

Causality

Jonas Peters
University of Copenhagen

Academic year 2020/2021 – Block 4

UNIVERSITY OF
COPENHAGEN



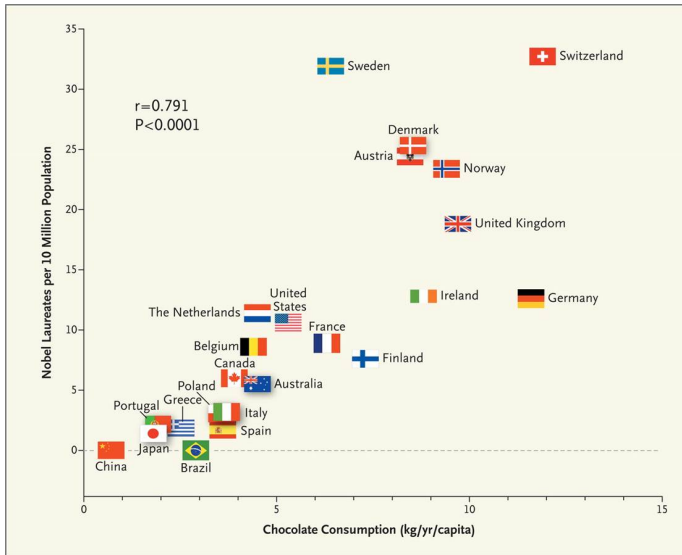
WELCOME!

These slides are used only for visualization. They are not stand-alone material but should be considered as an addition to the reading material, in particular

- Book. Peters, Janzing, Schölkopf: Elements of Causal Inference, MIT Press (see also errata).
- Hand-written notes.
- Code examples.

The slides contain many ideas and concepts that are developed by others and these are often not cited properly. For references, please see the above mentioned book.

Example: chocolate



F. H. Messerli: *Chocolate Consumption, Cognitive Function, and Nobel Laureates*, N Engl J Med 2012

Example: chocolate



B

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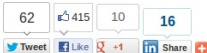
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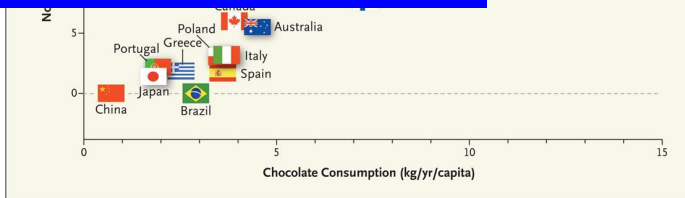
Forward



Eating chocolate produces Nobel prize winners, says study

By Oliver Nieburg, 11-Oct-2012

Related tags: noble prize, nobel laureate, Einstein, Marie Curie, chocolate, brain, Switzerland, Sweden, candy



F. H. Messerli: *Chocolate Consumption, Cognitive Function, and Nobel Laureates*, N Engl J Med 2012

Example: chocolate

Confectionery

HEADLINES | T

HEADLINES >

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Eating winner

By Oliver Niebu

Related tags: r Sweden, candy

Forbes

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PHARMA & HEALTHCARE | 10/10/2012 @ 5:02PM | 14,700 views

Chocolate And Nobel Prizes In Study

4 comments, 2 called-out

+ Comment Now + Follow Comments

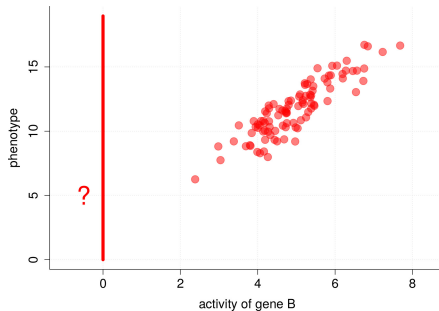
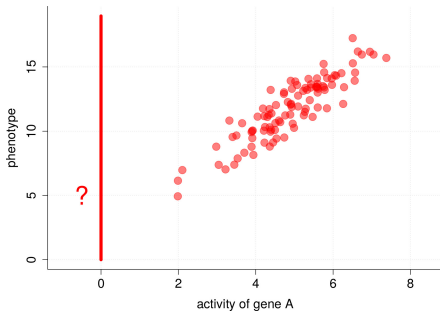
You don't have to be a genius to like chocolate, but geniuses are more likely to eat lots of chocolate, at least according to a new paper published in the August *New England Journal of Medicine*. Franz Messerli reports a highly



