Data Mining and Information Retrieval Laboratory, DMIR Lab

Non-linear Causal Discovery for Additive Noise Models with Multiple Latent Confounders

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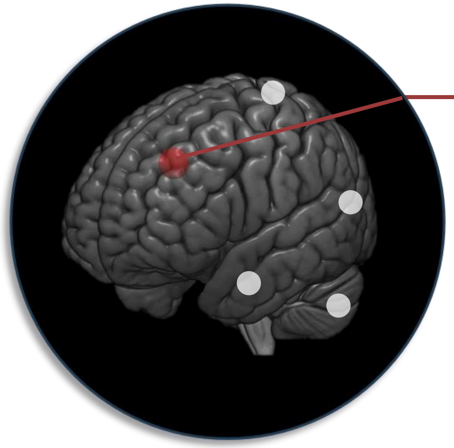
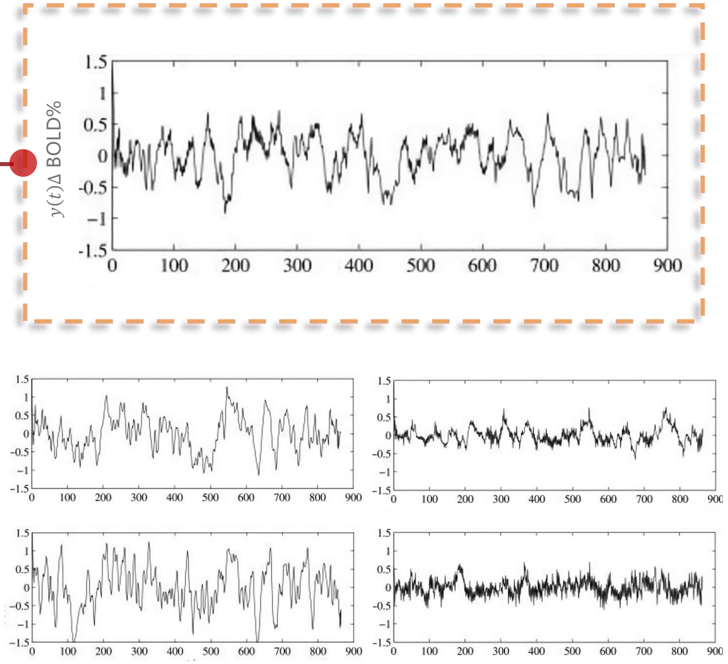
What specific questions as to causal networks learning do you care about?

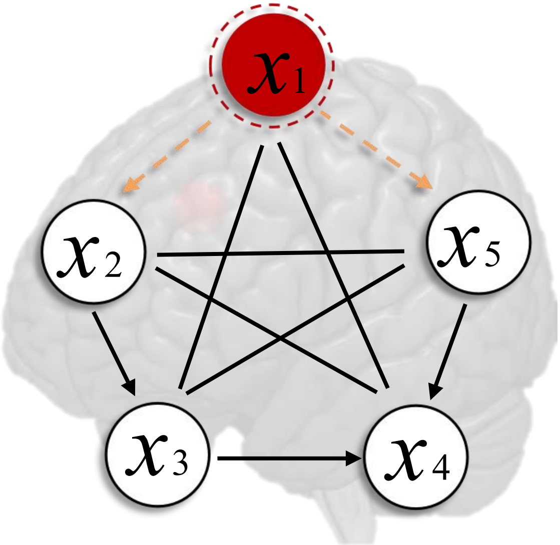
Question as to Causal Graphs Learning

Non-linear Causal Discovery with Latent Confounders



Regions of Interest
(ROI)





Brain “Networks"

[1] *Introduction to FSL*, [Andrew Jahn](https://)

[2] *Minati, Ludovico, et al.* "Synchronization, non-linear dynamics and low-frequency fluctuations: analogy between spontaneous brain activity and networked single-transistor chaotic oscillators." *Chaos: An Interdisciplinary Journal of Nonlinear Science 25.3 (2015).*

What assumptions and methodology give rise to the causal identification?

