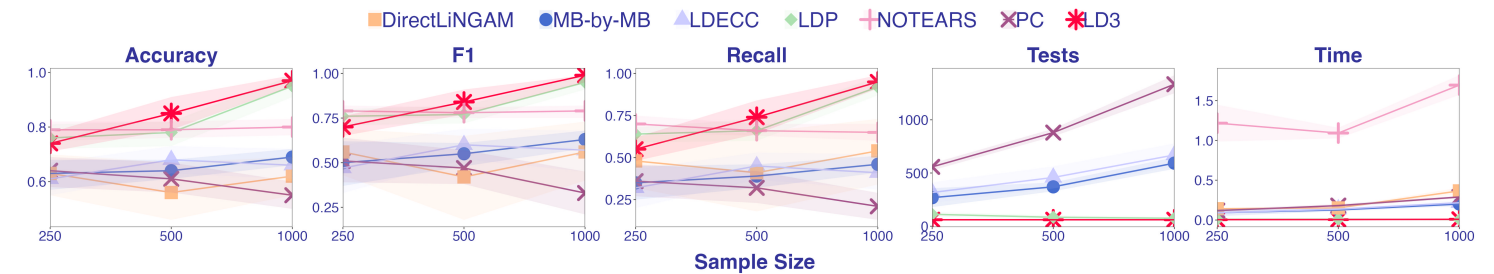


Fig. 3: Baseline results for parent discovery on the SANGIOVESE benchmark (btlearn). Independence test count (Tests) is reported for constraint-based methods. Time is in seconds. Shaded regions denote 95% confidence intervals over ten replicates.

CASE STUDY: PATIENT SEX & LIVER TRANSPLANT ALLOCATION

Fairness query: Are sex-based disparities due to direct discrimination? \Rightarrow **Graphical query:** Is sex (S) a parent of liver allocation (L)?

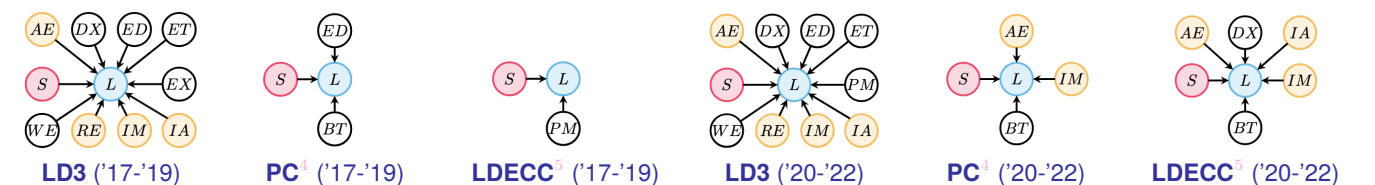


Fig. 4: Predicted parent sets for OPTN STAR datasets. **Known parents of L are in yellow.** Exposure = patient sex (S ; red), outcome = receiving a liver (L ; blue). AE = active exception case; BT = blood type; DX = diagnosis; ED = education; ET = ethnicity; EX = exception type; IA = initial age; IM = initial MELD; PM = payment method; RE = region; WE = weight. For all methods, $SDC = 1$ and $WCDE$ p -value = 0.000.

REFERENCES

[1] Plečko, D., and Bareinboim, E. 2024. Causal Fairness Analysis: A Causal Toolkit for Fair Machine Learning. Foundations and Trends in Machine Learning. [2] Maasch, J.; Pan, W.; Gupta, S.; Kuleshov, V.; Gan, K.; Wang, F. 2024. Local Discovery by Partitioning: Polynomial-Time Causal Discovery Around Exposure-Outcome Pairs. UAI. [3] Pearl, J. 2000. Causality: Models, Reasoning and Inference. Cambridge University Press. ISBN 978-0-521-77362-1. [4] Spirtes, P.; Glymour, C.; Scheines, R. Causation, Prediction, and Search. Springer. [5] Gupta, S.; Childers, D.; and Lipton, Z. 2023. Local Causal Discovery for Estimating Causal Effects. CLeaR.