

Sufficiency causatives

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Abstract

Against past analyses, we point out that the causative verbs *cause* and *make* have quite different inferential profiles, and argue that this is due to the fact that they assert different kinds of basic causal relations: *cause* asserts causal necessity, while *make* asserts causal sufficiency. We characterize these two notions in Schulz (2011)'s *structural causal models* and show how the analysis not only predicts correctly when one of these two causative verbs can be truthfully applied to a situation and the other cannot, but also can derive the *coercive implication* associated with *make* when (but only when) *make* embeds a VP denoting a volitional action. Along the way, we show that a suitably weakened sufficiency analysis also enables a univocal analysis of the German causative verb *lassen*, which has both 'permissive' (*let*) and 'coercive' (*make*) readings. On our account, these different readings arise from the backgrounding of different causal factors in the evaluation of the causative claim.

Keywords: causative, *cause*, *make*, *lassen*, sufficiency, necessity, causal models

1 Introduction

Like many languages, English has a range of periphrastic causative verbs, including *cause*, *make*, *have*, and *get*:

- (1) a. John caused the children to dance.
- b. John made the children dance.
- c. John had the children dance.
- d. John got the children to dance.

Each of (1a)-(1d) conveys that John in some way 'brought about' an event in which the

children danced. Nevertheless, these sentences cannot be treated as paraphrases of one another: each one carries implications that do not arise (naturally) from the others. (1b), for instance, suggests that John exerted force (physical or authoritative) over the children; (1c) is naturally interpreted as a claim that John (successfully) directed the children to dance; (1d) conveys that he intended the children to dance but had difficulty in achieving this; and (1a) invites an inference that John's involvement in bringing about the dancing was in some way indirect (e.g., he played their favorite song, thereby motivating them to dance of their own accord).

In investigating the meaning of periphrastic causatives, a plausible first hypothesis would be that each of the verbs in (1a)-(1d) shares a common semantic core – say, the relation CAUSE of (causal) 'bringing about' that is predicated by *cause*. To account for the divergent implications of (1a)-(1d), this basic core would be supplemented with additional entailments, specific to each individual causative verb.

In this paper, we argue against this view. We claim that the basic difference between the verbs in (1a)-(1d) lies in different 'bringing about' relations that these verbs encode. The argument is developed by examining the meaning and implications of the English causative *make*, and comparing it both to English *cause* as well as to the German periphrastic causative *lassen*. We show that the similarities and differences between these three verbs are best explained by establishing a basic distinction between those causatives predicating *causal sufficiency* and those which predicate *causal necessity*. We spell out these two notions in a formal system for representing and encoding causal dependencies (drawing on Schulz 2011). In addition to being distinct from their logical namesakes, *causal sufficiency* and *causal necessity* cannot be reduced to one another. By successfully treating the implications of *make* in terms of the causal sufficiency/causal necessity distinction, we argue more broadly that the 'common core' of periphrastic causatives resides in the fact that they all describe (formally-definable) causal dependence relations. The differences between them, on the other hand, follow directly from differences in the type and structure of the particular causal relationship which they pick out.

2 The implications of causative *make*

2.1 The coercive implication

As noted above, a common approach to the meaning of a periphrastic causative like *make* is to treat it as combining an assertion of CAUSE (that is, the 'bringing about' relation predicated by *cause*) with additional entailments that are specific to the verb in question.

In support of this approach, there is a wide range of inferences triggered by the use of *make*, but which do not arise with *cause*. For example, (1b) (in contrast to (1a)) might lead us to infer any or all of the following:

- (i) that John intended to bring about the dancing (Wierzbicka 1998);
- (ii) that the children were unwilling to dance ('coercive causation', Dixon 2005, Shibatani 1976);
- (iii) that John commanded or requested that the children dance ('directive causation', Shibatani 1976);
- (iv) that John wanted the children to dance (Stefanowitsch 2001);
- (v) that the children were aware that John wanted them to dance (Wierzbicka 1998).

None of these inferences can be maintained as an entailment of a univocal verb *make*,¹ however: we find felicitous examples that block or contradict each of (i)-(v).

Against (i) and (iv) (as well as (iii) and (v), less directly), causative *make* is perfectly compatible with adverbs like *accidentally* or *inadvertently*:²

- (2) a. ^γYes, I accidentally made [my 3-year old son] fall off the boogie board because holding the board and two bottles of fish food was a little much.
- b. ^γInstead of motivating him to improve, you've inadvertently made him tune you out.

Next, *make* causatives allow for both inanimate and eventive matrix subjects, even when they embed VPs denoting intentional actions. Examples (3a)-(3b) show that neither (iii) nor (v) necessarily follows from *make*:

- (3) a. ^γthis book made me get a divorce.
- b. My husband's arrest (finally) made me get a divorce.

Finally, it does not seem to be the case that the effect of a *make*-causative must be unwanted or undesirable, which argues against treating (ii) as an entailment:

¹We restrict attention throughout to 'causative' *make*, with the complementation pattern NP *make* NP VP, setting aside uses with an adjectival complement (*make her sick*), with two nominal complements (*make her president*, *make her a widow*) and as a generic creation verb with a single complement (*make ice cream*, *make a card*).

²We use the diacritic ^γ to indicate that a sentence was found on the internet, following the practice of Horn (2010). Sources for all naturally occurring examples can be found in Appendix C.

(4) ?I was scared, but they made me feel confident!

These data present a puzzle: if the meaning of *make* contains an assertion of *cause*, but does not encode any additional entailments, then we cannot explain why *make* gives rise to inferences like (i)-(v) where *cause* does not. One possibility, pursued by Wierzbicka (1998) and Stefanowitsch (2001), is to treat *make* as lexically ambiguous, postulating that inferences like (i)-(v) arise from different *makes*, selected for by features of the context like causer/causee animacy or volitionality, effect desirability, and so on.³ If we wish, on the other hand, to hold out for a uniform *make*, we might explain (i)-(v) as pragmatically-enriched reflexes of a more general entailment, associated with *make* but not with *cause*. Generalizing over examples (2)-(4), a plausible candidate for such an inference is what we call the **coercive implication** of *make*.

(5) **Coercive implication of *make*:**

$NP_S \text{ made } NP_O \text{ VP}$ implies that that $\llbracket NP_O \rrbracket$ did not make a free decision to $\llbracket VP \rrbracket$.

A *make*-causative, on this view, would comprise two entailments:

(6) $NP_S \text{ made } NP_O \text{ VP}$

a. $\llbracket NP_S \rrbracket$ caused $\llbracket VP(NP_O) \rrbracket$

b. $\llbracket NP_O \rrbracket$ did not make a free decision to $\llbracket VP \rrbracket$

What ‘making a free decision’ amounts to will need to be spelled out in more detail. However, it is not difficult to see how the more specific implications (i)-(v) could arise on the basis of (6a) and (6b), e.g., as inferences as to how it came about that the children in (5b) did not make a free decision to dance.

It turns out, however, that even the coercive implication cannot be an entailment of *make*. As an entailment, (5b) would impose specific selectional restrictions on *make*-complements. Since ‘making a free decision’ makes reference to the volitional state of the causee (the referent of NP_O), we expect *make* to combine only with agentive causees, and complements describing volitional actions. Neither of these selectional restrictions obtains: the flowers in (7) are non-volitional (indeed, inanimate), and feeling giddy in (8) is an experience, not a volitional action.

(7) The sun made the flowers wilt.

³To be more precise, in the construction grammar frameworks adopted by both Wierzbicka and Stefanowitsch, the relevant meanings are not attributed to an ambiguous lexical item *make*, but rather to a complex syntactic/semantic configuration in which *make* occurs.

- (8) His attention made her feel giddy.

We are back to the original puzzle: we would like a semantics for *make* that explains and predicts the coercive implication (and, relatedly, (i)-(v)), in those cases where ‘making a free decision’ is relevant (i.e., where the embedded VP denotes a volitional action). However, we cannot encode (6b) as an entailment. Without a second entailment for *make*, however, we are unable to account for the empirical differences between *make* and *cause* (at least in syntactically parallel examples like (1b) and (1a)).

2.2 *Cause, make, and causal necessity*

In pursuit of a univocal *make*, we have arrived at a point where our only option is to give up the idea that *make* asserts the same bringing-about relation as *cause*. This approach gains support from the fact that *cause* seems to give rise to inferences that are not (always) associated with *make*. Specifically, we want to suggest that while *cause* predicates causal necessity, *make* does not have a causal-necessity entailment.

Building on Lewis (1973), a prominent approach to *cause* ties its ‘bringing about’ relation to a counterfactual statement which asserts that the effect would not have taken place if the cause had not occurred.

- (9) a. The recession caused Jerry to lose his job.
b. (Other things being equal), if the recession had not happened, Jerry would not have lost his job.

For Lewis, counterfactuals like (9b) were partially constitutive of the causal relation asserted by (9a). Although the precise nature of the relationship remains a matter of some debate in the literature, the intuition that there is a tight connection between the two statements is widely attested, lending credence to the idea that *cause* expresses a type of causal necessity.⁴

It must be noted that there are examples of *make*-causatives which appear, like *cause*, to license inferences to counterfactuals expressing causal necessity. Example (10) is from

⁴It turns out – for reasons that are familiar from the philosophical literature on causation (Mackie 1965, Scriven 1971, Paul 1998, Hall 2004, a.o.) – that the right notion of causal necessity must be weaker than the counterfactual necessity expressed by (9b). The relevant examples involve situations where an effect is *overdetermined* by the presence of two (or more) independent causes, each of which would have been able to realize the effect in the absence of the other(s), or where one cause *pre-empts* another, which would have brought about the effect in the absence of the first. We will not treat such cases in this paper as our main concern is the comparison of different causatives, rather than the comparison of causatives to counterfactuals, but see Halpern and Pearl (2005), Halpern (2015) for a sophisticated treatment of such cases in a framework similar to the one we employ here.

Wierzbicka (1998):

- (10) a. She [Anand's mother]... made Anand pump the tires every morning.
- b. Anand would not have pumped the tires without some action taken by his mother.

However, we argue that causal necessity is never entailed by *make*. In fact, *make* is compatible with contexts in which the relevant counterfactual fails to hold. (11), taken from an installment of the Rachel Maddow show (emphasis ours) illustrates this point.

- (11) MADDOW: You worked for [the health insurance company] CIGNA for 15 years, you left last year. What **caused** you to change your mind about what you were doing and leave?

POTTER: Well, two things. One, it was kind of gradually. One instance or in one regard because I was becoming increasingly skeptical of the kinds of insurance policies that the big insurance companies are promoting and marketing these days. [...]

The other thing that really **made** me make this final decision to leave the industry occurred when I was visiting family in Tennessee a couple of summers ago, and [narrates the experience of happening on a 'healthcare expedition' where uninsured patients were treated by volunteer doctors in animal stalls at a fairground.]

In using *make* (in contrast to Maddow's *cause*), Potter does not commit himself to the claim that his experience at the healthcare expedition was a necessary condition for his ultimate decision to leave CIGNA. Indeed, he establishes ongoing dissatisfaction, and thus the possibility that he would have quit regardless of the expedition. Rather than representing a necessary cause, his experience, occurring when it did, functioned as the 'final straw' in a process that was already underway.

The contrast between *make* and *cause* is even clearer with a constructed example:

- (12) a. I usually go to soccer camp in the summer. Last year I was thinking about going to band camp instead, and I could not make up my mind. Then I broke my ankle, which settled things. I am so happy the injury made me skip soccer camp. I had the best summer ever!
- b. (≠) I would have gone to soccer camp if I had not broken my ankle.

In (12a), the speaker establishes a (contingent) possibility that she will not go to soccer camp, which turned into a certainty when she broke her ankle. Then she goes on to

claim (indeed, presuppose) that the injury *made* her skip soccer camp. If *make* asserted counterfactual necessity, paraphrased in (12b), this should result in infelicity, as the prior context explicitly denies the necessity of the cause. But no such infelicity is felt.

This contrasts with a minimally-different example in which *make* is replaced by *cause*:

- (13) I usually go to soccer camp in the summer. Last year I was thinking about going to band camp instead, and I could not make up my mind. Then I broke my ankle, which settled things. ?I am so happy the injury caused me to skip soccer camp. I had the best summer ever!

Here, the established possibility of a speaker-propelled decision results in a clash with the use of *cause* in the second sentence. The contrast between (12) and (13) is inexplicable if *make* entails *cause*. On the other hand, it is only to be expected if *cause* asserts causal necessity, but *make* does not.⁵

2.3 *Make* and causal sufficiency

We are now faced with the following question: how should the ‘bringing about’ component of causative *make* be analyzed? In examples (11)-(12), the cause expressed by the *make* statement acts as a tipping point; it was not what made the result possible, but rather what made it inevitable. Before the healthcare expedition in (11), it was possible that Potter would leave CIGNA: afterwards, his leaving was a done deal. Similarly, in (12), the speaker establishes a possibility of going to band camp; after the injury, band camp was a certainty.

We claim that this is what the ‘bringing about’-entailment of *make* amounts to: that the causing event made it *inevitable*, in a weak sense, that the effect happened.

- (14) **Sufficiency thesis.** A *make*-causative asserts that the cause was *causally sufficient* for the effect. That is, given the cause, the effect was inevitable, in sense to be made precise.

We think this is a rather natural form of causal dependence, but one that is often ignored in (formal) studies of causative meaning. Causal sufficiency captures the intuition that the effect follows directly as the *result* of the cause much more aptly than Lewis-style

⁵We remain, to some extent, agnostic about the precise relation or relations predicated by *cause*; there is a nontrivial body of literature arguing that the cause (or CAUSE) in *cause* is something more than counterfactual necessity. The point we wish to make is twofold: first, that *cause* asserts something that *make* evidently does not, and second, that this ‘something’ is causal necessity. This leaves open the possibility that *cause* is subject to additional constraints, whether contextual or structural. These remain to be investigated.

necessity analyses. In the next sections, we will try to make these intuitions precise, by developing a formal characterization of the notions of causal necessity and sufficiency in the *causal structural models* of Schulz (2011), building on work by Pearl (2000).

Here, we anticipate a positive consequence of pursuing the sufficiency thesis: we can explain the puzzle set up in Section 2.1. Specifically, causal sufficiency (spelled out correctly) should obviate the need to stipulate the coercive implication as a lexical entailment of *make*.

Roughly, the idea is this. If (15) asserts that John did something that made the children’s dancing inevitable, then the children could not have made a free decision to dance. For if they had freely decided, they could equally well have decided not to dance. But then, John’s action would not have been sufficient for their dancing.

(15) John made the children dance.

This leaves us with the following explananda. First, we would like to give an account of *causal necessity* that makes the right predictions for *cause*-sentences. Second, we want to formalize what it means for one event to be *causally sufficient* for another, and to develop an account that captures the ‘inevitability’ intuitions, in addition to predicting the coercive implication when (and only when) it arises. Finally, while we have denied – with good evidence – that *make* entails necessity, we note that many *make* assertions readily invite a necessity inference. Our third task, then, is to explain the source of this inference, alongside an account of *make*’s assertive content.

