# Modelling linguistic causation

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**Abstract**

This paper introduces a systematic way of analyzing the semantics of causative linguistic expressions, and of how causal relations are expressed in natural languages. The starting point for this broad agenda is an attempt to provide an explanation for the asymmetrical inferential relationship between two causative constructions: change-of-state (CoS) verbs and the verb *cause*, commonly ascribed to the former having an additional prerequisite of direct causation. The direct causation hypothesis, however, is fraught with empirical and theoretical challenges. At the theoretical level, capturing the felicity conditions specific to CoS verbs and the notion of direct causation requires a means of modelling complex causal structures. This is on no account a trivial task, as it necessitates, inter alia, modelling causation in a way that is germane to the linguistic expressions designating such relations. Hence, the main objective of this paper is to develop a framework for modelling the semantics of causal statements. For this purpose, this paper makes use of the framework of Structural Equation Modelling (SEM), and it demonstrates how this approach provides tools for a rigorous model-theoretic treatment of the differential semantics of causal expressions. This paper introduces formal logical definitions of different types of conditions using SEM networks, and show how this proposal and the formal tools it employs allow us to make sense of the asymmetric entailment relationship between the two constructions. In our proposal, CoS verbs do not require contiguity between cause and effect at all, but instead they require that its subject is set by default to a participant in completion event, the event which "completes" a sufficient set of conditions, such that following this event (but not before) the values of the set of conditions in the sufficient set entail that the effect occurs. According to this, the intuition of direct causation arises (epiphenomenally) from contrasting CoS verbs with overt *cause* sentences: the stronger selection pattern of the former - which requires a completion event - may exclude more temporally distant conditions, while the latter admits any necessary condition.

## 1 Why causal semantics requires causal selection

The occurrence of any event is contingent on many different factors. More precisely, any target event occurs as a consequence of a constellation of conditions, each of which may be individually necessary but which are only jointly sufficient to bring about the effect. As a simple example, consider a door that may be opened in one of two ways: (a) by means of an automated process requiring the presence of electricity, the door being unlocked, and an agent pressing the door-open button; or (b) by a manual process involving the presence of a door handle, the door being unlocked, and an agent turning the handle. Either of these two routes comprises a set of jointly sufficient conditions for the door to be open; and, within each set, each mentioned condition is necessary. Now imagine a situation in which a person walks up to the door, pushes the button and the door opens. An observer who wishes to describe what has just happened in causal terms, i.e., to mark the dependency between states-of-affairs in the world, faces several challenges. Any natural language makes available

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a number of causative constructions (verbs, connectives, see below) which can be used to describe this type of relation. However, these constructions typically supply a binary relationship, in which a single cause is linked to an effect (in this case, the door's opening). Thus, this observer encounters the problem of **causal selection**: deciding which among the set of necessary and jointly sufficient conditions should be singled out as the primary cause of the door's opening.

Causal selection has been widely discussed in philosophy and the cognitive sciences, and we will review it further in Section 3.1. Existing research on causal selection implicitly assumes that it is a singular cognitive process with a unitary linguistic implication. Accordingly, the same process of causal selection (always resulting in the selection of the same cause for a given situation) applies across all languages and constructions. This rationale goes back to David Hume's quest for a unitary account regarding the wherefore behind the attribution of the terms "cause" and "effect" to two things (events or individuals).

Less attention has been paid to a second, but equally important, selection problem faced by our hypothetical observer, which has been designated recently as **causative-construction selection (CC-selection)** (Bar-Asher Siegal et al., 2021): In generating a linguistic description of the situation, the observer not only needs to designate a particular (necessary) condition as cause, but also must decide which linguistic construction appropriately describes the relation underlying the observed course of events. Assuming that, in the former causal selection task, the observer selects the pushing of the button as the cause, two highly feasible alternatives to describe the event arise (see Table 1 for an array of such constructions[1]):

(1) Pushing the button opened the door.

(2) Pushing the button caused the door to open.

| **Causative constructions** | |
|---|---|
| **Dedicated verbs:** | *cause, make, allow, enable, get...* |
| **Connectives:** | *because (of), from, by, as a result of..* |
| **Change-of-state verbs:** | *open, boil...* |
| **Dedicated Morphology:** | *C-templates* (Semitics), *suffix -ita* (Korean) |

Table 1: Causative constructions

Linguistic studies commonly assume that the category of **caustive constructions** is defined by the semantic property of these constructions to express causal relations (Shibatani, 1976; Dowty, 1979; Comrie, 1981; Escamilla Jr, 2012). The theoretical upshot of accepting both the philosophical unified approach to causation and the linguistic assumption about the semantics of the causative expressions would be along the following lines:

> If all causative constructions denote causal relations, and if all causal relations lend themselves to a unified account, then **the semantics of all causative constructions should be the same.**

[1]Following Bar-Asher Siegal and Boneh (2020), by causative constructions we mean a semantically distinguished set of linguistic forms (including but not limited to those in Table 1) which encode a dependency between causes and effects with the following three components:

i) a cause (c);

ii) the effect of the cause (e); and

iii) the dependency (D) between c and e:
[c] D [e]

The terms "cause" (c) and "effect" (e) are used here loosely in a pre-theoretical manner. The use of the term "causative" or the division of the components to "cause" and "effect", at this point, neither indicates an assumption that a construction denotes causal relations, nor does it commit to the nature of (c) and (e). (c), (e) and D are used here in an uncommitted manner, relying on a pre-theoretical intuitions that they express some causal dependency, and it is our goal to understand the nature of these dependencies.

Indeed, philosophers and cognitive psychologists who analyse causation based on causal judgements rarely, if ever, factor in potential differences between the causative constructions in their research. Linguists, on the other hand, have contended that different causative constructions have different meanings (for various inferential differences between constructions, see Shibatani (1976); Thomason (2014); Maienborn and Herdtfelder (2017); Nadathur and Lauer (2020); Bar-Asher Siegal and Boneh (2019, 2020). For example, while a change-of-state (=CoS) causative (such as transitive 'open' in (1)) entails the truth of an overt *cause* sentence, an entailment in the other direction does not hold:

(3) a. Sam opened the door. $\models$ Sam caused the door to open.
 b. Sam caused the door to open. $\not\models$ Sam opened the door.

As indicated by the asymmetric entailment patterns in (3), and despite their obvious similarity in meaning, it has long been observed that a CoS causative like "open" and its periphrastic *cause* alternative are not semantically equivalent (Hall, 1965, 28). Sentence (3-b)—but, crucially, not (3-a)—can describe a situation in which Sam opened a window and the resulting wind gust pushed the door open. Thus, the linguistic perspective on causal language yields a conclusion which contradicts the one above:

**It is not the case that the semantics of all causative constructions is the same.**

This ostensible paradox can be solved by either discarding or changing one of the premises. One alternative is to advocate a pluralistic notion of causation (cf. similar approaches in philosophy: Hitchcock (2003); Hall (2004); and in cognitive psychology: Waldmann and Hagmayer (2013)) on which each causative construction potentially denotes a different "type" of causal dependency (Bar-Asher Siegal and Boneh, 2019). The second option is to fine-tune the assumption about the relation between causative constructions and causal relations. This paper follows the latter path, developing a new approach. More specifically, **we subsume all causal relations relevant for the meaning of causal language under a unified concept of causation, but modify it by positing different construction-specific requirements.** On this rationale, each construction is subject to specific constraints – contingent on its semantics – regarding which conditions, among a set of conditions in a causal model, can represent the cause in a given causal statement. Developing this approach translates to two tasks:

**Task 1:** Modelling causality and developing a corresponding semantic framework to capture the meaning of causative constructions within this model. This will help unravel the relationship between the causative expressions and causal relations.
**Task 2:** Delineating the differences between causative constructions in a systematic and principled way.

By accomplishing these tasks, we will provide a systematic way of analyzing the semantics of causative linguistic expressions, and of how causal relations are expressed in natural languages. More broadly, identifying the semantic features of linguistic causative expressions will lead to a better understanding of how we perceive and model causal relationships in our interactions with the world.

For this purpose we will use the framework of Structural Equation Modelling (SEM) adapted to represent causal relations (for our purposes we group SEM and causal Bayesian networks (CBN) together). This approach has been influential across a wide range of fields, including computer science, statistics, engineering, epidemiology, and philosophy and psychology (Pearl, 2000; Spirtes et al., 2000; Steyvers et al., 2003). Such studies use directed acyclic graphs to model causality, by representing dependencies between states of affairs as dependencies between valued variables. These models take various qualitative notions of causal dependence as primitives, and philosophers, including Woodward (2003) and Hitchcock (2020), have used them to account for either the meaning or content of such primitives. Over the last decade, several works in linguistics (Schulz, 2011; Henderson, 2010; Snider and Bjorndahl, 2015; Baglini and Francez, 2016; Ciardelli et al., 2018) have likewise proposed to use the SEM approach in order to model the truth conditions of various expressions, including causal statements (Nadathur and Lauer, 2020). This is a promising avenue, as SEM provides tools for a rigorous model-theoretic treatment of the differential semantics of causal expressions.

The two broad tasks will be achieved by providing an explanation to the asymmetry between the causative constructions introduced in (3). For these purposes we will introduce formal logical definitions of different types of conditions using SEM networks, and show how this proposal and the formal tools it employs can allow us to make sense of the asymmetric entailment patterns in (3).

