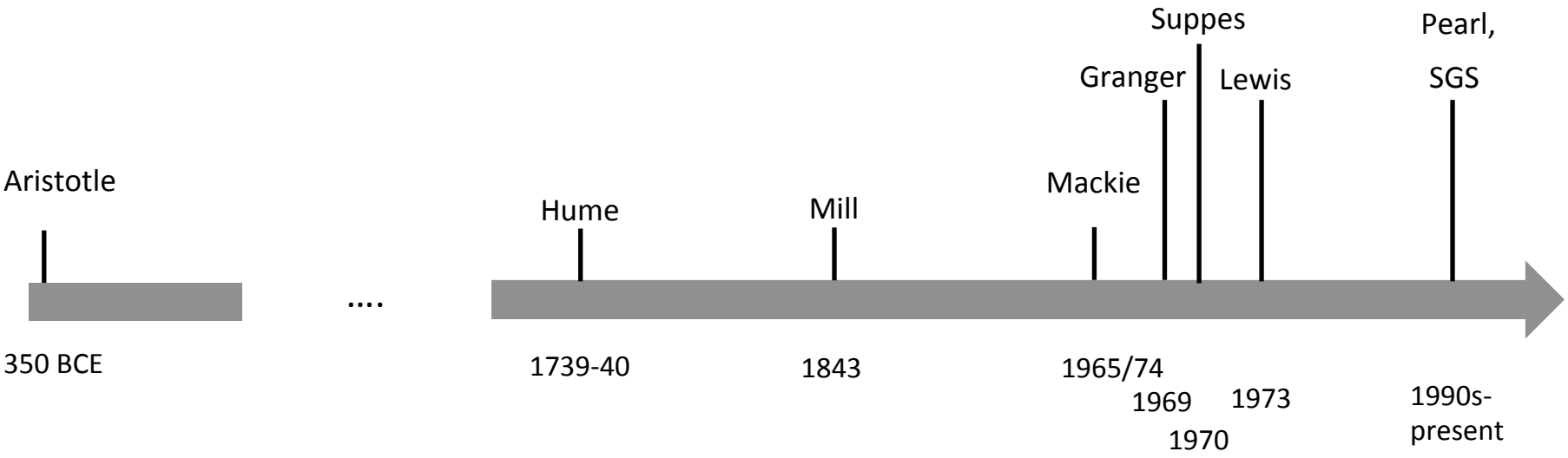
Causal Inference: prediction, explanation, and intervention

Lecture 2: Regularities, counterfactuals and token causality

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Three topics today

- Regularities: effect always/usually follows cause
- Counterfactuals: how would things have been if the cause hadn't happened
- Token causality: what caused a particular event


Aristotle
....
Hume
Mill
Mackie
Granger
Suppes
Lewis
Pearl,
SGS
350 BCE
1739-40
1843
1965/74
1969
1970
1973
1990s-
present

Aristotle: four causes

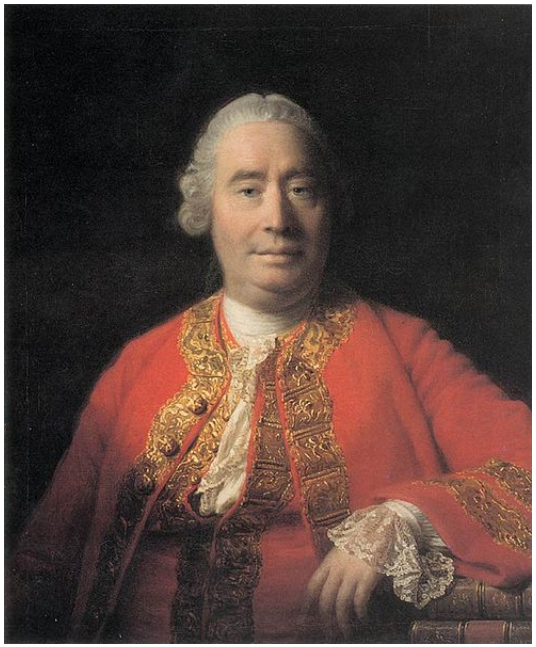
- Material: what something is made of
  - Components of my laptop
- Formal: what it means to be something
  - Laptop is a portable computer
- Efficient: source/producer of the thing
  - How apple transforms the materials into a laptop
- Final: the purpose for doing something
  - Bought a laptop to make lecture slides

Hume

Two questions:

1) What *is* a cause?

2) How can we *identify* causes?



Hume's impact

"…when I assert "Every event of class A causes an event of class B," do I mean merely, "Every event of class A is followed by an event of class B," or do I mean something more? Before Hume, the latter view was always taken; since Hume, most empiricists have taken the former."

Bertrand Russell. Human Knowledge: Its Scope and Limits. Simon and Schuster, 1948, page 454.

Broad idea

- C causes E if every event of type C is followed by another of type E
- Billiard balls
  - One ball hits another and causes it to move
  - See all objects of similar type (ball) hit other objects of type (ball), where the second then begins to move

Regularity vs. Necessity

- Day and night
- Ice cream and warm weather
- Thunder and lightning
- Dead grandmothers and exams

- HIV and AIDs
- Oxygen and a lit match
- Running for president and becoming president