3 Representing causal necessity and sufficiency

Lewis’s (1973) influential analysis aimed at reducing causal dependence to counterfactual dependence. In recent years, however, several researchers have favored a reversal of this order of explanation: rather than treating counterfactual conditionals as constitutive of causation, these proposals assume that the semantics of counterfactuals are sensitive to independently-acquired knowledge of causal dependencies in a given situation or context (Bennett 1984, Pearl 2000, Schaffer 2004, Hiddleston 2005, Schulz 2011, Briggs 2012, Kaufmann 2013). Seen from this direction, the tight connection between *cause* and counterfactuals derives from their reliance on the same underlying body of (causal) information.

In describing the semantics of periphrastic causatives, then, we propose to import a causal modeling approach (see also Sloman et al. 2009). Generally speaking, we take

the view that judgements about causal consequence are made over a given ‘network’ of causal dependencies between events and facts, just as judgements about logical consequence are computed over a set of analytical relations between propositions and formulas. Causal information is not, in these models, reducible either to linguistic or purely analytic notions, but is simply taken to comprise part of a speaker’s knowledge about a given discourse context. As such, it can form part of the licensing background for certain utterances, as in recent accounts proposing that Karttunen’s (1971) *implicative verbs* presuppose relations of causal necessity and sufficiency between their matrix content and complement propositions (Baglini and Francez 2016, Nadathur 2016). In bringing causal models to bear on lexical semantics, the central idea is that a network of causal dependencies is not only part of what lexical semantics informs us about and operates on, but also represents a parameter of discourse that is developed and manipulated pragmatically.

For present purposes, we build on Schulz (2011)’s *dynamics* framework for causal entailment, which in turn relies on the interventionist or ‘structural equations’ school of causal modeling developed in Pearl (2000) and elsewhere. We do not believe that anything crucial relies on the choice of a particular framework for representing causal dependencies; our choice is motivated by convenience and for continuity with (what we believe to be) the related class of implicatives. Our aim here is simply to establish that the types of relationships that can be formally articulated in a causal model are both explanatory and predictive with respect to periphrastic causatives. The choice between types of model can be refined subsequently, perhaps on the basis of experimental data (Wolff and Song 2003, Livengood and Rose 2016).⁶

We will develop our analysis in several stages. In Section 3.1, we introduce Schulz’s framework and develop definitions of causal sufficiency and causal necessity that naturally suggest themselves in that framework, taking inspiration from Baglini and Francez (2016) and Nadathur (2016)’s work on implicatives. In Section 3.2, we illustrate the workings of these notions with examples that tease causal sufficiency and causal necessity apart, and in Section 3.3, we articulate our view of why it is that *make* assertions often invite a necessity inference. In Section 4, we turn to the coercive implication of *make*: while it turns out that sufficiency as developed in Section 3.1 is not enough to predict the coercive implication, it is precisely what it required to account for the puzzling behav-

⁶Arguably, the most important choice to be made in representing causal relationships is between dependency and production theories. Pearl-type theories belong to the first class, while the force-dynamics framework (Talmy 1988, Wolff 2007) is the best-known of the production theories. There are arguments in favour of either type of approach, as their explanatory strengths are to some extent complementary; for a more detailed comparison, see Copley and Wolff (2014). We do not take a strong position on the merits of one class of theory over another. The framework adopted here simply provides a straightforward system in which to formalize and examine our central claim with respect to sufficiency in causative constructions.

ior of another causative verb – German *lassen*. In Section 4.3, we present an extension of Schulz’s framework that allows us to define a notion of ‘strong sufficiency’ that leads to the coercive implication.

3.1 Dynamics and causal dependence

Schulz starts from a *dynamics*, which represents and encodes knowledge of the causal structure over a finite set of (salient) propositions P . In the way we employ it here, a dynamics can be thought of as a contextually-developed background parameter, which can be augmented, queried, and modified by discourse contributions.

Definition 1. A *dynamics* for a language over a finite set of propositions P is a tuple $\mathcal{D} = \langle B, F \rangle$ where:

- (a) $B \subseteq P$ is the set of background variables.
- (b) F is a function that maps elements X of $I = P - B$ to tuples $\langle Z_X, f_x \rangle$, where Z_X is an n -tuple of elements of P and f_x a two-valued truth function $f_x : \{0, 1\}^n \rightarrow \{0, 1\}$. F is rooted in B .

Background (or exogenous) variables represent propositions which do not depend on any others in P for their values. The complement set I of *inner* (endogenous) variables represents those propositions which depend causally on each other, and on variables in B . Dependent variables are associated with a function that identifies both the set of immediate causal ancestors for a proposition, as well as the nature of the direct dependencies. The requirement that this function F be rooted in B prevents cyclicity in causal dependencies, by ensuring that a ‘walk backwards’ through the causal ancestors of any variable always ends in B .

Definition 2. Let $B \subseteq P$ be a set of proposition letters, and F a function mapping elements of $I = P - B$ to tuples $\langle Z_X, f_x \rangle$ as above. Let R_F be the relation that holds between the letters X, Y if $Y \in Z_X$. Let R_F^T be the transitive closure of R_F . F is **rooted** in B if $\langle P, R_F^T \rangle$ is a poset and B is the set of its minimal elements.

Schulz works with the strong three-way Kleene logic, in which propositions are valued from $\{u, 0, 1\}$. We will refer to a 0-1 valuation as a *determination* of a variable, while a u -valued variable is *undetermined*. We call a complete valuation of P in this logic a *situation*; a fully-determined situation is a *world*. We refer to the set of variables determined by a situation s as $\text{dom}(s)$ (see Appendix A). Given a situation s , we can check whether

the determined variables have any causal consequences: Schulz defines the operator \mathcal{T}_D which in essence ‘runs’ the dynamics for one step.⁷

Definition 3. Let \mathcal{D} be a dynamics, with s a situation. We define the situation $\mathcal{T}_D(s)$ by:

- (a) if $X \in B$, then $\mathcal{T}_D(s)(X) = s(X)$
- (b) if $X \in I$, with $Z_X = \{X_1, \dots, X_n\}$, then
 - i. if $s(X) = u$ and $f_X(s(X_1), \dots, s(X_n))$ is defined, $\mathcal{T}_D(s)(X) = f_X(s(X_1), \dots, s(X_n))$
 - ii. if $s(X) \neq u$ or $f_X(s(X_1), \dots, s(X_n))$ is undefined, $\mathcal{T}_D(s)(X) = s(X)$.

A finite number of iterations of \mathcal{T}_D will necessarily exhaust the set of consequences of a given starting situation, producing a fixed point (see Schulz 2011 for proof). This result allows us to define causal entailment, in parallel to logical entailment.

Definition 4. Let \mathcal{D} be a dynamics. A situation s **causally entails** a proposition ϕ if ϕ is true at the least fixed point s^* of \mathcal{T}_D relative to s :

$$s \models_{\mathcal{D}} \phi \text{ iff } \llbracket \phi \rrbracket^{s^*} = 1$$

While the predicates we are investigating here deal with the relation of one fact (the purported cause) to another (the effect), causative statements are always interpreted in the context of a fixed set of background assumptions. What we need, then, are relations of causal necessity and causal sufficiency that hold between two facts *relative* to a given situation. We start with the following relations between situations and facts, inspired by Baglini and Francez (2016) and Nadathur (2016). Causal sufficiency follows easily from causal entailment, but causal necessity requires a bit more care, since it invokes alternative states of the world. We present Definition 5a without comment, but see Appendix B for discussion of the formal choices made here.

Definition 5. Let \mathcal{D} be a dynamics over P . Let s be a situation and let $X \in P - B$. Let $A_X = \{Y \in P \mid R_F^T(X, Y)\}$ be the set of causal ancestors of X .

- (a) s is **causally necessary** for X iff, for any situation s' with:
 - i. $\text{dom}(s) \cap A_X \subseteq \text{dom}(s') \cap A_X$ and

⁷For a proper treatment of overdetermination and pre-emption (cf. footnote 4) clause (b) of Definition 3 must be slightly modified, so as to allow \mathcal{T}_D to set the the value of an inner variable X even if not *all* of its direct ancestors have values, but enough of them have values to determine the value of X (see Schulz 2007, p. 221, Def. 6.4.17 for a definition along these lines). We refrain from adopting this modification here, as it would complicate the proofs in Appendix A.

ii. $\exists Y \in \text{dom}(s) \cap A_X$ with $s(Y) \neq s'(Y)$ and

iii. $s'(X) \neq 1$

we have $s' \not\models_{\mathcal{D}} X$.

(b) s is **causally sufficient** for X iff $s \models_{\mathcal{D}} X$

To consider the necessity or sufficiency of a particular fact relative to a situation, we simply add it to the situation and observe the consequences. For any situation s , variable X , and value x , we use the notation $s[X \mapsto x]$ to represent the situation which reassigns the value of X to x and is otherwise identical to s .

Definition 6 (Necessity and sufficiency of facts). *Let s be a situation, and let X, Y be literals such that $s \not\models_{\mathcal{D}} X, s \not\models_{\mathcal{D}} Y$.*

(a) $X = 1$ is **causally necessary** for Y relative to s iff $s[X \mapsto 1]$ is causally necessary for Y .

(b) $X = 1$ is **causally sufficient** for Y relative to s iff $s[X \mapsto 1]$ is causally sufficient for Y .

These definitions capture the intuitions discussed in Sections 1.3-1.4. Causal necessity ‘opens up’ the possibility of a particular outcome E , represented in a dynamics as a causal pathway or pathways to E . It does not ensure the realization of E , since it does not ensure the realization of a full pathway to E . Causal sufficiency, on the other hand, guarantees the completion of a pathway to the effect in question, thus guaranteeing the effect as well. Note that we restrict consideration (in both cases) to background situations which are not by themselves sufficient for either the causing fact or the effect. This is essential for a reasonable definition of sufficiency. If we allow the causing fact to be causally entailed by the background situation, we must also allow the effect to be entailed (since adding the causing fact is sufficient for the effect). If we allow both facts to be entailed by the background situation, then any fact in a cause-entailing background situation will be sufficient for the effect, even if it is not a causal ancestor of the effect. If we allow only the effect to be entailed by the background situation, then any fact not entailed by the background situation will be sufficient for the effect, again regardless of its causal connections. Insufficiency of the background situation for cause and effect is already guaranteed by Definition 5a, so adding these conditions makes no difference here.

3.2 *Make (and cause) again*

Our contention is that the notions of necessity and sufficiency just defined are at play in the semantics of periphrastic causatives. While *cause*, along with e.g. *enable* and others,

links its arguments by causal necessity, *make* belongs to a second class of causatives, which relate their arguments via causal sufficiency. Preliminary proposals for the denotations of these verbs are given in (16)-(17). We assume that periphrastic causatives at base express relations between two facts or events; when the subject argument is an individual, rather than an eventive nominal, we take this to stand in for some event in which the individual was a participant. In (16)-(17), we represent this event by C ; s_C represents the context situation, or the fixed set of background facts. $w_{@}$ is the world of evaluation (the ‘actual world’).

- (16) Given a context situation $s_C \subseteq w_{@}$, $\llbracket X \text{ cause } Y \text{ to VP} \rrbracket^{\mathcal{D}} = 1$ in context s_C iff C is causally necessary for $E = \llbracket \text{VP} \rrbracket(\llbracket Y \rrbracket)$ relative to s_C , and $w_{@}(C) = w_{@}(E) = 1$
- (17) Given a context situation $s_C \subseteq w_{@}$, $\llbracket X \text{ make } Y \text{ VP} \rrbracket^{\mathcal{D}} = 1$ in context s_C iff C is causally sufficient for $E = \llbracket \text{VP} \rrbracket(\llbracket Y \rrbracket)$ relative to s_C , and $w_{@}(C) = 1$.⁸

These proposals are preliminary. In Section 4, we will refine (17) to address several remaining issues. We will leave (16) in place for the remainder of this paper, as it is sufficient for our purpose here, i.e., to contrast sufficiency causatives like *make* with necessity causatives like *cause*.⁹

3.2.1 A necessary and sufficient cause: the joke scenario

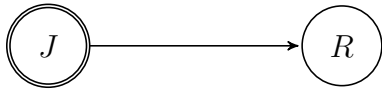
Let us first see how this works with a very simple example, involving only two variables (a cause and effect).

- (18) *Context:* Juno was at a comedy show, and the comedian told a particularly risqué

⁸There is an asymmetry in the semantic definitions of *cause* and *make*; namely, while $w_{@}(E) = 1$ is part of the asserted content of a *cause* statement, we do not propose to include it in the asserted content of *make*. This is because this fact follows as a direct entailment of the causal sufficiency semantics, and therefore does not need to be directly stipulated in the lexical semantics of causative *make*. We do not believe that this choice has any relevant consequences.

⁹It should be noted that we are sympathetic to the view, prevalent in the extensive literature on *cause*/CAUSE causation, that the ‘bringing about’ relation expressed by *cause* may be subject to additional constraints, possibly obviating the need for stipulating the realization of the *cause*-effect in (16). Defining *cause* in terms of (only) causal necessity is intended to be preliminary, in a strict sense. The central claim we wish to make in this paper is that certain periphrastic causatives, *make* in particular, express causal sufficiency. Attendant to this is the claim that a semantics for *make* cannot simply be built on a semantics for *cause*: the meaning of *cause* contains an element that the meaning of *make* does not. The main idea expressed by (16) is that this element is causal necessity.

We are, independently of this, interested in what other constraints the *cause* relation is subject to, and in particular, how this causative compares to others, such as *enable*, which also, *prima facie*, appear to encode a necessity component. However, we leave this as a matter for future investigation; as the judgements involved seem to be rather subtle, we suspect that experimental work will play an important role in understanding *cause* (see, for instance Wolff and Song 2003, Sloman et al. 2009).



$$f_R = \begin{array}{c|c} J & R \\ \hline 0 & 0 \\ 1 & 1 \\ \hline \end{array}$$

Figure 1: Dynamics for the joke scenario

joke. Juno blushed on hearing the joke.

- a. The joke caused Juno to blush.
- b. The joke made Juno blush.

Figure 1 represents the dynamics for this toy example. We have only two variables, $J =$ whether the comedian tells the joke and $R =$ whether Juno blushes. J is a background variable, since it does not (in the given context) depend on any other circumstances or events. R is an inner variable, with $Z_R = \{J\}$, and f_R as defined in Figure 1.

Since there are only two variables, and R depends entirely on J , J is both necessary and sufficient for R , with background situation $s_0 = \{\langle J, u \rangle, \langle R, u \rangle\}$:

(19) $s_0[J \mapsto 1]$ is necessary for R .