The structure of this paper is a follows. Section 2 reviews the longstanding debate around how to capture the semantic asymmetry between overt and CoS causatives in terms of the relative (in)directness of the causal relations they describe, and the lack of an empirically satisfying solution. The next two sections aim to accomplish Task 1. In Section 3, we frame the problem as one of causal selection and introduce the formal framework of Structural Equation Models. Section 4 provides the formal definitions for our analysis, which are applied in the formal semantic analysis in Section 5, and by this we accomplish Task 2. Section 6 concludes.

## 2 The direct causation puzzle

As seen in (3), the CoS causative[2] entails the truth of the overt *cause* sentence, but an entailment in the other direction does not hold. The entailment pattern in (3) indicates that *cause* can be applied in a broader range of situations than a corresponding CoS causative. As shown in (4), a subset of these situations, including cases where Sam's action precipitates the opening of the door indirectly, or by extended causal chains, are not felicitously described using *open*.

(4) # Sam opened the door.
*Context A: Sam asked someone else to open the door.*
*Context B: Sam opened a window and the resulting gust of wind opened the door.*

This difference is commonly ascribed to the CoS verb having an additional prerequisite of direct causation, such that the causative relation holds between a spatiotemporally contiguous cause and effect, with a causer directly (often physically) manipulating a causee (Shibatani 1976, 31; Pinker 1989, 48) without an intervening third event (Fodor, 1970; Katz, 1970; Rapoport, 1999, inter alia).[3] While the idea that a CoS verb describes a causal relation which is 'more direct' than its paraphrase with *cause* remains popular, the contiguity-based hypothesis faces well-documented empirical problems as well theoretical challenges (see Neeleman and Van de Koot (2012) for a recent review of the problems with the direct causation hypothesis).

At the empirical level, there are several phenomena which complicate the direct-contingency hypothesis. Examples such as (5) show that CoS causatives do not wholly prohibit intervening causes. Note also that any of the intervening causes in (5)(a-b) could be selected as the causal subject in a similar situation.

(5) a. Opening bus lanes to motorcycles will redden the streets of London with cyclists' blood.
[*opening bus lanes* > *accidents increase* > *some cyclists die*]
b. A large fleet of fast-charging cars will melt the grid.
[*many electric cars on roads* > *many cars charging simultaneously* > *high electricity demand* > *heating of electric cables* > *melting of the grid*]

[2]See Rapaport Hovav and Levin (2002) and Beavers (2013) among others, for syntactic and semantic justifications for considering CoS as a defined category of verbs.

[3]See Wolff (2003, 3-4). for a review of the literature on direct causation. In this paper Wolff deals with a similar puzzle, and provides the no-intervening cause hypothesis to capture the notion of direct causation. Wolff works in a different framework of causation than the one assumed in this paper, (see also Copley et al. (2015)). It is beyond the scope of this paper to discuss why we do not take this approach. See Bar-Asher Siegal and Boneh (2020) for an introduction to the distinction between the *dependency* account and the *productive* accounts of causation.

(from Neeleman and Van de Koot 2012)

But while some intervening events appear to be unproblematic for the CoS verbs in (5), intervening agents are another story. The fact that intervening agent-controlled events disrupt the acceptability of CoS causatives was first observed by Katz (1970) and illustrated by the following scenario:

(6) # The gunsmith killed the sheriff.
*Context: A sheriff has his six-shooter gun faultily repaired by the local gunsmith. As a result, his weapon jams at a critical moment during a gunfight with a bandit and the sheriff is killed.*

Katz concludes that "clearly, the gunsmith caused the death of the sheriff, but equally clearly, the gunsmith did not kill him". The point is that while there is a causal chain from the gunsmith's faulty repair to the sheriff dying, the faulty repair nevertheless fails to meet some condition of causal "directness" or "immediacy" required by the CoS causative. What appears to differentiate felicitous examples in (5) from the infelicitous example (6) is the presence of an intervening agent in the latter: that is, the bandit who fires the shot which actually kills the sheriff (see also Cruse 1972 and Shibatani 1976). This would suggest that intervening events do not preclude the licensing of CoS verbs as long as no intervening event is controlled by an agent. But the role of agents in the licensing of CoS verbs is still more complex, as illustrated by contrasting examples like those in (7).

(7) a. The eclipse ended the concert.
[*lunar eclipse* > *distracts musicians* > *concert ends*]
b. ??By inspiring the conductor to create wonder through collective silence, the eclipse ended the concert.
[*lunar eclipse* > *conductor stops conducting* > *concert ends*]

Notice that both sentences in (7) involve agent-involved intervening causes, but only the latter involves an event that is fully controlled by a volitional agent (the conductor). This suggests that the initial cause of a extended causal chain may be selected as the subject of a CoS verb if and only if no event in that chain is controlled by a *volitional* agent.

In this paper, we will shed light on the asymmetry between CoS and overt causatives both in terms of their entailment patterns (3) and in the empirical puzzles related to the notion of causal directness (5)-(7) by elaborating on the restrictions that CoS causatives place on what can be selected as a linguistic subject. Following (Dowty, 1979, 106), we treat this as an issue of **causal selection**: which factors can be selected to be expressed as "the cause" in the causative statement. While Dowty focused on selecting a cause in a chain, when there is an ordered sequence of factors in which each factor in the chain causes the next, we consider more broadly the selection of a cause among a set of contributing factors (i.e. causally necessary conditions, among a set of sufficient set of conditions, as in the opening example of the door). Thus, while the empirical puzzles regarding the semantics of CoS verbs concern causes in a chain (hence the issue of directness), we frame it as a broader issue of selection of causes (see Section 3.1). This has the benefit of assuming a single formal framework which relates CoS verbs' licensing conditions to the conditions evidenced by other types of causal constructions which do not show "directness" effects.

To illustrate causal selection in more detail, consider why—in a regular scenario of an opening of an automatic door (when electricity flows uninterrupted through the network)—sentence (8) is acceptable while (9) is not:

(8) {Sam/pushing the button/the button} opened the door.

(9) #Electricity opened the door.

While in this case it could still be explained with the notion of direct causation, relying on temporal contiguity (assuming that only the last condition to be fulfilled can be selected as the subject of CoS verbs), let us consider a case in which Sam is on a train which allows the door open button to be held down before the train stops and the door opens as soon as the train completely stops. If

Sam presses the button of the door before the train reaches the station, (8) is still acceptable while (10) is not, despite the fact that the door does not immediately open, and it depends on the arrival of the train to the station.[4]

(10) #The train's arrival to the station opened the door.
*Context: Automatic train door with safety delay until the train stops.*

What we argue in this paper is that in order to be represented as the subject of a CoS verb, the selected participant must be part of an event whose occurrence **causally ensures** the occurrence of the effect (which is represented by the VP). In other words, that the subject must be part of an event that after its occurrence of this event, the the effect, denoted by the VP, must occur as well. This hypothesis has two corollaries:

1. Participants from events cannot be selected as the cause of a CoS verb if the event in which they are involved must be followed by (independent) volitional action from an agent or agents. This explains the unacceptability of Katz's sheriff example (6) and the conductor example (7-b).

2. Participants from events whose occurrence causally determines the occurrence of the effect can be represented as the subject of a CoS construction. Hence, all stages in deterministic chains, in which each event guarantees the occurrence of the next, can be represented as the subjects of such sentences, explaining the acceptability of Neeleman & Van de Koot's examples (5) and the distracting eclipse example in (7-a).

To motivate our analysis, we briefly review several insights from the philosophical and the cognitive sciences literature which point us towards a rich model of causal dependencies. We will formalize these insights, as we adopt the Structural Equation Modelling (SEM) approach, and show how such a model allows us to explain construction-specific inferences, the contrasting entailment patterns between CoS and *cause* constructions (illustrated in (3)) and the other observations we encountered in this section regrading the causal statements expressed in a CoS construction.

# 3 Modelling Causation

## 3.1 Causal Selection

Causative constructions encode some dependency between causes and effects, and a common assumption is that this dependency is a reflection of the concept of causality itself. This assumption relies on a fairly standard philosophical view, according to which causation is a binary relation between a single cause and its effect (Hume and others, 2000, /1748),[5] and at least since Davidson (1967) it is often assumed that the relata are individual events . That is, causal relationships are assumed to have the form C(ause) CAUSE E(ffect), where C and E are events (as proposed in Lewis 1973, 1986). A claim that we would like to entertain is that the restriction to such binary relations between a single C and E are, in fact, features only of linguistic expressions (cf. Hitchcock 2020). Causality itself is a more complex notion, that involves relations between multiple factors, and a consequence. In this approach, selecting a single "cause" is part of a restriction of linguistic expressions (of course, it is possible to mention multiple causal factors using a linguistic causative construction if they constitute conjunctions within the subject).

Although the idea that causation is a binary relation between a single cause and its effect, is taken to be trivial among philosophers and linguists,[6] we find support for the alternative view proposed

[4]This sentence can be improved somewhat under focus for some speakers: *Actually, it was the arrival of the train to the station that opened the door.*

[5]After making the distinction between Ideas and Relations in Part I of *A Treatise of Human Nature*, in Part III section II, Hume introduces the notion of causation as a *relation* between a cause and an effect.

[6]Linguists often argue about the nature of the relata, whether the relation hold between events or propositions or individuals, see McCawley (1976); Talmy (1976); Dowty (1979); Croft (1991); Pesetsky (1996); Doron (2003); Pylkkänen

here as far back as Mill 1884. Mill pointed out that the binary relation between a (single) cause and a consequent—typical of causative statements—provides only a partial picture of the set of factors that are responsible for the result. Since the notion of causation aims to capture what brings about a result, then causative relations are necessarily between *a set* of causal factors and a result.