Regularities and experience



Hear noise

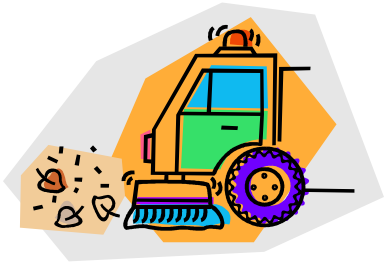
Past experience leads to expectation



Go to window to verify



Prediction was false

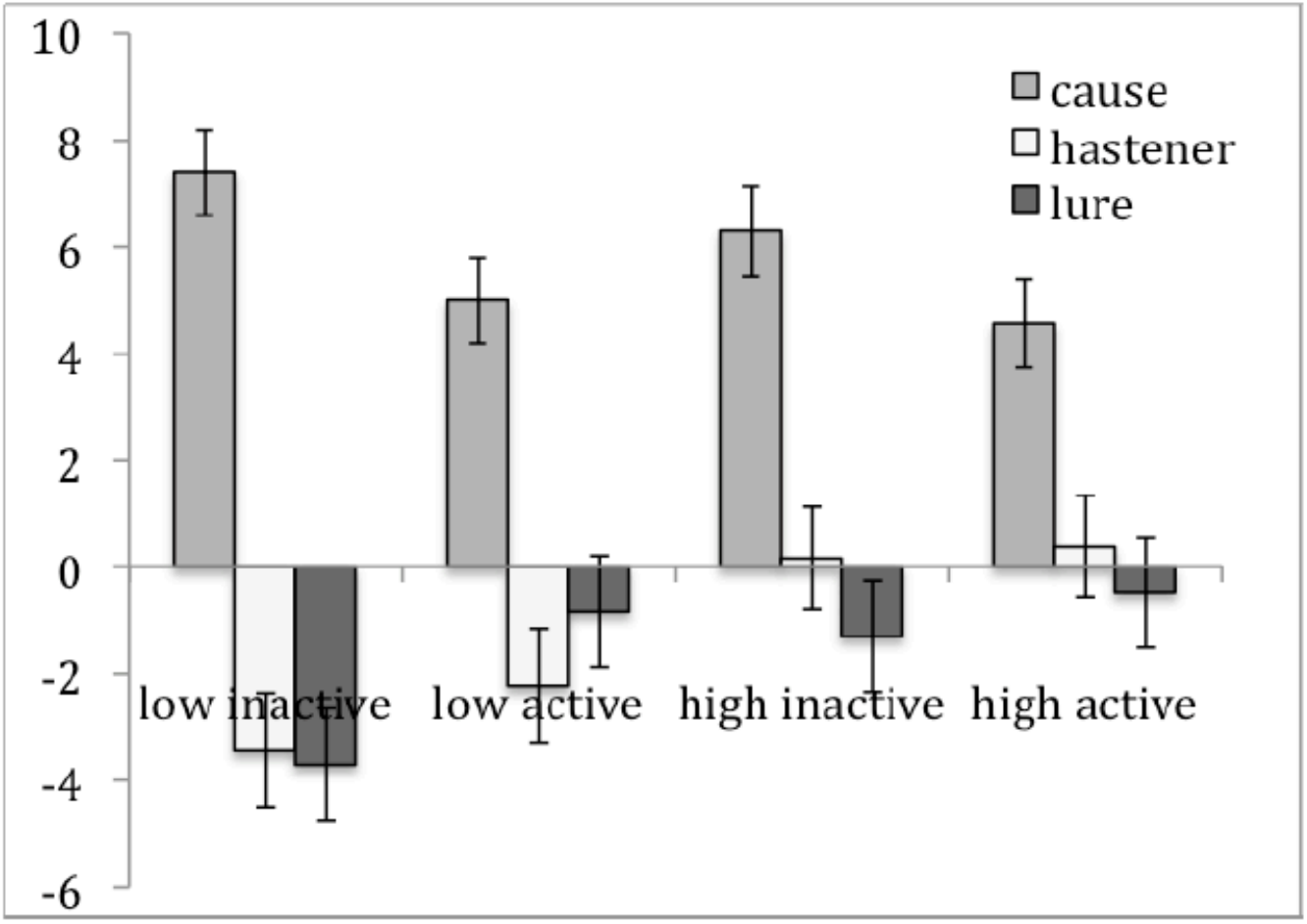


Only with empirical evidence, can we make and test predictions

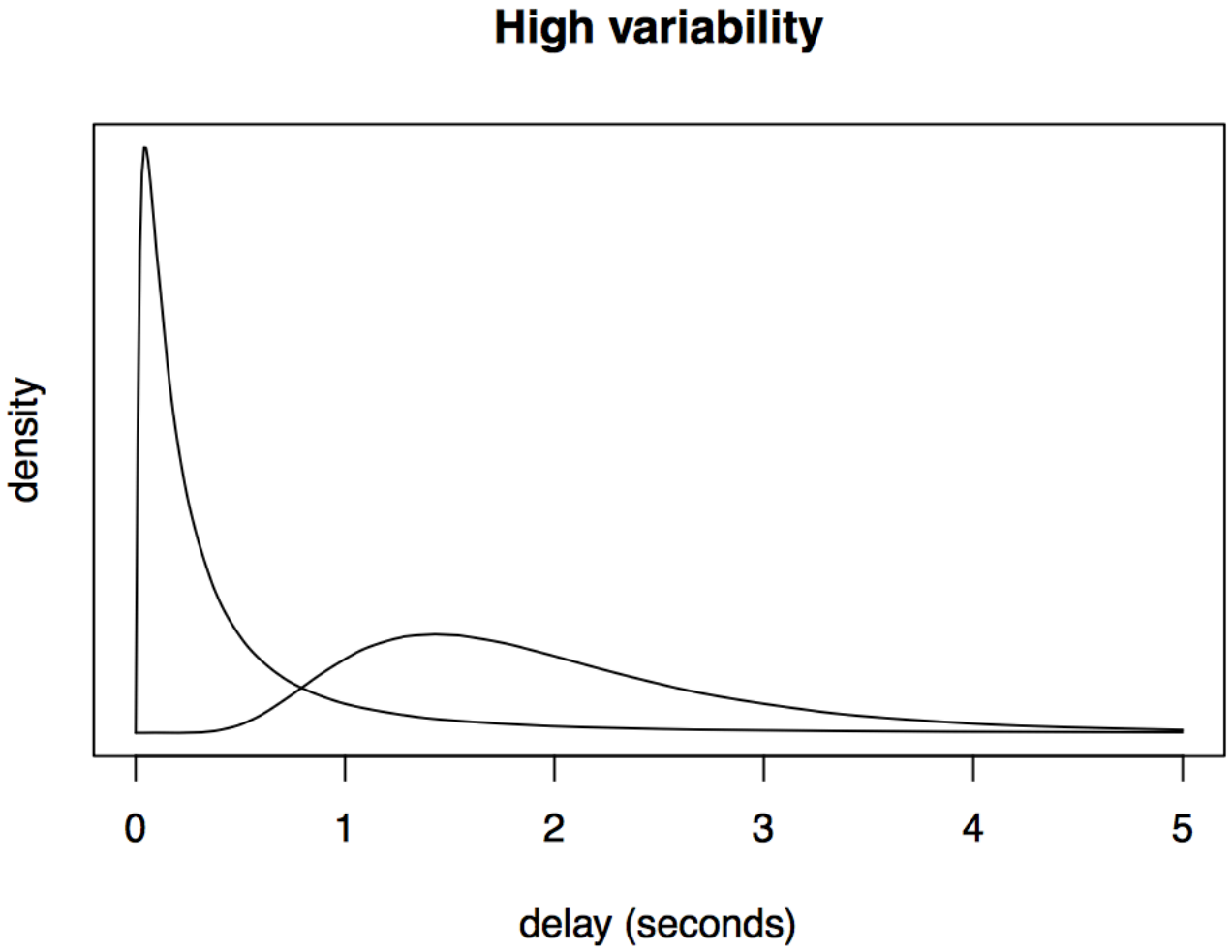
Contiguity

- C and E nearby in time/space
  - Being bitten by a mosquito and seeing a welt develop
  - Taking aspirin, headache better 24 hours later

Contiguity and psychology



Lagnado, D. A., & Speekenbrink, M. (2010). The influence of delays in real-time causal learning. *The Open Psychology Journal*, *3*(2), 184-195


High variability
density
0
1
2
3
4
5
delay (seconds)

Problems with contiguity

- Longterm causal processes
  - Childhood trauma, aggression as adult
  - Smoking and lung cancer
  - Tax policy and job growth
- Remote causes
- Absences
  - Not watering a plant and it dying

Temporal priority

- Cause not just near same time but also earlier than effect
- Consistent with psychological work (Lagnado & Sloman)

Lagnado, D. A., & Sloman, S. A. (2006). Time as a guide to cause. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*(3), 45

Problems with temporal priority

- Simultaneous causation (electron pairing)
- Reverse causation
- Delays
- Observation artifacts (gun firing, flash, loud noise)

Necessary connection

- Effect always follows from cause
- Effect is not produced without cause

- C→E and E→C
  - not E or C AND not C or E
  - Thus, (not E and not C) or (C and E)

Problems with necessary connection

- Multiple causes of an effect
  - Different ways of getting lung cancer, smoking not necessary
- Probabilistic causes
  - Not every smoker gets lung cancer

Theory vs empiricism

Theoretical definition

- Contiguity
- Temporal priority
- Necessary connection

Empirical definition

- Contiguity
- Temporal priority
- Constant conjunction

Hume, empirical definition of cause