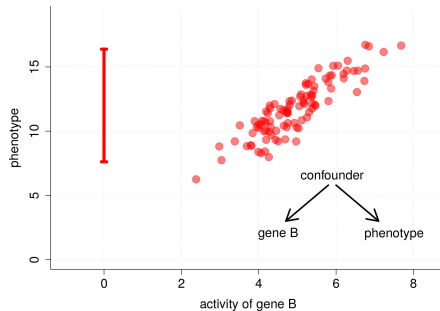
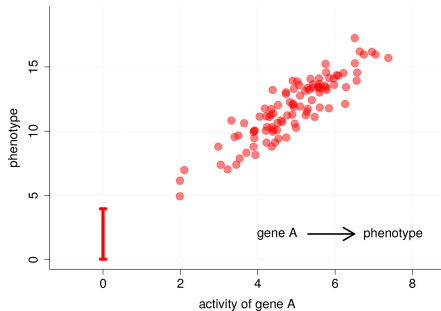
F. H.

12

Consider the following problem.



Causality matters!



BRITISH MEDICAL JOURNAL

LONDON SATURDAY SEPTEMBER 30 1950

SMOKING AND CARCINOMA OF THE LUNG

PRELIMINARY REPORT

BY

RICHARD DOLL, M.D., M.R.C.P.

Member of the Statistical Research Unit of the Medical Research Council

AND

A. BRADFORD HILL, Ph.D., D.Sc.

Professor of Medical Statistics, London School of Hygiene and Tropical Medicine; Honorary Director of the Statistical Research Unit of the Medical Research Council

In England and Wales the phenomenal increase in the number of deaths attributed to cancer of the lung provides one of the most striking changes in the pattern of mortality recorded by the Registrar-General. For example, in the quarter of a century between 1922 and 1947 the annual number of deaths recorded increased from 612 to 8,287, an increase of 13.5 times. This remarkable increase is

whole explanation, although no one would deny that it may well have been contributory. As a corollary, it is right and proper to seek for other causes.

Possible Causes of the Increase

Two main causes have from time to time been put forward. (1) A general increase in the consumption of tobacco, and (2) a change in the habits of smoking, from the pipe to the cigarette.

Example: smoking

BRITISH MEDICAL JOURNAL

TABLE VII.—*Estimate of Total Amount of Tobacco Ever Consumed by Smokers; Lung-carcinoma Patients and Control Patients with Diseases Other Than Cancer*

Disease Group	No. Who have Smoked Altogether					Probability Test
	365 Cigs.—	50,000 Cigs.—	150,000 Cigs.—	250,000 Cigs.—	500,000 Cigs. +	
Males:						
Lung-carcinoma patients (647)	19 (2.9%)	145 (22.4%)	183 (28.3%)	225 (34.8%)	75 (11.6%)	$\chi^2=30.60$; $n=4$; $P<0.001$
Control patients with diseases other than cancer (622) ..	36 (5.8%)	190 (30.5%)	182 (29.3%)	179 (28.9%)	35 (5.6%)	
Females:						
Lung-carcinoma patients (41) ..	10 (24.4%)	19 (46.3%)	5 (12.2%)	7 (17.1%)	0 (0.0%)	$\chi^2=12.97$; $n=2$; $0.001 < P < 0.01$ (Women smoking 15 or more cigarettes a day grouped together)
Control patients with diseases other than cancer (28) ..	19 (67.9%)	5 (17.9%)	3 (10.7%)	1 (3.6%)	0 (0.0%)	

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Director of the Statistical

no one would deny that it
utory. As a corollary, it is
other causes.

of the Increase

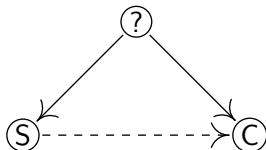
m time to time been put for-

Example: smoking

BRITISH MEDICAL JOURNAL

TABLE VII.—*Effect of Smoking on the Incidence of Lung Cancer*

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Males:					
Lung-carcinoma patients (647)	36 (5.8%)	190 (30.5%)	182 (29.3%)	179 (28.9%)	35 (5.6%)
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Consumed
patients with

Probability
Test

$\chi^2 = 30.60$;
 $n = 4$;
 $P < 0.001$

$\chi^2 = 12.97$;
 $n = 2$;
 $0.001 < P < 0.01$
(Women
smoking 15
or more cig-
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NG