> "[Causation] is seldom, if ever, between a consequent and a single antecedent [...] but usually between a consequent and the sum of several antecedents; the concurrence of all of them being requisite to produce [...] the consequent. In such cases it is very common to single out one only of the antecedents under the denomination of Cause, calling the others merely Conditions." (Mill 1884, A System of Logic, Volume I, Chapter 5, §3)

Consequently, a standard methodology in the philosophical and cognitive science literature is to describe a scenario potentially involving a relation of c(ause) and e(ffect), and to inquire whether it is possible to assert that "c is the cause of e". In some discussions, a distinction is drawn between the definite and the indefinite cause: "c is a cause of e" versus "c is the cause of e". While in the the former the (c) can be any factor that contributes to the occurrence of the effect, in the latter the (c) is the one factor that it is most natural to be marked as *the* cause in causal judgements. Lewis (1973), for example, emphasizes that his analysis of causation in terms of counterfactuality involves *a* cause and not *the* cause. The definite-article version is more salient to causal selection. Some describe this selection as an operation designed to tease apart real **causes** (the causes) vs. mere background/enabling **conditions** (any cause). An illustration is the classic case of a burned-down house: While the house would not have caught fire had there been no oxygen or flammable material in the surrounding space, a discarded cigarette butt is considered to be The Cause of the fire.

The distinction introduced by Mill (1884), stands at the heart of numerous discussions in philosophy, history, legal theory, and cognitive psychology that endeavored to motivate the signaling out of one factor as The Cause among various causal conditions. (Hart and Honoré, 1959; Mackie, 1965, 1974; White, 1967; Hesslow, 1983; Einhorn and Hogarth, 1986; Hilton and Slugoski, 1986; Cheng and Novick, 1991). The various accounts have made it clear that selections in this regard cannot be motivated by characterizing the dependency between (c) and (e) in terms of logical necessity and sufficiency, as the selected causes and all the other conditions (which do not apparently qualify for causal selection) can stand in similar logical relationships to an effect. Therefore, other types of criteria have been suggested such as conversational pragmatics with respect to moral responsibility (Driver, 2008), motivational bias (Alicke and Sedikides, 2011), or conversational considerations related to accountability (Samland and Waldmann, 2016). Recent works have argued that the main factor is abnormality, that is, one of the conditions is treated as in some way more relevant than the rest because its abnormality is salient (Knobe, 2010; Halpern and Hitchcock, 2015; Blanchard and Schaffer, 2017; Icard et al., 2017). An event is characterized as "abnormal" if it violates a norm, either statistical (Hilton and Slugoski, 1986) or prescriptive (Sytsma et al., 2012). Thus, going back to the case of the burned-down house, the fact that the discarded cigarette butt would be considered to be The Cause of the fire, can be either related to the lack of responsibilty of the person who left the cigarette butt, or to the fact that this is the only factor that altered the normal course of events, and that all of the other factors were expected in the normal state-of-affairs.

Other situational features have also been suggested as relevant for the selection of The Cause, including the temporal order in which potential causes occur (Einhorn and Hogarth, 1986; N'gbala and Branscombe, 1995; Henne et al., 2021). Others focused on conversational principles, given assumptions about the state of knowledge and interests of the seeker of a causal judgment (Beebee, 2004, 296).

None of these studies, however, consider causal selection as as reflected in the use of linguistic expressions. A notable exception is Wolff (2003), who investigates the cognitive correlates of the linguistic notion of "direct causation", examining the effect of specific constructions. We propose that the selection of the cause is also a linguistic phenomenon, as it depends on the way causal relations are described by language, and which of the conditions can be selected as The Cause varies

(2008); Neeleman and Van de Koot (2012) for the various options within linguistics as to what are the relata of the causal relations expressed by the linguistic constructions.

depending on which causative construction is being used. Accordingly, **the content of causal judgments depends not only on the causal relations "out in the world" or on our cognitive perception of such relations, but also on linguistic facts, in particular, the lexical restrictions associated with the chosen constructions.** We follow Bar-Asher Siegal et al. (2021), who argue that next to the selection of the cause among that various causal factors, there is also a Causative-Construction-Selection (cc-selection). In this process the speaker has to select, along with the cause, a causative construction which appropriately describes the relation behind the observed course of events. They demonstrate, based on a set of experiments, that different constructions have different licensing parameters. Thus, for a given set of conditions and a given effect, instead of asking: "which condition among the set of conditions is selected to be the cause?", we would ask the following:

> With respect to each of the relevant conditions, can it be encoded as the cause in a statement of a singular instance?

This way does not assume that only one condition can be selected as "the cause", as it can definitely be the case that more than one of the conditions, in a given scenario, can be represented as the cause in a statement of a singular instance (by "singular instance" we refer to a causal judgement with respect to a specific cause and a specific effect. Such statements stand in contrast to "general instance" which states general causal regularity or law.) Moreover, since the answer to this question varies depending on the causative constructions that is being used, we should attempt to answer the following question:

> With respect to each of the relevant condition, can it be encoded as the cause in a statement of a singular instance expressed by a specific causative construction?

The novelty in this approach is that we are not asking for a given construction, which of the conditions would be selected by a speaker as its cause. Instead, we ask, given that a speaker wish to describe the dependency between a certain event/action and a certain result, which of the linguistic expressions are available for her. By asking this version of the research question on causal selection, the results of previous studies about causal selection are interpreted differently. Instead of considering various parameters, such as intention, foreseeability, norm violation, as factors for selecting the cause (as they were considered in previous studies in other disciplines) these factors are taken to be parameters that license the use of a certain linguistic construction in given circumstances, and based on previous knowledge about the causal structure of the world. **Taking this approach, these factors are taken as part of the meaning/truth conditions of linguistic expressions. Thus, from a linguistic point of view, the discussion of these parameters is a discussion about the semantic components of causative constructions.**

As a matter of fact, we take cc-selection to be more crucial in the choice of a statement than causal selection, since causal selection is restricted by the linguistic availabilities resulting from the construction choice. Consider again the door example: determining whether "the cause" of the door to open was electricity, the person or the pushing of the button requires these possibilities to be stated. The previous discussions on causal selection took the nature of the dependency for granted, and then treats the construction as basically aiming to convey that type of dependency, whereas in our approach causal selection is coming secondary to cc-selection.

We turn now to introduce the framework of SEM, as it turns out, it is also a convenient way to represent the fact that causality is a relation between sets of factors. We will then aim to characterize the selection of the cause with tools provided by this type of model.

## 3.2 Structuring a Model for Causation

In a regular conversation, interlocuters share common knowledge about the causal laws that govern the world, and rely on it in making claims. Thus, when a speaker sees that 1) Sam pressed a button, and 2) a door was opened, and asserts "Sam opened the door", it is most likely that the speaker either want to inform aout the opening of the door, or about the identity of the person who did the opening. Her claim is not intended to convey to her listener the existence of a causal relationship between button-pressing and door-opening. Rather, on the assumption that knowledge of this causal relationship is shared between herself and her interlocuter, we can say that they share a causal model of the world.[7] Having such a model, she can use the claim that "Sam opened the door" to report on her actual observations – that Sam pressed the button and that the door opened. According to this, causal statements relies on causal knowledge, and are not necessarily **about** the causal relations in the world.

What does the causal knowledge licensing her claim comprise? It contains the information that, everything else being equal, if a certain state of affairs obtains, then the door must open, and that unless such conditions are met, the effect – the opening of the door – will not take place. But is that all? Does this knowledge involve only a set of regularities about which conditions lead to which state of affairs? Causal selection and CC-selection indicate that speakers must be sensitive to additional information about the characteristics of the participants of the causal relations in the world, as this information determines the content of the causal statements. As will become clear below, it is in this context that the semantics of the causative expressions matters.

To describe a situation in which the door opens with the pressing of the button, the observer might also choose the sentence "Sam caused the door to open" instead of "Sam opened the door". However, as stated in (3), the two alternative (and equally applicable) descriptions have an asymmetrical inferential relationship. Earlier in Section 2, we mentioned that one common explanation for this asymmetry appeals to the idea that CoS verbs have a prerequisite of "direct causation". As reviewed earlier, the direct-causation hypothesis, however, is fraught with empirical problems, and in addition it encounters various theoretical challenges. At the theoretical level, capturing the felicity conditions specific to CoS verbs requires a means of modelling potentially complex causal chains. This is on no account a trivial task (Dowty, 1979; Thomason, 2014), as it necessitates, inter alia, modelling causation in a way that is germane to the linguistic expressions designating such relations. Hence, the main objective of this paper (in line with Task 1 of the paper) is to develop a a framework for modelling the semantics of causal statements and to use this framework to capture the factors licensing causal inferences in natural languages. It is in this context that we apply the above-mentioned SEM framework in linguistics.

This paper rests on the assumption that the semantics of the causative expressions is indicative of what constitutes our causal knowledge, in the following way:

- The requirements for licensing causative judgments (CC-selection) involve constraints as to which conditions can be represented as the cause in a specific state of affairs. These requirements are the de facto truth conditions of these expressions, and as such they constitute the meaning of these expressions.

- These constraints must correlate with what speakers know about the conditions and about the relation between them (time order, internal dependence etc.).

Thus, modelling the meaning of these expressions is directly related to capturing our cognitive causal knowledge. Consequently, we will illustrate this by proposing for the two constructions that stand at the heart of the current discussion, CoS verbs and overt *cause*, a hypothesis about the set of constraints imposed by the constructions on the selection of their causes, and these constraints must be captured by the model.