An object precedent and contiguous to another, and where all the objects resembling the former are placed in a like relation of priority and contiguity to those objects that resemble the latter.

Hume 1739, 172

Counterexamples to Hume recap

- Contiguity: absences and omissions
- Temporal priority: electron pairing
- Constant conjunction: Tide the Hudson and Traffic on the West Side Highway
- Resemblance: jet lag, but only going west

Regularities

- Why is Hume's theory insufficient?
- How do we distinguish between patterns and causality?
- What about complex causes?
  - Environment+genetics

- After a hack-a-thon, many of the hackers become ill. What happened?









- What's the **same** in all cases when effect happens?
- What's **difference** between when effect happens and doesn't?
- How does effect's **magnitude** vary with magnitude of cause?

Agreement

What do instances of the effect all have in common?

					Headache
Alan	X	X	X	X	Yes
Betty	X		X	X	No
Carl		X		X	Yes
Diane			X	X	Yes

Agreement

What do instances of the effect all have in common?

					Headache
Alan	X	X	X	X	Yes
Betty	X		X	X	No
Carl		X		X	Yes
Diane			X	X	Yes

This is also necessity

Difference

- What's different when effect occurs and does not?

					Fatigue
Ethan	X	X	X	X	Yes
Fran	X	X	X	X	Yes
Greg	X	X		X	No
Hank	X	X	X	X	Yes

Difference

- What's different when effect occurs and does not?

					Fatigue
Ethan	X	X	X	X	Yes
Fran	X	X	X	X	Yes
Greg	X	X		X	No
Hank	X	X	X	X	Yes

This is also sufficiency

Joint method

Combining agreement and difference

					Upset stomach
Alan	X	X	X	X	Yes
Betty	X		X		Yes
Carl		X		X	No
Diane			X	X	No

Both necessity and sufficiency

Joint method

Combining agreement and difference

					Upset stomach
Alan	X	X	X	X	Yes
Betty	X		X		Yes
Carl		X		X	No
Diane			X	X	No

Both necessity and sufficiency

Residues

- Say we know that staying up late causes fatigue

					Fatigue	Upset stomach
Alan	X	X	X	X	X	Yes
Betty	X		X		X	Yes
Carl		X		X		No
Diane			X	X	X	No

Residues

- Say we know that staying up late causes fatigue

					Fatigue	Upset stomach
Alan	X	X	X	X	X	Yes
Betty	X		X		X	Yes
Carl		X		X		No
Diane			X	X	X	No