Related Work, Issues, and Motivation

- **Probabilistic Graphical Models (GPMs)**
  - Constraint-based method: the PC algorithm
    Spirtes, C. N. Glymour, et al. (2000)
- **Structure Causal Models (SCMs)**
  - Functional-based methods: LiNGAM, CAM
    Shimizu, P. O. Hoyer, et al. (2006)
- **Methods for Latent Confounders (Variables)**
  - Hybrid-based approach: MLC-LiNGAM
    Chen et al. (2021)
  - Define "latent variables paths" by the CAM-UV approach
    Maeda and Shimizu (2021)

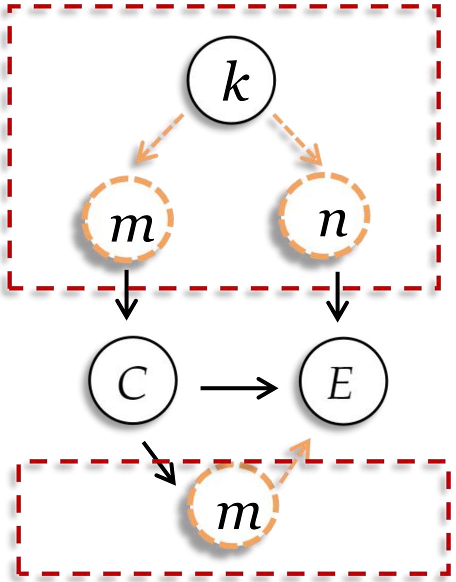


Illustration of "Latent Variables Paths"

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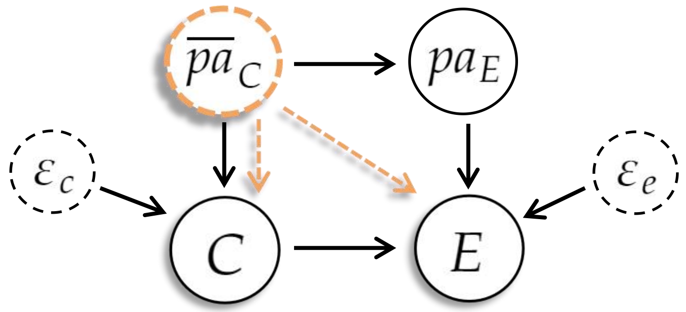
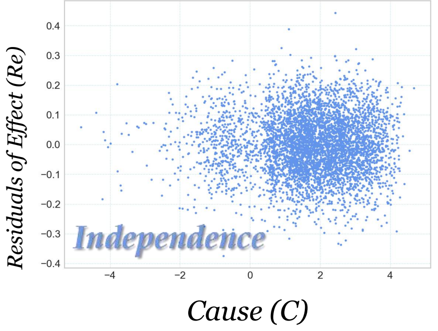
Assumptions and Methodology for Identification

Related Work, Issues, and Motivation

Unobserved Indirected Confounding



*Regressing **Effect** on **Cause***



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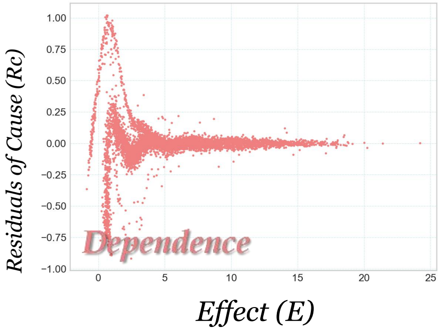
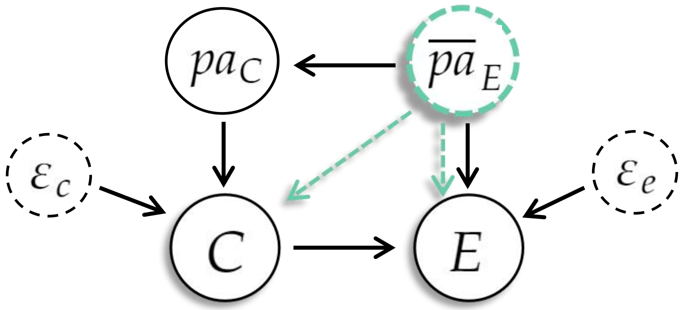
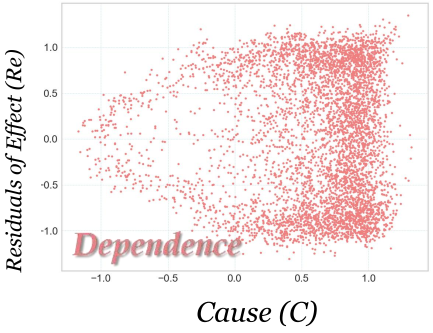