There is only one alternative situation to consider: $s_0[J \mapsto 0] = \{\langle J, 0 \rangle, \langle R, u \rangle\}$. The smallest fixed point is $s' = \{\langle J, 0 \rangle, \langle R, 0 \rangle\}$ and $\llbracket R \rrbracket^{s'} = 0 \neq 1$.

(20) $s_0[J \mapsto 1]$ is sufficient for R .

- a. $s_0[J \mapsto 1] = \{\langle J, 1 \rangle, \langle R, u \rangle\}$.
- b. $s_1 = \mathcal{T}_{\mathcal{D}}(s_0[J \mapsto 1]) = \{\langle J, 1 \rangle, \langle R, 1 \rangle\}$
- c. s_1 is a fixed point and $\llbracket R \rrbracket^{s_1} = 1$.

Hence, proposals (16)-(19) predict that both *cause* and *make* should be felicitous descriptions of this situation, and this is indeed the case. This example demonstrates that our central claim – that *make* and *cause* predicate different types of ‘bringing about’ relations – is compatible with an empirical picture on which *make* and *cause* are sometimes interchangeable. Crucially, however, contexts in which they are interchangeable must be (causally) structured in such a way as to satisfy both causal necessity and causal sufficiency between the stated cause and effect; thus, interchangeability of the verbs gives us specific information about the structure of the context of utterance.

3.2.2 Necessary, but insufficient causes: the Titanic scenario

Example (20) demonstrates how a simple dynamics works, but does not allow us to check for the proposed distinction between *cause* and *make*. Next we consider a more complex scenario: the ‘event cascade’ leading to the sinking of the Titanic.

(21) *Context:* In the case of the Titanic, a number of individually survivable and unrelated factors conspired to produce a disaster. The ship was designed to withstand a breach of up to four of its watertight compartments, and the proximate cause of sinking has been definitively identified as the fact that six of the compartments were breached in the aftermath of a collision with an iceberg.

In order for the impact to have this result, the rivets on the ship’s hull must have already been weakened in some way. Even this is not enough to explain the full extent of the damage, if other cautionary procedures were in place: independently, it has been alleged that the ship’s captain did not exercise enough caution when sailing through treacherous waters. New information suggests that the Titanic had also been experiencing an ongoing fire in the hull leading up to the disaster.¹⁰ We know that the ship struck an iceberg, and assuming that the hull fire was actual, it would have been sufficient to weaken the hull rivets. We have no direct evidence for the captain’s behaviour.

- a. A fire in the hull caused the Titanic to sink.
- b. ?A fire in the hull made the Titanic sink.

We give a dynamics for this in Figure 2. We have three background variables: F = whether the hull fire occurred, I = whether the ship struck an iceberg, N = whether the captain was guilty of negligence. Let W = whether the hull rivets were weakened, B = whether more than four watertight compartments were breached, and S = whether the ship sank. W , B , and S are inner variables, with $Z_W = \{F\}$, $Z_B = \{N, I, W\}$, and $Z_S = \{B\}$.

Let the background context be s_I , which determines the iceberg impact but nothing else:

¹⁰Journalist Senon Molony: “The official Titanic inquiry branded [the sinking] as an act of God. This isn’t a simple story of colliding with an iceberg and sinking. It’s a perfect storm of extraordinary factors coming together: fire, ice and criminal negligence.” (<http://www.independent.co.uk/news/uk/home-news/rms-titanic-evidence-fire-senan-molony-belfast-new-york-southampton-sink-april-1912-a7504236.html>)

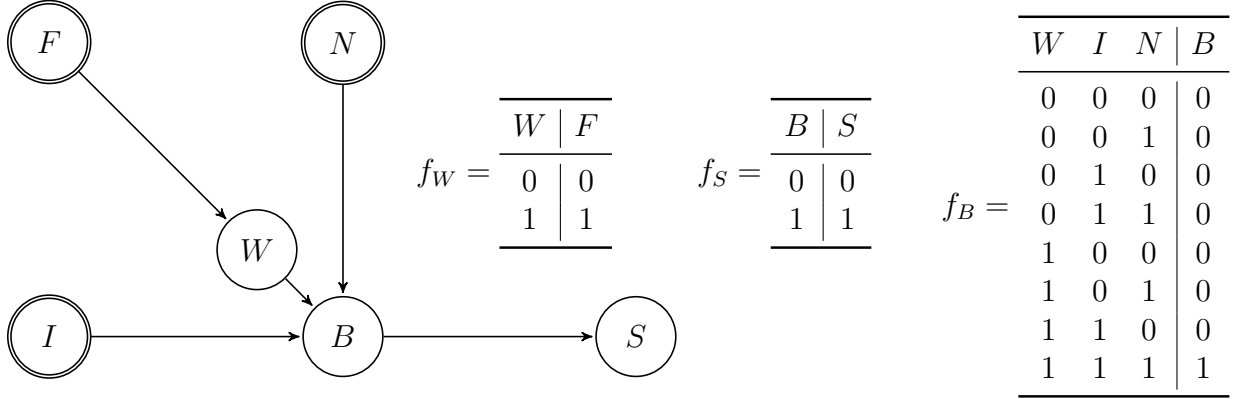


Figure 2: Dynamics for the sinking of the Titanic

$$(22) \quad s_I = \begin{bmatrix} I \mapsto 1 \\ F \mapsto u \\ N \mapsto u \\ W \mapsto u \\ B \mapsto u \\ S \mapsto u \end{bmatrix}$$

We show that F is necessary but insufficient for S relative to s_I :

(23) $s_I[F \mapsto 1]$ is necessary for S .

$$a. \quad s_I[F \mapsto 1] = \begin{bmatrix} I \mapsto 1 \\ F \mapsto 1 \\ N \mapsto u \\ W \mapsto u \\ B \mapsto u \\ S \mapsto u \end{bmatrix}$$

- b. Since $f_B = I \wedge F \wedge N$ and $f_S = B$, (see Figure 2), any situation s' such that at least one of $s'(I) = 0$, $s'(F) = 0$, or $s'(N) = 0$ will have $s' \models_{\mathcal{D}} \neg S$.
- c. $\text{dom}(s_I[F \mapsto 1]) \cap A_S = \{I, F\}$, and $s_I[F \mapsto 1](I) = s_I[F \mapsto 1](F) = 1$. The alternatives s' to be considered have either $s'(F) = 0$ or $s'(I) = 0$ or both; therefore any such alternative has $s' \not\models_{\mathcal{D}} S$.

(24) $s_I[F \mapsto 1]$ is insufficient for S .

$$\begin{array}{l}
\text{a. } s_1 = \mathcal{T}_D(s_I[F \mapsto 1]) = \left[\begin{array}{l} I \mapsto 1 \\ F \mapsto 1 \\ N \mapsto u \\ W \mapsto 1 \\ B \mapsto u \\ S \mapsto u \end{array} \right] \text{ is the least fixed point of } s_I[F \mapsto 1]. \\
\text{b. } s_1 \not\models_D S, \text{ so } s_I[F \mapsto 1] \not\models_D S.
\end{array}$$

Since the hull fire is necessary but insufficient for the ship’s sinking in the given context, our analysis predicts that *cause*, but not *make*, will be felicitous. This is indeed what we see with (21).

3.2.3 A sufficient, unnecessary cause: the doctor scenario

Next, let us consider a toy example involving a sufficient but unnecessary condition.

- (25) Context: Alex has been experiencing back pain. He is thinking of going to walk-in hours at the doctor’s office tomorrow, if he isn’t too tired. His wife sees him wincing. She calls and makes him an appointment for the next day, which she drives him to.
- a. ?Alex’s wife caused him to go to the doctor.
 - b. Alex’s wife made him go to the doctor.

The dynamics for this scenario has seven variables. The background variables are P = whether Alex experiences pain, T = whether he is tired, and N = whether Alex’s wife is watching when he winces. The inner variables are W = whether Alex winces, A = whether his wife makes him an appointment, D = whether she drives him, and G = whether Alex goes to the doctor tomorrow. $Z_W = \{P\}$, with $f_W = P$; $Z_A = \{W\}$, with $f_A = W$; $Z_D = \{A\}$, with $f_D = A$; $Z_G = \{P, T, D\}$, with f_G as given in Figure 3.

Let the background context be s_{PN} , the situation which verifies P and N , and leaves all other variables undetermined.

We assume that the individual-denoting noun phrase “Alex’s wife” in this case stands in for the action taken by his wife in making an appointment, that is, for variable A . In this context, A is a sufficient but unnecessary condition for G . It is sufficient because A ensures D , which is in turn sufficient for G , but unnecessary because, given P , $\neg T$ also ensures G (note that $f_G = (P \wedge \neg T) \vee D$).

- (26) A is sufficient, relative to s_{PN} , for G .

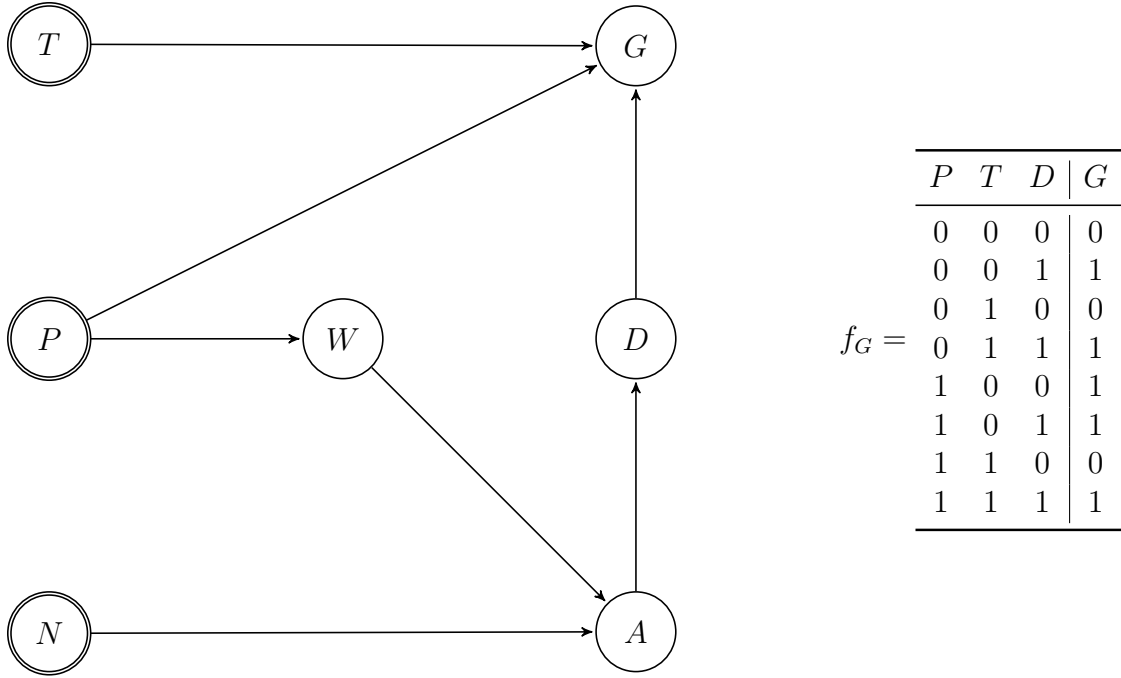


Figure 3: Dynamics for the doctor scenario

a. $s_{PN}[A \mapsto 1] = \begin{bmatrix} T \mapsto u \\ P \mapsto 1 \\ N \mapsto 1 \\ W \mapsto u \\ A \mapsto 1 \\ D \mapsto u \\ G \mapsto u \end{bmatrix}$

b. $s_1 = \mathcal{T}_D(s_{PN}[A \mapsto 1]) = \begin{bmatrix} T \mapsto u \\ P \mapsto 1 \\ N \mapsto 1 \\ W \mapsto 1 \\ A \mapsto 1 \\ D \mapsto 1 \\ G \mapsto u \end{bmatrix}$

$$\text{c. } s_2 = \mathcal{T}_{\mathcal{D}}(s_1) = \begin{bmatrix} T \mapsto u \\ P \mapsto 1 \\ N \mapsto 1 \\ W \mapsto 1 \\ A \mapsto 1 \\ D \mapsto 1 \\ G \mapsto 1 \end{bmatrix}$$

d. s_2 is the least fixed point of $s_{PN}[A \mapsto 1]$, and $\llbracket G \rrbracket^{s_2} = 1$

(27) A is not necessary for G , relative to s_{PN} .

a. Let $s_T = s_{PN}[A \mapsto 1][A \mapsto 0, T \mapsto 0]$. Then $\text{dom}(s_{PN}[A \mapsto 1]) \cap A_G \subset \text{dom}(s_T) \cap A_G$, and $s_{PN}[A \mapsto 1](A) = 1 \neq s_T(A) = 0$.

b. The smallest fixed point of s_T is $s_3 = \begin{bmatrix} T \mapsto 0 \\ P \mapsto 1 \\ N \mapsto 1 \\ W \mapsto 1 \\ A \mapsto 0 \\ D \mapsto 0 \\ G \mapsto 1 \end{bmatrix}$ and $\llbracket G \rrbracket^{s_3} = 1$

On the proposals above, this accounts for the felicity of (27b) and the infelicity of (27a).

These examples, while simple, demonstrate the complementary distribution of *cause* and *make* in cases where causes are either necessary or sufficient, but not both. This is good evidence that proposals (16) and (17) are on the right track.

Let us consider our progress on the desiderata set out at the end of section 1.4. First, we have provided an account of causal necessity that makes good on the connection between *cause*-statements and counterfactuals: *cause*-statements, like counterfactuals, express a type of necessity, and are evaluated over the same kind of structures. Next, we have formalized causal sufficiency and used this relation to set forward a proposal for the assertive content of *make* as a sufficiency causative, and have demonstrated that *make* is felicitous in situations which validate this relation but do not validate causal necessity. We have yet to examine the necessity inference that often arises with *make*-statements; this is the subject of the next section.

3.3 Causal perfection

Examples like the doctor scenario demonstrate that *make*-causatives can be used felicitously in contexts where a designated effect *E* was possible prior to the occurrence of the specified cause *C* – that is, in which *C* was not required in order for a causal pathway leading to *E* to be realized. Nevertheless, *make*-causatives are often associated with the inference that their causes represent necessary conditions for their effects. This is readily apparent, for instance, with *make*-causatives that are offered to absolve someone of responsibility for an undesirable action or event.

- (28) a. *Context*: the speaker is on trial for participating in the blocking of a coal train in Spokane, Washington. The action was undertaken in an effort to protest and/or curtail global warming.
- b. \neg Climate change made me do it.

(28b) is not only intended to convey that the defendant in the case had no choice but to do ‘it’ (block the train), but also that he would not have taken this (illegal) action if he had not been forced to do so. In other words, the exculpatory *make*-causative (28b) suggests that climate change represents not only a sufficient but also a necessary condition for the resulting action.

