Causal models for syntacticians and semanticists

Bridget Copley, SFL (CNRS/Paris 8)
bridget.copley@cnrs.fr

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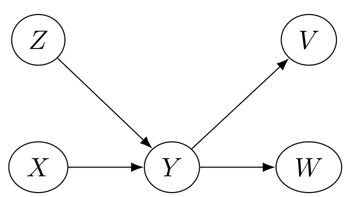
Converging On Causal Ontology Analyses (COCOA)
Mini-class: Thursdays May 6, 13, and 27 at 15h Paris time on zoom, students especially welcome.
Workshop: Thursday June 3 and Thursday June 10 19h-22h Paris time on zoom, with the participation of Rebekah Baglini, Elitzur Bar-Asher Siegal, and Prerna Nadathur among others, students especially welcome.
Monthly zoominar thereafter, dates to be announced.

1 Introduction



A causal model is a formal representation of the structure that causal relations give to (our conceptual model of) the world.

- Statistics vs. semantics
- In general, causal models provide **richer interpretations** for **simpler denotations** than what we may be used to in formal semantics.
- Since the denotations are simpler, and since the morphosyntax remains simple, **the syntax-semantics interface can be simpler**.

Can we hold our ontology lightly? Korzybski (1933):

A. A map may have a structure similar or dissimilar to the structure of the territory.

B. Two similar structures have similar 'logical' characteristics. Thus, if in a correct map, Dresden is given as between Paris and Warsaw, a similar relation is found in the actual territory.

C. A map is not the territory.

What can causal models help us with? Location in a causal chain, entrainment, generalizations over different kinds of causal relations, multiple influences, mediating influences, side effects,"The cause", "forward" and "backward" reasoning, ability, goal-directed action, dispositional causation, declining to act, conditionals, ...

2 What is a causal model?

For our purposes, a causal model is a **formal representation** of the **structure** that **causal relations** give to our **conceptual model** of the world.

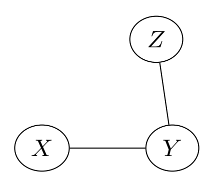
A causal model is NOT a theory of causation.

Causal structures are formally represented by means of a *directed acyclic graph* (DAG):

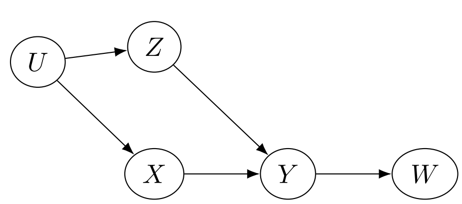
Pearl (2000), Pearl and Mackenzie (2018)

- There is a set V of variables that are the vertices (or nodes) of the graph.
- These are connected by a set of edges (or arrows) E.
- The edges are *directed* and represent the dependency of one value on another. For instance, Ⓐ → Ⓑ represents that the value of Ⓑ is dependent in some way on the value of Ⓐ.
- Absence of an edge between two variables means that the values are independent of each other.

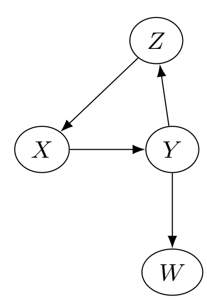
Compare (1) to a *non-directed* graph:



(1) U: season
({spring, summer, winter, fall})
X: sprinkler ({on, off})
Z: rain ({yes, no})
Y: wet ({yes, no})
W: slippery ({yes, no})



Compare (1) to a *cyclic* graph:



A plausible valuation for this model: U = summer, X = on, Z = no, Y = yes, W = yes.

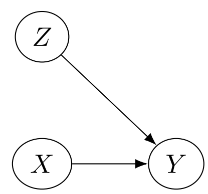
A valuation table:

U	X	Z	Y	W
summer	on	no	yes	yes
summer	off	no	no	no
summer	on	no	yes	yes
spring	off	yes	yes	yes
...	...	...	...	...

- Variables without arrows pointing at them are *exogenous* variables; their value depends only on circumstances that are not represented in the model. Variables with arrows pointing at them are *endogenous* variables.
- There is an asymmetry between exogenous variables and endogenous variables
- Numerical values of endogenous variables can often be expressed with an equation over the variables that point to it. When this is the case, we can call the model a "structural equation model".

