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# Direct Causation: A New Approach to an Old Question

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# Direct Causation: A New Approach to an Old Question

## Abstract

Causative constructions come in lexical and periphrastic variants, exemplified in English by Sam killed Lee and Sam caused Lee to die. While use of the former, the lexical causative, entails the truth of the latter, an entailment in the other direction does not hold. The source of this asymmetry is commonly ascribed to the lexical causative having an additional prerequisite of “direct causation", such that the causative relation holds between a contiguous cause and effect (Fodor 1970, Katz 1970). However, this explanation encounters both empirical and theoretical problems (Nelleman & van der Koot 2012). To explain the source of the directness inferences (as well as other longstanding puzzles), we propose a formal analysis based on the framework of Structural Equation Models (SEMs) (Pearl 2000) which provides the necessary background for licensing causal inferences. Specifically, we provide a formalization of a 'sufficient set of conditions' within a model and demonstrate its role in the selectional parameters of causative descriptions. We argue that “causal sufficiency” is not a property of singular conditions, but rather sets of conditions, which are individually necessary but only sufficient when taken together (a view originally motivated in the philosophical literature by Mackie 1965). We further introduce the notion of a “completion event” of a sufficient set, which is critical to explain the particular inferential profile of lexical causatives.

# Direct causation: A new approach to an old question

Rebekah Baglini and Elitzur A. Bar-Asher Siegal[*]

## 1 Introduction

### 1.1 A Linguistic Puzzle

English causative constructions come in many different forms. Among them are the often-contrasted lexical and periphrastic *cause* constructions, exemplified by *Sam killed Lee* and *Sam caused Lee to die*. Despite their obvious similarity in meaning, it has long been observed that the two expressions are not semantically equivalent. As seen in (1), the lexical causative entails the truth of the periphrastic, but an entailment in the other direction does not hold.

(1) a. Sam killed Lee. $\models$ Sam caused Lee to die.
b. Sam caused Lee to die. $\not\models$ Sam killed Lee.

The entailment pattern in (1) indicates that *cause* can be applied in a broader range of situations than a corresponding lexical causative. A subset of these situations, including cases where Sam's action precipitates Lee's death through negligence and extenuated causal chains, are not felicitously described using *kill*.

The source of this difference is commonly ascribed to the lexical causative having an additional prerequisite of "direct causation", such that the causative relation holds between a contiguous cause and effect, and no third event is allowed to intervene (Fodor 1970, Katz 1970:inter alia).[1] While the idea that the lexical causative sentence describes a causal relation which is 'more direct' than its paraphrase with *cause*, the contiguity-based hypothesis faces at least two species of problems. At the theoretical level, capturing causal directness requires a means of modeling potentially complex causal chains (Dowty 1979). At the empirical level, linguistic examples such as (2) show that lexical causatives do not wholly prohibit intervening causes. Note also that any of the intervening causes in (2)(a-b) could be selected as the causal subject in a similar situation.

(2) a. Opening bus lanes to motorcycles will redden the streets of London with cyclists' blood.
Implied causal chain: [*opening bus lanes* > *accidents increase* > *some cyclists die*]
b. A large fleet of fast-charging cars will melt the grid.
Implied causal chain: [*many electric cars on roads* > *many cars charging simultaneously* > *high electricity demand* > *heating of electric cables* > *melting of the grid*]
(from Neeleman and Van de Koot 2012)

In this paper, we aim to shed light on the original puzzle in (1) by elaborating on the restrictions that lexical causatives have on what can be selected as a linguistic subject.

