

# A Gentle Introduction to Structural Causal Models

Daniel Saggau

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# Motivation

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# Introduction (1)

- ▶ Machine learning has provided many insights into different research problems
- ▶ One issue is the consideration of 'What are we actually predicting'?
- ▶ Mainstream tools are build on association-based learning
- ▶ Associations are not enough for high stake settings
- ▶ In disciplines like psychology or economics people are less interested in associational learning
- ▶ We want causation and not correlation

## Introduction (2)

Causal assumptions differentiate causal models from association learning methods.

Association-based Concepts	Causal Concepts
Correlation	Randomization
Regression	Confounding
Conditional Independence	Disturbance
Likelihood	Error Terms
Odds Ratio	Structural Coefficients
Propensity Score	Spurious Correlation

# History

▶ Path Analysis -> SEM -> SCM



# How to build a SCM

- ▶ Consists of system of equations
- ▶ Assignment equation  $':=$ ' rather than regular equation  $'=$ '
- ▶ is a nonparametric SEM
- ▶ has functional form rather than using probabilities
- ▶ entails features from the PO framework and graphical representation
- ▶ Exogenous factors are part of the model specification

## SCM Applications:

- ▶ Flexible simulations for higher order problems (intervention, counterfactual)
- ▶ Graphical visualization via directed acyclic graph
- ▶



## Graphical Illustration

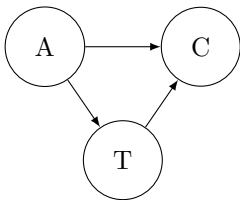


Figure 1: Probabilistic Model

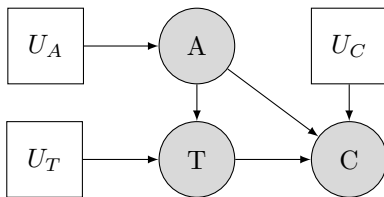


Figure 2: Structural Causal Model

# Fundamental Differences (1)

- ▶ conflict whether to use graphs or not
- ▶ A SEM is a parametric specification used in applied sciences (parameters contested)
- ▶ A Bayesian causal network is another popular causal model using conditional probabilities and NO functions
- ▶ Differences in performance between BCN and SCM

# Performance Evaluation

Method	CBN	SCM
Prediction	<ul style="list-style-type: none"><li>• Unstable</li><li>• Volatile to parameter changes</li><li>• Re-Estimate entire model</li></ul>	<ul style="list-style-type: none"><li>• Stable</li><li>• More Natural Specification</li><li>• Only estimate <math>\Delta</math> CM</li></ul>
Intervention	<ul style="list-style-type: none"><li>• Costly for Non-Markovian Models</li><li>• Unstable(Nature CP)</li><li>• Only generic estimates(<math>\Delta</math> CP)</li></ul>	<ul style="list-style-type: none"><li>• Pot. Cyclic Representation</li><li>• Stable(Nature Eq.)</li><li>• Context specific(Invariance of Eq.)</li></ul>
Counterfactuals	<ul style="list-style-type: none"><li>• <b>Impossible</b></li><li>• no information on latent factors(<math>\epsilon</math>)</li></ul>	<ul style="list-style-type: none"><li>• Possible</li><li>• Inclusion of latent factors</li></ul>

# Assumptions

## **Error terms**

Regression: Omissible outside factor SCM/SEM; Latent influential factor that is pivotal for the model specification but not observable

# Pearls Causal Hierachy

Table 3: Pearls Hierachy of Causation (2009)

Method	Action	Example	Usage
Association $P(a b)$	Co-occurrence	What happened. . .	(Un-)Supervised ML, BN, Reg.
Intervention $P(a do(b), c)$	Do-manipulation	What happens if . . .	CBN,MDP,RL
Counterfactual $P(a_b a', b')$	Hypotheticals	What would have happened if. . .	SCM ,PO

# Causality -In Between Physical and Social Sciences

# Causality and Time

- ▶ Time in Physical Sciences: Mechanical and exact
- ▶ Time in Social Sciences: Often Vague
- ▶ Regular Time Specification is also more vague
- ▶ To accomodate that issue, research on differential equation based SCMs started