We turn, therefore, to the structure of causal model. Such a model serves two functions: a. It provides a framework for a formal theoretical semantic account of the causative constructions; and b. It provides information about the causal knowledge required for making causal statements. We will construct such models within the SEM framework.

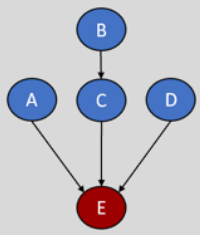
In this approach, dependencies between states of affairs are represented as a set of pairs of propositions and their truth values. Thus, for the automatic door example, we can define the following

[7] In this approach we are taking the model as a given and characterize its structure in formal terms. Accordingly, we have a different goal than others who characterize the way the causal model is constructed. (Pearl, 2000, 43-44), for example, aims to capture the structure which scientists attempt to identify from the available observations in the world.

variables (pairs of propositions and truth values) in A-E in Figure 1 below. The fact that some variables depend on others for their value is represented by structural entailments in F-G. These entailments do not derive from logical inferences or from lexical relations, but instead reflect background knowledge about the mechanism of a specific door, and how they capture the dependencies that exist between certain state-of-affairs. In other words, this is a formal way to capture what is often referred to in the literature as ”world knowledge”.

Variables can be classified as belonging to one of two types: Exogenous or “outer” variables do not depend on any other variable for their value. Endogenous or “inner” variables are valued based on the values of variables on which they casually depend. In our door example above, the exogenous variables are [A., B., D.]. The endogenous variables are [C., E.].

Note that there is an asymmetry in structural entailments. Lines (F) and (G) in Figure 1 provides the set of necessary conditions for a certain value of another variable (Button=1; Circuit=1.) In our case, only if all conditions of a specific set are fulfilled (Circuit=1, Electricity=1, Lock=0) will the door be open (Door opens=1). Accordingly, given the model in formalized in Figure 1, when one variable of the relevant set (G) has a different value (Circuit=0 or Electricity=0 or Lock=1), it is enough to infer that the door is close (Door opens=0). In other models, about which we will elaborate later, there might be alternative sets of conditions that will also entail the opening of the door. The ”take away” is that **dependencies, are always between certain values of variables and certain values of another variable (they are between propositions.)**




A Lock: =1 if door is locked; else =0
B Button: =1 if pressed; else =0
C Circuit: =1 if closed; else =0
D Electricity: =1 if running; else =0
E Door opens: =1 if opens; else =0
F Button =1 ⊨ Circuit =1
**G**: Circuit =1 & Electricity =1 & Lock =0 ⊨ Door opens =1

Figure 1: Directed graph and Variable and Structural equations

We use the term **condition** for any variable that is relevant for (i.e., causally influences) the value of another. By “relevant” we mean that the value of the condition can be invoked (either alone or in conjunction with other conditions) to determine the value of a variable that causally depends on it. Thus, such structures allow us to identify both the set of immediate causal ancestors for a proposition, as well as the nature of the direct dependencies.

Dependencies within the SEM framework can also be represented qualitatively with directed acyclic graphs model (as in Figure 1). Nodes correspond to variables, and arrows indicate the direction of dependency. The value of an originating node dictates the value of nodes it points to. The variables and structural equations above correspond to the graph in Figure 1. Thus these dependencies represented by links illustrate which nodes represent, what we informally refer to as ”conditions”. A graph merely identifies the variables that have direct influence on the endogenous variables. It does not specify the exact nature of the dependency.

# 4 Formal definitions

## 4.1 Causal structure and causal model

We can turn now to provide a formal description of relevant causal structures. Following what has been portrayed informally with the graphs in Figure 1, Definition 1 captures formally the relations between propositions (the nodes) within a model.

**Definition 1 (Causal Structure)**: A causal structure of a set of proposition letters $\mathcal{P}$ is a directed acyclic graph (DAG) in which each node corresponds to a distinct element of $\mathcal{P}$, and each link represents direct functional relationship among the corresponding propositions.

A causal structure (such as the one represented in Figure 1) is the structural basis for a "causal model" in Definition 2:

**Definition 2 (Causal Model)**: A causal model is a pair $M =< D, \Theta_D >$ consisting of a causal structure D and a set of parameters $\Theta_D$ compatible with $D$. The parameters $\Theta_D$ assign a function $\psi_i = f_i(\Sigma)$ to each $\psi_i \in \mathcal{P}$, where $\Sigma$ is the set of all nodes that $\psi_i$ causally depends on in $D$.

Taking the linguistic perspective, a causal model captures speaker's knowledge about the relationship between facts in the world, and what is expected to result when certain conditions are fulfilled. It reflects knowledge about the dependencies between state-of-affairs in the world. With respect to the semantics of causal statements, our claim is that this kind of knowledge form the basis for licensing a speaker's linguistic judgments.

In principle, this type of causal model allows any kind of variable (variables for degrees on a thermometer, variables for the speed of the car, etc.) For our purposes, we restrict consideration to variables as a set of proposition letters $\mathcal{P}$, and their values are their truth values. To capture the nature of causal dependence, we use a three-valued logic with the values 1, 0 and u(ndefined). Undefined, for our purposes, is an epistemic notion (cf. Kleene (1952): 335). It does not represent some kind of vagueness, but merely a lack of knowledge about the value of the proposition. This 3-valued epistemic logic is consistent with our approach that we capture the speakers' causal knowledge and model it within the SEM framework. Accordingly, part of this knowledge is which causal inferences are possible for speakers to make, even when they do not have the complete information about all the conditions (the values of all exogenous variables). In our example, if one knows that the button for opening the door is pressed and that electricity is flowing in the (relevant) circuit, but she doesn't know whether the door is locked or unlocked, then she cannot infer that the door will open. In contrast, if she knows that it is locked, even if she does not know whether the bottom is pressed or not, the speaker may infer that the door is closed.

Definition 3 formulates how the truth values of propositions in the model are determined (cf. Schulz 2007). Exogenous variables take their value independently (e.g. via world knowledge, or knowledge of a given situation), while endogenous variables are valued model-internally (i.e. based on the truth values of nodes it causally depends on). Thus, Definition 3 distinguishes between the set of variables $\Sigma$ whose interpretation are given, the so-called exogenous variables, and the rest $(\mathcal{P} - \Sigma)$, whose values are assigned by the model $M$, the endogenous ones.

**Definition 3 (Truth values generated by a causal model)**: Let $\mathcal{P}$ be a set of proposition letters and $\mathcal{L}$ the closure of $\mathcal{P}$ under conjunction and negation. Furthermore, let $M =< D, \Theta_D >$ be a causal model for $\mathcal{P}$, and $I : \Sigma \rightarrow 0, 1, u$ an interpretation of a set of variables $\Sigma$ of $M$. For arbitrary $\psi \in \mathcal{L}$ we define the interpretation of $\psi$ with respect to $M$ and $I$, $[[\psi]]^{M,I}$ recursively as follows:
$[[\psi]]^{M,I}$ = I($\psi$), if $\psi \in \Sigma$,
$[[\psi]]^{M,I} = [[F(\psi)]]^{M,I}$, if $\psi \in \mathcal{P} - \Sigma$
$[[\neg\psi]]^{M,I} = 1$, iff $[[\psi]]^{M,I} = 0$ and
$[[\psi \wedge \phi]]^{M,I} = 1$, iff $[[\psi]]^{M,I} = 1$ and $[[\phi]]^{M,I} = 1$.

Following this definition, an appropriate way to represent causal relations will be in a truth-table, which provides the value of one proposition, given the truth-values of a set of propositions it depends on. The truth table in Table 2 represents a partially valued model for the case of the automatic door, whose structure was shown by Figure 1, and reflects the dependency between the truth value assigned to the effect and the various causal factors (button, circuit closure, electricity, lock mechanism).

It's worth noting again, that in some cases, lack of knowledge about one of the causal factors (propositions with the value u) leads to lack of knowledge about the effect, and in other cases there is enough knowledge to infer that the door is close (Door opens=0). There are never cases in which there is lack of knowledge about the relevant factors (circuit closure, electricity, lock mechanism) and that it is still possible to infer that the door is open (Door opens=1). In other words, in this model, it is enough to know that either the circuit is not closed, or that the electricity doesn't run, or that the door is locked to infer that the door is close, but to infer that the door is open one must have a knowledge about all three conditions. This asymmetry is crucial for understanding the notion of sufficiency in a causal context. Notions such as "sufficient set" and "necessary conditions" were used so far in an informal, intuitive sense; we turn now to define them formally within the SEM framework.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Button | 1 | 1 | 1 | 1 | 0 | 0 | 0 | u | u | u | u | u | u | u | u | u | 1 |
| Circuit | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | u | u | u | 1 |
| Electricity | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | u |
| Lock | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 |
| Door-open | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | u | u |

Table 2: Automatic door example

## 4.2 Redefining sufficiency

### 4.2.1 Mackie's INUS conditions

In our running example, each of the factors (in the particular sufficient set, as portrayed in Figure 1) is *necessary* to open the door, but only the entire set of factors is *sufficient* for an opening of the door. This insight that causation involves a relation between a set of necessary conditions, which together are sufficient to bring about the result was first informally proposed by Mackie (1965). In our formal framework, we recast Mackie's notion of INUS conditions as follows: a set of variables which are Insufficient but Necessary alone, but together Unnecessary but Sufficient. While Mackie uses these terms informally and in the logical sense, here they are in the sense of these notions as defined (subsequently) over the structure of a causal model.