### 1.2 How to Address the Problem

Both lexical causative and complex predicates with *cause* belong to the larger group of causative constructions. Following Bar-Asher Siegal and Boneh (forthcoming), 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:

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[1] See (Wolff 2003:3-4) for a review of the literature on direct causation.

| **Causative constructions** | |
|---|---|
| Overt verbs: | *cause, make, allow, enable, get...* |
| Connectives: | *because (of), from, by, as a result of..* |
| Change of state verbs: | *open, boil...* +morphology |
| Affected datives | |
| Experiencer *have* | |

Table 1: Causative constructions

i) a cause (c);

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

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

There is a strong tendency among linguists to assume that (D) is the locus of causal meaning common to all causative constructions.[2] However, as we saw in (1), different causative constructions support different causal inferences, despite sharing the common skeleton of cDe. What is the source of these distinct inferences? One approach is to assume that each causative construction potentially denotes a different "flavor" of D, admitting a plurality of CAUSE operators with different semantic commitments (Bar-Asher Siegal and Boneh 2019). An alternative approach, which we will follow, assumes a unified concept of D for all causal relations, but posits different construction-specific requirements on a causal model. More specifically, we assume that each construction has specific constraints on what can be linguistically selected as a cause among a set of factors in a causal model. This requires a reconsideration of how to model causal statements, and what exactly causative constructions express.

To motivate our analysis, we briefly review several insights from the philosophical literature which point us towards a richer a model of causal dependencies. To formalize these insights, we adopt a structural equations model approach based on Pearl (2000) for evaluating causal claims, and show how such a model allows us to license construction-specific inferences regarding the nature of the causal relation D. According to this approach, causal statements inevitably involve "causal selection", i.e. parameters pertaining to the constraints on the selection of a particular causal factor. In our formal semantic analysis, we precisely specify the parameters for constraints on selecting a main cause in lexical constructions. In articulating these parameters, we will explain why, for example, in a regular scenario of an opening of an automatic door sentence (3) is acceptable while (4) is not:

(3) $\{$John/the pushing the button/the button$\}_B$ opened the door.
(4) #Electricity$_E$ opened the door.

In addition, we relate these parameters to the contrasting entailment patterns between lexical and *cause* constructions, illustrated in (1).

The goals of the present paper are threefold:

1. To show that Structural Equation Models (SEMs) for causal relations provide the necessary background for licensing causal inferences reflected in language.

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[2] The view that an all-encompassing, causative meaning component underlying the diverse linguistic causative constructions can be found for example in McCawley (1968) or Copley and Harley (2015), and this is an inheritance of an old tradition in philosophy. However, in other disciplines such as philosophy and cognitive psychology, a pluralistic notion of causation has been recently advocated. Within philosophy, see for instance, Hitchcock (2003), Hall (2004), Psillos (2009) who argue in favor of theories of causal pluralism, allowing the co-existence of different notions of causation; within cognitive studies Waldmann and Hagmayer (2013), *inter alia*, also indicate that people have a pluralistic conception of causation. See, Bar-Asher Siegal and Boneh (forthcoming) for an elaboration on causal pluralism in recent literature.

2. To propose a formalization of a ‘sufficient set of conditions’ within a model and explain its relevance in selectional parameters. Contrary to recent claims that causal sufficiency holds between a single condition and an effect (Baglini and Francez 2016, Lauer and Nadathur 2017, Martin 2018, Bar-Asher Siegal and Boneh 2019), 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), develop it further, and introduce new supporting evidence from causative expressions in natural languages.

3. To show that contrastive inference patterns exhibited by causative constructions in English can be precisely captured in relation to SEMs with INUS conditions. Moreover, our analysis is shown to explain longstanding puzzles relating to direct causation.

## 2 Modeling Causation

Recall that causative constructions encode a dependency between causes and effects. The assumption is that this dependency is a reflection of the concept of causality itself. This assumption relies on a a fairly standard philosophical view, according to which causation is a binary relation (Hume 2016:/1748), and it is often assumed that the relata are events Davidson (1967). That is, causal relationships have the form C causes E, where C and E are events (such as Lewis 1973, 1986). A claim that we would like to entertain is that binary relations between C and E are, in fact, features only of linguistic expressions (cf. Hitchcock forthcoming). Causality itself is a more complex notion, that involves a relations between multiple factors, and a consequence. 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).

