

Quant II

Lab 3: Causal Graph

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Today's plan

- Causal Graph Basics
- Causal Graph v.s. Potential Outcome

Causal Graph

- Each data generation process is a distribution $P(X, Y, D, U)$
 - X : observables
 - Y : outcome
 - D : treatment
 - U : unobservables

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- Each data generation process is a distribution $P(X, Y, D, U)$
 - X : observables
 - Y : outcome
 - D : treatment
 - U : unobservables
- Causal graph can tell us how the distribution looks like, under the assumptions:
 - There is some directed acyclic graph G representing the relations of causation among the our variables.
 - The Causal Markov condition: The joint distribution of the variables obeys the Markov property on G .
 - Faithfulness: The joint distribution has all of the conditional independence relations implied by the causal Markov property, and only those conditional independence relations.
- The graph also has the noise term but we ignore them for convenience.

Example 1

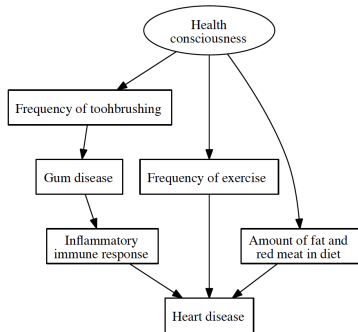


Figure 22.2: Graphical model illustrating hypothetical pathways linking brushing your teeth to not getting heart disease.

Example 1

- We have

$$\begin{aligned} & p(\textit{Yellowteeth}, \textit{Smoking}, \textit{Asbestos}, \textit{Tarinlungs}, \textit{Cancer}) \\ &= p(\textit{Smoking}) p(\textit{Asbestos}) \\ &\quad \times p(\textit{Tarinlungs} | \textit{Smoking}) \\ &\quad \times p(\textit{Yellowteeth} | \textit{Smoking}) \\ &\quad \times p(\textit{Cancer} | \textit{Asbestos}, \textit{Tarinlungs}) \end{aligned}$$

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- We can get any conditional density

- but we also know:

$$p(\textit{Heartdisease} | \textit{Brushing} = b) \neq p(\textit{Heartdisease} | \textit{do}(\textit{Brushing} = b))$$

- We want to make it happen.

With do calculus

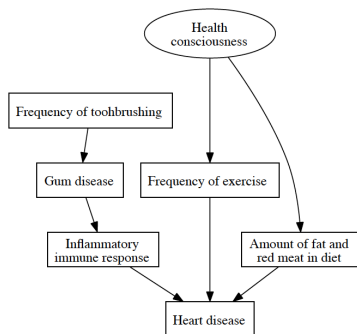


Figure 22.3: The previous graphical model, “surgically” altered to reflect a manipulation (*do*) of brushing.

Conditioning

- Generally: introducing information about a variable into the analysis by some means (function form is unnecessary).
 - Controlling (e.g. in regression)
 - Subgroup analysis (e.g. restrict analysis to employed women)
 - Sample selection (e.g. only collect data on poor whites)
 - Attrition, censoring, nonresponse (e.g., analyze only respondents or survivors)

- Path does not take the direction into account

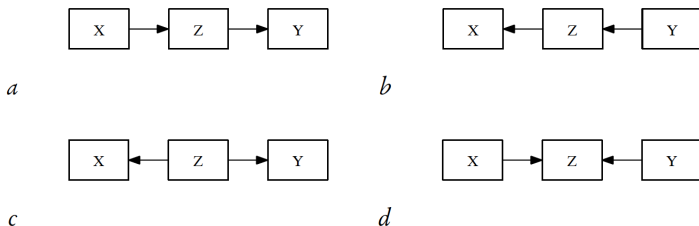


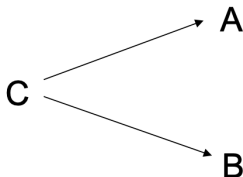
Figure 22.4: Four DAGs for three linked variables. The first two (*a* and *b*) are called **chains**; *c* is a **fork**; *d* is a **collider**. If these were the whole of the graph, we would have $X \not\perp\!\!\!\perp Y$ and $X \perp\!\!\!\perp Y|Z$. For the collider, however, we would have $X \perp\!\!\!\perp Y$ while $X \not\perp\!\!\!\perp Y|Z$.