Concomitant variation

Alan		5lbs
Betty		1lb
Carl		6lbs
Diane		8lbs

Mill's Methods recap

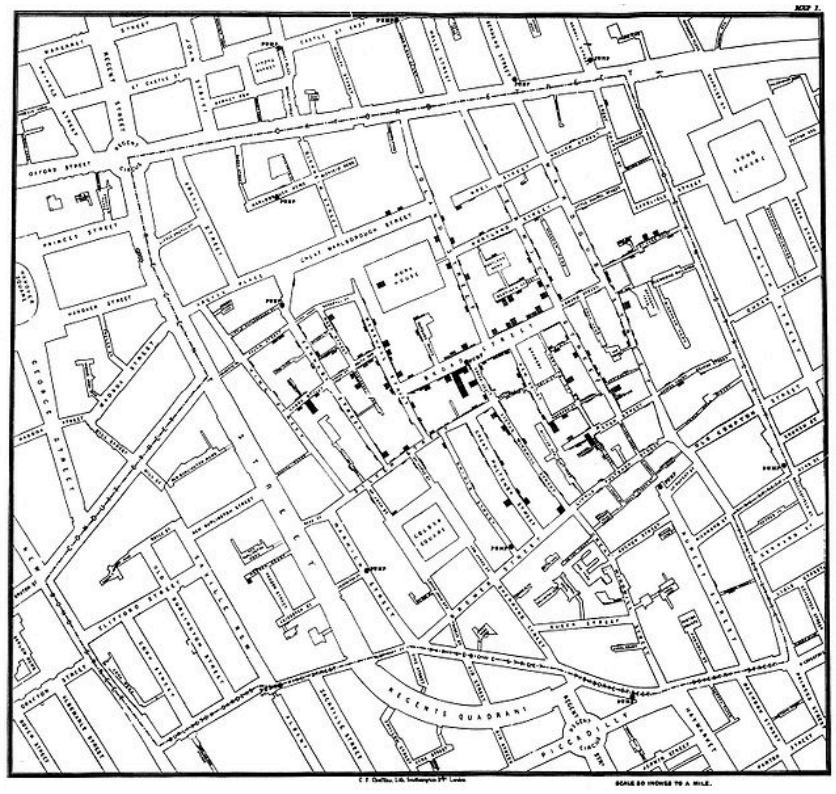
- **Agreement**: what is common in all cases where effect occurred
- **Difference**: what is different between cases where effect occurred and did not occur
- **Joint method of agreement and difference**
- **Concomitant variations**: look at degree of cause and how it relates to degree of effect
- **Residues**: deduce cause in cases with multiple causes and multiple effects

Problems with Mill's methods

- Probabilistic relationships
- Complex relationships
  - Multiple factors in common
- Multiple causes of effect
- Unmeasured cause
- Only states that there are at least two or more instances, and relationship must hold in all cases
  - If many cases for relationship, two against, then it won't be found

Cholera

- Cholera epidemic, no certainty about how the disease spreads – pollution, water, etc
- 1854 London: some areas much worse than others, but why?



Cholera deaths by area 1853-4

Location	# houses	Cholera deaths	Death per 10K houses
Southwark & Vauxhall Company	40,046	1263	315
Lambeth Company	26,107	98	37
Rest of London	256,423	1422	59



John Snow

On proceeding to the spot, I found that nearly all the deaths had taken place within a short distance of the [Broad Street] pump. There were only ten deaths in houses situated decidedly nearer to another street-pump. In five of these cases the families of the deceased persons informed me that they always sent to the pump in Broad Street, as they preferred the water to that of the pumps which were nearer. In three other cases, the deceased were children who went to school near the pump in Broad Street…

With regard to the deaths occurring in the locality belonging to the pump, there were 61 instances in which I was informed that the deceased persons used to drink the pump water from Broad Street, either constantly or occasionally…

The result of the inquiry, then, is, that there has been no particular outbreak or prevalence of cholera in this part of London except among the persons who were in the habit of drinking the water of the above-mentioned pump well.

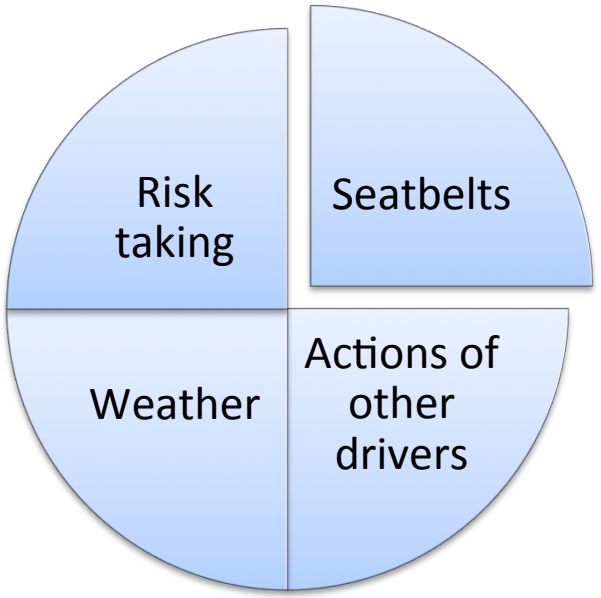
I had an interview with the Board of Guardians of St James's parish, on the evening of the 7th inst [Sept 7], and represented the above circumstances to them. In consequence of what I said, the handle of the pump was removed on the following day.

—John Snow, letter to the editor of the *Medical Times and Gazette*

- Seatbelts have been shown to reduce the likelihood that someone in a car accident will die
- Paradoxically, after introduction of seatbelts the number of car accident deaths does not decrease and in some cases actually increases

Regularities - Mackie

- Multiple causes for an effect
- Multiple components of each cause
  - Making sure each really required, not just associated with others



Some definitions

- Necessary condition: whenever E occurs, C occurs
- Sufficient condition: whenever C occurs, E occurs

INUS condition

A cause is an insufficient (I) but non-redundant (N) part of an unnecessary (U) but sufficient condition (S)