The idea that causation is a binary relation, then, is almost trivial among philosophers and linguists. Mill, however, points 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 produces/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)

Discussions on *causal selection* is a common theme in the philosophical literature (cf. Hitchcock and Knobe 2009 and Cheng and Novick 1991), but while a common assumption is that they are about the essence of causal relations, in our approach this is a linguistic phenomenon: specific linguistic expressions implies such selections. As noted by Bar-Asher Siegal and Boneh (forthcoming), the principles that guide the selection of the so-called “real cause” vary from one causative constructions to another. To illustrate the concept of causal selection it will be helpful to return to the concrete scenario of the automatic door. For the door to be opened, there are several factors that will be relevant: that the button is pushed; that electricity is running; that the button is connected to the opening mechanism via some circuitry; and that a manual lock has not been engaged.

We can begin to model causal scenarios like the automatic door example using structural equation models (SEMs). Dependencies between states of affairs are represented in a SEM by a set of propositions (variables) and truth values. We take structural equation models to represent and encode knowledge of the causal structure, thereby licensing linguistic judgments. Thus, for the automatic door example, we can define the following variables (pairs of propositions and truth values) in A-E in Table 2 below. The fact that some variables depend on others for their value is represented by structural entailments in F-G. 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., E.]. The endogenous variables are [C., D.].

| | |
|---|---|
| A. | Lock: =1 if door is locked; else =0 |
| B. | Button: =1 if pressed; else =0 |
| C. | Circuit: =1 if closed; else =0 |
| D. | Door opens: =1 if opens; else =0 |
| E. | Electricity: =1 if running; else =0 |
| F. | Button =1 $\models$ Circuit =1 |
| G. | Circuit =1 & Electricity =1 & Lock =0 $\models$ Door opens =1 |

Table 2: Variables and structural equations

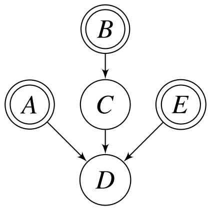

Figure 1: Directed graph

We use the term condition for any variable that is relevant for the value of another. By "relevant" we mean that the value of the condition is 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.

As shown in Figure 1, dependencies defined within a SEM can be represented qualitatively in a directed graph. 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. Graphically, conjoined conditions are indicated by arrows pointing to a single point on a dependent node. We can turn now to provide a formal description of causal structures. Following what has been portrayed informally with the graphs in Figures 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 $\mathscr{P}$ is a directed acyclic graph (DAG) in which each node corresponds to a distinct element of $\mathscr{P}$, and each link represents direct functional relationship among the corresponding propositions.

The causal structure (represented in Figure 1) is the structural basis for a "causal model" in Definition 2. A causal model captures speaker's knowledge about the relationship between facts in the world, and what is expected to result given that certain conditions has been fulfilled. This will form the basis for licensing a speaker's linguistic judgments.

**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 $\psi_i \in \mathscr{P}$, where $\Sigma$ is the set of all nodes that $\psi_i$ causally depends on in $D$.

Having defined a causal model, Definition 3 formulates how the truth values of propositions in the model are determined. 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). To capture the nature of causal dependant, we use a three-valued logic with the values 1, 0 and u(ndefined). In the case of endogenous variables, Undefined is in epistemic terms and represents lack of knowledge of the speaker about the value of the proposition.

**Definition 3 (Truth values generated by a causal model)**: Let $\mathscr{P}$ be a set of proposition letters and $\mathscr{L}$ the closure of $\mathscr{P}$ under conjunction and negation. Furthermore, let $M =< D, \Theta_D >$ be a causal model for $\mathscr{P}$, and $I : \Sigma \rightarrow 0, 1, u$ an interpretation of a set of variables $\Sigma$ of $M$. For arbitrary $\psi \in \mathscr{L}$ 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 $\psi \in \mathscr{P} - \Sigma$ and $[[F(\psi)]]^{M,I}$ is defined (0/1)
$[[\neg\psi]]^{M,I} = 1$, 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 represents the value of one proposition, given the truth-values of a set of propositions it depends on. The truth table in Table (3) represents a fully 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).

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | u | u | u | u |

Table 3: Automatic door example

## 3 Redefining Sufficiency

In our example, each of the factors 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 informally envisioned 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.