Coorelation is not causaltion

$$A \longrightarrow C \longrightarrow B$$

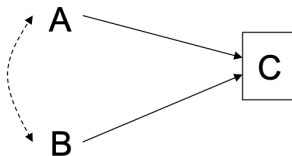
(1) Direct and indirect causation

$$A \not\perp\!\!\!\perp B \text{ and } A \perp\!\!\!\perp B|C$$



(2) Common cause confounding

$$A \not\perp\!\!\!\perp B \text{ and } A \perp\!\!\!\perp B|C$$



(3) Conditioning on a common effect (“collider”): Selection

$$A \perp\!\!\!\perp B \text{ and } A \not\perp\!\!\!\perp B|C$$

\longleftrightarrow : non-causal (spurious) association. $\boxed{}$: conditioning.

Coorelation is not causaltion

Pearl's Sprinkler Example

A: It rains

B: The sprinkler is on

C: The lawn is wet

Hollywood Success

A: Good looks

B: Acting skills

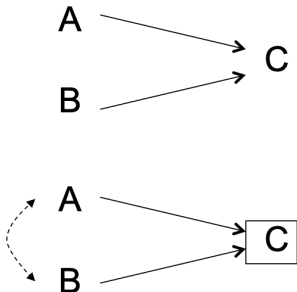
C: Fame

Academic Tenure Example

A: Productivity

B: Originality

C: Tenure



In all three examples, conditioning on the collider C induces a spurious association between two variables, A and B, that don't cause each other and share no common cause, i.e. that are marginally independent in the population.

D-separation

- We need some correlation, but it must be causal
- We need to rule out non-causal ones.
- The concept of d-separation (“directional separation”, Pearl 1988) subsumes the three structural sources of association and gives them a name.
- d-separation determines which paths transmit association, and which ones don't.

Block and Active

- Consider paths from X to Y , and we have a conditioning set \mathcal{S} .
- We say If \mathcal{S} **blocks** every undirected path from X to Y , then they must be conditionally independent given \mathcal{S} .
- An unblocked path is also called **active**.
- A path is active when every variable along the path is active; if even one variable is blocked by \mathcal{S} , the whole path is blocked.

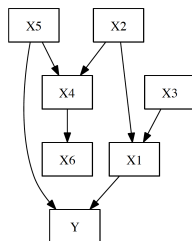
Definition

- A variable Z along a path is active, conditioning on \mathcal{S} , if
 - Z is a collider along the path, and in \mathcal{S} ; or,
 - Z is a descendant of a collider, and in \mathcal{S} ; or
 - Z is not a collider, and not in \mathcal{S} .
- Turned around, Z is blocked or de-activated by conditioning on \mathcal{S} if
 - Z is a non-collider and in \mathcal{S} ; or
 - Z is collider, and neither Z nor any of its descendants is in \mathcal{S}

D-separation and Conditional Independence

- In words, S blocks a path when it blocks the flow of information by conditioning on the middle node in a chain or fork, and doesn't create dependence by conditioning on the middle node in a collider (or the descendant of a collider).
- Only one node in a path must be blocked to block the whole path. When S blocks all the paths between X and Y , we say it d-separates them.
- A collection of variables U is d-separated from another collection V by S if every $X \in U$ and $Y \in V$ are d-separated.
- In every distribution which obeys the Markov property, d-separation implies conditional independence. If the distribution is also faithful to the graph, then conditional independence also implies d-separation.

Example 2



- Consider Y =Grades in Quant2, X_1 =Efforts spent on Quant2, X_2 =prior knowledge in statistics, X_3 =workload this semester, X_4 =Understanding of Neal, X_5 =amount learned in Quant1, X_6 =grades in Quant1
- Is X_3 and X_5 ; X_3 and Y independent?
- What should we control?