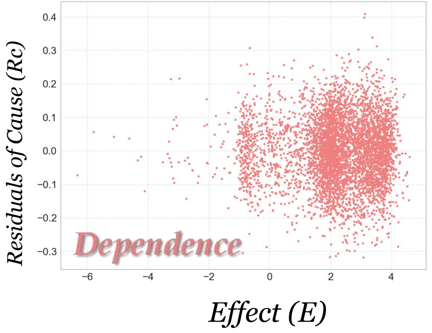
Unobserved Indirected Confounding



*Regressing **Effect** on **Cause***



*Regressing **Cause** on **Effect***



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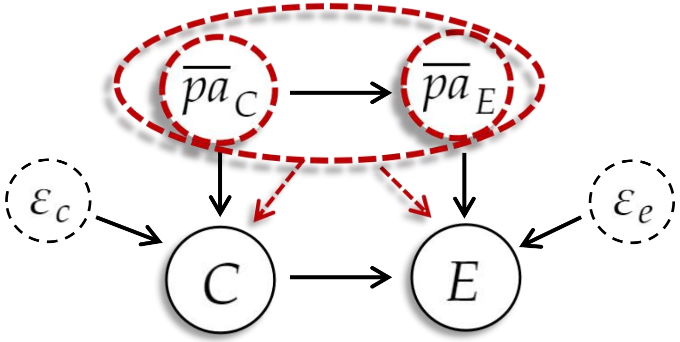
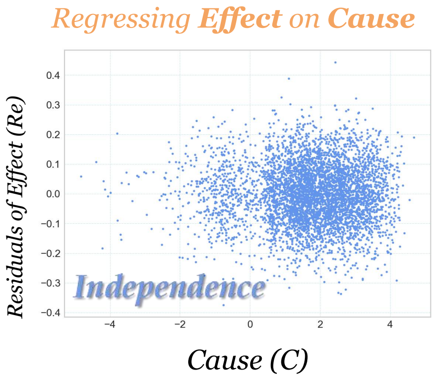
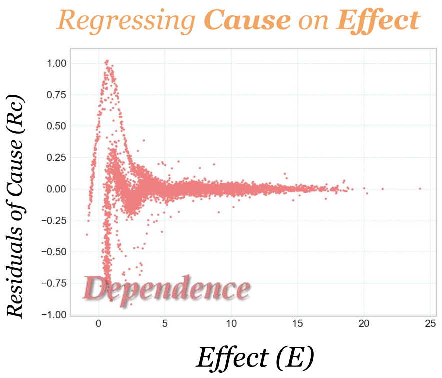
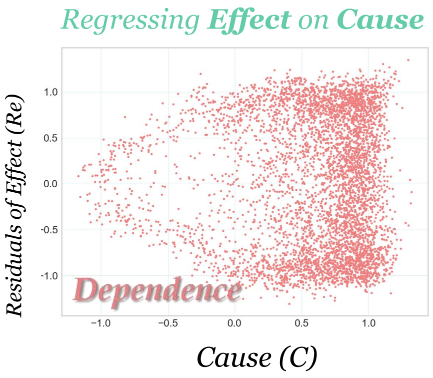
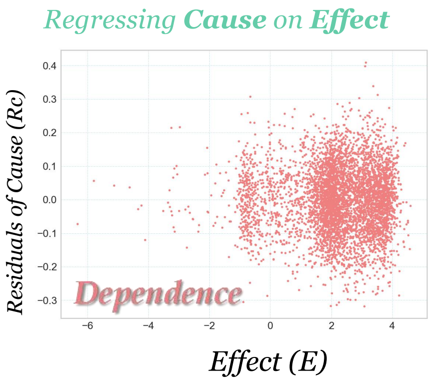
Related Work, Issues, and Motivation











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In order to make it more clear,

What is the **most important idea for modeling** this case?

Primary Ideas for Modelling

Causal Models: Latent Additive-Noise-Models (L-ANMs)

Nonlinear causal discovery with additive noise models. Hoyer et al. (2008)

- **Model Definition (Theory)**
  - Directed acyclic graphs (DAG) : $\boldsymbol{X} = \{x_1, x_2, \ldots, x_d\}, \ \boldsymbol{\varepsilon} = \{\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_d\}.$
  - Data generation procedure:

$$x_i := \sum_{x_j \in \boldsymbol{pa}_i} f_{ij}(x_j) + \xi_i. \quad (\xi_i := \varepsilon_i \cup \boldsymbol{f}(\overline{\boldsymbol{pa}}_i).)$$