There is a well-known precedent for this kind of inference: **conditional perfection**. Geis and Zwicky (1971) observe that conditional statements, which assert the sufficiency of their antecedents for their consequents, often ‘invite an inference’ to their converses, as in (29a)-(29b). Taken together, the assertion and inference convey a ‘perfected’ conditional – that is, a biconditional, as in (29c) – which presents the antecedent as both necessary and sufficient for the consequent.

- (29) a. If you study the material carefully, you will get an A on the test.
- b. $\sim \rightarrow$ If you do not study the material carefully, you will not get an A on the test.
- c. (29a) + (29b) \equiv If and only if you study the material carefully will you get an A on the test.

Conditional perfection has generated an extensive literature, which we do not propose to add to here (see, among others: van der Auwera 1997, Horn 2000, von Stechow 2001, Franke 2009). Although different analyses differ in their details, recent treatments agree that the inference in (30b) represents an essential ‘first step’ in the chain of pragmatic reasoning that leads to perfection.

- (30) a. If you study the material carefully, you will get an A on the test.
 b. \sim If you don't study the material carefully, you might not get an A on the test.

This inference arises rather naturally from the use of a conditional statement. In most contexts, the unconditional consequent represents a pragmatic alternative to the conditional. Since the unconditional is more informative than the conditional, use of the conditional leads us to infer, via an application of scalar reasoning, that the unconditional does not hold.¹¹ Taken together with the asserted content of the conditional (29a), this yields the inference in (30b).

(30b) sets the stage for full conditional perfection. Whether or not the perfection process is completed – whether we move from (30b) to the converse conditional (29b) and thus to the biconditional (29c) – depends heavily on the discourse context, including features like the assumed epistemic authority of the speaker, her control over the truth value of one or both of the antecedent and consequent, and/or the discursive question (or *question under discussion*; Roberts 2012[1996]) to which the conditional is taken to respond (see von Stechow 2001, van Canegem-Ardijns and van Belle 2008, Franke 2009, Nadathur 2013). In general, we get perfection when the speaker is expected (and assumed able) to give ‘complete’ information about the truth value of the conditional consequent. This leads to the conclusion that the stated condition – the antecedent – is the *only* condition on which the consequent’s truth depends. The antecedent then becomes a necessary condition for the consequent, by virtue of being the sole sufficient condition.

We propose that the necessity inference of *make*-causatives is another instance of the ‘perfection’ phenomenon, in this case **causal perfection**. Examples (11)-(12), given earlier, argue against treating the necessity inference as an entailment of *make*. (31) demonstrates that necessity is defeasible, lending further support to a pragmatic account of causal perfection.

- (31) Being unable to schedule all my classes made me drop my second major. But even

¹¹The alternatives involved in reasoning from (30a) to (30b) – the conditional and its unconditional consequent – are not only comparable in terms of informativity, but also in terms of linguistic complexity. The stronger alternative is also less costly in terms of production effort, since it is simpler. While inference (30b) would usually be analyzed as a scalar implicature, Lauer (2013) suggests that the joint effect of the strength and complexity orderings (both of which indicate a preference for the same alternative, the unconditional) give rise to a stronger inference. On his view, the inference from (30a) to (30b) belongs to a class of non-optional **Need-a-Reason** implicatures, which are non-defeasible despite their pragmatic nature, because they arise from the need to rationalize the speaker’s choice of the (doubly) dispreferred alternative. The upshot of this is that a version of the not-unconditional inference is predicted to arise with any use of a conditional statement.

if the schedule had worked out, I would probably have dropped it, because it was getting difficult to afford the extra tuition costs.

It is important to note that the reasoning that leads to the first step of conditional perfection (30b) cannot proceed in the same way in the case of *make*-causatives. Unlike conditional statements, which are informationally weaker than their unconditional consequents, *make*-causatives are actually more informative than a simple assertion of their effects. Moreover, *make*-sentences are frequently used in contexts in which it is already mutually known that the effect obtained, in which case a plain assertion of the consequent would be uninformative.

- (32) a. Climate change made me block the train.
b. \vdash I blocked the train.

It turns out, however, that a sufficiency semantics for *make* gives us the ‘first step’ of causal perfection for free. Given a situation s , if proposition C is causally sufficient for proposition E , Definition 6 requires that E cannot follow as a causal consequence of s alone.¹² Thus, *make*-causatives are only felicitous in contexts that support (33a).

- (33) Cause C made effect E happen.
a. Prior to/in the absence of C , E might not have happened.

This gets us to the same place as (30b) in the derivation of causal perfection.

Turning back to ‘excuse’ examples like (28), we observe that the perfecting inference for *make*-causatives takes the same shape as conditional perfection. In particular, (28) suggests that the stated cause was the only path (in context) for the realization of E . This is good evidence in support of the idea that the mechanisms responsible for deriving the two perfection inferences are one and the same.¹³

The contextual factors that govern the application of this mechanism are unlikely to be the same for conditionals and *make*-causatives, despite the similarity of the result. Essentially, this is because the two constructions are associated with different sets of entailments. *Make*-causatives comprise at least two entailments: a statement with the structure

¹²Recall, from Definition 6, that causal sufficiency of a fact X for another fact Y relative to a background situation s is defined only if $s \not\vdash_{\mathcal{D}} Y$ (as well as $s \not\vdash_{\mathcal{D}} X$).

¹³Recent work on conditional perfection argues that this mechanism is some form of **exhaustive interpretation**, either (pragmatic) exhaustive interpretation in the sense of Groenendijk and Stokhof (1984) and Schulz and van Rooij (2006), or via exhaustification as a grammatical operation (*exh*), after Fox (2007) and Chierchia et al. (2012). Analysis in the former vein include von Stechow (2001), Franke (2009), and Nadathur (2013); in the latter style, Herburger (2015).

of (33) both asserts directly that C holds, and that C is causally sufficient for E . From these two entailments we get a third, which is that the effect E occurred. ‘Excuse’ uses of *make*-causatives demonstrate that causal perfection can easily arise when the truth of the effect is contextually established (producing the explanatory feel of these uses). On the other hand, conditionals only assert the sufficiency of their antecedents for their consequents; they are often perfected when they respond to a discursive question that aims to establish the truth or falsity of their consequents (see Franke, Nadathur).

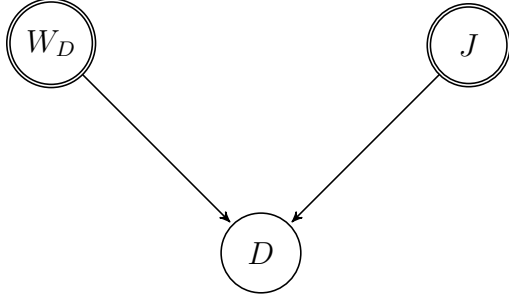
A thorough examination of the contextual factors and/or discursive questions that ‘invite’ causal perfection is beyond the scope of the present paper, and must be left for future work.¹⁴ We note, however, that the inference to necessity represents an inference about the structure of the dynamics; it carries the information that, immediately prior to C , any other causal pathways to E had been closed. Since the dynamics relevant to a given discourse will almost always be underspecified, a *make*-causative may be used to ‘fill in the gaps’ between a contextually-established situation and a particular observed outcome – i.e., to explain how the outcome came about. In addition to taking into account the structure that has so far been established in the dynamics, the availability of causal perfection will presumably be sensitive to the purpose to which a *make*-causative is being put: for instance, to the contrast between an explanatory use (e.g., the excuses cases), uses which simply establish which of a possible salient set of pathways was the one actually taken to get to E , or uses in which the central aim is to establish the truth of E .

We also expect that causal perfection will depend on the range of options available for describing causal pathways – that is, on the set of periphrastic causatives (or similar lexical items) available in a given language. If different languages carve up the space of causal dependency relations differently, then the set of contexts which support causal perfection should change. For example, in a hypothetical language with a periphrastic causative that asserts both the necessity and the sufficiency of a cause C for an effect E , we would no longer predict a necessity inference from use of a sufficiency-only causative; the stronger alternative could have been used instead, if a perfected meaning was intended.

4 The coercive implication

As we have seen, the sufficiency analysis gives a plausible treatment of a range of cases. However, as it is stated, it does *not* derive the coercive implication. To see why, consider

¹⁴If the analysis from exhaustive interpretation is on the right track, then we might expect causal perfection in contexts where the speaker would be expected to supply any conditions that might cause a particular effect; that is, in contexts where a *make*-causative responds to a question along the lines of “What brings (brought) E about?” or “Why does (did) E happen?”.



| | W_D | J | D |
|---------|-------|-----|-----|
| $f_D =$ | 0 | 0 | 0 |
| | 0 | 1 | 0 |
| | 1 | 0 | 0 |
| | 1 | 1 | 1 |

Figure 4: Dynamics for the scenario in example (34)

the following example.

- (34) *Context:* The children have been eager to dance all night. However, John is their (strict) parent, and they are only allowed to dance if he gives his explicit permission. Finally, John relents and gives permission. The children dance happily.
- a. ??John made the children dance.

In the situation described in (35), the *make* statement is arguably false or at the very least highly misleading. However, it comes out true under our preliminary analysis. In Figure 4, we give a plausible causal dynamics for the situation, with W_D = whether the children want to dance, J = whether John gives permission, D = whether the children dance.

Clearly, in this dynamics, $J = 1$ is sufficient for $D = 1$ relative to the background situation $s_W = \{\langle W_D, 1 \rangle, \langle J, u \rangle, \langle D, u \rangle\}$:

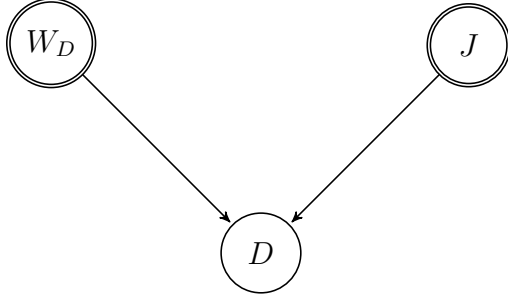
- (35) a. $s_W[J \mapsto 1] = \{\langle W_D, 1 \rangle, \langle J, 1 \rangle, \langle D, u \rangle\}$
 b. $s_1 = \mathcal{T}_D(s_W[J \mapsto 1]) = \{\langle W_D, 1 \rangle, \langle J, 1 \rangle, \langle D, 1 \rangle\}$
 c. s_1 is a fixed point and $\llbracket D \rrbracket^{s_1} = 1$

This problematic prediction arises because nothing prevents the (necessary) desire of the children to dance from being part of the background facts s_C . This problem is fully general. Whenever a cause C is sufficient, relative to a situation s for an effect E , there are three possibilities for the relationship between C , E and a third variable W_E standing for the will of the causee to bring about E :^{15,16}

- (i) W_E is causally irrelevant to E , i.e. either W_E is not among the causal ancestors of E ,

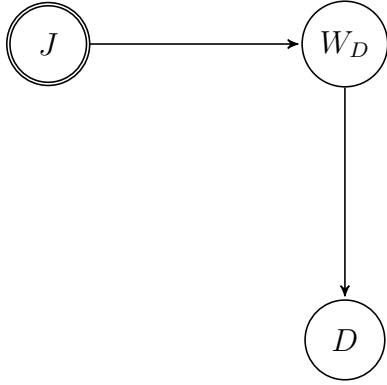
¹⁵For simplicity, we assume here that, if W_E is causally relevant to E at all, then $W_E = 1$ facilitates E , but $W_E = 0$ does not. If we lift this assumption, there are two alternative options paralleling (ii) and (iii), but the essential picture is unchanged.

¹⁶It is easy to see that one of these three options must obtain. Suppose otherwise, i.e. that W_E is causally relevant to E , $W_E = 1$ is not determined by C in s , but W_E is not part of s . Then $W_E = 1$ will not be part of $s[C \mapsto 1]^*$ and hence (because W_E is causally relevant to E), $s[C \mapsto 1] \not\vdash_D E$.



| | | | D |
|-------|-----|---|-----|
| W_D | J | | |
| 0 | 0 | 0 | |
| 0 | 1 | 1 | |
| 1 | 0 | 1 | |
| 1 | 1 | 1 | |

Figure 5: Dynamics for a scenario in which $J = 1$ (e.g., a command by John) makes W_D irrelevant. $J = 1$ is sufficient for $D = 1$, relative to $s_\emptyset = \{\langle W_D, u \rangle, \langle J, u \rangle, \langle D, u \rangle\}$



| | | | W |
|---------|--|-----|-----|
| | | J | |
| $f_W =$ | | 0 | u |
| | | 1 | 1 |

| | | | D |
|-----|---|--|-----|
| W | | | |
| 0 | 0 | | |
| 1 | 1 | | |

Figure 6: Dynamics for a scenario in which $J = 1$ (e.g., a bribe offered by John) determines $W = 1$. $J = 1$ is sufficient for $D = 1$, relative to $s_\emptyset = \{\langle W_D, u \rangle, \langle J, u \rangle, \langle D, u \rangle\}$

or it is, but when C holds, the value of W_E never makes a difference to the value of E .

- (ii) W_E is causally relevant to E , but C is causally sufficient relative to s for $W_E = 1$.
- (iii) W_E is causally relevant to E and it is not determined by C , but $W_E = 1$ is part of s_C (the background situation).

The coercive implication is true in cases where (i) and (ii) apply — either the will of the causee was irrelevant for the effect, or the cause made it so that the causee could not but want the effect. In Figure 5 and 6, we give dynamics that instantiate these cases. What we would like to exclude, for the kind of sufficiency asserted by *make*, is cases like (iii), where C counts as sufficient for E because $W_E = 1$ is taken to be part of the ‘background’ situation s_C . It appears that *make* is not compatible with this situation. However, it turns out that there is a causative verb that is: the German causative *lassen*.

4.1 German *lassen* between coercion and permission

German *lassen* is surprising from the perspective of English, in that it can be interpreted in two ways when the embedded VP denotes a volitional action: (36) can mean either that John directed or coerced the children to dance (in that case, it is best translated with *make*), or it can mean that John permitted the children to dance or otherwise removed an obstacle to their dancing (in that case, it is best translated with English *let*).^{17,18}

- (36) Hans hat die Kinder tanzen lassen.
Hans has the children dance let
- a. 'Coercive' or 'Directive' reading:
'Hans made the children dance / Hans had the children dance.'
 - b. 'Permissive' reading:
'Hans let the children dance / allowed the children to dance.'

While authors like Huber (1980), Enzinger (2010) and Pitteroff (2014) assume that causative *lassen* is a single lexical item with an 'underspecified' semantics that gives rise to these two readings, there is to our knowledge no explicit proposal as to how this curious semantic behavior of *lassen* is to be accounted for.

But now we have one: we claim that *lassen* always asserts causal sufficiency in the sense of Definition 6. The variation in interpretation is tied to whether a desire of the causee is taken to be part of the background situation ('permissive' reading) or whether such a desire is irrelevant or ensured by the sufficient cause ('directive' or 'coercive' read-

¹⁷The surface form *lassen* has a variety of readings. Superficially most similar to the causative in (36) is the 'non-interference' *lassen*, best translated in English with *leave*:

- (i) Hans hat das Bild hängen (ge)lassen.
Hans has the picture hang let
'Hans left the picture (hanging at the wall).'