The last part of this definition—"together Unnecessary but Sufficient"—clarifies that in modelling the causal structure of the world, we are not aiming to simply describe what happened in a specific case, but the nature of relations between various factors and a specific possible result. In light of this we should also consider the fact that different sets of conditions can lead to the same result. In our running example of the automatic door, in the opening section we mention the possibility of a door that can be alternatively opened using an alternative manual mechanism, e.g. by turning a handle. The causal model must also represent this alternative mechanism, which constitutes an alternative sufficient set. The two alternative mechanisms for opening the door are independent from each other (one can open the door in one way or another) despite sharing the condition Lock. Thus, we have updated the door scenario such that the causal model represents two constellations of factors which partially overlap, but in a given instance of actual causation only one set represents the actual causal pathway for a particular opening event. This is reflected in Figure 2, which updates Figure 1 with one new variable (A) and one new inference relation (I). In the graphs, we follow VanderWeele and Robins (2009) and circle conjoined conditions, i.e., when the value of the descendant is determined by the value of a combination of set of variables.

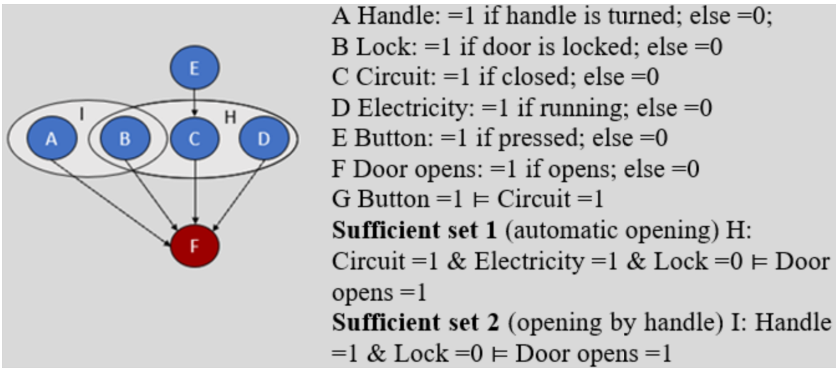



Figure 2: Graphical models of two sufficient sets of condition for an effect F

It must be emphasized that sufficiency, according to Mackie, is defined as a characteristic of a set causal factors, and not of a single condition. Despite the wide familiarity in the literature with the notion of INUS conditions (Mackie, 1965), still the literature on causation, in philosophy, in cognitive sciences and in linguistics, often treats causal sufficiency as a relation that holds between a single condition and an effect. Thus, one finds the following type of informal definitions for necessity and sufficiency:

**Necessity:** If C were not to occur, E would also not occur.
**Sufficiency:** If C were to occur, E would also occur.

There have also been a number of attempts to capture this distinction formally. Pearl (2000, 286), for example, captures the notion of sufficiency in terms of production. A variety of formal definitions from recent literature in linguistics to sufficient causes can be found in Baglini and Francez (2016); Nadathur and Lauer (2020); Martin (2018); Bar-Asher Siegal and Boneh (2019). Similarly, works in cognitive sciences make use of the notion of sufficient causes as well (see Mandel (2003), and more recently Icard et al. (2017)). However, as we we have seen, it is crucial to formally define the notion of sufficiency as a relation between a set of conditions and a proposition, and also to provide in this context a formal definition of INUS condition within a SEM framework. We turn now to provide a formal definition of necessary conditions and for sufficient sets of conditions, based on the formal modelling of causal structures introduced in the previous section (Definitions 1-3).

The main challenge in capturing the concept of INUS condition has to do with the fact that each condition is defined as being part of a sufficient set, and in turn the set itself is defined by its members (all of which are necessary for the effect). We need therefore to have an independent anchor to begin defining this relation. We use the notion of **causal relevance**,[8] in Definition 5, which is broader, and simply requires some causal dependency (not sufficient), and a definition of a situation (Definition 4) for a set of valued propositions.

**Definition 4 (Situation)**: A set of pairs of propositional variables $\Sigma$ in $\mathcal{P}$ and their 0/1 valuation is a situation.

As noted earlier, and as was captured earlier by the truth tables, causal relations are not held between variables, but between certain states-of-affairs - which are represented by propositions. Thus, the notion of situations, allows us to represent the relations between a set of conditions (represented by variables and their values) and the effect (also represented by a variable and its value). We can thus, turn to define causal relevancy in Definition 5:

[8]See Hobbs (2005), who developed a similar idea through the notion of "causal complex".

**Definition 5 (Causal relevance)**: A situation $S$ (consisting of a set of pairs of propositions $\Sigma$ in $\mathcal{P}$ and their values) of $M$ is causally relevant for a certain value of the variable $\psi$, when the interpretation of $\psi$ with respect to $M$ and $I$ is defined (1 or 0), when $I : \Sigma^c$ (the complement set of $\Sigma$ in $\mathcal{P}$) assigns $u$ for all its members.

Causal relevancy is a relation between a situation (a set of variables and their values) and another proposition (a variable and its value). It only indicates that an inference can be made from the conjoined interpretations of variables to the value of the other variable. The fact that the value of $I$ is defined (1 or 0), when the complementary set of $\Sigma$ in $\mathcal{P}$ assigns $u$ for all its members, guarantees that all of the relevant factors are included in the situation. However, it is possible that not all of the pairs of the set $s$ are equally relevant. In our running example the set $\{ < Handle, 1 >, < Lock, 0 >, < Electricity, 1 > \}$ is causally relevant for $< Dooropen, 1 >$, but we would like to capture the fact that the pair $< Electricity, 1 >$ is superfluous. That it is unnecessary for the specific result (there will be a similar effect also if the situation was $< Electricity, 0 >$). We, therefore, turn now to capture the notion of causal necessity in Definition 6.

In the spirit of Mackie, we are looking for an INUS condition, thus a condition is necessary for the occurrence of a certain effect is defined with respect to a situation (a set of conditions).

Armed with the notion of **causal relevancy** and with a definition for **a situation**, we can formally define (Definition 6) causal necessity which is a relation between two valued propositions (*a* cause and its effect).

**Definition 6 (Causal necessity)**: $\chi$ is causally necessary for a certain value of $\psi$ in a situation $S$, i.e. the variable and its value in $S$ ($S\chi$) is necessary for a certain value of $\psi$ (0 or 1) if: There is a set of propositional variables $\Sigma$ and there are two situations $S$ and $S'$, which are two situations of $\Sigma$, such that

i. the situation S is causally relevant for a propositional variable $\psi$
ii. $I : \Sigma \rightarrow 0, 1$ is an interpretation of the set of variables $\Sigma$ of $M$, in situation $S$ and $I' : \Sigma \rightarrow 0, 1$ an interpretation of the set of variables $\Sigma$ of $M$, in situation $S'$ and
iii. $S\chi \neq S'\chi$.
iv. The cardinality of the complement set $J$, such that $J = S - S'$ is 2, and the two members of $J$ are the pair of $\chi$ and its value, different in each pair, and
v. $[[\psi]]^{M,I} \neq [[\psi]]^{M,I'}, and$
vi. There is no interpretation $I''$ of the set of variables $\Sigma$, in which $S'\chi = S''\chi$ and $[[\psi]]^{M,I'} \neq [[\psi]]^{M,I''}$.

(i) allows us to ignore the value of all other propositions letters which are not part of the situation $s$. This has to do with the fact that per Definition 5, causal relevancy assures that the values of all other variables in the model do not affect the value of the result (they are assigned the value u). In addition due to (i) the values of $S\chi$ and $S'\chi$ in (iii) are 0 or 1, u is excluded.
With (i-v) in Definition 6, we can isolate the contribution of one proposition $\chi$ and its truth value for a certain value of another proposition letter. (vi) relies on the insight of (Von Wright, 1974, 7) about the interdefinable relation between sufficient and necessary conditions: *Necessary*$(p, q) \equiv$ *Sufficient*$(\neg p, \neg q)$. Accordingly, if a certain condition is necessary within a set of conditions, for a certain result, then its absence is sufficient for the non-occurrence of the result. In the case of the electronic door, when we consider the manual scenario Handle=1 is a necessary condition for Door open=1. Since, when considering the causal relevant situation, whenever Handle=0, then Door open=0 as well. This asymmetry emphasizes again the reason for defining conditions as causally necessary for **a certain value of** $\psi$ and not for *the* truth-value of a variable in general.

We would briefly note about the fact that Definition 6 for *necessity* is very similar in spirit to Lewis's (1973) definition of causation in terms of *counterfactuality*. One can consider situations as formal definitions of possible worlds, and consequently the two situations $s$ and $s'$, as two most similar possible worlds. But at the same time it also highlight the importance of considering causal factors in a context of sets of other causal factors (à la Mackie). It is beyond the scope of the current paper to provide a complete comparison between this approach and Lewis' account for causation. We will breifly note that the main differences derive from the fact that while Lewis spoke about statements of actual causation (*token-clausal claim*), and therefore accessed similarity to the actual world, we are speaking about *type-causal claim*, about the causal model of what *can be* a cause (see, Woodward 2003, 40 and Hausman (2005)). Therefore, necessity, in Definition 6, is defined by comparison between possible situations, without a reference to the actual world (see also Halpern and Pearl (2005) for a conceptual comparison between SEM and Lewis's definition of actual causation in counterfactual terms).

Once we have a definition of causal necessity, and of situations it is possible to define (Definition 7) a sufficient set, whose all members are necessary.