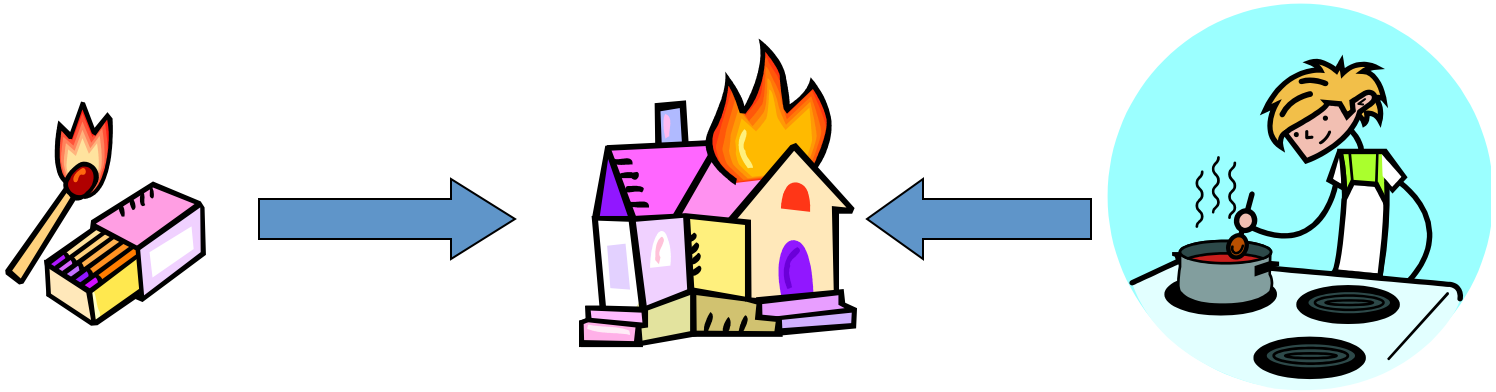
INUS conditions

C is an INUS condition of E iff for X, Y: (C^X)v Y is necessary and sufficient condition of E, but C is not sufficient, and X is not sufficient

- C ^ X is sufficient for E
- C ^ X is not necessary for E
- C may be insufficient by itself
- C is non-redundant part of C ^ X

INUS example

- Lit match (C) may cause house fire (E)
- Many cases where lit match does not cause fire
- Many cases of fire without lit match (Y)
- For lit match to cause fire, need oxygen, flammable materials, etc. (X)



C E y

INUS conditions summary

- X are conditions needed for C to cause the effect
- Y is a set of sufficient conditions for E
- C is INUS condition of E iff:
  - For some X and some Y (CX or Y) is necessary and sufficient condition of E
  - C is not a sufficient condition of E
  - X is not a sufficient condition of E
- There are sets of conditions that result in effect, cause is necessary part of one of those sets.

Some more definitions

- **Minimal sufficient condition**: A^B^C is a minimal sufficient condition for E if it's sufficient and no subset is sufficient
- **At least an INUS condition**: C is at least an INUS condition of E iff either C is an INUS condition or a minimum sufficient condition or C is a necessary and sufficient condition or C is part of a necessary and sufficient condition

- Are all causes INUS conditions?
- Are all INUS conditions causes?

Problems for INUS

- Insufficient to rule out spurious relationships
  - Common cause of two effects
  - Chance regularities
- Strength of contribution
- Relative nature

Murder mystery

- June 27, 2005: A sleepwalker, Benjamini Adoyo goes to sleep disorder clinic. Had been wandering through house, and sometimes shaking his wife while standing over her and babbling. He had no memory of these episodes.
- August 10, 2005: After sleep study, center says he has non-REM parasomnia.
- October 17, 2005: Visits clinic again. Medication increased.
- October 19, 2005: Adoyo is arrested and charged with killing his wife

- In general, parasomniacs can kill people with no intention, awareness or memory of committing the crime
- Is it murder or a result of his sleep disorder?

The Case of the Sleeping Slayer. Scientific American, September 2012, p 34-39.

Sleepwalker or murderer?

- 911 call, 3:41 am October 19, 2005

  Operator: What's going on?
  Adoyo: You just get here
  Operator: You need to tell me what's going on.
  Adoyo: Somebody is dead
  Operator: Somebody is dead?
  Adoyo: Yes.
  Operator: Where are they at?
  Adoyo: In their house. Somebody is dead. Get here.

- Confessed, but was confused and asked about wife's welfare
- Core question: parasomnia was known prior to incident, but was it the cause of wife's murder?

The verdict

- Wasn't nearby wife (proximity is important)
- Usually no motive, but had been arguing with wife
- Assaulted wife in bedroom with hammer, chased into hall & bathroom, stabbed and strangled her
- Unusual to see so many mechanisms at once
- Adoyo pled guilty to second degree murder

Token causality

- What happens in general, versus what happened in a particular instance
  - Parasomnia causing murder, versus parasomnia causing murder of Adoyo's wife
- Why do we need to talk about it separately?

Mackie on token causality

- Analyzing C as cause of event E on particular occasion:
  - C is at least an INUS condition of E
  - C was present on the occasion
  - Components of X were present
  - Every disjunct in Y that doesn't contain C as a conjunct was absent on the occasion

House fire

- Did a lit match cause a fire?
- Only if
  - Lit matches cause fires
  - Present
  - Other needed conditions present
  - No other factors causing fires present

Problems for Mackie on singular causality

- Overdetermination
  - If multiple causes present, can't analyze them
- Preventer/producer

Counterfactuals

- How do we distinguish between things that are necessary in that they are required for the effect, and those that just co-occur?
- Had things been different, what would have happened?

Counterfactual approach

- Remember Hume:
  - An object, followed by another, and where all the objects similar to the first are followed by objects similar to the second (regularity)
  - If first object had not been, second never would have existed (counterfactual definition)