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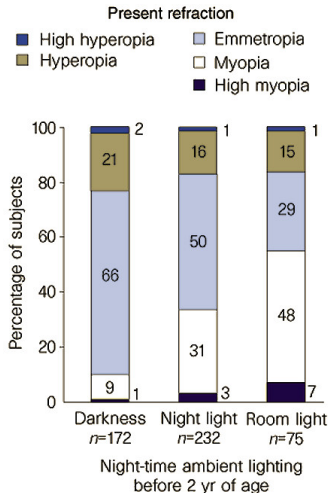
Director of the Statistical

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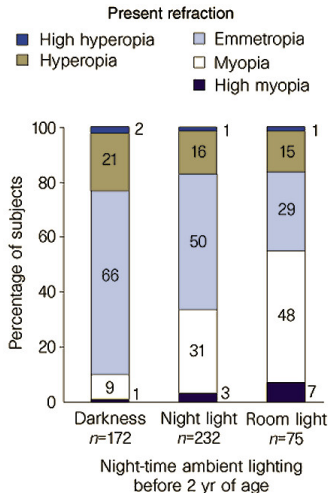
of the Increase

m time to time been put for-

Example: myopia



Example: myopia



“the strength of the association . . . does suggest that the absence of a daily period of darkness during childhood is a potential precipitating factor in the development of myopia”

Quinn, Shin, Maguire, Stone: *Myopia and ambient lighting at night*, Nature 1999

Example: myopia

Patente

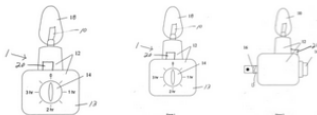
Night light with sleep timer

US 20050007889 A1

ZUSAMMENFASSUNG

A timer a light and an optional music source is located on or in a housing of a nightlight assembly. When this assembly is plugged into a source of electric power, the timer is set to a selected time for the light and optional music to remain on. After this selected time has elapsed, the light and music automatically turns off, allowing for sleep in appropriate darkness and silence.

BILDER (3)



BESCHREIBUNG

ANSPRÜCHE (18)

Veröffentlichungsnummer	US20050007889 A
Publikationstyp	Anmeldung
Anmeldenummer	US 10/614,245
Veröffentlichungsdatum	13. Jan. 2005
Eingetragen	8. Juli 2003
Prioritätsdatum [?]	8. Juli 2003
Erfinder	Karin Peterson
Ursprünglich Bevollmächtigter	Peterson Karin Lyn
Zitat exportieren	BiBTeX , EndNote , F
Klassifizierungen	(4)
Externe Links:	USPTO , USPTO-Zuordnung , Esp

Example: myopia

Patente

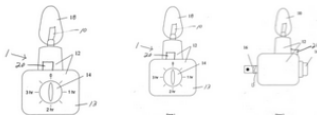
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BILDER (3)



Question: Does the night light with sleep timer help?

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Example: kidney stones

	Treatment A	Treatment B
	$\frac{273}{350} = 0.78$	$\frac{289}{350} = 0.83$
	$\frac{562}{700} = 0.80$	

Assume: treatment is chosen only based on size of stones.

Charig et al.: *Comparison of treatment of renal calculi by open surgery, (...)* , British Medical Journal, 1986

Example: kidney stones

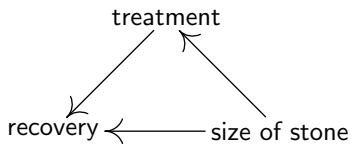
	Treatment A	Treatment B
Small Stones ($\frac{357}{700} = 0.51$)	$\frac{81}{87} = 0.93$	$\frac{234}{270} = 0.87$
Large Stones ($\frac{343}{700} = 0.49$)	$\frac{192}{263} = 0.73$	$\frac{55}{80} = 0.69$
	$\frac{273}{350} = 0.78$	$\frac{289}{350} = 0.83$
	$\frac{562}{700} = 0.80$	

Assume: treatment is chosen only based on size of stones.

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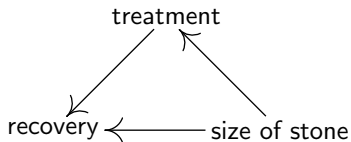
Example: kidney stones

underlying ground truth:



Example: kidney stones

underlying ground truth:



Question: What is the expected recovery if all get treatment B?

(Make treatment independent of size.)