> **Definition 7 (Sufficient set)**: A situation $s$ is defined as a sufficient set for a certain interpretation of $\psi$, if the set of propositions $\Sigma$ whose values are defined in $S$, is causally relevant for the proposition $\psi$, and all members of S are causally necessary for $\psi$.
> $\{X \in S|$ such that $x$ is causally necessary for $\psi\}$

#### 4.2.2 *A* sufficient set vs. *a completed* Sufficient set

Being causally necessary for a certain value of $\chi$ is a transitive relation. This is especially relevant for cases of deterministic chains of causes. Thus, if a certain value of $\phi$ is causally necessary (in a certain situation) for a certain value of $\psi$, and this value of $\psi$ is causally necessary for a certain value of $\chi$, then this value of $\phi$ is causally necessary for the relevant value of $\chi$. Or putting it somewhat more formal:

> Given that, $\psi$ in the situation $S$ is causally necessary for a certain value of $\chi$, and
> $N$ is a superset situation of the situation $S$, and contains only one additional member: $\phi$.
> If $N\phi$ ($\phi$ in the situation $N$) is causally necessary for the valuation of $S\phi$ (to make things simple, we will assume that it also constitutes the sufficient set),
> then, $N\phi$ is also causally necessary for the for the valuation of $\chi$.
> Moreover, in this case if $S$ is a sufficient set for the value of $\chi$, $N$ must be as well a sufficient set for this value of $\chi$.

.

In the case of the electric door, pressing the button is a necessary condition for closing the circuit. Thus, since the circuit, in the relevant situation, is an INUS condition for opening the door, pressing the button is also an INUS condition. Consequently, in our returning to Figure 1, the three following situations constitute sufficient sets of the value 1 of F.:

- Sufficient Set 1 $\{<E,1>,<C,1>,<D,1>,<B,0>\}$
- Sufficient Set 2 $\{<C,1>,<D,1>,<B,0>\}$
- Sufficient Set 3 $\{<E,1>,<D,1>,<B,0>\}$

At this point we depart from Mackie. While for him, an INUS is a member of a *sufficient set*, that contains all necessary conditions (*a completed sufficient set*,) according to our definition, a *sufficient set* is causally relevant and all its members are necessary, but this set doesn't necessarily consist of **all** the necessary conditions. In the case of deterministic chains, various different sets of INUS conditions entail the effect (basically, in the case of a deterministic chain, it is enough that one of the INUS condition in that chain is part of the rellevant sufficient set). Thus, there can be other necessary

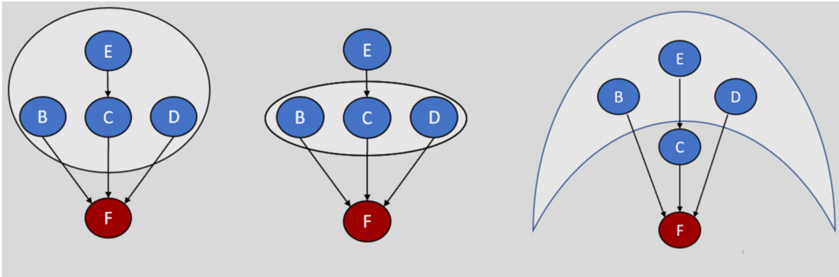



Figure 3: The various sufficient sets

conditions which are not part of the sufficient set. Accordingly, the same INUS condition can be a member of different sufficient sets. As will become clear later - this last observation, will be crucial for solving the linguistic puzzle about "direct causation" we began with. We will return in Section 5.5) to the notion of *a completed sufficient* set as well, and define it formally.

# 5 Application to causal constructions in natural languages

## 5.1 Explaining the different causal inferences

What does the SEM approach buy us? On such causal modelling approach, causal judgments are made over a given "network" of causal dependencies between propositions. Our approach assumes that this network is part of a speaker's knowledge about a given discourse context, and it provides the background for licensing certain utterances and inferences.

We propose that causative constructions share the same notion of causation, in that they commonly rely on SEM, while construction-specific entailments and pragmatic inferences are captured in the same model as parameters on the selection of a cause among a set of conditions.[9] As noted earlier (section 3.1), while discussions in philosophy and the cognitive sciences, often concerned with *causal selection* and characterize the choice of "the cause" among the many individually necessary and jointly sufficient conditions on which any effect depends, there is a different linguistic phenomenon of *causal selection*, the cc-selection, which pertains to the choice of linguistic constructions used to express causal relations. In this context we aim to answer the following question: given that a speaker wishes to describe the relation between one of the INUS conditions and the effect, which of the linguistic constructions are available.

We would like to answer this question by using the SEM framework with some additions. According to this approach, the framework of SEM provides a basis for explaining construction-specific inference patterns which are sensitive to information implicit in the model.

We can illustrate this approach with the semantics of overt *cause*. As already claimed by Mackie (1965), and more recently advocated by Nadathur and Lauer (2020) this verb can select as its subject any condition on which the value of the effect causally depends—i.e. any INUS condition. Going back to the example of the electronic door, all of the conditions can be represented as the subject of this construction to describe an opening of the door, as illustrated in (11):

(11) {Sam's pushing the button$_E$/the button$_E$/Sam$_E$/electricity$_D$/the closed circuit$_C$} **caused** the door to open.

Mackie (1965: 247), in fact, already clarified that a statement which asserts a singular causal sequence of such a form as "A caused P," makes, implicitly, the following claims:

1. A is at least an INUS condition of P, it is part of a sufficient set B.

2. A was present on the occasion in question.

[9] Bar-Asher Siegal and Boneh (2020)) demonstrate that in some causative constructions causality is asserted while in other it is either presupposed or implied. However, this is beyond the scope of the current discussion. For our purposes it is important that SEM can capture all these options, as the notion of causality is captured in a similar way.

3. All other members of the sufficient set B were present on the occasion in question.

4. Every other set C that could together bring about P was absent on the occasion in question.

Thus, the causative component of the verb *cause* is represented formally in (12). This is not a representation of the lexical entry "cause", but merely a representation of the logical constraints on the selection of the cause in this construction.
The function SUFF(ICIENT) takes two situations (Definition 5) and returns 1 if the first (Σ) is a sufficient set in the model $M$ for a specific result ($R$), the second situation, which has a single pair. Given a felicitous causal statement, with a certain condition Q represented as the cause, the following is true about Q in the causal model:

(12) **Overt *cause***
$\exists Q \exists R \exists e \exists \Sigma{:}\text{SUFF}(\Sigma, R)^M = 1 \;\&\; (Q \in \Sigma^M) \;\&\; \Sigma(e) \;\&\; \forall \Omega \, [\, (\Omega \neq \Sigma) \;\&\; \text{SUFF}(\Omega, R)^M = 1 \rightarrow \neg\Omega\ (e)]$

The formula in (12) captures the requirement that the subject of the verb *cause* will be part of a condition which is characterized as an INUS condition, i.e. a member of a sufficient set, and according to Definition 7 all the members of this set are also necessary. While in SEM conditions are represented as propositions, we follow a long tradition since Dowty (1979) that the DPs and the VPs in the actual causal statements are "representatives" of these propositions. The DP in the subject position denotes a participant in the CAUSE state-of-affairs, and the VP describe the EFFECT.

This formula of the constraints provides the requirements for this construction to be used to express statements of a singular instance of causation - i.e., about an actual causation. While the causal model provides generalizations about types of situations (set of propositions), actual causation is about relations between specific eventualities (see *inter alia* Hausman (2005)). Thus, the formula in (12) also indicates that there is an eventuality (e) in which all conditions are fulfilled, and no other sufficient sets of conditions were fulfilled in the relevant eventuality (below we will add further nuance to this point). For the sake of simplicity, we assume that all conditions are still fulfilled at the relevant time; there are of course cases in which it is enough that they occurred before the time of the occurrence of the selected cause and initiated the occurrence of other conditions.

Pragmatic factors can further constrain which INUS conditions can be selected in a certain context. For example, among a set of causal factors, that which is the least expected might be selected for realization as the causal subject (see Section 3.1 for the literature on causal selection; for some recent empirical studies on this see Bar-Asher Siegal et al. (2021)), since this paper focuses on CoS causatives we will not elaborate on this aspect any further.

Turning now to the lexical CoS construction, we argue that its specific parameters governing the selection of a main cause (c) give it a different inferential profile from overt *cause*. To see this more clearly, it will be useful to evaluate the appropriateness of alternative CoS causative descriptions—differing only in their selected subject—given a common contextual background. In effect, this involves finding the causal descriptions whose parameters best fit the particular details of the context given an underlying causal model. Starting with our model for the operation of an automatic door in Figure 1 and the default scenario, in which Sam presses the button and opens the automatic door, we observe that speakers prefer the sentences in (13) to the alternative in (14):

(13) $\{$Sam's pushing the button/the button/Sam$\}_E$ **opened** the door.

(14) Electricity$_D$ **opened** the door.

But the default preference for (13) over (14) can be reversed if we adjust the contextual background. Imagine applying the same model to a different scenario: Sam pushes down the button but nothing happens, because of a momentary power outage. When power returns, the door opens. Given this alternative scenario, speakers' acceptability judgments shift to prefer (14).

We propose that, unlike overt *cause*, CoS causatives are sensitive to a "last straw effect"—they must select the condition that completes *a* sufficient set, a condition after which any remaining necessary conditions in the particular active pathway are also guaranteed. Assuming that statements of a singular instance of causation are about events, we should have the following in mind:

A. Completion involves events taking place in time.

B. Completion also involves a sensitivity to event-related changes in the value of conditions.

C. In light of A & B, given that events have time in which the value of associated variables in the model can be changed (0>1 or 1>0), **occurrence of events, for our purposes, can be defined in terms of change of values.** (cf. Halpern and Pearl 2001: 196, AC2).