The last part of this definition—"together Unnecessary but Sufficient"—clarifies that in modeling the causal structure of the world, we are not only describing 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. For example, in the running example of the automatic door, we can imagine that the door 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 case of actual causal relation only one set represents the actual causal pathway for a particular opening event. This is reflected in Table 4, which updates Table 2 with one new variable (A') and one new inference relation (D')

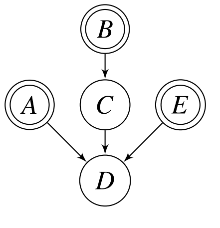

Figure 2: Automatic opening

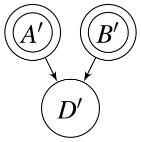

Figure 3: Opening by handle

Sufficiency, as mentioned in goal 2 in Section 1.2, is therefore defined as a characteristic of a set causal factors, and not of a single condition. We turn now to provide a formal definition to necessary

| | |
|---|---|
| **Sufficient set 1** | |
| A | Lock: =1 if door is locked; else =0 |
| B | Button: =1 if pressed; else =0 |
| C | Circuit: =1 if closed; else =0 |
| D | Door opens: =1 if opens; else =0 |
| E | Electricity: =1 if running; else =0 |
| F | Button =1 $\models$ Circuit =1 |
| G | Circuit =1 & Electricity =1 & Lock =0 $\models$ Door opens =1 |
| **Sufficient set 2** | |
| A’ | Lock: =1 if door is locked; else =0 |
| B’ | Handle: =1 if handle is turned; else =0 |
| D’ | Handle =1 & Lock =0 $\models$ Door opens =1 |

Table 4: Updated table

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, in Definition 4, which is broader, and simply requires some causal dependency (not sufficient), and a definition of a situation (Definition 5) for a set of valued propositions.

**Definition 4 (Causal relevance)**: A set of variables $\Sigma$ of $M$, is causally relevant for a proposition $\psi$ when the interpretation of $\psi$ with respect to $M$ and $I$ is defined, when $I : \Sigma^c$ (the complementary set of $\Sigma$ in $\mathscr{P}$) assigns $u$ for all its members.

**Definition 5 (Situation)**: A set of pairs of propositions $\Sigma$ in $\mathscr{P}$ and their values is a situation. We refer to the set of propositions and their value in a situation $s$ as $dom(s)$.

Armed with the notion of **causal relevancy** and with a definition of **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. its value in $s$ ($S\chi$) is necessary for a certain value of $\psi$ (0 or 1) if: There is a set $\Sigma$ and there are two situations $s$ and $s'$, which are two situations of $\Sigma$, such that

i. $\Sigma$ is causally relevant for a proposition $\psi$

ii. $I : \Sigma \to 0,1$ is an interpretation of the set of variables $\Sigma$ of $M$, in situation $s$ and $I' : \Sigma \to 0,1$ 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 complementary set $J$, such that $J = dom(s) - dom(s')$ 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. 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. This asymmetry is also the reason for defining conditions as causally necessary for **a certain value of** $\psi$ and not for *the* truth-value in general.

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 value are defined in $s$, is causally relevant for the proposition $\psi$, and all members of $dom(s)$ are causally necessary for $\psi$ in the situation $s$. $\{X \in dom(s)|$ such that $x$ is causally necessary for $\psi\}$

Now, it must be noted that being causally necessary for a certain value of $\psi$ is a transitive relation: If a certain value of $\phi$ is causally necessary for a certain value of $\chi$, and the value of $\chi$ is causally necessary for a certain value of $\psi$, then this value of $\phi$ is causally necessary for the relevant value of $\psi$. In other words, if a superset situation $n$ of situation $s$ contains only one additional member $n(\phi)$, which is causally necessary for the valuation of $s(\chi)$, then $n(\phi)$ is also causally necessary for that certain value of $\psi$ in the situation $n$.
Moreover, in this case if $s$ is a sufficient set for the value of $\psi$, $n$ must be as well a sufficient set for this value of $\psi$. At this point we depart from Mackie. While for him, an INUS is a member of a specific *sufficient set*, in fact it can be a member of different sufficient sets. In our returning to Table (3), the following situations constitute sufficient sets of the value 1 of E.: $\{< A,1 >,< C,1 >,< D,0 >\},\{< B,1 >< C,1 >,< D,0 >\},\{< A,1 >,< B,1 >,< C,1 >,< D,0 >\}$.