- **Empirical Regressor (Algorithm)**
  - Non-linear **Identifiable Condition** as to x_j and ξ_i:

$$\underbrace{x_i - \sum_{x_h \in \boldsymbol{pa}_i \setminus \{x_j\}} f_{ih}(x_h)}_{\mathcal{R}_i} = f(x_j) + \underbrace{\left(\sum_{x_k \in \overline{\boldsymbol{pa}}_i} f_{ik}(x_k) + \varepsilon_i \right)}_{\xi_i}.$$

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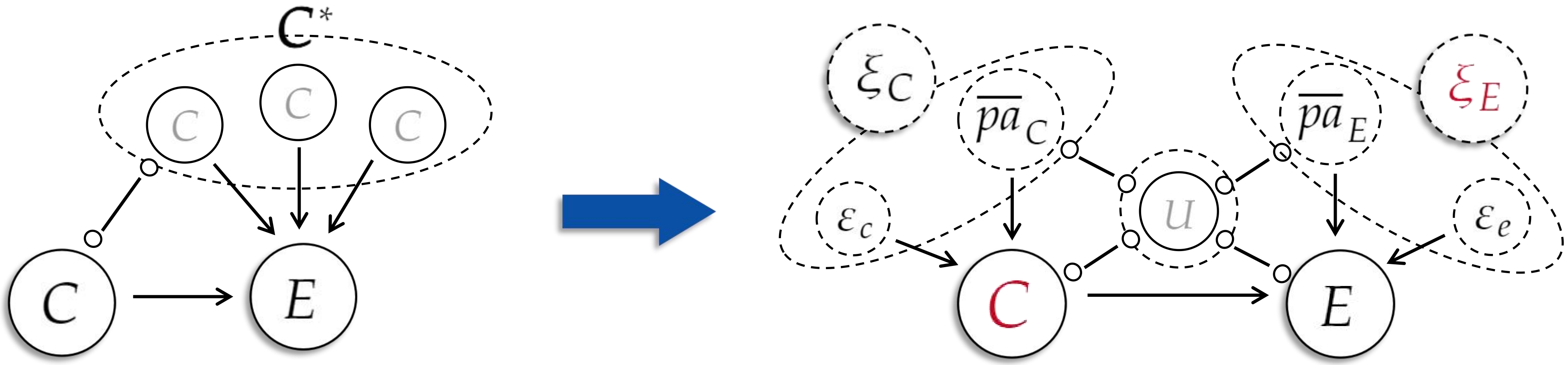
Based on this model,

what is the intuition for the new causal identification

Models and Assumptions for Identification

Contribution-1: The Latent-ANM Condition



Nonlinear Identifiable Condition:

$$\boxed{(\xi_E \perp\!\!\!\perp C)} \wedge (\xi_E := \varepsilon_E \cup \boldsymbol{f}(\boldsymbol{C}^*))$$

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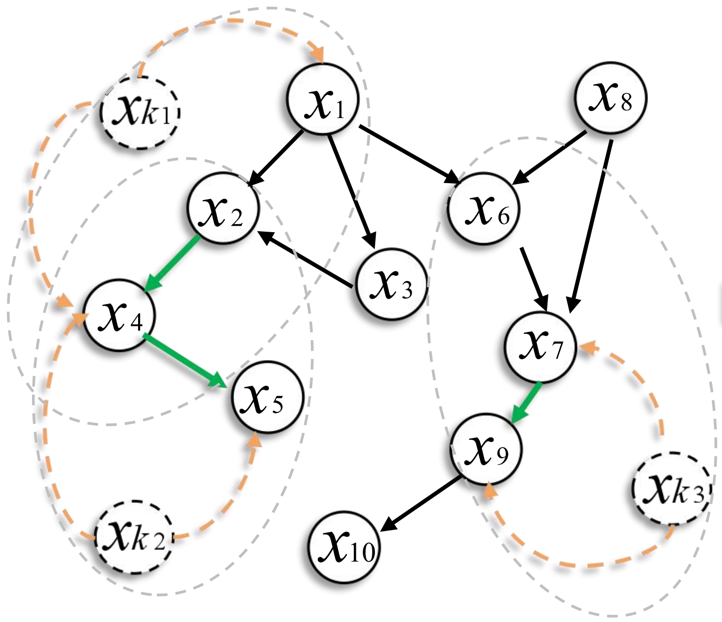
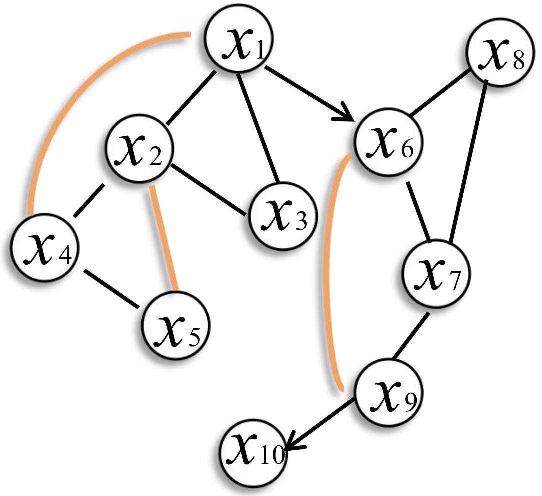
Models and Assumptions for Identification