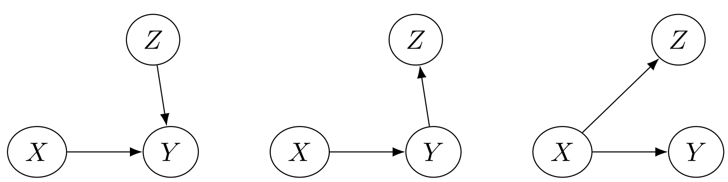
(2) X: force on object
Y: acceleration of object
Z: mass of object

$X \times Z = Y$



(3) Taxonomy of basic 3-node structures:

Collider Chain Fork



Exercise 1: Which scenario in (4) matches with which structure in (3)?

(4) a. X = Temperature of oven Y = Time bread has been in oven, Z = Reading of thermometer in bread
b. X = Dose in mg of medication 1, Y = Blood pressure, Z = Dose in mg of medication 2
c. X = Age of child, Y = Child's shoe size, Z = Score on reading test

Probabilities can also be used.[1]

(5) X = the probability of having been vaccinated, Z = the probability of having the virus, Y = the probability that this person has the virus

For our purposes at the moment, it will be useful to consider the variable values the truth values of propositions: $\{1, 0\}$.

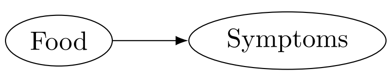
Exercise 2: Which scenario in (6) matches which structure in (3)?

(6) a. $X = [\![$Mary gives John a book$]\!]$, $Y = [\![$John is happy$]\!]$, $Z = [\![$The book is in John's possession$]\!]$
b. $X = [\![$Mary throws the basketball$]\!]$, $Y = [\![$The wind blows hard on the basketball$]\!]$, $Z = [\![$The basketball goes in the basket$]\!]$
c. $X = [\![$Mary wants to write$]\!]$, $Y = [\![$Mary has a writing implement$]\!]$, $Z = [\![$Mary writes$]\!]$

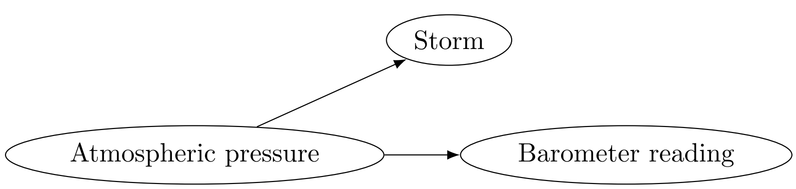
[1] This use of causal models is very common now in the sciences. You may hear about *Bayes' rule* and *the Markov condition* with respect to probabilistic causal models, but we don't need to talk about those today.

2.1 Intervention

(7)



(8)



Pearl (2000); Woodward (2006)

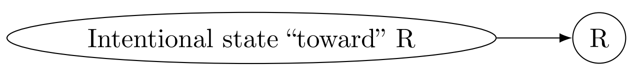
(9) $do(X = x)$: Set the value of X to x and erase all arrows that point to X.

3 Using causal models in semantics

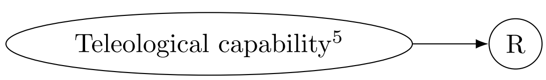
3.1 Causal relations

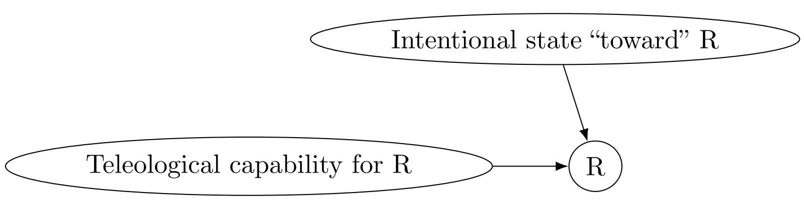
The arrows are NOT to be read as CAUSE,[1]
***leads to*,[2] material implication,[3]**
or Talmian forces.[4]
The arrows ARE to be read as
"the value of (A) affects the value of (B)",
"the value of (A) influences the value of (B)", or
"the value of (B) listens to the value of (A)".

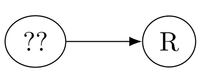
(10) *vaccinate*



(11) *break*







How do we represent causal verbs such as *prevent* and *enable*? We will need to notate whether an influence is "toward" a result or "away from" a result.

Talmy (1976, 1988, 2000), Wolff and Song (2003); Wolff (2007)

[1] See, e.g., Dowty (1979).