## 4 Returning to the Puzzle

What do SEMs buy us? On such causal modeling 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 presuppose SEMs, 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.

For example, periphrastic *cause* (as already claimed by Mackie 1965, and more recently advocated by Lauer and Nadathur 2017) can select as its subject any condition on which the value of the effect causally depends—i.e. any INUS condition (5).

(5) {John's pushing the button$_B$/the button$_B$/John$_B$/electricity$_E$/the closed circuit$_C$} **caused** the door to open.

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 (Beebee 2004:296 and Hitchcock and Knobe 2009).

The causative component of the verb *cause* is represented formally in (6). The function SUFF(ICIENT) takes a situation (Def. 5) and returns 1 if it is a sufficient set in the model for a specific result ($R$).

(6) **Periphrastic cause**
$\exists Q \exists e \exists t \exists S{:}\textsc{suff}(S)^{M,R} = 1\ \&\ (Q \in S^M\ \&\ Q(e))$

The formula in (6) 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.

Turning now to the lexical causative, we argue that its specific parameters governing the selection of a main cause (c) give it a different inferential profile from periphrastic *cause*. To see this more clearly, it will be useful to evaluate the appropriateness of alternative lexical 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 Table 2/Figure 1 and the default scenario, in which John presses the button and opens the automatic door, we observe that most speakers prefer the sentences in (7) to the alternative in (8):

(7) $\{$John's pushing the button/the button/John$\}_B$ **opened** the door.
(8) Electricity$_E$ **opened** the door.

But the default preference for (7) over (8) can be reversed if we adjust the contextual background. Imagine applying the same model in Table 2/Figure 1 to a different scenario: John 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 (8).

We propose that, unlike periphrastic *cause*, lexical causatives are sensitive to a "last straw effect"—they must select the condition that completes *a* sufficient set. We can capture the notion of completion in the following way:

A. Completion involves events taking place in time.
B. Completion also involves a sensitivity to event-related changes in the value of conditions. Given that events have time in which the value of associated variables in the model can be changed ($0>1$ or $1>0$), and occurrence, for our purposes, will be defined in terms of change of values.

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 (cf. Martin 2018, who proposes that the condition must be "the sufficient cause").

The lexical causative'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 (7) is the preferred causal description by default, and sentence (8), which substitutes Electricity as the subject, is ruled out. The notion of a completion event is needed to explain why judgments reverse—favoring (8) over (7)—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 the lexical causative 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 (8) is the most felicitous description.

The causative component of a lexical causative verb is represented formally in (9). The function SUFF(ICIENT) takes a situation (Def. 5) and returns 1 if it is a sufficient set in the model for a specific result ($R$).

(9) **Lexical causative**

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

The formula in (9) 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 semantics of the lexical causative in formula (9), we can now explain the asymmetrical entailment pattern between cause and lexical causatives observed in (1). Because the (c) expressed by a lexical causative 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 (6) and (9), corresponding to periphrastic *cause* and the causal component of a lexical causative, respectively.

Another upshot of our proposed analysis is that it reconciles the famous "directness" inference of the lexical causative while also predicting the acceptability of sentences like (2), which describe scenarios where other causal factors intervene between the selected cause and the effect. Lexical causatives, according to the current proposal, do not require contiguity between cause and effect at all. The intuition of direct causation arises (epiphenomenally) from contrasting lexical causatives with periphrastic *cause*: the stronger selection pattern of the former may exclude more temporally distant conditions, while the latter admits any necessary condition. This gives the illusion of a stronger contiguity requirement for lexical causatives. Accordingly, lexical causatives do not impose restrictions on the selection of a causal factor in the case of deterministic causal chains, as seen in (2). When each intervening condition is understood to be fully determined by a preceding necessary condition, 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 Table 2 also admits variation in the 'size' of the sufficient set selected by the lexical causative *open*: (10) 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).

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

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