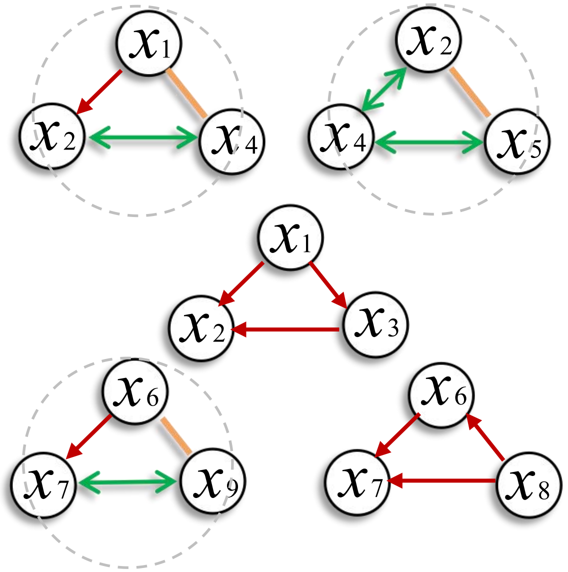
Contribution-2: The Nonlinear-MLC Algorithm



Unidentifiable Non-linear Causation



Spurious Edges



Causal Inference

Based on L-ANMs Identification

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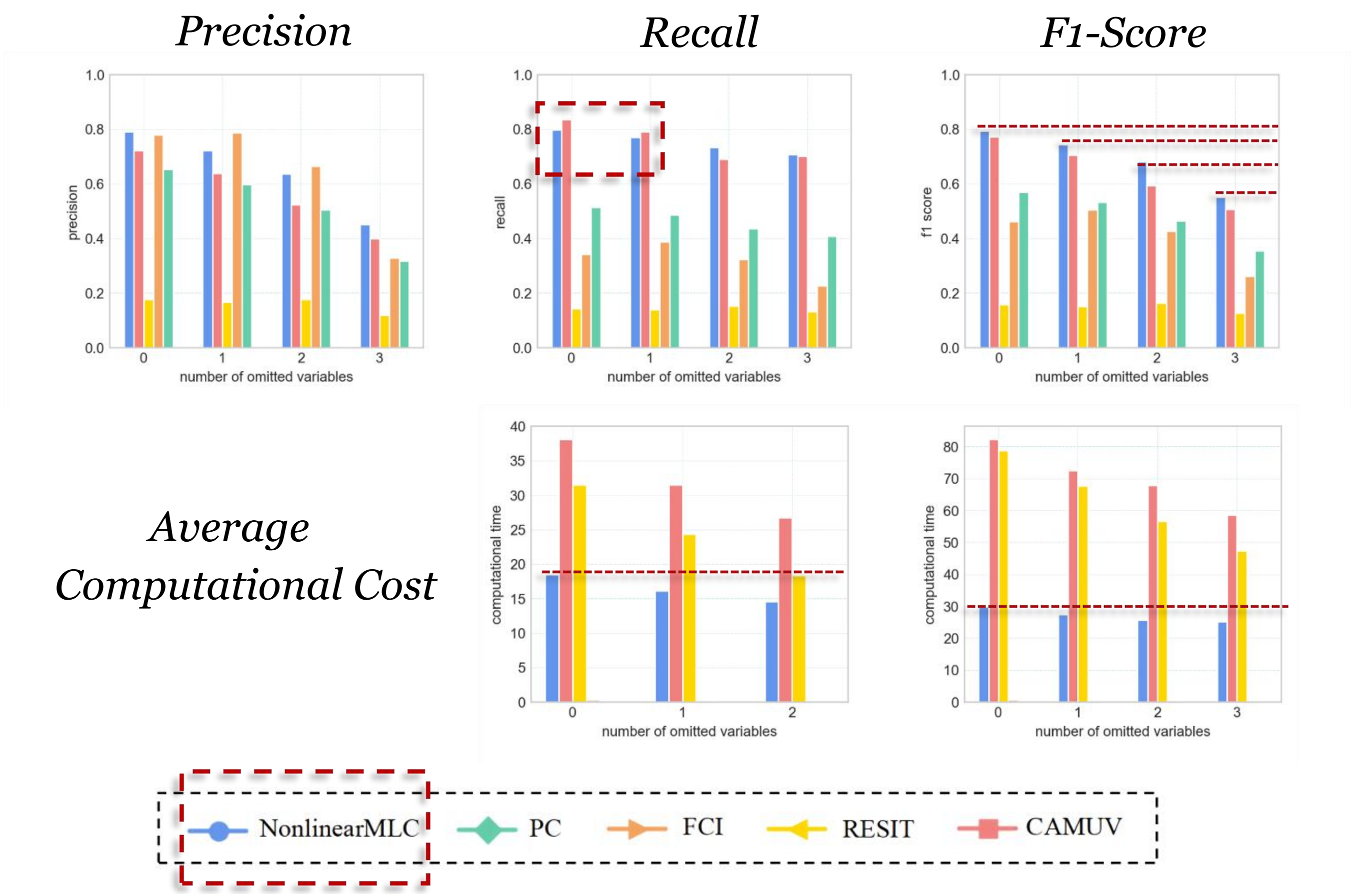
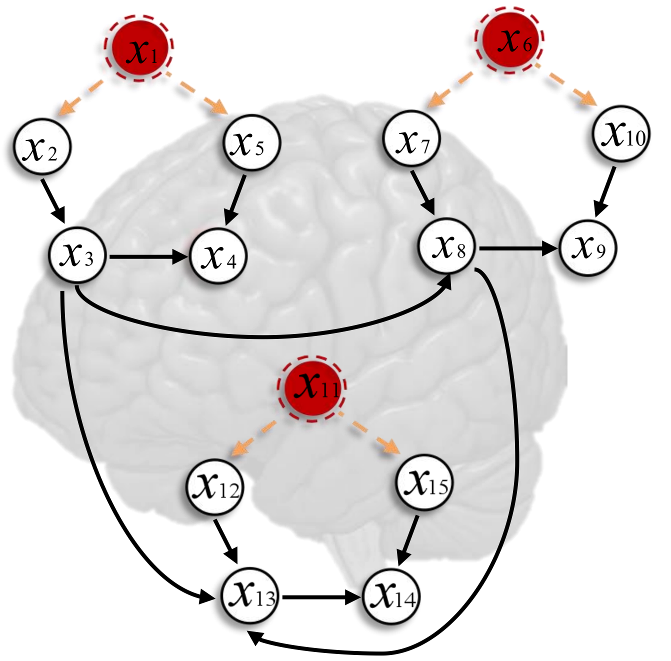
How did you evaluate your approach?

(the “Nonlinear-MLC” algorithm)

Testing for the Approach

Performance on Functional Magnetic Resonance Imaging Data





Brain "Networks"
from fMRI Data (NetSim-3)

[1] *https://www.fmrib.ox.ac.uk/datasets/netsim/index.html*

[2] *Smith, Stephen M., et al.* "Network modelling methods for FMRI." *Neuroimage 54.2 (2011): 875-891.*

Finally, how can I **get start** to apply the approach?

(for general non-linear causal discovery)

Get Start

Source

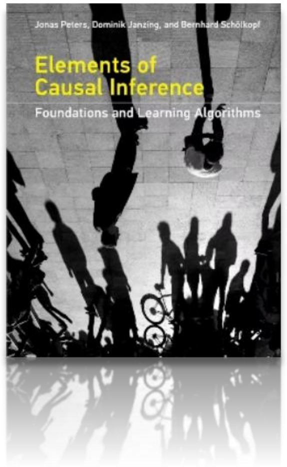
- **caudimlc: Light Python Package for Hybrid-Based Causal Discovery**
  - Provide easy-to-use **Python APIs** to learn an empirical causal graph with relative efficiency
  - Integrate implementations of **hybrid-based approaches** and micro workflow of causal discovery
  - **Github**: https://github.com/xuanzhichen/cadimulc

- **A Quote from *Elements of Causal Inference***

  Jonas Peters, Dominik Janzing, and Bernhard Schölkopf

  "Statistical causal methods do not need to be motivated by the proofs of the identifiability results."

  "Causal methods that follow the proofs closely are often inefficient in making use of the data."



Thanks for Watching

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