Huber (1980) and Enzinger (2010) (cf. also Gunkel 2003) argue that this *lassen* is a separate lexical item, on the grounds that it differs syntactically from the causative *lassen* in (36). Further, *lassen* also allows for a 'causative passive' (iia) and the '*lassen* middle' (iib). The former arguably should be considered a variant of the causative *lassen*, but we still set it aside here. For discussions of both constructions from a syntactic perspective, see Pitteroff (2014), and references therein.

- (ii) a. Hans hat die Blumen (von Peter) giessen lassen.
Hans has the flowers by Peter water let
'Hans had the flowers watered (by Peter)'
- b. Dieser Wein lässt sich trinken.
This wine lets itself drink
'This wine drinks easily/well.'

¹⁸The same 'ambiguity' has been described for Swedish *låta* (Lundin 2003, Rawoens 2013).

ing).

4.2 A first refinement: taking time into account

Lassen behaves as one would expect a sufficiency causative to behave in the scenarios we examined in Section 3.2. First, (37) is true in the joke scenario:

- (37) Der Witz ließ Juno erröten.
The joke let Juno blush
'The joke made Juno blush.'

Similarly, (38) is true in the doctor scenario:

- (38) Alex' Frau hat ihn den Arzt aufsuchen lassen.
Alex' wife has him the doctor see let
'Alex wife made him see the doctor.'

Finally, in lieu of the Titanic scenario, we present a similar but simpler scenario in (39). Like *make*, *lassen* can be used to describe the 'final straw' cause (i.e., the cause that renders its effect inevitable), but not a merely necessary one:

- (39) The lighthouse was built with a very sturdy foundation, designed to withstand high winds at the tower top, but the foundation sustained structural damage in an earthquake about ten years ago. Even that would have been fine, but this year, we had record-setting winds and the worst hurricane season anyone can remember, and given the prior damage, it could not take the extra strain.
- a. **false:** Das Erdbeben hat den Leuchtturm einstürzen lassen.
the earthquake has the lighthouse collapse let
'The earthquake made the tower collapse.'
 - b. **true:** Der starke Sturm hat den Leuchtturm einstürzen lassen
the strong storm has the lighthouse collapse let
'The strong storm made the tower collapse.'

However, this example reveals a shortcoming in the present analysis: so far, nothing we have said ensures that (39a) comes out false in the given context. Consider the simple dynamics in Figure 7, where Q = whether the earthquake happens, S = whether the storm happens and L = whether the lighthouse collapses. In this dynamics, $Q = 1$ in fact *is* sufficient for $L = 1$, relative to the situation $s_S = \{\langle S, 1 \rangle, \langle Q, u \rangle, \langle L, u \rangle\}$ (the case is actually

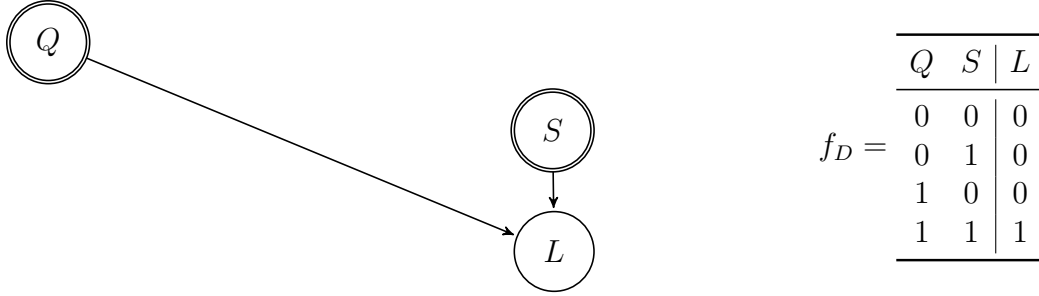


Figure 7: Dynamics for the lighthouse scenario

equivalent, *modulo* variable names, to the scenario in Figure 4).¹⁹

In this case, the problem is arguably *timing*. s_S cannot serve as the ‘background’ situation for a claim about causal sufficiency of $Q = 1$ because s_S fixes a value for S , and the storms happened *after* the earthquake. We hence propose the following constraint on ‘background’ situations:

(40) **Background situation constraint**

The background situation relative to which a claim of causal sufficiency or necessity is evaluated can only contain facts that are settled at the evaluation time of the causative claim. By default, the evaluation time is the time of the cause.²⁰

With this, the contrast in (40) follows: $S = 1$ is sufficient for $L = 1$ relative to situation $s_Q = \{\langle Q, 1 \rangle, \langle S, u \rangle, \langle L, u \rangle\}$, which satisfies (40) as the earthquake (Q) happens before the storm (S). Conversely, $Q = 1$ would be sufficient only relative to the situation s_S , which does not meet the constraint in (40). Hence (39a) comes out false, but (39b) comes out true.

¹⁹Of course, this also reveals that the success of our preliminary analysis in the Titanic case was not entirely innocent – it rested on the fact that the variable N was set to u in the background situation. This modeling choice was somewhat justified there, because it was supposed to be *unknown* whether the captain was negligent. In the lighthouse scenario, by contrast, all causal factors are assumed known, which reveals the shortcoming in the preliminary analysis.

²⁰It appears that the evaluation time of a causative claim can be shifted by adverbials like *in the end* or *ultimately*, in which case more facts can be held constant in the evaluation of a causative claim: (i) sounds much better in the lighthouse scenario than the sentence without an adverbial.

- (i) ?In the end/ultimately, the earthquake made the tower collapse.

For reasons that are unclear to us at the moment, clefting makes (i) almost impeccable:

- (ii) In the end/ultimately, it was the earthquake that made the tower collapse.

4.3 Strong and weak sufficiency

The challenge now is to state what differentiates *make* from *cause*, in such a way that this difference predicts the coercive implication. To recap, this means that we need *make* to assert a kind of sufficiency that excludes that $C = 1$ counts as sufficient cause for $E = 1$ if $W_E = 1$ (the will of the causee to do E) is causally necessary for $E = 1$. Given that we want to simultaneously account for the behavior of *lassen*, we actually need two notions of sufficiency: a strong one (for *make*) which excludes such cases and a weak one (for *lassen*) that allows them, as long as $W_E = 1$ is taken to be part of the ‘background’ facts.

Ultimately, we think that time is of the essence in this case as well. Suppose that the children made a free decision to dance, i.e. that John neither ensured that the children *wanted* to dance, nor was their will immaterial: they would not have danced if they did not want to. Then, we maintain, what John did could not have been (strongly) sufficient for the dancing of the children, even if the children wanted to dance *at the time of John’s action*. The reason is that, if the children made a free decision to dance, they could have changed their minds after this time, and so when the time of the (potential) dancing came around, they would not have danced.

We cannot give a full treatment of time in the present paper, as integrating causal dynamics with a temporal dimension raises a host of non-trivial issues. Instead, we extend Schulz’s system in a rather minimal way, allowing certain variables to be ‘fickle’ — they can change values at any time during the calculation of causal consequence.

To this end, we partition the background variables B into two sets: \mathbb{S} and \mathbb{V} :

Definition 7 (Dynamics with fickles). *A dynamics with fickles for a language \mathcal{L}_P is a tuple $\mathbb{D} = \langle \mathbb{S}, \mathbb{V}, F \rangle$ where \mathbb{S} and \mathbb{V} are disjoint sets and $\langle \mathbb{S} \cup \mathbb{V}, F \rangle$ is a dynamics in the sense of definition 1.*

- *The variables in \mathbb{S} are called the **stable background variables**.*
- *The variables in \mathbb{V} are called the **fickle background variables**.*

\mathbb{S} , the stable variables, are treated as before: once set, they never change their values. \mathbb{V} , the fickle variables, however, are set to arbitrary values at each iteration step. As a result, there is no longer a function $\mathcal{T}_{\mathbb{D}}$ that gives us the unique ‘causal successor’ of any situation, but instead, there is a relation $\mathcal{C}_{\mathbb{D}}$ between situations such that $s_1 \mathcal{C}_{\mathbb{D}} s_2$ iff s_2 can be derived from s_1 by (perturbing the fickle variables and) running the dynamics one step:

Definition 8 (The relation $\mathcal{C}_{\mathbb{D}}$). *Let $\mathbb{D} = \langle \mathbb{S}, \mathbb{V}, F \rangle$ be a dynamics with fickles for a language \mathcal{L}_P . Then $\mathcal{C}_{\mathbb{D}}$ is that relation between situations for \mathcal{L}_P such that: $s_1 \mathcal{C}_{\mathbb{D}} s_2$ iff there is a determination $\vec{V} \mapsto \vec{v}$ of the fickle variables, such that $\mathcal{T}_{\mathbb{D}}(s_1[\vec{V} \mapsto \vec{v}]) = s_2$.*

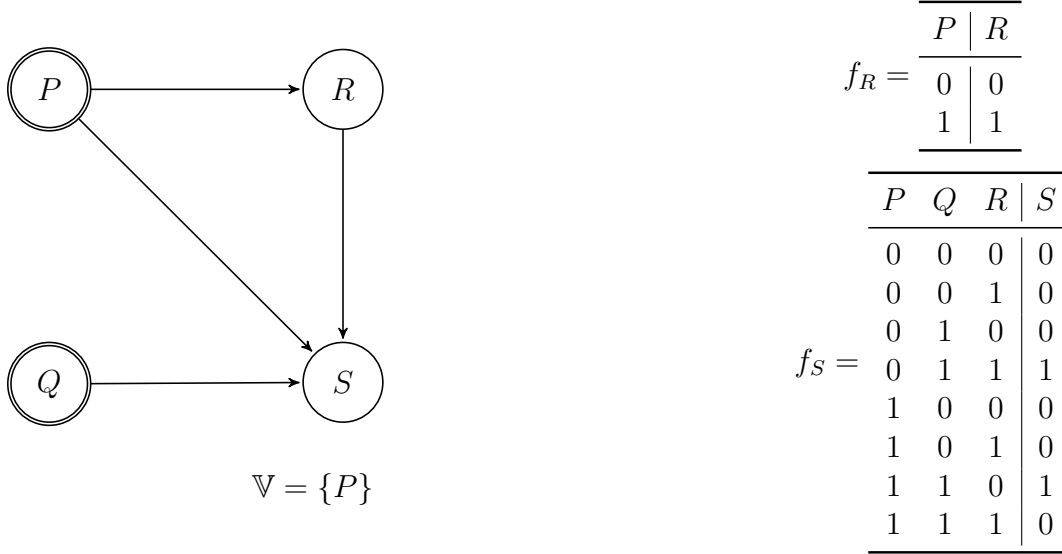


Figure 8: Example dynamics with fickle variables

The resulting dynamics still converges in a finite number of steps (Definitions and proofs are in Appendix A.2): after a finite number of iterations, additional applications of the $\mathcal{C}_{\mathbb{D}}$ -operation will not change the internal variables any more. Since stable background variables never are changed by the dynamics, that means that after the point of ‘convergence’, only the fickle variables change with further iterations.

To see how this new dynamics differs from Schulz’s, consider the scenario given in Figure 8, together with the situation $s_{PQ} = \{\langle P, 1 \rangle, \langle Q, 1 \rangle, \langle R, u \rangle, \langle S, u \rangle\}$. The causal development of this situation under Schulz’s $\mathcal{T}_{\mathcal{D}}$ is given in (41). In this case, S ends up being set to 0. In fact, it is easy to see that, under Schulz’s dynamics, no situation that only determines background variables can lead to $S = 1$.

$$(41) \quad \begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto u \\ S \mapsto u \end{bmatrix} \xrightarrow{\mathcal{T}_{\mathcal{D}}} \begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto 1 \\ S \mapsto u \end{bmatrix} \xrightarrow{\mathcal{T}_{\mathcal{D}}} \begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto 1 \\ S \mapsto 0 \end{bmatrix} \xrightarrow{\mathcal{T}_{\mathcal{D}}} \begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto 1 \\ S \mapsto 0 \end{bmatrix}$$

The sequence in (41) is a valid causal development under the new dynamics, as well. However, since fickle variables potentially change at any iteration step, there are alternative possibilities. In (42), we give one that results in $S = 1$:

| \vec{r}_1 | P | Q | R | S | |
|-------------|-----|-----|-----|-----|---------------|
| r_{1-1} | 1 | 1 | u | u | $P \mapsto 1$ |
| r_{1-2} | 1 | 1 | 1 | u | $P \mapsto 1$ |
| r_{1-3} | 1 | 1 | 1 | 0 | $P \mapsto 1$ |
| r_{1-4} | 1 | 1 | 1 | 0 | |

| \vec{r}_2 | P | Q | R | S | |
|-------------|-----|-----|-----|-----|---------------|
| r_{2-1} | 1 | 1 | u | u | $P \mapsto 1$ |
| r_{2-2} | 1 | 1 | 1 | u | $P \mapsto 1$ |
| r_{2-3} | 1 | 1 | 1 | 0 | $P \mapsto 0$ |
| r_{2-4} | 0 | 1 | 1 | 0 | |

| \vec{r}_3 | P | Q | R | S | |
|-------------|-----|-----|-----|-----|---------------|
| r_{3-1} | 1 | 1 | u | u | $P \mapsto 1$ |
| r_{3-2} | 1 | 1 | 1 | u | $P \mapsto 0$ |
| r_{3-3} | 0 | 1 | 1 | 1 | $P \mapsto 1$ |
| r_{3-4} | 1 | 1 | 1 | 1 | |

| \vec{r}_4 | P | Q | R | S | |
|-------------|-----|-----|-----|-----|---------------|
| r_{4-1} | 1 | 1 | u | u | $P \mapsto 0$ |
| r_{4-2} | 0 | 1 | 0 | u | $P \mapsto 1$ |
| r_{4-3} | 1 | 1 | 0 | 1 | $P \mapsto 1$ |
| r_{4-4} | 1 | 1 | 0 | 1 | |

| \vec{r}_5 | P | Q | R | S | |
|-------------|-----|-----|-----|-----|---------------|
| r_{5-1} | 1 | 1 | u | u | $P \mapsto 0$ |
| r_{5-2} | 0 | 1 | 0 | u | $P \mapsto 0$ |
| r_{5-3} | 0 | 1 | 0 | 0 | $P \mapsto 1$ |
| r_{5-4} | 1 | 1 | 0 | 0 | |

| \vec{r}_6 | P | Q | R | S | |
|-------------|-----|-----|-----|-----|---------------|
| r_{6-1} | 1 | 1 | u | u | $P \mapsto 1$ |
| r_{6-2} | 1 | 1 | 1 | u | $P \mapsto 0$ |
| r_{6-3} | 0 | 1 | 1 | 1 | $P \mapsto 0$ |
| r_{6-4} | 0 | 1 | 1 | 1 | |

| \vec{r}_7 | P | Q | R | S | |
|-------------|-----|-----|-----|-----|---------------|
| r_{7-1} | 1 | 1 | u | u | $P \mapsto 0$ |
| r_{7-2} | 0 | 1 | 0 | u | $P \mapsto 0$ |
| r_{7-3} | 0 | 1 | 0 | 0 | $P \mapsto 1$ |
| r_{7-4} | 1 | 1 | 0 | 0 | |

| \vec{r}_8 | P | Q | R | S | |
|-------------|-----|-----|-----|-----|---------------|
| r_{8-1} | 1 | 1 | u | u | $P \mapsto 0$ |
| r_{8-2} | 0 | 0 | 0 | u | $P \mapsto 0$ |
| r_{8-3} | 0 | 0 | 0 | 0 | $P \mapsto 0$ |
| r_{8-4} | 0 | 0 | 0 | 0 | |

Table 1: Sequences for the scenario in Figure 8

$$(42) \quad \begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto u \\ S \mapsto u \end{bmatrix} \xrightarrow[\mathcal{T}_{\mathcal{D}}]{P \mapsto 0} \begin{bmatrix} P \mapsto 0 \\ Q \mapsto 1 \\ R \mapsto 0 \\ S \mapsto u \end{bmatrix} \xrightarrow[\mathcal{T}_{\mathcal{D}}]{P \mapsto 1} \begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto 0 \\ S \mapsto 1 \end{bmatrix} \xrightarrow[\mathcal{T}_{\mathcal{D}}]{P \mapsto 1} \begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto 0 \\ S \mapsto 1 \end{bmatrix}$$

Overall, there are eight different maximal developments for s_{PQ} , given in Table 1 in the overview notation that we will use for subsequent examples. Each subtable represents one causal development (= sequence of situations), each row in the subtable represents one situation. In the final column, we indicate how the fickle variables are (re)set for the next iteration. The sequence in (41) is \vec{r}_1 in this table, while the one in (42) is \vec{r}_4 .