Counterfactuals and Hume

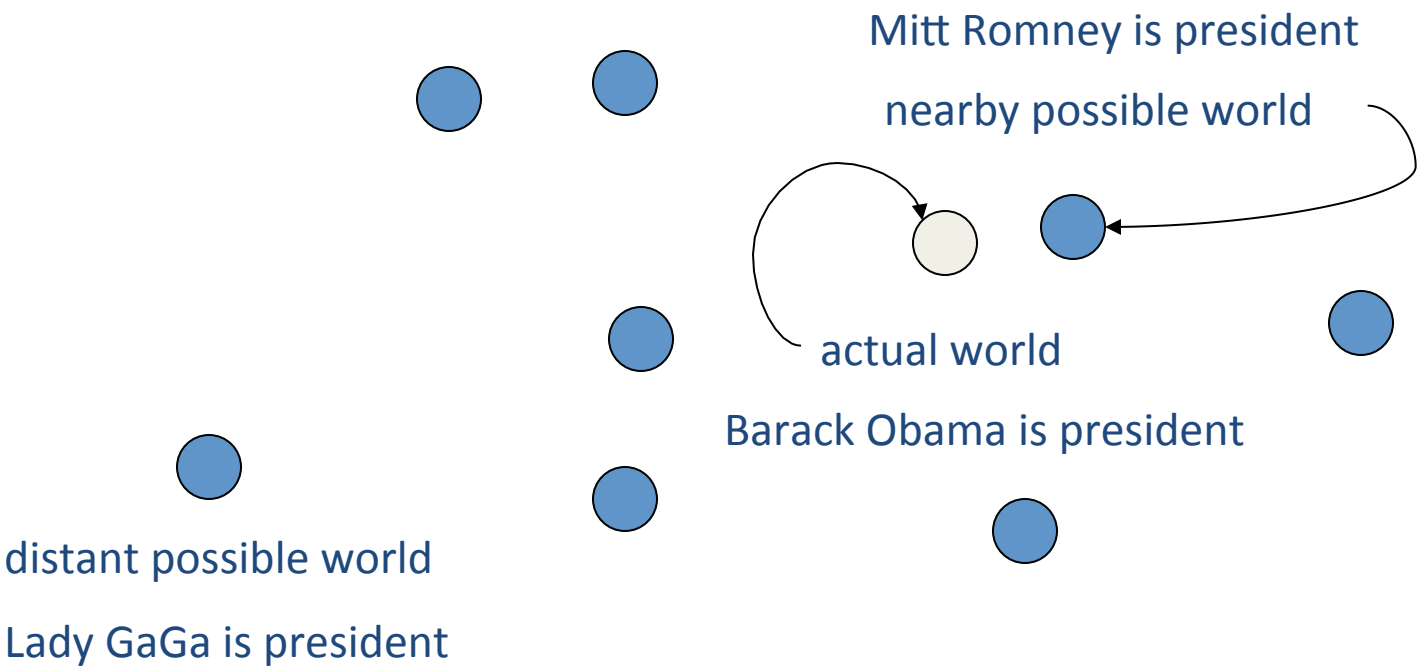
- Day as a cause of night. Meets all three conditions
- Definition (1): if use only first part of definition, still have correlation between day/night
- Definition (2): removes causal connection between day/night. If day had not been, night would still exist

Counterfactual (basic idea)

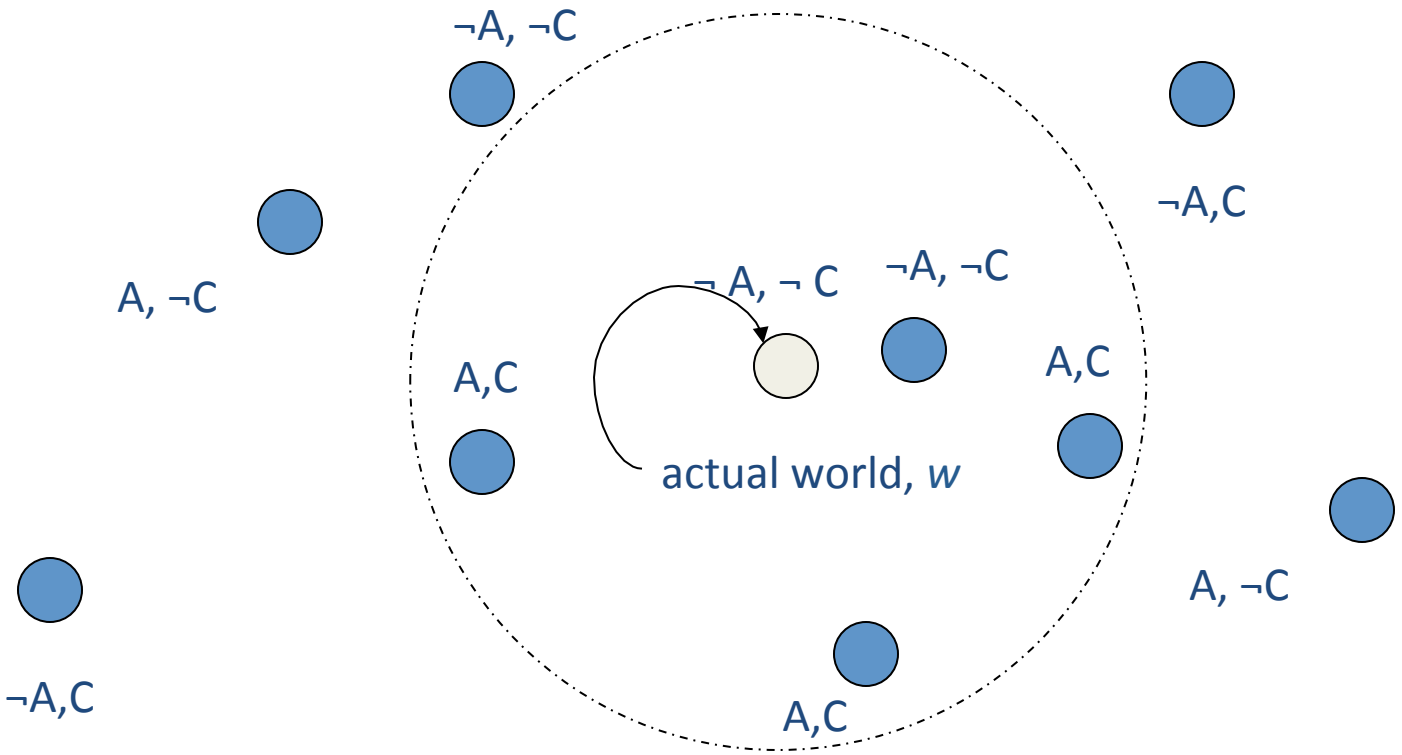
- Had C not have happened, E would not have either
- Ex: umbrella vendors and rain