Short Summary

- “Blocked” (d-separated) paths don’t transmit association.
- “Unblocked” (d-connected) paths may transmit association.
- Three blocking criteria (key!!)
 - Conditioning on a non-collider blocks a path
 - Conditioning on a collider, or a descendent of a collider, unblocks a path
 - Not conditioning on a collider leaves a path “naturally” blocked.

- **Adjustment Criterion** (Shpitser et al. 2010)
- Total causal effect of D on Y is identifiable if one can condition on (“adjust for”) a set of variables S that
 - blocks all non-causal paths between D and Y
 - without blocking any causal paths between D and Y
- Equivalently: d-separate D and Y along all non-causal paths while leaving all causal paths d-connected)

Backdoor Criterion

- The backdoor criterion is a narrower version of the adjustment criterion that omits some unnecessary conditioning sets.
- **Backdoor Criterion** (Pearl 1995)
- Definition: A set of variables \mathcal{S} satisfies the backdoor criterion relative to an ordered pair of variables (D, Y) in a DAG if:
 - no node in \mathcal{S} is a descendant of D , and
 - \mathcal{S} blocks (d-separates) every path between D and Y that contain an arrow into D (so-called “backdoor paths”).
- Theorem: The total causal effect of D on Y is non-parametrically identifiable given \mathcal{S} if \mathcal{S} meets the backdoor criterion.

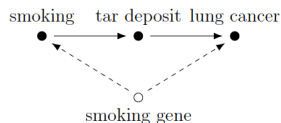
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- This looks familiar: we control confounders and no post-treatment variables.
 - Note this is DAG: so no arrows from Y to D
 - Not necessarily confounder itself

- It should be intuitive to think about some biases:
 - selection bias (we conditional on $selection = 1$)
 - post-treatment bias (we block the causal chain)
 - Bias amplification (one case: we control parents but not confounder)

Post-treatment Variables

- But (only) sometimes it can be useful: **Frontdoor Criterion**



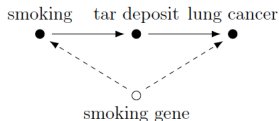
(a) Original Pearl DAG for front-door criterion

- D : smoking; X : tar deposit; Y : lung cancer -
unobserved U : smoking gene

- $P(X|D = d) = P(X|do(d))$, and
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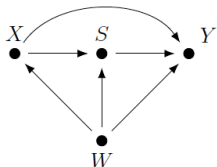
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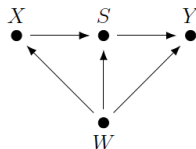
- $P(X|D = d) = P(X|do(d))$, and
 $P(Y|D = d, X = x) = P(Y|do(x), D = d)$
- $P(Y|do(d)) = \sum_{d'} \sum_x P(Y|X = x; D = d') P(d') P(X = x|D = d)$

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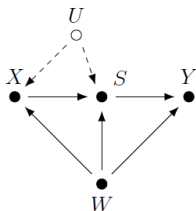
- Different types of post-treatment variables



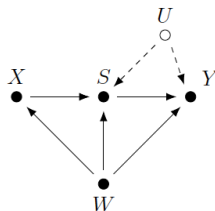
(a) Mediation



(b) Surrogates



(c) Invalid Surrogates



(d) Invalid Surrogates

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 - some of the key assumptions in instrumental variables settings are not naturally captured in DAGs, - the identification of the Local Average Treatment Effect (LATE) is not easily derived in a DAG approach

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- Simultaneity
 - by definition, DAG doesn't allow simultaneity
- Conditioning set and confounders (what are they)
 - Counterfactuals
 - For PO, you need model assumption
 - For DAG, you need a structural assumption

Further readings:

- Elwert, Felix. 2013. “Graphical Causal Models.” Handbook of Causal Analysis for Social Research.
- Glynn, Adam N., and Konstantin Kashin, 2018, “Front-door versus back-door adjustment with unmeasured confounding: Bias formulas for front-door and hybrid adjustments with application to a job training program.” Journal of the American Statistical Association
- Guido W. Imbens, 2020, “Potential Outcome and Directed Acyclic Graph Approaches to Causality: Relevance for Empirical Practice in Economics”