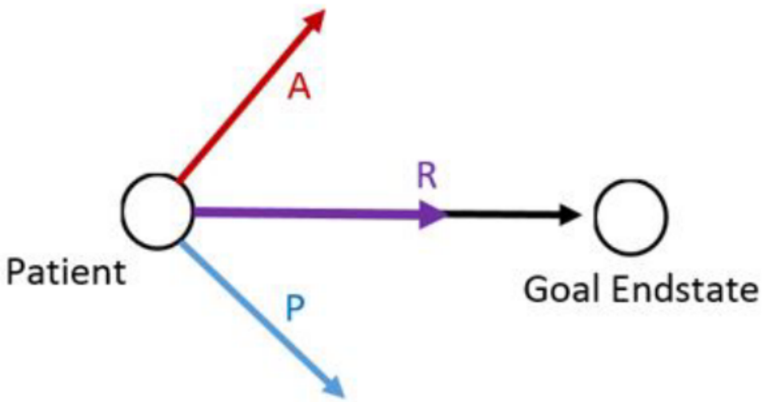
[2] See Ramchand (2008).

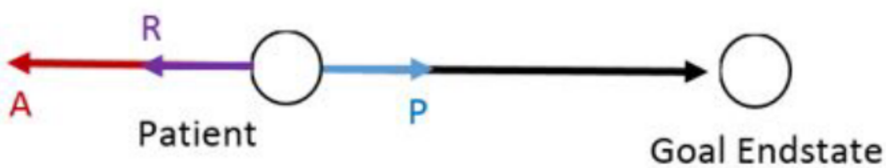
[3] Material implication:

P	Q	$P \Rightarrow Q$
1	1	1
1	0	0
0	1	1
0	0	1

[4] For Talmy (1976, 1985, 2000) *prevent*, e.g., is modeled by using two forces in opposition. Here we can instead model an inhibition of a state (even perhaps a prevention) with a single arrow.

[5] Teleological capability for R: Folli and Harley (2008)





Where we have $\textcircled{X} \rightarrow \textcircled{Y}$ and where when X increases, Y increases, let's call this a "+" or *excitatory* edge:

X	Y
1	.1
2	.2
3	.3
4	.4

X	Y
.5	1
.78	1.3
.9	1.5
1.5	2.3

X	Y
1	1
0	0

Where we have $\textcircled{X} \rightarrow \textcircled{Y}$ and where when X increases, Y decreases, let's call this a "-" or *inhibitory* edge:

X	Y
1	.1
2	.01
3	.001
4	.0001

X	Y
.0006	55,679
.0008	16,450
.0010	9611
.0012	5001

X	Y
1	0
0	1

Exercise 3: Supposing we are using truth values, if Ⓐ → Ⓑ, does a B=1 event occur? If your answer is no, what needs to be the case to guarantee that a B=1 event occurs?

Exercise 4: How would you represent *enable* and *prevent*?

See also Lauer and Nadathur (2017) for *cause* and Baglini and Siegal (2019) for jointly sufficient conditions.

3.2 Times

There is NO representation of time in a causal model.

Forks do NOT represent branching time.
Forks represent multiple effects of a single cause.

However... there *is* a representation of time in grammar. So we need to somehow get a *network* (the causal structure) to talk to a *line* (the timeline, represented in language). Note that syntax is also basically a line, at least in oral-auditory language.

3.3 Events, situations, and possible worlds

The variables are NEITHER events NOR situations.
They ARE *variables* that have *values*.
$X = x$ sort of corresponds to an eventuality or a situation.

Possibilia/possible scenarios/worlds/situations (?) correspond to lines in the valuation table

U	X	Z	Y	W
summer	on	no	yes	yes
summer	off	no	no	no
summer	on	no	yes	yes
spring	off	yes	yes	yes
...	...	...	...	...

(12) A node (e.g. Ⓐ) corresponds to a proposition evaluated at a situation (e.g. $P(s)$) which gets a truth value (from the set of values {1,0}).

Can we put the lines of the valuation table in a preferred order? Sure, why not (cf. Kaufmann (2012)).

4 How can causal models simplify our denotations?

4.1 We get the benefits of explicitly talking about causal relations

Quantification over atomic possible worlds[5] IS TO explicit causal relations

AS

Optimality Theory[6] IS TO transformational phonology

- Multiple influences (including "circumstances") no longer require quantification over atomic possible worlds.
- Multiple effects are easily representable.