It is not an accident that all sequences reach a stable state after the same number of iterations. This is guaranteed for an arbitrary dynamics and situation (Proposition A.12). Using these stable states, we can define two sets of (sequences of) situations (formal definitions of these sets in Appendix A.2):

- (43) a. $S_{\mathbb{D}}^*(s)$: The set of *all* causal developments of s , truncated at the point of stability.
- b. $S_{\mathbb{D}}^\downarrow(s)$: The set of those causal developments in which all variables of s (in-

cluding the fickle ones) maintain their values, truncated at the point of stability.

In the previous example, $S_{\mathbb{D}}^* = \{\vec{r}_1, \vec{r}_2, \vec{r}_3, \vec{r}_4, \vec{r}_5, \vec{r}_6, \vec{r}_7, \vec{r}_8\}$ while $S_{\mathbb{D}}^\downarrow = \{\vec{r}_1\}$.²¹

We use these sets to define two notions of causal consequence:

- (44) Strong causal consequence:
 $s \models_{\mathbb{D}} \phi$ if all developments in $S_{\mathbb{D}}^*(s)$ make ϕ true.
- (44) Weak causal consequence:
 $s \vDash_{\mathbb{D}} \phi$ if all developments in $S_{\mathbb{D}}^\downarrow(s)$ make ϕ true.

And two notions of causal sufficiency for facts, relative to situations:

- (45) a. A fact $X = x$ is *strongly causally sufficient* for a formula ϕ relative to a situation s_C such that $\llbracket \phi \rrbracket^{s_C} \neq 1$ iff
- $$s_C[X \mapsto x] \models_{\mathbb{D}} \phi$$
- b. A fact $X = x$ is *weakly causally sufficient* for a formula ϕ relative to a situation s_C such that $\llbracket \phi \rrbracket^{s_C} \neq 1$
- $$s_C[X \mapsto x] \vDash_{\mathbb{D}} \phi$$

Since it is guaranteed that $S_{\mathbb{D}}^\downarrow \subseteq S_{\mathbb{D}}^*(s)$, strong causal consequence implies weak causal consequence, and hence strong sufficiency implies weak sufficiency.

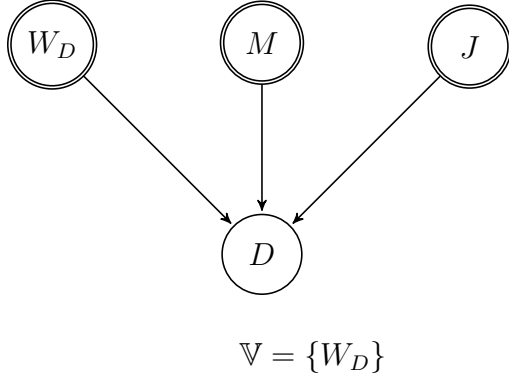
It should come as no surprise that we also want to propose that variables pertaining to whether an agent wants to perform an action should be considered fickle, at least as long as the agent is considered to be choosing freely. If she is not, then the variable W_E should be an endogenous variable.²²

4.3.1 Illustration 1: A weakly, but not strongly sufficient cause

As an illustration of how the two kinds of sufficiency work, consider the scenario captured in the dynamics in Figure 9, which is an extension of Figure 4. Where W_D = whether the children want to dance; M = whether there is music playing, J = whether John gives permission.

²¹Note that $S_{\mathbb{D}}^\downarrow(s)$ is not always a singleton. It will only be one if s determines all fickle variables.

²²In this case, W_E will be fully determined by its causes. We have to live with this dichotomy between ‘absolute free choice’ (= no causal influence on the will of the agent) and ‘absolute unfree choice’ (= prior causes determine the will of the agent) as long as we maintain the deterministic conception of causal dependencies used by Schulz (2011). See Hiddleston (2005) and Schulz (2007, Ch. 6) for variations of the causal model approach that give up the determinism assumption.



| W_D | M | J | D |
|-------|-----|-----|-----|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 |
| 0 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 0 |
| 1 | 1 | 1 | 1 |

Figure 9: Extended dynamics for the scenario in example (34)

| \vec{t}_1 | W_D | M | J | D | u | $W_D \mapsto$ |
|-------------|-------|-----|-----|-----|-----|-----------------|
| t_{1-1} | 1 | 1 | 1 | u | | $W_D \mapsto 1$ |
| t_{1-2} | 1 | 1 | 1 | 1 | | $W_D \mapsto 1$ |
| t_{1-3} | 1 | 1 | 1 | 1 | | |

| \vec{t}_2 | W_D | M | J | D | u | $W_D \mapsto$ |
|-------------|-------|-----|-----|-----|-----|-----------------|
| t_{2-1} | 1 | 1 | 1 | u | | $W_D \mapsto 1$ |
| t_{2-2} | 1 | 1 | 1 | 1 | | $W_D \mapsto 0$ |
| t_{2-3} | 0 | 1 | 1 | 1 | | |

| \vec{t}_3 | W_D | M | J | D | u | $W_D \mapsto$ |
|-------------|-------|-----|-----|-----|-----|-----------------|
| t_{3-1} | 1 | 1 | 1 | u | | $W_D \mapsto 0$ |
| t_{3-2} | 0 | 1 | 1 | 0 | | $W_D \mapsto 1$ |
| t_{3-3} | 1 | 1 | 1 | 0 | | |

| \vec{t}_4 | W_D | M | J | D | u | $W_D \mapsto$ |
|-------------|-------|-----|-----|-----|-----|-----------------|
| t_{4-1} | 1 | 1 | 1 | u | | $W_D \mapsto 0$ |
| t_{4-2} | 0 | 1 | 1 | 0 | | $W_D \mapsto 0$ |
| t_{4-3} | 0 | 1 | 1 | 0 | | |

Table 2: Sequences for the scenario in Figure 9

Now let

$$s_{MW} = \begin{bmatrix} W_D \mapsto 1 \\ M \mapsto 1 \\ J \mapsto u \\ D \mapsto u \end{bmatrix}$$

There are four maximal developments starting with s_{MW} , displayed in Table 2. We have:

- (46) a. $S^*(s_{MW}[J \mapsto 1]) = \{\vec{t}_1, \vec{t}_2, \vec{t}_3, \vec{t}_4\}$
b. $S^\downarrow(s_{MW}[J \mapsto 1]) = \{\vec{t}_1\}$

Further, we have:

- (47) a. $\llbracket D \rrbracket^{\vec{t}_1} = \llbracket D \rrbracket^{\vec{t}_2} = 1$
b. $\llbracket D \rrbracket^{\vec{t}_3} = \llbracket D \rrbracket^{\vec{t}_4} = 0$

And hence:

- (48) a. Relative to s , $J = 1$ is *not* strongly sufficient for D ,

| \vec{u}_1 | W_D | J | D |
|-------------|-------|-----|-----------------------------|
| u_{1-1} | 1 | 1 | $u \quad W_D \rightarrow 1$ |
| u_{1-2} | 1 | 1 | $1 \quad W_D \rightarrow 1$ |
| u_{1-3} | 1 | 1 | 1 |

| \vec{u}_2 | W_D | J | D |
|-------------|-------|-----|-----------------------------|
| u_{2-1} | 1 | 1 | $u \quad W_D \rightarrow 1$ |
| u_{2-2} | 1 | 1 | $1 \quad W_D \rightarrow 0$ |
| u_{2-3} | 0 | 1 | 1 |

| \vec{u}_3 | W_D | J | D |
|-------------|-------|-----|-----------------------------|
| u_{3-1} | 1 | 1 | $u \quad W_D \rightarrow 0$ |
| u_{3-2} | 0 | 1 | $1 \quad W_D \rightarrow 1$ |
| u_{3-3} | 1 | 1 | 1 |

| \vec{u}_4 | W_D | J | D |
|-------------|-------|-----|-----------------------------|
| u_{4-1} | 1 | 1 | $u \quad W_D \rightarrow 0$ |
| u_{4-2} | 0 | 1 | $1 \quad W_D \rightarrow 0$ |
| u_{4-3} | 0 | 1 | 1 |

Table 3: Situation sequences for the dynamics in Figure 5 assuming $\mathbb{V} = \{W_D\}$

since, e.g. $t_3 \in S^*(s)$ and $\llbracket D \rrbracket^{t_3} = 0^{23}$

- b. Relative to s , $J = 1$ is weakly sufficient for D ,
since for all $t \in S^\downarrow$: $\llbracket D \rrbracket^t = 1$

Assuming now that *make* asserts strong sufficiency and *lassen* asserts weak sufficiency, we predict that (49a) is false while (49b) is true in this scenario, as desired.

- (49) a. *bad, in context:* John made the children dance.
b. *good, in context:* John hat die Kinder tanzen lassen.
John has the children dance let
‘John let the children dance.’

4.3.2 Illustration 2: A weakly and strongly sufficient cause

Now, consider again the dynamics in Figure 5, and assume that $\mathbb{V} = \{W_D\}$. Then $J = 1$ is strongly causally sufficient for D , relative to situation $s_W = \{\langle W_D, 1 \rangle, \langle J, u \rangle, \langle D, u \rangle\}$. The relevant sequences are given in Table 3.

- (50) a. $S_{\mathbb{D}}^*(s_W) = \{\vec{u}_1, \vec{u}_2, \vec{u}_3, \vec{u}_4, \}$
b. $S_{\mathbb{D}}^\downarrow(s_W) = \{u_1\}$
c. $\llbracket D \rrbracket^{\vec{u}_1} = \llbracket D \rrbracket^{\vec{u}_2} = \llbracket D \rrbracket^{\vec{u}_3} = \llbracket D \rrbracket^{\vec{u}_4} = 1$

Since $J = 1$ is strongly sufficient for D , it is also weakly sufficient and hence both (49a) and (49b) are predicted to be true, which again accords with intuition.

And, of course, in the scenario in Figure 6, corresponding to a situation in which John induced the children to dance by making them want to dance (by offering a bribe, or by describing the physical and psychological benefits of dancing), $J = 1$ will likewise be

²³It is not hard to see that, as long as a particular value of a fickle variable is necessary for E , then no $C = c$ can be sufficient for E (Fact A.17).

strongly sufficient for D : In this case, W_D is not a background variable (hence not fickle), but rather an internal one.²⁴

4.4 Summary

In this section, we have tried to make good on the intuition that *make* and *lassen* assert a kind of sufficiency, while *cause* asserts a kind of necessity. This basic difference leads to quite different inferential profiles for the causative verbs, which is initially obscured due to the pragmatic process of *causal perfection*. Nonetheless, the difference between the two kinds of causatives is revealed in felicity contrasts when they are applied to necessary, but insufficient causes (such as the earthquake in the lighthouse scenario), or when they are applied to sufficient, but unnecessary causes (as in the doctor or band camp scenarios).

Further, we have elucidated some of the differences between English *make* and German *lassen*. While the behavior of these verbs in the scenarios just mentioned indicate that they are both sufficiency causatives, only *make* invariably has the coercive implication when combined with VPs denoting volitional actions. *Lassen* is ‘ambiguous’ between a coercive and a permissive reading in this case. We attributed this difference to a difference in *strength* of the sufficiency asserted by the two predicates: *lassen* only says that the cause was sufficient *given that all background facts remain in place*, while *make* says that the cause was sufficient even under changes to variables that are expected to change without notice.

We do not want to claim that our analysis captures all semantic differences between these two sufficiency causatives, but we think it is a valuable first step. One of the remaining challenges is that *lassen* can seem odd when the ‘coercion’ is direct, i.e., physical force is involved. Suppose we are in a bar, and a drunk patron is starting to stir up trouble. Elliot, the bouncer, asks him to leave, but he refuses. Finally, Elliot picks up the troublemaker and physically carries or pushes him out the door. (51) is an unexceptional truthful description of this event, while (52) has a ring of ironic understatement. We leave this issue for future research.

- (51) Elliot made the troublemaker leave.
- (52) ?Elliot hat den Randalierer gehen lassen.
Elliot has the troublemaker go let
‘Elliot made the troublemaker leave.’

²⁴This scenario has *no* fickle variables. In that case, strong and weak sufficiency fall together with each other and with causal consequence in Schulz’s system (Fact A.16).

5 Conclusion

We have argued that the differing inferential profiles of causatives like *make*, *lassen*, and *cause* are due to fundamental differences in the kind of causal dependence asserted by these predicates. Where some causatives assert the (causal) necessity of a cause for an effect, others assert (a type of) sufficiency. As a consequence of this type of analysis, a first question to ask about any periphrastic causative (crosslinguistically) is what kind of causal dependency it asserts. Here, we summarize diagnostics for the types of causatives we have argued for in this paper:

(53) If a verb *V* is a **strong sufficiency causative** (like *make*), then:

$NP_S V NP_O VP \dots$

- a. ... triggers a coercive implication if *VP* denotes a volitional action. The coercive implication is disjunctive:
 - (i) either NP_S made the will of NP_O irrelevant to the effect;
 - (ii) or NP_S ensured that NP_O wanted the effect to occur.
- b. ... does *not* truthfully apply to a cause that led to the effect only in conjunction with another necessary cause that occurred later (as in the lighthouse scenario).
- c. ... truthfully applies to a cause that was sufficient, but not necessary (as in the bandcamp and doctor scenarios).