TV
PG
DL

Lewis: possible worlds



Comparing possible worlds



A-worlds where C holds are closer to *w* than A worlds where C doesn't hold

Counterfactual (definition)

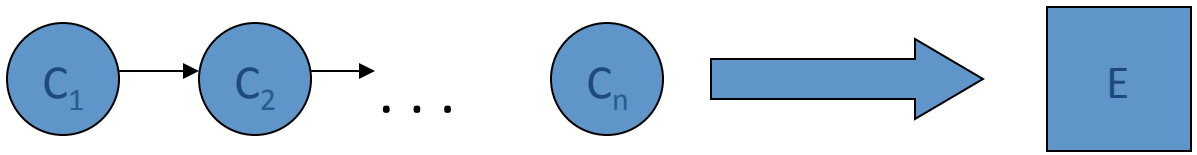
- Counterfactual of two propositions A and C:
  - A$\Box\!\!\rightarrow$C: if A was true, C would be true
  - Truth condition: A$\Box\!\!\rightarrow$C is true (in actual world w) iff:
    - No possible A-worlds (vacuous case) or
    - Some A-world where C holds is closer to w than is any A-world where C doesn't hold

Counterfactual dependence

- Had rock not been thrown at window, it would not have broken
- If I hadn't gone to Beijing, I wouldn't be jet lagged
- Had I worn sunblock, I would not have gotten a sunburn

Causal dependence between events

- Whether e depends on whether or not c
- Represented by: $c \mathrel{\Box\!\!\rightarrow} e$ and $\neg c \mathrel{\Box\!\!\rightarrow} \neg e$
- If each c_i depends causally on c_{i-1} and e depends causally on c_n, then c_1 is a cause of e



Causal chains

- Previous example was a chain of causes
- Causal relationship is transitive
  - Dependence relationship doesn't have to be
- e may still have occurred without c_1

- **Definition**: c is a cause of e if e is causally dependent on c or if there is a chain of causal dependence between c and e.

Rasputin

Rasputin was led to a cellar and served cake and wine laced with cyanide – enough poison to kill 5 men.

This failed, so he was shot in the back.

Once again Rasputin survived…only to be shot again.

They then bound him and threw him in an icy river.

He escaped the bonds, but drowned.

What caused his death?

Problems with counterfactuals: transitivity

- Al gives Jones CPR(C), without which he would have died
- Jones recovers, and flies to New York(F), where he has a violent death (D).
- C is cause of F, F is a cause of D
- But, C did not cause D: whether or not C happened, Jones would have died.
- There is a **causal chain** between C and D

- $C \mathrel{\square\!\!\rightarrow} F$
- $F \mathrel{\square\!\!\rightarrow} D$
- Thus, $C \rightarrow D$

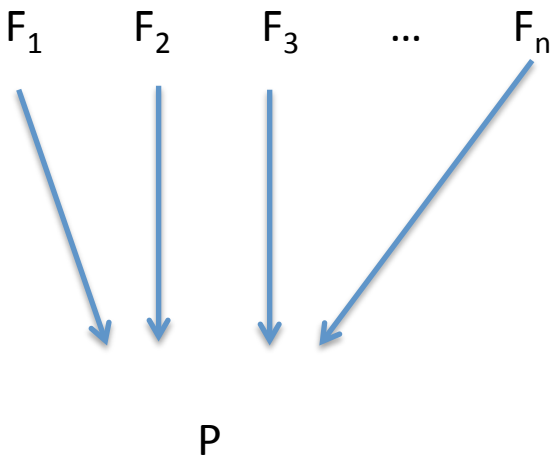
- Not:
- $C \mathrel{\square\!\!\rightarrow} F$
- $F \mathrel{\square\!\!\rightarrow} D$
- Thus, $C \mathrel{\square\!\!\rightarrow} D$

Types of redundant causation

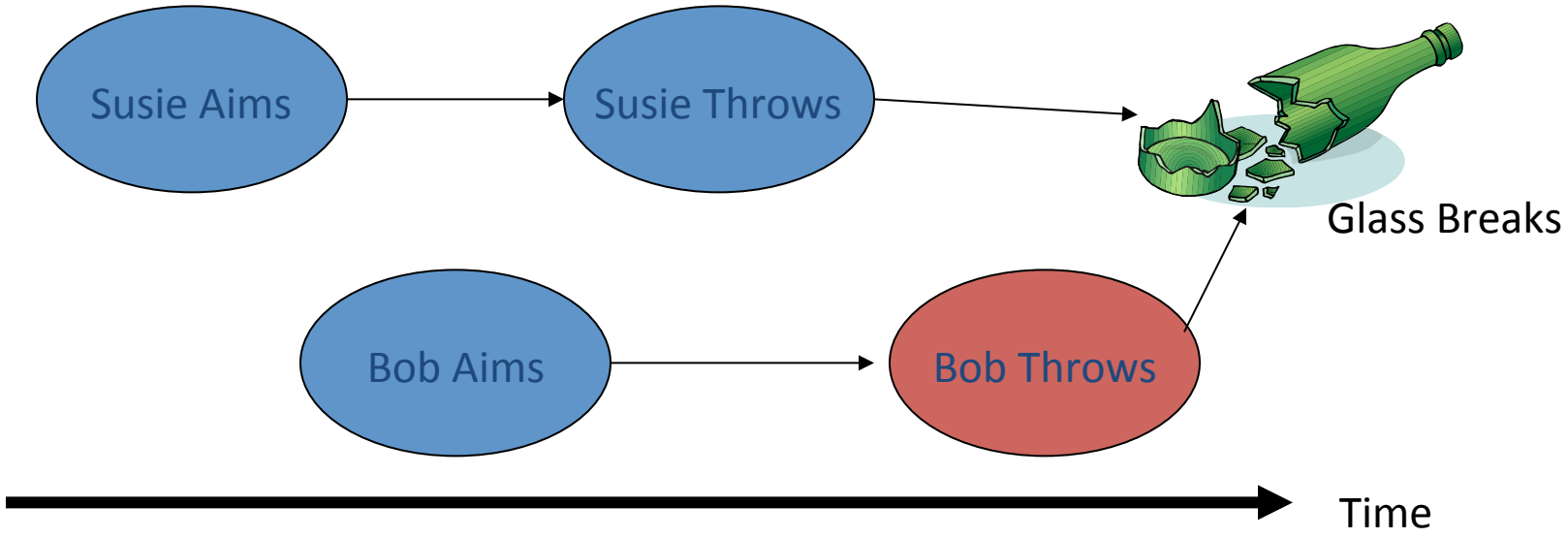
- Overdetermination
  - Multiple causes occur, any could have caused effect
- Preemption
  - (early) Two or more causal processes begin but only one completes and produces effect
  - (late) Two or more processes run to completion but only one is responsible for effect