[5] Kratzer (1981, 1991); Portner (2009)

[6] Prince and Smolensky (2008)

4.2 We get the benefits of talking about causation without talking about time

- Entrainment can be represented (Talmy, 2000; Copley and Harley, 2015; Filip, 2004)
- Causal influences do not have to happen in the same time/space/situation (contra Copley and Harley (2015))

4.3 We can easily represent goal-directed action

- Lauer and Condoravdi (2012); Kamp (2015); Grano (2016)
- We don't have to say how many events there are on the way to the goal (Tovena, 2010)

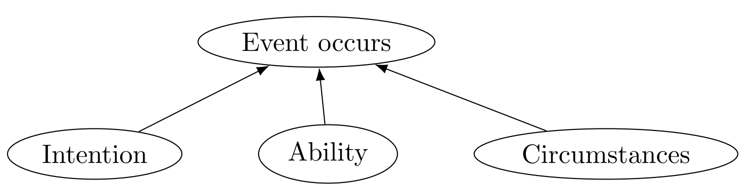
4.4 We get the benefits of assuming a closed world

- Having to do partitions on atomic possible worlds = the cost of not being able to assume a closed world!
- Suppose propositions P, Q, R are true only in the following worlds, and false in other worlds:
  $P(w_1) = 1$, $P(w_2) = 1$, $P(w_3) = 1$, $P(w_4) = 1$
  $Q(w_5) = 1$, $Q(w_6) = 1$, $Q(w_7) = 1$, $Q(w_8) = 1$
  $R(w_1) = 1$, $R(w_3) = 1$, $R(w_5) = 1$, $R(w_7) = 1$
- But suppose all we care about is whether P is true and whether Q is true.
- Then we should treat certain worlds as being the same for our purposes; this is a partition. | w_1w_2 | w_3w_4 | w_5w_6 | w_7w_8 |
- In a causal model, however, we can just make nodes out of P and Q (with arrows pointing from them to whatever we need them to point at) and then say that we have a closed world.[7]

[7] This discussion is related to an old question about whether possible worlds are atomic or constructed (Partee, 1977). See also "*ceteris paribus*" and "efficacy": Copley and Harley (2015); Louie (2015).

4.5 We get the benefit of talking about causal powers (abilities, dispositions)

- Abilities and dispositions are usually given a conditional representation
- Ability: If a tries to bring about ϕ then ϕ (Thomason (2005); see also Hackl (1998))
- Dispositions: An object is disposed to M when C iff it would M if it were the case that C (Fara, 2001)
- But it is a bit of a mystery why such basic concepts, that often have little to no morphology, have these big conditional meanings



- Causal models let us make sense out of their conditions as nodes in a set such that the nodes are jointly sufficient for something to happen (Baglini and Siegal, 2019)
- See also Baglini and Francez (2016); Nadathur (2021), and references therein for ability (and cf. Mari and Martin (2007))

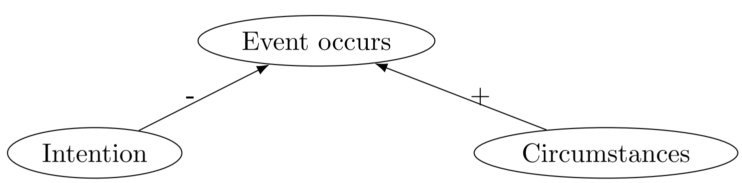
4.6 We get the benefits of the taxonomy of causal structures

4.6.1 Colliders

- *être en train de* (Copley and Roy, 2015)

(13) a. #Il est en train de pleuvoir.
it is in midst of rain-INF
intended: 'It's raining.'
b. Il est en train de pleuvoir sur notre pique-nique.
it is in midst of rain-INF on our picnic
'It's raining on our picnic.'

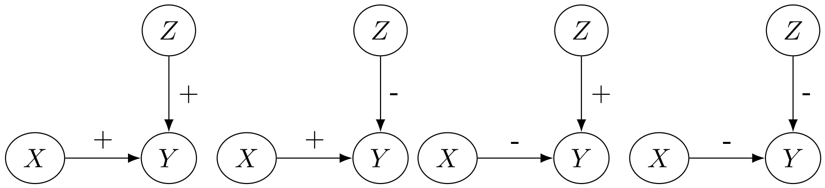
(14) a. Qu'est-ce que tu manges?
what is-it that you eat
'What are you eating?'
b. Qu'est-ce que tu es en train de manger?
what is-it that you are in midst of eat-INF
'What (the hell) are you eating?'