By incorporating information about time of occurrence to the nodes in a causal model, causal factors take on a temporal ordering. This allows us to identify the unique **completion event**, the event which "completes" a sufficient set, such that following this event (but not before) the values of the set of conditions in the sufficient set entail that the effect occurs (Martin 2018 proposes that the condition must be "the sufficient cause". This is a very similar intuition, since when sufficiency is taken as a characteristic of an individual condition, then the last condition, might be perceived as *de facto* the sufficient cause).

The CoS verb's selection pattern shows a sensitivity to exactly this type of event-related change in the value of conditions in a sufficient set: its subject is set by default to a participant in this **completion event**. When opening an automatic door under normal conditions, then, this completion event will generally correspond to the Button condition. Thus, sentence (13) is the preferred causal description by default, and sentence (14), which substitutes Electricity as the subject, is ruled out. The notion of a completion event is needed to explain why judgments reverse—favoring (14) over (13)—when the door scenario is changed such that the button is depressed beginning at time $t$-1, but a power outage prevents the door from opening until electricity is restored at time $t$. This alternative context involves two non-simultaneous event-related conditions in the sufficient set (Button and Electricity). This shows that whenever the temporal order of events is retrievable contextually, the felicity conditions of CoS verbs require the selection of the factor corresponding to the completion event given the temporal ordering. The power outage scenario presents a temporal ordering in which Electricity completes the sufficient set, and therefore sentence (14) is the most felicitous description.

These observations were recently confirmed by Bar-Asher Siegal et al. (2021), who demonstrate in a series of experiments that participants were highly sensitive to the completion of a sufficient set when CoS verbs were used. Participants demonstrated different acceptance rates of causative constructions depending on which causal condition the statement referred to. When the causal condition completed the sufficient set, CoS verbs were considered appropriate. By contrast, when asked about necessary condition that did not complete the sufficient set, CoS verbs were considered less appropriate than overt causatives.

The restrictions on the selection of the causative component of a CoS verb is represented formally in (15):

(15) **Lexical causative**

$\exists Q \exists R \exists e \exists t \exists \Sigma{:}\textsc{suff}(\Sigma, R)^M = 1\ \&\ (Q \in \Sigma^M)\ \&\ \Sigma(e)\ \&\ \tau(e) \subseteq t\ \&\ \forall t' < t \forall e' : \tau(e') \subseteq t' \rightarrow [\neg Q(e')]\ \&\ \forall \Omega[(\Omega \neq \Sigma)\ \&\ \textsc{suff}(\Omega, R)^M = 1 \rightarrow \neg\Omega\ \ (\text{e})]$

The formula in (15) amounts to a description of a **completion event**: a condition $Q$ is part of the set of conditions that constitutes a sufficient set. At the time $t$ of the event affecting the value of $Q$ (i.e. prior to it, for all events, $\neg Q$), the model determines that the occurrence of the effect must take place, as the sufficient set $S$ holds at the time of the event. Since prior to $t$ the sufficient set $S$ did not hold (since $Q$ is part of the sufficient set), the event at time $t$ is the completion event.

By incorporating the notion of a completion event into the selectional constraints of a CoS verb in formula (15), we can now explain the asymmetrical entailment pattern between *cause* and CoS verbs observed in (3). Because the (c) expressed by a CoS verb will always correspond to a condition which is individually a necessary condition, the truth of a corresponding *cause* sentence is entailed. However, the reverse entailment pattern does not hold, since *cause* can select a condition which does not complete a sufficient set. This can be seen clearly in the logical relationship between the two formulae in (12) and (15), corresponding to overt *cause* and the causal component of a COS verb, respectively.

## 5.2 Solving the puzzle of direct causation

Another upshot of our proposed analysis is that it reconciles with the famous "directness" inference of the CoS verb while also predicting the acceptability of sentences like (5), which describe scenarios where other causal factors intervene between the selected cause and the effect. We will argue that the events represented as the subjects of those sentences do complete sufficient sets, despite the fact that there are other causal factors that occur after them.

CoS verbs, according to the current proposal, do not require contiguity between cause and effect at all, but instead require a completion of *a* sufficient set. The intuition of direct causation arises (epiphenomenally) from contrasting CoS verbs with overt *cause* sentences: the stronger selection pattern of the former - which requires a completion event - may exclude more temporally distant conditions, while the latter admits any necessary condition.[10] This gives the illusion of a stronger contiguity requirement for CoS verbs.

In light of this we can return to the puzzle raised by the sentences in (5) - in which all stages in the chain can be represented as the cause in the CoS verb construction. This has to do with two things which were raised in our discussion:

1. The process of causal selection, from the linguistic point of view, does not assume that only one condition can be selected as the cause (see above 3.1). Therefore, more than one causal factor can be selected.

2. The selection of CoS verbs is sensitive to the completion of *a* sufficient set, and as emphasized in 4.2.2, in the case of deterministic causal chains, there can be a variety of sufficient sets. In fact, there can in principle be as many sufficient sets as there are conditions on the chain, since each of them, can be a member of a different sufficient set. Consequently, any stage of this chain, has the potential of completing *a* sufficient set.

Combining these two observations, CoS verbs do not impose restrictions on the selection of a causal factor in the case of deterministic causal chains, as seen in (5). When each intervening condition is understood to be fully determined by a preceding necessary condition (or set thereof), any non-terminal node in the chain corresponds to the completion event of *a* sufficient set. Thus, each condition in the chain ("opening bus lanes", "accidents increase") is available for selection as the subject. The automatic door scenario in Figure 1 also admits variation in the 'size' of the sufficient set selected by the CoS verb *open*: (16) shows that the subject can be a participant in the Button condition or the dependent Circuit condition, since each of these conditions can complete a different sufficient set (as demonstrated at the end of Section 3 in Figure 3).

(16) {The pushing of the button$_B$/the closing of the circuit$_C$} opened the door.

[10] In various studies it has been shown that "recency" is a factor in causal selection (Einhorn and Hogarth, 1986; N'gbala and Branscombe, 1995; Henne et al., 2021). The fact that in deterministic chain any condition can be selected as the subject, indicates that it is not the time order that matters but being a condition that completes a sufficient set. Henne et al. (2021) also noted that recency is a factor only when all conditions are required to be fulfilled.

## 5.3 Role of agents

With CoS verbs, events may intervene between the selected cause and the effect as long as they are part of a fully deterministic causal chain. This is not the case when intervening conditions are understood to be events controlled by volitional agents, as we saw with Katz's example of the sheriff in (17).

(17) #The gunsmith killed the sheriff. (Repeated from (6))
*Context: A sheriff has his six-shooter gun faultily repaired by the local gunsmith. As a result, his weapon jams at a critical moment during a gunfight with a bandit and the sheriff is killed.*

Linguistic facts suggest that inexplicit agentive actions (e.g. causee actions) are sometimes presupposed to be somewhat deterministic. To see that this is the case, consider the following contrast.

(18) The eclipse ended the concert.
[*lunar eclipse* > *distracts musicians* > *concert ends*]

(19) ??By inspiring the conductor to create wonder through collective silence, the eclipse ended the concert.
[*lunar eclipse* > *conductor stops conducting* > *concert ends*]

(20) The eclipse led to the cancellation of the concert by inspiring the conductor to create wonder through collective silence.
[*lunar eclipse* > *conductor stops conducting* > *concert ends*]

In the first case (18), the eclipse is perceived as deterministically influencing the musicians, so that the concert cannot continue. In (19), the eclipse is understood to prompt a decision on the part of the conductor to cancel the concert. In this case, the eclipse "inspires" the conductor to behave in a certain way, leaving open the possibility that he could have behaved differently. While the causal model should indicate the dependency between the eclipse and the cancellation of the concert, as this is the causal knowledge that licenses both (18) and (20), it is clear that this dependency is not deterministic. One option is that the model contains a regular causal relation between the eclipse and the conductor's decision, but that it allows "violations of the causal laws" (cf. Schulz (2011)); another option is that causal models can capture also non-deterministic connection, allowing fluctuation based on agents' decisions (cf. Nadathur and Lauer (2020)). The sentence in (20) is in a different causative construction (not involving a CoS verb), and it must rely on a model that includes both the eclipse and the conductor's action.[11]

Regardless of the way that models capture indeterministic causal chains, the role of the volitional action impact the identification of the available sufficient sets, and as a result the eclipse itself cannot be the completion event (all sufficient sets must include the conductor's decision), hence the unacceptability of (19), since it fails to select that final condition to complete a sufficient set. For our purposes, the contrast between (18) and (19) shows that when the agent's volition is explicit, that it affects the selection of earlier conditions as the cause of the CoS construction.

## 5.4 Foreseeablility

Cases in which the satisfaction of one of the necessary conditions is foreseeable seems to violate the requirement of the completion of a sufficient set. Consider again a situation where Sam is on a train and presses the button of the door before the train reaches the station; buy only when the train stops at the station does the door open. In such a case (21) is still acceptable, while (22) is less natural.

(21) {Sam/the pushing the button/the button} opened the door.

[11] When causation is indeterministic, causal relevancy (as defined in Definition 5,) does not hold. In such cases the dependency, represented in the graph is different, but it is possible to argue that a very similar definition to necessity (Definition 6) still holds ((cf. Woodward (2003, 42,211)). This is, however, beyond the scope of this paper.