Problems with counterfactuals: overdetermination

- Firing squad



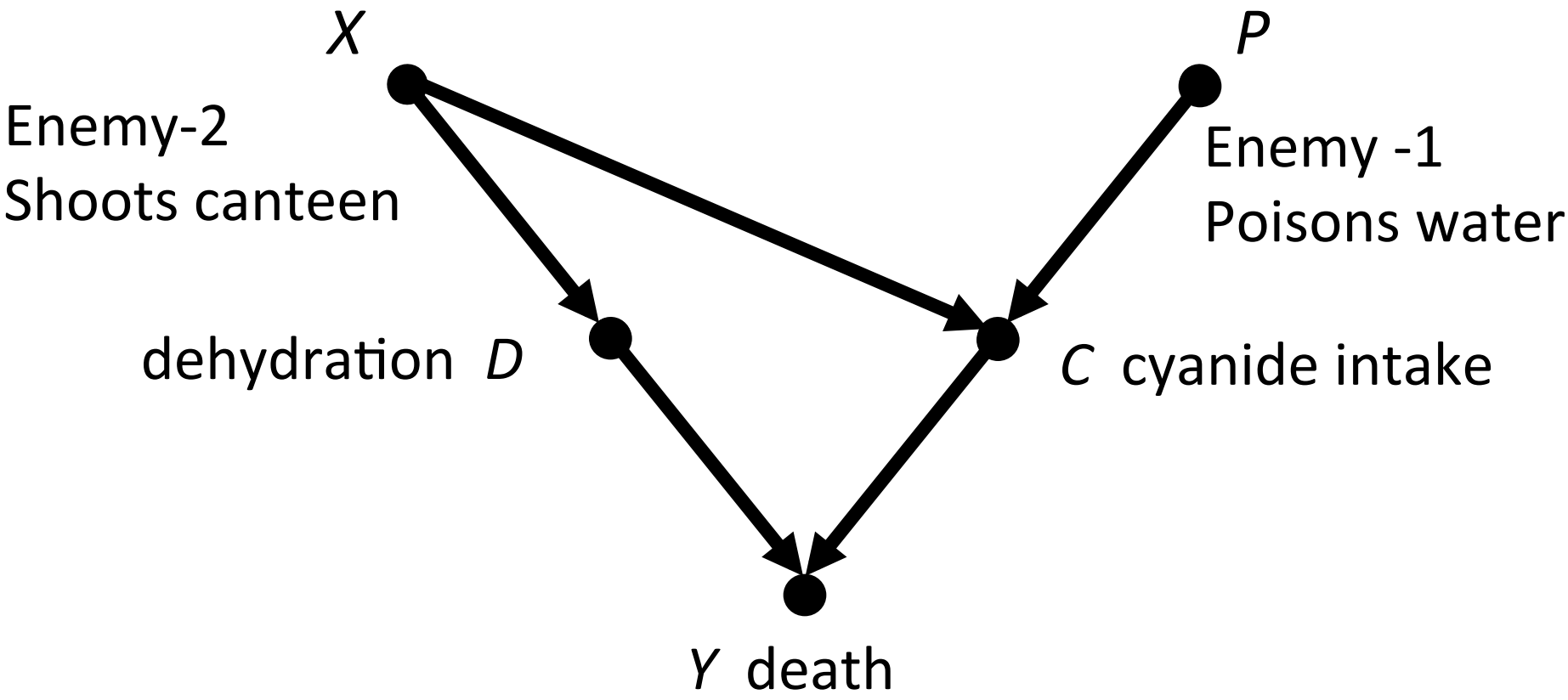
Problems with counterfactuals: late preemption



Problems with counterfactuals: late preemption

- Troponin levels are used as markers for cardiac injury
  - Raised in hours after a heart attack
  - Also raised due to endurance exercise
- Ben runs a marathon Sunday, has a silent heart attack Tuesday, and his doctor finds he has elevated troponin levels Thursday

Problems with counterfactuals: late preemption



Problems with counterfactuals: early preemption

- Early preemption = backup causes
- Bob and Susie take turns
- Gene produces phenotype, silences backup gene

Examples?

- Transitivity
- Overdetermination
- Early preemption
- Late preemption

Lewis's update

- "Whether" an event occurs is too strict
- Really want to know cause made a difference to how & when it occurred
- New definition: Where *c* and *e* are distinct events, *c influences e* if and only if there is a substantial range of *c*1, *c*2, … of different not-too-distant alterations of *c* (including the actual alteration of *c*) and there is a range of *e*1, *e*2, … of alterations of *e*, at least some of which differ, such that if *c*1 had occurred, *e*1 would have occurred, and if *c*2 had occurred, e2 would have occurred, and so on.

Alterations

- Bob and Susie
  - Altering Susie's throw changes breaking, but altering Bob's doesn't
- Desert traveler
- Early preemption
- Trumping
  - Sergeant and major give same order, which is being obeyed?

For next time

The probability of death (D) within 30 minutes of poisoning (O) is 0.8

But if an antidote (A) is given within 10 minutes of poisoning, the probability of death is reduced to 0.001

However the antidote has occasional side effects, so the probability of death when an antidote is given in the absence of the poison is still 0.001

Is O a cause of death? Is A?

Read CPT Sections 2.3