Example: advertisement

Relation to RL

The screenshot shows a Google search results page for the query "buy coffee beans". The browser's address bar shows the URL: <https://www.google.dk/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8&client=ubuntu#q=buy%20coffee%20beans>. The search bar contains the text "buy coffee beans". Below the search bar, there are tabs for "All", "Images", "Maps", "Videos", "More", and "Search tools". The "All" tab is selected. The search results show "About 2.220.000 results (0,26 seconds)". The first result is "Buy Coffee Beans Online - NextDayCoffee.co.uk" with a green "Ad" label. The second result is "Trade Commodities Online - Buy and Sell Oil,Gold,Silver,Wheat" with a green "Ad" label. The third result is "Kicking Horse, 454 Horse Power, Dark, Whole Bean Coffee, 12.3 oz" with a green "Ad" label. The fourth result is "Fair Trade Beans - Purchase Fair Trade Certified - FairTradeUSA.org" with a green "Ad" label. The fifth result is "Buy Coffee Beans Online from Coffee Bean Shop" with a green "Ad" label. The page also shows a "Sign In" button in the top right corner and a "Settings" gear icon in the bottom right corner.

buy coffee beans - Google Search - Chromium

buy coffee beans

https://www.google.dk/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8&client=ubuntu#q=buy%20coffee%20beans

Google

buy coffee beans

Sign In

All Images Maps Videos More Search tools

About 2.220.000 results (0,26 seconds)

Buy Coffee Beans Online - NextDayCoffee.co.uk

Ad www.nextdaycoffee.co.uk/CoffeeBeans +44 1698 842528

Big Savings On Coffee Beans, Buy Now - Next Day Delivery

Coffee Beans Single Bags 100% Arabica Coffee

Coffee Pods & Capsules Caffe Roma Coffee

Trade Commodities Online - Buy and Sell Oil,Gold,Silver,Wheat

Ad www.plus500.dk/Commodities

Kr 185 Trading Bonus! Plus500 CFDs.

Listed on the AIM · CFD Provider · Tight Spreads · 25 € Trading Bonus · Free demo account

Fastest growing UK CFD platform – LeapRate

Gold CFDs · Oil CFDs · Silver CFDs

Kicking Horse, 454 Horse Power, Dark, Whole Bean Coffee, 12.3 oz

Ad www.iherb.com/

\$5 Off Your First iHerb Order! Affordable Shipping to Denmark.

100k+ Product Reviews · Referral Rewards · 24/7 Customer Service

Trial Pricing Products · International Shipping · \$5 Off for New Customers

Fair Trade Beans - Purchase Fair Trade Certified - FairTradeUSA.org

Ad www.fairtradeusa.org/

Empower Farmers Around the World

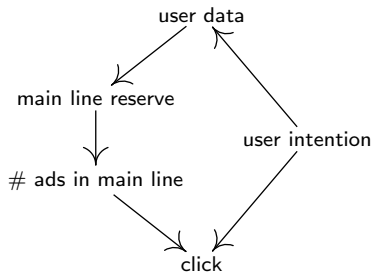
Buy Coffee Beans Online from Coffee Bean Shop

<https://www.coffeebeanshop.co.uk/>

You can now buy some of the finest coffee beans from around the world. Order superb coffee blends

Example: advertisement

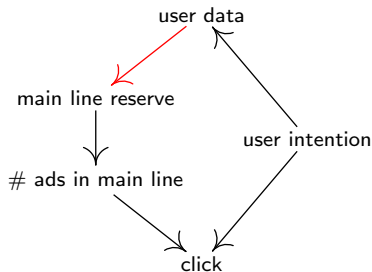
Relation to RL



Bottou et al.: *Counterfactual Reasoning and Learning Systems: The Example of Computational Advertising*, JMLR 2013

Example: advertisement

Relation to RL



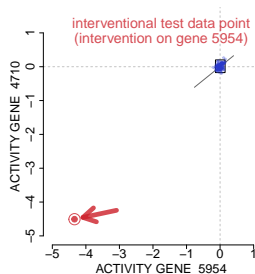
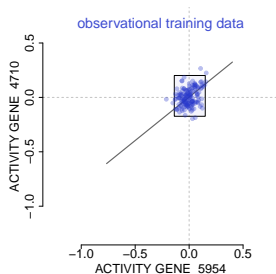
Question: How do we choose an optimal main line reserve?