(22) #The train's arrival to the station opened the door.
*Automatic train door with safety delay until the train stops.*

The fact that the foreseeability is a factor for a selection of non-final condition in the case of CoS was indeed confirmed in experiments by Bar-Asher Siegal et al. (2021). However, since usually completion of a sufficient set is a very strong requirement for the acceptability of this construction, we need to adjust our analysis such that a condition can still be considered as "the last straw" if after its occurrence all other conditions are foreseeable.

One option for doing this is to assume that there are two perspectives from which completion can take place: **An objective take -** the last event which completes a sufficient set (and then only time-order matters); and **a subjective take -** the last condition which the agent didn't know that will be fulfilled (hence foreseeability matters). This difference is formally captured between (23), which repeats (15), and (24) in which the completion event is te that last event that the individual I K(knows) about its occurrence.

(23) **Lexical causative - the objective take**
$\exists Q \exists R \exists e \exists t \exists \Sigma{:}\textsc{suff}(\Sigma, R)^M = 1 \;\&\; (Q \in \Sigma^M) \;\&\; \Sigma(e) \;\&\; \tau(e) \subseteq t \;\&\; \forall t' < t \forall e' : \tau(e') \subseteq t' \rightarrow [\neg Q(e')] \;\&\; \forall \Omega \; [(\Omega \neq \Sigma) \;\&\; \textsc{suff}(\Omega, R)^M = 1 \rightarrow \neg \Omega \; (e)]$

(24) **Lexical causative - the subjective take**
$\exists Q \exists R \exists e \exists t \exists \Sigma{:}\textsc{suff}(\Sigma, R)^M = 1 \;\&\; (Q \in \Sigma^M) \;\&\; K(\Sigma, I, e) \;\&\; \tau(e) \subseteq t \;\&\; \forall t' < t \forall e' : \tau(e') \subseteq t' \rightarrow [\neg K(Q, I, e'] \;\&\; \forall \Omega \; [(\Omega \neq \Sigma) \;\&\; \textsc{suff}(\Omega, R)^M = 1 \rightarrow \neg \Omega \; (e)]$

An alternative solution, relies on the fact that all causal models are partial, as there are endless conditions whose occurrences are taken for granted. In the case of the automatic door, it is easy to list conditions that were not included in the original model: some positive (for example those related to the source of the electricity) and some negative (for example, that nothing would block the door from the other side). The latter, for example, is always relevant after the pressing of the button, but this condition is usually ignored when structuring a model, thus it is not part of the relevant causal model for licensing a specific causative construction.

Thus, it is possible that similarly, conditions that their occurrences are taken for granted (either past events or future-foreseeable events) are not considered part of the relevant sufficient sets, and consequently the time of their occurrence does not matter. In a more principled way, it is possible to say that the selection of the completion event is the selection of the time from which the occurrence of the result is known to be necessary. It is therefore, reasonable, that foreseeable events are taken for granted in such calculations, and therefore the necessary occurrence of the result is computed earlier.

## 5.5 A possible counterexample, and one more definition

What if, in the case of the door with two opening systems (as depicted in Figure 2), it takes 5 seconds from the time of pressing the button until the circuit closes. John pressed the button, but while he was waiting, Sam turned the handle. In this case, who opened the door? Clearly we would say that the former didn't and the latter did. John, however, completed *a* sufficient set, and at the time of its occurrence no other sufficient set was completed. Thus this state-of-affairs confirms the condition represented by (15), and the sentence "John opened the door" should be accepted; in contrast, when Sam turned manually the handle a different sufficient set was already completed, and according to (15) it could not be selected, and the sentence "Sam opened the door" should be unacceptable. But this of course is not the case.

Although pressing the button completes *a* sufficient set, according to Definition 7, this is not enough: since the 5 seconds delay mechanism is yet another necessary condition that must be fulfilled to ensure the outcome, when another person opened the door manually this condition failed to be fulfilled. Here we return to Mackie's notion of sufficient set, which consists of all of the necessary conditions. Thus, for our purposes we must return to the distinction we make earlier between two notions: ***a*** **sufficient set**, and ***a*** **completed sufficient set**: Once all sufficient sets are identified, it is logically possible to identify which are subsets of the other. Among such sets, **the completed sufficient set** for this interpretation of $\chi$ (among these sets):

> **Definition 8 (A completed sufficient set)**: **the completed sufficient**: A situation $s$ is the completed sufficient set for a certain value of $\psi$, which is the superset of all comparable sufficient sets.

In light of this observation we may conclude that both definitions are relevant for licensing a CoS verb with respect to a specific condition: A subject of a CoS construction, must be, on the one hand, part of an event that completes *a* sufficient set, and at the same time must be part of **the** (only) completed sufficient set that all its conditions were fulfilled. In the case of the door, while pressing the button completes the sufficient set 1 in Figure 3, not all of the conditions of its completed-sufficient set (set 3) were fulfilled. In contrast, the turning of the handle is part of a completed sufficient set of conditions whose members were all fulfilled.

In light of this we need to reformulate what licences the cause in the CoS construction, which is based on (15), with the addition of the function **COMPSUFF** that takes two situations and returns 1 if the first (Y) is a completed sufficient set in the model for a specific result (R):

(25) **Lexical causative**
$\exists Q \exists R \exists e \exists t \exists \Sigma \exists \Upsilon$:$\textsc{suff}(\Sigma, R)^M = 1$ & $\textsc{compsuff}(\Upsilon, R)^M = 1$&$(Q \in \Sigma^M)$ & $(Q \in \Upsilon^M)$ & $\Sigma(e)$ & $\tau(e) \subseteq t$ & $\forall t' < t \forall e' : \tau(e') \subseteq t' \rightarrow [\neg Q(e')]$ & $\forall \Omega$ $[(\Omega \neq Y)$ & $\textsc{compsuff}(\Omega, R)^M = 1 \rightarrow \neg \Omega(e)]$

The requirement of singularity, is relevant only for the completed sufficient set, and not for the sufficient set, which the cause, represented by the subject, completed.

# 6 Conclusion

The common assumption in the linguistic literature is that the category of causative constructions is defined by their shared semantic property of expressing causal relations. However, if we combine this assumption with a unified account of causation, then we should expect the semantics of all causative constructions should be the same. This expectation stands in contrast to the fact that different causative constructions have different meanings, as they demonstrate various inferential differences between constructions.

This paper developed a new approach to solve the apparent contradiction between these assumptions and linguistic data. While we subsume all causal relations relevant for the meaning of causal language under a unified concept of causation, we modify it by positing different construction-specific requirements. On this rationale, each construction is subject to specific constraints—contingent on its semantics—regarding which conditions, among a set of conditions in a causal model, can represent the selected cause in a given causal statement.

Developing this approach required us to model causality and to develop a corresponding semantic framework to capture the meaning of causative constructions within this model. We have shown how Structural Equation Modelling (SEM) can be used as formal models of the semantics of causal statements to capture the necessary background for licensing the diversity of causal inferences reflected in language.

Taking the linguistic perspective, a causal model captures a speaker's knowledge about the relationship between facts in the world, and what is expected to result when certain conditions are fulfilled. With respect to the semantics of causal statements, we argued that this kind of knowledge forms the basis for licensing a speaker's linguistic judgments. Illustrated using two constructions, CoS verbs and overt *cause*, we proposed a hypothesis about the set of constraints imposed by the constructions on the selection of their causes, and how these constraints can be captured by the model. In this way, we shed light on the asymmetry between CoS and overt causatives both in terms of their entailment patterns (3) and in the empirical puzzles related to the notion of causal directness (5)-(7) by elaborating on the restrictions that CoS causatives place on what can be selected as a linguistic subject.

Thus, this approach substantiated the recent claim of Bar-Asher Siegal et al. (2021) that, next to causal selection (the selection of the cause among that various causal factors), there is a causative-construction-selection (cc-selection) as well. In this process the speaker selects, along with the cause, a causative construction which appropriately describes the relation behind the observed course of events. Thus, for a given set of conditions and a given effect, there is a cc-selection that involves the following question: "With respect to each of the relevant condition, can it be encoded as the cause in a statement of a singular instance expressed by a specific causative construction?" **Taking this approach, the factors that affect the cc-selection are taken as part of the meaning/truth conditions of linguistic expressions.**

As became clear, cc-selection is more crucial in the choice of a statement than causal selection, due to the fact that causal selection is restricted by the linguistic availabilities resulting from the linguistic choice. Previous discussions on causal selection took the nature of the dependency for granted, and then treated the construction as basically aiming to convey that type of dependency, whereas in our approach causal selection is coming secondary to cc-selection.

The framework of SEM is also a convenient way to represent the fact that causality is a relation between sets of factors, and it allowed us to characterize the selection of the cause with tools provided by this type of model. As part of this analysis, we have also proposed a formalization of a 'sufficient set of conditions' within a model and explained its relevance in selectional parameters. Contrary to recent analyses which assumes that causal sufficiency holds between a single condition and an effect, we argue for basing sufficiency on sets of conditions which are individually necessary but only sufficient when taken together. We discuss the original motivations for this view from Mackie (1965), who uses these terms informally and in the logical sense. In this paper, these terms were defined over the structure of a causal model, and we introduced new supporting evidence from causative expressions in natural languages.

Finally, we have shown that contrastive inference patterns exhibited by causative constructions in English can be precisely captured in relation to SEM with additional characterization of the conditions. Moreover, our analysis was shown to explain longstanding puzzles relating to COS causative verbs and direct causation.

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