(15) Quand je rêve de moi, je cours. Je veux dire, je suis en train de courir.
when I dream of me, I run. I want say-INF am in midst of run-INF

'When I dream of myself, I run/am running. I mean, I am running.'

Exercise 5: Assuming as usual that we are using truth values and a closed world, is it always possible to determine the value of (Y) in these colliders?



(16)

X	Y
1	1
0	0

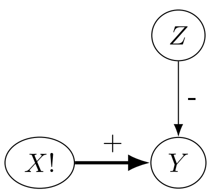
+

Z	Y
1	0
0	1

=

X	Z	Y
1	1	1
1	0	?
0	1	?
0	0	0

(17) A winner-take-all solution



X!	Y
1	1
0	0

+

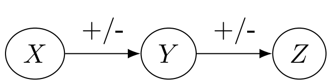
Z	Y
1	0
0	1

=

X!	Z	Y
1	1	1
1	0	1
0	1	0
0	0	0

- This does a similar job to ordering the lines of the table according to which are the best. That is, worlds where X "gets what it wants" is better than worlds where it doesn't. So, 101 and 010 worlds are better than 100 and 010 worlds.

4.6.2 Chains

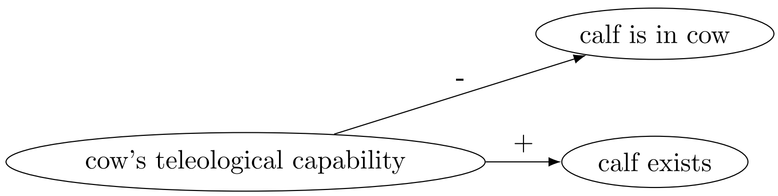


- Mediator (Y): agent's possession of an instrument, location of agent in *aller pour/go to* constructions.

- In benefactives and malefactives: Y is what we normally think of as the result, which has an excitatory or inhibitory effect on someone else's state of happiness (Z).

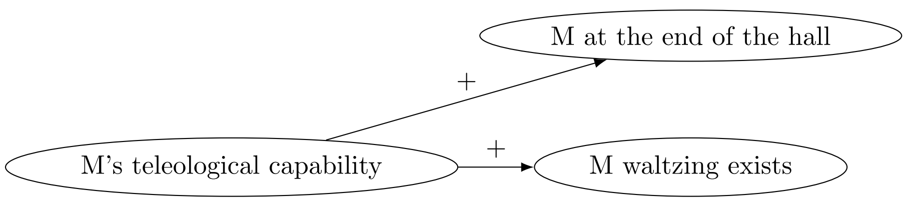
4.6.3 Forks

- Verbs of extrusion Harley (2005): *bleed, sweat, calve, spawn*?

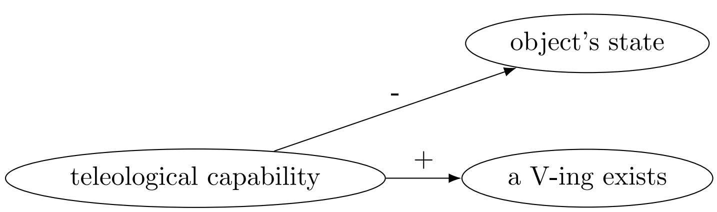


- Manner-of-motion with goal?

(18) Matilda waltzed to the end of the hall.



- Exceptions to manner-result complementarity? ((Beavers and Koontz-Garboden, 2020), pace Levin and Hovav (1991, 2006) such as *drown, fry, electrocute* etc.



5 Upgrading causal models for semantics

Today we added two things:

- Excitatory/inhibitory marking (+/-)
- Magnitude of arrows / winner-take-all, to do the job of ordering sources

I hand-waved at adding another thing:

- A timeline (or situation sequence?) to which nodes are mapped

What else will we need?

- We will need agents to do interventions (how?)
- We will need to model the difference between eventivity and stativity (Copley, 2020)
- We will probably need to mark a difference between dispositional states and mere flukes
- We will need dynamicity and a discourse model

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