Bottou et al.: *Counterfactual Reasoning and Learning Systems: The Example of Computational Advertising*, JMLR 2013

Example: gene interactions

genetic perturbation experiments for yeast

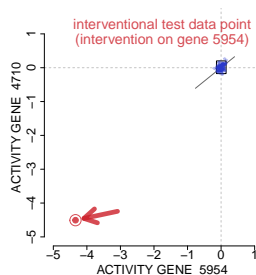
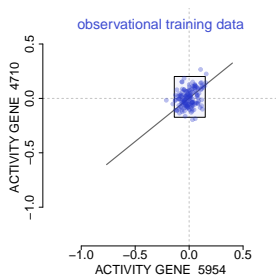
- $p = 6170$ genes
- $n_{obs} = 160$ wild-types
- $n_{int} = 1479$ gene deletions (targets known)



Example: gene interactions

genetic perturbation experiments for yeast

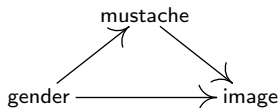
- $p = 6170$ genes
- $n_{obs} = 160$ wild-types
- $n_{int} = 1479$ gene deletions (targets known)



- Causal relationships are often stable!

Kemmeren et al.: Large-scale genetic perturbations reveal reg. networks and an abundance of gene-specific repressors. Cell, 2014

Example: mustache



(a) Intervening vs Conditioning on Mustache, Top: Intervene Mustache=1, Bottom: Condition Mustache=1

Kocaoglu et al: *CausalGAN: Learning Causal Implicit Generative Models with Adversarial Training*, arXiv:1709.02023

- Classical statistics:
statistical model:

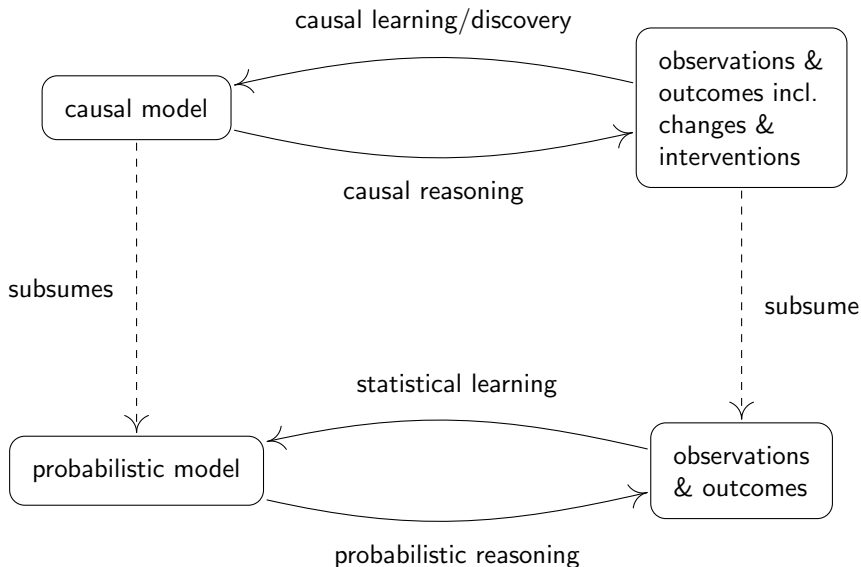
- Classical statistics:
statistical model: $\{P_\theta, \theta \in \Theta\}$

- Classical statistics:
statistical model: $\{P_\theta, \theta \in \Theta\}$
observed data: from P_{θ_0}

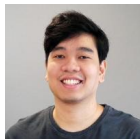
- Classical statistics:
statistical model: $\{P_\theta, \theta \in \Theta\}$
observed data: from P_{θ_0}
inference: investigate θ_0
prediction: use parts of P_{θ_0}

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statistical model: $\{P_\theta, \theta \in \Theta\}$
observed data: from P_{θ_0}
inference: investigate θ_0
prediction: use parts of P_{θ_0}
- Causality is often about

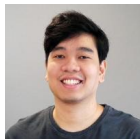
- Classical statistics:
statistical model: $\{P_\theta, \theta \in \Theta\}$
observed data: from P_{θ_0}
inference: investigate θ_0
prediction: use parts of P_{θ_0}
- Causality is often about asking questions about distributions different from the one we have data from.
- We need models relating these distributions.
- We need tools to do causal inference.