Weak sufficiency causatives (like *lassen*) lack the property in (53a), but have (53b) and (53c).
By contrast:

(54) If a verb *V* is a **necessity causative** (like *cause*), then:

$NP_S V NP_O VP \dots$

- a. ... does not give rise to a coercive implication.
- b. ... truthfully applies to a cause that led to the effect only in conjunction with other necessary causes, even if those occurred later (as in the lighthouse scenario).
- c. ... does *not* apply to a cause that was sufficient, but not necessary (as in the band camp and doctor scenarios).

It is not, of course, a given that these are the only types of dependence that can be asserted by a causative verb. Nor do we claim that a given verb asserts at most one of the preceding relations: there might well be causatives that establish both the necessity and

sufficiency of a cause for an effect. A verb of this sort would be assertable in contexts like the joke scenario, where we saw that both *cause* and *make* were felicitous. Given the constraints that sufficiency and necessity together impose on the structure of a causal dynamics, we would expect the kind of causation expressed by a joint sufficiency/necessity causative to be rather direct (again, as in the joke scenario). Alongside a broader exploration of the range of causal relations expressed crosslinguistically by analytic and productive causatives, this notion of directness raises an intriguing possibility (explored in Martin 2017) for further research: the 'direct' causation that is often attributed to lexical causatives (in comparison to their analytic counterparts) might be analyzable as involving both causal necessity and sufficiency in a contextually-determined dynamics.

Appendices

A Definitions and proofs

A.1 Languages, situations, worlds and interpretation

Definition A.1 (Language). For a set of proposition letters P , let \mathcal{L}_P be the closure of P under negation \neg , conjunction \wedge and disjunction \vee .

Definition A.2 (Worlds, situations, domain and incrementation). For a language \mathcal{L}_P :

- A *world* for \mathcal{L}_P is any function $w : P \rightarrow \{0, 1\}$
- A *situation* for \mathcal{L}_P is any function $s : P \rightarrow \{0, 1, u\}$
- For any situation s , its **domain** is

$$\text{dom}(s) := \{X \in P \mid s(x) \neq u\}$$

- For any situation $s, Y \in P, y \in \{1, 0, u\}$, the **incrementation of s with Y and y** is the situation

$$s[Y \mapsto y](X) := \begin{cases} y & \text{if } X = Y \\ s(X) & \text{otherwise} \end{cases}$$

- For any situation $s, n \in \mathbb{N}, \vec{Y} \in P^n, \vec{y} \in \{0, 1, u\}^n$, the **incrementation of s with \vec{Y} and \vec{y}** is the situation

$$s[\vec{Y} \mapsto \vec{y}] := s[Y_1 \mapsto y_1][Y_2 \mapsto y_2] \dots [Y_n \mapsto y_n]$$

Definition A.3 (Interpretation function). For a language \mathcal{L}_P and situation s , let $\llbracket \cdot \rrbracket^s$ be the Strong Kleene Interpretation of \mathcal{L}_P with model s . That is, for formula $p \in P, \phi, \psi \in \mathcal{L}_P$:

1. $\llbracket p \rrbracket^s = s(p)$.
2. $\llbracket \neg \phi \rrbracket^s = \begin{cases} 1 & \text{if } \llbracket \phi \rrbracket = 0 \\ 0 & \text{if } \llbracket \phi \rrbracket = 1 \\ u & \text{otherwise.} \end{cases}$
3. $\llbracket \phi \wedge \psi \rrbracket^s = \begin{cases} 1 & \text{if } \llbracket \phi \rrbracket = \llbracket \psi \rrbracket = 1 \\ 0 & \text{if } \llbracket \phi \rrbracket = 0 \text{ or } \llbracket \psi \rrbracket = 0 \\ u & \text{otherwise.} \end{cases}$

$$4. \llbracket \phi \vee \psi \rrbracket^s = \begin{cases} 1 & \text{if } \llbracket \phi \rrbracket = 1 \text{ or } \llbracket \psi \rrbracket = 1 \\ 0 & \text{if } \llbracket \phi \rrbracket = \llbracket \psi \rrbracket = 0 \\ u & \text{otherwise.} \end{cases}$$

A.2 Dynamics with fickle variables

Definition A.4 (Dynamics with fickle variables). A *dynamics with fickle variables* for a language \mathcal{L}_P is a tuple $\mathbb{D} = \langle \mathbb{S}, \mathbb{V}, F \rangle$ where \mathbb{S} and \mathbb{V} are disjoint sets and $\langle \mathbb{S} \cup \mathbb{V}, F \rangle$ is a dynamics in the sense of definition 1.

- The variables in \mathbb{S} are called the **stable background variables**.
- The variables in \mathbb{V} are called the **fickle background variables**.

Definition A.5 (The relation $\mathcal{C}_{\mathbb{D}}$). Let $\mathbb{D} = \langle \mathbb{S}, \mathbb{V}, F \rangle$ be a dynamics with fickle variables for a language \mathcal{L}_P . Then $\mathcal{C}_{\mathbb{D}}$ is that relation between situations for \mathcal{L}_P such that: $s_1 \mathcal{C}_{\mathbb{D}} s_2$ iff there is a determination $\vec{v} \mapsto \vec{v}'$ of the fickle variables, such that $\mathcal{T}_{\mathbb{D}}(s_1[\vec{v} \mapsto \vec{v}']) = s_2$.

Definition A.6 (The set $Seq_{\mathbb{D}}$). For any dynamics with fickle variables \mathbb{D} and any situation s for a language \mathcal{L}_P let $Seq_{\mathbb{D}}(s)$ be the set of infinite sequences s_1, s_2, s_3, \dots such that $s_1 = s$ and for all $n \in \mathbb{N} : s_n \mathcal{C}_{\mathbb{D}} s_{n+1}$.

Definition A.7 (X -stability). Let \vec{s} be an infinite sequence of situations and X be a set of variables. Then s is **X -stable at n** iff for all $k \in \mathbb{N} : s_{n+k} \upharpoonright_X = s_n \upharpoonright_X$.

Further \vec{s} is **X -stable (simpliciter)** iff it is X -stable at 1.

Fact A.8. For any $\mathcal{L}_P, \mathbb{D}, s$ and any $\vec{r} = r_1, r_2, r_3 \dots \in Seq_{\mathbb{D}}(s)$ and any $n \in \mathbb{N} :$

- If $n > 1$, then $\text{dom}(r_n) \cap \mathbb{V} = \mathbb{V}$
(All situations in all sequences but the first are defined on all fickle variables).
- \vec{r} is \mathbb{S} -stable.
- $r_n \upharpoonright_{\text{dom}(r_n) - \mathbb{V}} \subseteq r_{n+1} \upharpoonright_{\text{dom}(r_{n+1}) - \mathbb{V}}$.
(The situations in each sequence are increasing on all values except the fickle variables.)
- If $\text{dom}(r_n) = \text{dom}(r_{n+k})$, then $r_n \upharpoonright_{\mathbb{S} \cup I} = r_{n+k} \upharpoonright_{\mathbb{S} \cup I}$

Proof. i. Immediate: Definition A.5, and the construction of \vec{r} .

- By Definition 3 of $\mathcal{T}_{\mathbb{D}}$, the causal consequence operator cannot change the value of background variables.

iii. Since \vec{r} is \mathbb{S} -stable, we need only consider variables $X \in I = P - (\mathbb{S} \cup \mathbb{V})$. Suppose $X \in I$. For arbitrary n , if $r_n(X) = u$, then $r_{n+1}(X)$ is given by $\mathcal{T}_{\mathcal{D}}$: $X \in \text{dom}(r_{n+1})$ iff $Z_X = \{X_1, \dots, X_k\}$ for some $k \in \mathbb{N}$ and $f_X(r_n(X_1), \dots, r_n(X_k))$ is defined. If $r_n(X) = 0$ or $r_n(X) = 1$, we have $r_{n+1}(X) = r_n(X)$. This follows from Definition 3 of $\mathcal{T}_{\mathcal{D}}$, and by construction of a sequence \vec{r} . Writing $u \leq 0, u \leq 1$, this shows that $r_n(X) \leq r_{n+1}(X)$ for all $n \in \mathbb{N}, X \in I$. The fact follows.

iv. Corollary of iii. □

Fact A.9. For any \mathbb{D}, s and any $\vec{r}, \vec{r}' \in \text{Seq}_{\mathbb{D}}(s)$ and any $n \in \mathbb{N} : \text{dom}(r_n) = \text{dom}(r'_n)$.

Proof. Induction on n . For $n = 1$, trivial since $r_1 = r'_1 = s$.

Now suppose $\text{dom}(r_n) = \text{dom}(r'_n)$. For any situation, its domain is partitioned by \mathbb{S}, \mathbb{V} and I . So it is sufficient to note that:

$$\text{i. } \text{dom}(r_{n+1}) \cap \mathbb{V} = \text{dom}(r'_{n+1}) \cap \mathbb{V} \quad [n + 1 > 1 \text{ and (Fact A.8 (i))}]$$

$$\text{ii. } \text{dom}(r_{n+1}) \cap \mathbb{S} = \text{dom}(r'_{n+1}) \cap \mathbb{S} \quad [\text{Fact A.8 (ii)}]$$

iii. By Definition A.5 and Definition 3, the determination of a variable in I solely depends on which variables are determined in the predecessor situation. By the induction hypothesis, $\text{dom}(r_n) = \text{dom}(r'_n)$. But then, $\text{dom}(r_{n+1}) \cap I = \text{dom}(r'_{n+1}) \cap I$. □

Definition A.10 ($\mathcal{T}_{\mathcal{D}}$ -sequence). Let \mathbb{D} a dynamics with fickle variables, s a situation, and \vec{v} an assignment of values to fickle variables. The $\mathcal{T}_{\mathcal{D}}$ -sequence (of s) for \vec{v} is that sequence of situations s_1, s_2, s_3, \dots such that $s_2 = \mathcal{T}_{\mathcal{D}}(s[\vec{\mathbb{V}} \mapsto \vec{v}])$ and for all $n > 1$: $s_{n+1} = \mathcal{T}_{\mathcal{D}}(s_n)$.

Fact A.11. For any \mathbb{D}, s , there is at least one $\mathcal{T}_{\mathcal{D}}$ -sequence. Further, all $\mathcal{T}_{\mathcal{D}}$ -sequences are in $\text{Seq}_{\mathbb{D}}(s)$ and are $(\mathbb{V} \cup \mathbb{S})$ -stable.

Proposition A.12. For any \mathbb{D}, s , there is $n \in \mathbb{N}$ such that all sequences in $\text{Seq}_{\mathbb{D}}(s)$ are $(\mathbb{S} \cup I)$ -stable at n .

Proof. Let t be an arbitrary $\mathcal{T}_{\mathbb{D}}$ -sequence in $\text{Seq}_{\mathbb{D}}(s)$. Let z be the number of iterations of $\mathcal{T}_{\mathbb{D}}$ needed to reach a fixed point (for existence proof, see Schulz 2011). Obviously, t is I -stable at z . Hence $\text{dom}(t_z) = \text{dom}(t_{z+k})$. But then, by Fact A.9, for any arbitrary sequence $\vec{r} \in \text{Seq}_{\mathbb{D}}(s) : \text{dom}(r_z) = \text{dom}(r_{z+k})$. And hence, by Fact A.8 (iv), $r_z \upharpoonright_{\mathbb{S} \cup I} = r_{z+k} \upharpoonright_{\mathbb{S} \cup I}$. That is, \vec{r} is $(\mathbb{S} \cup I)$ -stable at z . □

Definition A.13. For any \mathbb{D}, s , let k be the smallest n such that the sequences in $\text{Seq}_{\mathbb{D}}(s)$ are $(\mathbb{S} \cup I)$ -stable at n and define: $S_{\mathbb{D}}^*(s) := \{r_1, r_2, \dots, r_{k+1} \mid \vec{r} \in \text{Seq}_{\mathbb{D}}(s)\}$ and $S_{\mathbb{D}}^\downarrow(s) := \{\vec{r} \in S_{\mathbb{D}}^*(s) \mid \vec{r} \text{ is dom}(s)\text{-stable}\}$

Definition A.14. We extend the function $\llbracket \cdot \rrbracket$ to finite sequences of situations:

$$\llbracket \phi \rrbracket^{\mathbb{D}, s_1, \dots, s_n} = \llbracket \phi \rrbracket^{\mathbb{D}, s_n}$$

Recall that Σ_s is the set of literals made true by a situation s . With this, we define:

$$\Sigma_s \models_{\mathbb{D}} \phi \text{ iff } \forall \vec{r} \in S_{\mathbb{D}}^*(s) : \llbracket \phi \rrbracket^{D, \vec{r}} = 1$$

$$\Sigma_s \vDash_{\mathbb{D}} \phi \text{ iff } \forall \vec{r} \in S_{\mathbb{D}}^\downarrow(s) : \llbracket \phi \rrbracket^{D, \vec{r}} = 1$$

Definition A.15. For any \mathbb{D} variable C , value c and formula ϕ such that $\llbracket \phi \rrbracket^s \neq 1$:

- i. $C = c$ is **strongly sufficient** for ϕ (given s) iff $s[C \mapsto c] \models_{\mathbb{D}} \phi$.
- ii. $C = c$ is **weakly sufficient** for ϕ (given s) iff $s[C \mapsto c] \vDash_{\mathbb{D}} \phi$.

We note two facts. The first ensures that the introduction of fickle variables minimally changes the dynamics. The second establishes that in the presence of necessary fickle variables, no cause can be sufficient.

Fact A.16 (Dynamics with fickle variables are equivalent to classical dynamics if there are no fickle variables). Let $\mathbb{D} = \langle \mathbb{S}, \mathbb{V}, F \rangle$ be a dynamics with fickle variables and $\mathcal{D} = \langle \mathbb{S} \cup \mathbb{V}, F \rangle$ its corresponding classical dynamics and s a situation. Then if $\mathbb{V} = \emptyset$:

$$s \models_{\mathbb{D}} \phi \text{ iff } s \vDash_{\mathbb{D}} \phi \text{ iff } s \vDash_{\mathcal{D}} \phi$$

Proof. Suppose that $\mathbb{V} = \emptyset$. Then $s' \mathcal{C}_{\mathbb{D}} s''$ iff $s'' = \mathcal{T}_{\mathcal{D}}(s')$. But then, $S^*(s) = S^\downarrow(s)$ is a singleton $\{s_1, \dots, s_n\}$ such that $s_{i+1} = \mathcal{T}_{\mathcal{D}}(s_i)$ for all i , and s_n is the situation at the fixed point of $\mathcal{T}_{\mathcal{D}}$ relative to s . \square

Fact A.17 (Necessary fickle variables prevent sufficiency). Let $\langle \mathbb{S}, \mathbb{V}, F \rangle$ be a dynamics with fickle variables such that for some variable $X \in \mathbb{V}, E \in I, Z_E = \langle \dots, X, \dots \rangle$ and f_E such that $f_E(\langle \dots, x, \dots \rangle) = 1$ only if $x = 1$. Then for no situation $s, C = c$ is sufficient for E relative to s .