- Questions: lectures, TA sessions and padlet (better than emails/absalon messages)
- TA: Sorawit (James) Saengkyongam



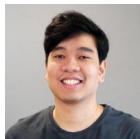
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Exam Students:

- 6 mandatory assignments (up to two people)
- 5 assignments need to be passed (hand-in in time)
- oral exam (22.6./23.6. via zoom)

- Questions: lectures, TA sessions and padlet (better than emails/absalon messages)
- TA: Sorawit (James) Saengkyongam



Exam Students:

- 6 mandatory assignments (up to two people)
- 5 assignments need to be passed (hand-in in time)
- oral exam (22.6./23.6. via zoom)

Exam PhD Students:

- No assignments (mark exercise for feedback)
- Report at the end (23.6.) about paper, data study or own research problem.
- Cannot contain recycled material.

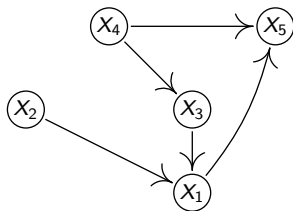
All information on absalon.

Hand-written notes 1

Definition: d -separation

X_i and X_j are d -separated by S if all paths between X_i and X_j are blocked by S .

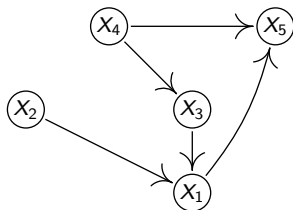
Check, whether all paths blocked!!



Definition: d -separation

X_i and X_j are d -separated by S if all paths between X_i and X_j are blocked by S .

Check, whether all paths blocked!!



$\circ \dots \rightarrow \textcolor{green}{\circ} \rightarrow \dots \circ$ blocks a path.

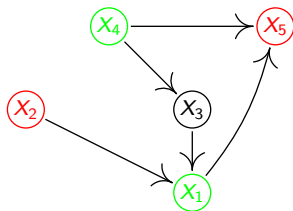
$\circ \dots \leftarrow \textcolor{green}{\circ} \rightarrow \dots \circ$ blocks a path.

$\circ \dots \rightarrow \circ \leftarrow \dots \circ$ blocks a path.

Definition: d -separation

X_i and X_j are d -separated by S if all paths between X_i and X_j are blocked by S .

Check, whether all paths blocked!!



○ ... → ● → ... ○ blocks a path.

○ ... ← ● → ... ○ blocks a path.

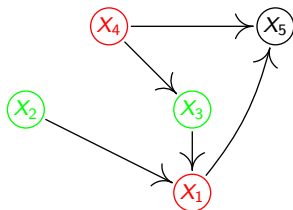
○ ... → ○ ← ... ○ blocks a path.

X_2 and X_5 are d -sep. by $\{X_1, X_4\}$

Definition: d -separation

X_i and X_j are d -separated by S if all paths between X_i and X_j are blocked by S .

Check, whether all paths blocked!!



○ ... → ● → ... ○ blocks a path.

○ ... ← ● → ... ○ blocks a path.

○ ... → ○ ← ... ○ blocks a path.

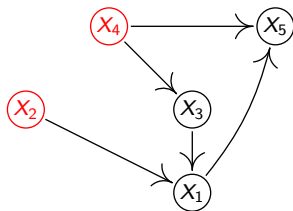
X_2 and X_5 are d -sep. by $\{X_1, X_4\}$

X_4 and X_1 are d -sep. by $\{X_2, X_3\}$

Definition: d -separation

X_i and X_j are d -separated by S if all paths between X_i and X_j are blocked by S .

Check, whether all paths blocked!!



○ ... → ● → ... ○ blocks a path.

○ ... ← ● → ... ○ blocks a path.

○ ... → ○ ← ... ○ blocks a path.

X_2 and X_5 are d -sep. by $\{X_1, X_4\}$

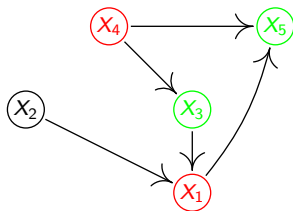
X_4 and X_1 are d -sep. by $\{X_2, X_3\}$

X_2 and X_4 are d -sep. by $\{\}$

Definition: d -separation

X_i and X_j are d -separated by S if all paths between X_i and X_j are blocked by S .

Check, whether all paths blocked!!



○ ... → ○ → ... ○ blocks a path.

○ ... ← ○ → ... ○ blocks a path.

○ ... → ○ ← ... ○ blocks a path.

X_2 and X_5 are d -sep. by $\{X_1, X_4\}$

X_4 and X_1 are d -sep. by $\{X_2, X_3\}$

X_2 and X_4 are d -sep. by $\{\}$

X_4 and X_1 are NOT d -sep. by $\{X_3, X_5\}$

Hand-written notes 2