Proof. Suppose otherwise and let $\vec{V} \mapsto \vec{v}$ be an arbitrary setting of fickle variables such that $\vec{v}(X) = 0$. Let $\vec{s}^{\vec{v}}$ be the $\mathcal{T}_{\mathcal{D}}$ -sequence of $s[C \mapsto c]$ for \vec{v} . Let k be such that $s_k^{\vec{v}}$ be the least fixed point of $\mathcal{T}_{\mathcal{D}}$ relative to $s[C \mapsto c][\vec{V} \mapsto \vec{v}]$. Since $C = c$ is sufficient for E , it must

be that $s_k^v(E) = 1$ and $s(E) = u$. Let i be the smallest n such that $s_{n+1}^v(E) = 1$. It must be that $s_i^v(X) = 1$. But \mathcal{T}_D -sequences are \mathbb{V} -stable, so $s_i^v(X) = s_1^v(X) = s[C \mapsto c][\vec{V} \mapsto \vec{v}] = 0$. Contradiction. \square

B Cause and causal necessity

Our focus in this paper was the existence and interpretation of sufficiency causatives. We set aside any serious treatment of a number of issues associated with the semantics (and metaphysics) of *cause* (or CAUSE) and causal necessity. We cannot do these topics justice here either, much less offer any new solutions to old problems, but a few points regarding the modeling choices made in this paper are nevertheless in order.

Although the definition of causal necessity provided in Section 3 may, at first glance, seem unintuitive, it follows naturally from the process of formalizing common-sense intuitions about the meaning of necessity over the type of causal structures we deal with here. Definition B.1 reproduces Definition 5a for ease of reference.

Definition B.1. *s is causally necessary for X iff, for any situation s' with:*

- i. $\text{dom}(s) \cap A_X \subseteq \text{dom}(s') \cap A_X$ and
- ii. $\exists Y \in \text{dom}(s) \cap A_X$ with $s(Y) \neq s'(Y)$ and
- iii. $s'(X) \neq 1$

we have $s' \not\models_{\mathcal{D}} X$.

We define internal consistency:

Definition B.2. *In a dynamics \mathcal{D} , a situation s is internally consistent if, for all inner variables X such that $X \in \text{dom}(s)$, we have:*

$$s[X \mapsto u] \not\models_{\mathcal{D}} \begin{cases} \neg X & \text{if } s(X) = 1 \\ X & \text{if } s(X) = 0 \end{cases}$$

In other words, a situation is internally consistent if there is no inner variable whose determination 'breaks the rules' of \mathcal{D} with respect to the other determined variables.

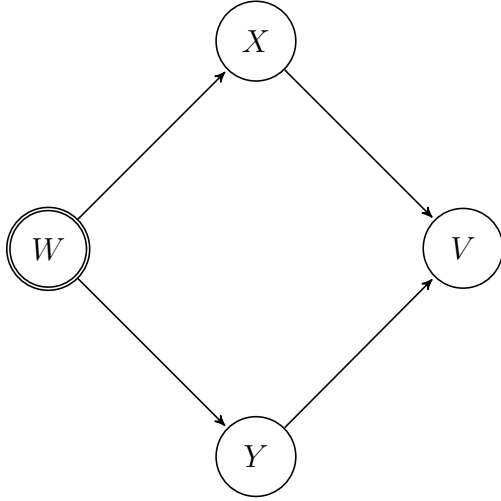
Definition B.3. *Given a dynamics \mathcal{D} with $X \in P - B$, X is causally realizable if there is at least one situation s such that s is internally consistent, $\text{dom}(s) \neq \{X\}$, and $s \models_{\mathcal{D}} X$. We call such a situation s a causal pathway to X.*

Note that if X is not causally realizable, then D must be defined so that there is no 0-1 assignment \vec{z} to Z_X such that $f_X(\vec{z}) = 1$. In other words, f_X is the constant function at 0. If X is false regardless of the determinations of its causal ancestors, then it does not in any real sense depend on them. We regard any dynamics permitting such an arrangement to be degenerate, and assume that, in any permissible dynamics, all inner variables are causally realizable.

Given a causally realizable inner variable X , causal necessity should (intuitively) pick out facts that *must* hold in order for X to be realized. This follows by analogy with analytic necessity. Any causal pathway to X must ‘go through’ these facts. Since, by construction of a dynamics, we can freely vary the values of variables on which X does not depend (those in $P - A_X$), the facts under consideration are restricted to determinations of variables from A_X . In other words, the relevant facts are those determinations of variables in A_X which are causally entailed by the situation m_X , defined as the intersection of all causal pathways m to X . (Here, we define the intersection s of two situations s_1 and s_2 as the situation which contains all of the determinations that appear in both s_1 and s_2 , and which assigns u to all other variables in P .)

Since the values of variables in $P - A_X$ do not affect the value of X , we are presented with a modeling choice. No determination outside of A_X will be entailed by *all* causal pathways to X (that is, by m_X). One possibility would be to treat all situations which determine variables in $P - A_X$ as unnecessary for X . This restriction, while reasonable, would mean that we cannot talk about necessity in any situation in which facts irrelevant to the effect under discussion are part of the background or common ground. We often describe such situations as necessary for some subsequent event, on the basis of the facts they contain which are relevant. This suggests that we would like a definition for necessity that extends beyond situations determined only on A_X . Concretely, we follow Baglini and Francez (2016) here in assuming that the presence of ‘irrelevant’ facts in a situation does not count towards the assessment of causal necessity.

These constraints lead us to Definition B.1. Let s be a situation which contains a determination $\langle Y, y \rangle$ for $Y \in A_X$ such that $m_X \not\models_{\mathcal{D}} \langle Y, y \rangle$. Then there is some causal pathway m to X such that $m \models_{\mathcal{D}} \neg \langle Y, y \rangle$. But, by Definition B.3 (of causal pathways), the existence of m guarantees the existence of another pathway, m' , with $\neg \langle Y, y \rangle \in m'$. We can, therefore, ‘flip’ some set of determinations in s and arrive at a new situation s' (with $\text{dom}(s) \cap A_X \subseteq \text{dom}(s') \cap A_X$) such that $s' = m'$; by definition, $s' = m' \models_{\mathcal{D}} X$. Conversely, if s only contains determinations of A_X that are entailed by m_X , then every causal pathway to X entails these determinations, and there is no situation s' with $s' \models_{\mathcal{D}} X$ which entails (or contains) the negation of one of these determinations.



$$\begin{array}{c}
 \overline{W \mid X} \\
 f_X = \begin{array}{c|c} 0 & 0 \\ 1 & 1 \end{array} \\
 \overline{\overline{W \mid Y}} \\
 f_Y = \begin{array}{c|c} 0 & 1 \\ 1 & 0 \end{array} \\
 \overline{\overline{X \ Y \mid V}} \\
 f_X = \begin{array}{cc|c} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \\ 1 & 1 & 1 \end{array}
 \end{array}$$

Figure 10: A toy dynamics where X is not consistently realizable

This definition has several positive consequences:

Fact B.4. *If a situation s is such that $s \models_{\mathcal{D}} \neg X$, s is not necessary for X .*

Proof. If $s \models_{\mathcal{D}} \neg X$, then s entails (pointwise) a vector \vec{z} of values for the variables in Z_X such that $f_X(\vec{z}) = 0$. Since X is causally realizable, there is at least one vector \vec{z}_1 such that $f_X(\vec{z}_1) = 1$, with $\vec{z}_1 \neq \vec{z}$. If s determines Z_X , then let $s' = s[Z_X \mapsto \vec{z}_1]$; $s' \models_{\mathcal{D}} X$, and s is not necessary for X . If s does not determine all of Z_X , then $\exists Y \in A_X$ such that s determines Y ; let $\langle Y, y \rangle$ represent this determination. Then define $s' = s[Y \mapsto \neg y][Z_X \mapsto \vec{z}_1]$: $\text{dom}(s') \cap A_X \supseteq \text{dom}(s) \cap A_X$ and $s' \models_{\mathcal{D}} X$. \square

In a special set of cases, where X is causally but not consistently realizable, the predictions made by Definition B.1 accord with intuition. We illustrate with a toy example here:

(55) Consider a dynamics \mathcal{D} as in Figure 10. Any internally consistent valuation of P has $V = 0$, since $V = X \wedge Y$, but $X = W$ and $Y = \neg W$. By definition B.1, the situations

$$s_{X,u} = \{\langle W, u \rangle, \langle X, 1 \rangle, \langle Y, u \rangle, \langle V, u \rangle\},$$

$$s_{X,0} = \{\langle W, 0 \rangle, \langle X, 1 \rangle, \langle Y, u \rangle, \langle V, u \rangle\}, \text{ and}$$

$s_{XY} = \{\langle W, u \rangle, \langle X, 1 \rangle, \langle Y, 1 \rangle, \langle V, u \rangle\}$ are necessary for V , but $s_{X,1} = \{\langle W, 1 \rangle, \langle X, 1 \rangle, \langle Y, u \rangle, \langle V, u \rangle\}$ is not.

- a. $\text{dom}(s_{X,u}) = \{X\}$, and $s_{X,u}(X) = 1$ so the only allowable alternative s' must have $s'(X) = 0$. But $V = X \wedge Y$, so no s' with $s'(X) = 0$ is such that $s' \models_{\mathcal{D}} V$.

- b. $\text{dom}(s_{X,0}) = \{X, W\}$. The allowable alternatives s' either have $s'(X) = 0$ or $s'(W) = 1$. If $s'(X) = 0$, $s' \not\models_{\mathcal{D}} V$ as above. If $s'(W) = 1$, then $s' \models_{\mathcal{D}} \neg Y$, and since $V = X \wedge Y$, $s' \not\models_{\mathcal{D}} V$.
- c. $\text{dom}(s_{XY}) = \{X, Y\}$. The allowable alternatives s' either have $s'(X) = 0$ or $s'(Y) = 0$; by the above reasoning, neither type of situation can entail V .
- d. $\text{dom}(s_{X,1}) = \{X, W\}$. The situation $s_{X,0}$ is an allowable alternative to $s_{X,1}$, and $s_{X,0} \models_{\mathcal{D}} Y$. Since $s_{X,0}(X) = 1$, then $s_{X,0} \models_{\mathcal{D}} V$. The non-necessity of $s_{X,1}$ for V follows directly from the fact that $s_{X,1} \models_{\mathcal{D}} \neg V$; this means that we can change a variable determination in $s_{X,1}$ and reach a situation which contains a causal pathway to V .

Definition B.1 differs in a small but important way from Baglini and Francez's version. Translated into the notation we use, they provide the following:

Definition B.5. (Baglini and Francez 2016). *A situation s is **causally necessary** for a variable $X \in P - B$, iff, for any alternative situation s' such that:*

- i. $\text{dom}(s) \cap A_X = \text{dom}(s') \cap A_X$ and
- ii. $\exists Y \in \text{dom}(s) \cap A_X$ with $s(Y) \neq s'(Y)$ and
- iii. $s'(X) \neq 1$

we have $s' \not\models_{\mathcal{D}} X$.

The crucial difference between B.1 and 5 is in clause i. B.5 requires only that we consider alternative situations which determine precisely the same set of causal ancestors (for the effect X) as s does, whereas we permit alternatives s' which determine new (additional) causal ancestors of X , as long as these also change a relevant determination in s . This change is motivated by examples such as the following:

- (56) Consider a simple dynamics with three variables. Let $B = \{W, X\}$, and let $Y \in I$ with $Z_Y = B$ and $f_Y = W \vee X$. Intuitively, W and X are individually sufficient for Y , and neither W nor X is necessary.

Given this dynamics, two conclusions follow from Definition B.5:

- (57) a. The situation $s_{WX} = \{\langle W, 1 \rangle, \langle X, 0 \rangle, \langle Y, u \rangle\}$ is not necessary for Y , as desired. The relevant alternative situations are the ones which 'flip' the value of W , X , or both. Consider, for instance, $s' = s_{WX}[X \mapsto 1]$. Then $s' \models_{\mathcal{D}} Y$.

- b. The situation $s_W = \{\langle W, 1 \rangle, \langle X, u \rangle, \langle Y, u \rangle\}$ is necessary for Z , counter to intuition.

The situation s determines only one variable, so there is only one alternative situation to consider: $s' = s_W[W \mapsto 0]$. But s' is its own least fixed point; in the absence of a determination for X , the dynamics does not allow us to determine Y , so we have $s' \not\models_{\mathcal{D}} Y$, as required by B.5.

In other words, it follows from Definition B.5 that an intuitively unnecessary situation can become necessary simply in the absence of a determination for a crucial variable in an alternative pathway to the effect under consideration. This unfortunate contrast is neutralized in the updated definition, which imposes a less strict clause (a) requirement on alternative situations: $\text{dom}(s) \cap A_X \subseteq \text{dom}(s') \cap A_X$.

- (58) By Definition 5, neither s_W nor s_{WX} is necessary for Y :

The situation $s' = \{\langle W, 0 \rangle, \langle X, 1 \rangle, \langle Y, u \rangle\}$ is an allowable alternative to either s_W or s_{WX} . $\text{dom}(s_W) \cap A_Y \subset \text{dom}(s') \cap A_Y$, $\text{dom}(s_{WX}) \cap A_Y = \text{dom}(s') \cap A_Y$, and s' flips the value of X from its previous determination in either case. Since $s'(W) = 1$, $s' \models_{\mathcal{D}} Y$.

The fact that neither s_W nor s_{WX} is necessary for Y is the formal realization of our intuition that W is not necessary for Y in the given dynamics. (The fact that X is unnecessary follows from symmetric reasoning.)

C Sources for naturally occurring examples

Below, example numbers refer to the number under which the example occurs in the main text.

- (2a) Yes, I accidentally made [my 3-year old son] fall off the boogie board because holding the board and two bottles of fish food was a little much.

<http://www.trekaroo.com/activities/ko-olina-ocean-adventures-honolulu-hawaii>

Last retrieved on: 2017-06-20

- (2b) Instead of motivating him to improve, you've inadvertently made him tune you out.

http://mycrains.crainnewsnewyork.com/executive_inbox/2009/06/post.html

Last retrieved on: 2017-06-20

- (3a) this book made me get a divorce.

<https://www.amazon.com/Adonis-Selected-Margellos-Republic-Letters/dp/0300181256>

Last retrieved on: 2017-07-05

- (4) I was scared, but they made me feel confident!

https://www.tripadvisor.com/ShowUserReviews-g55328-d1777941-r391405874-Foxfire_Mountain_Adventures-Sevierville_Tennessee.html

Last retrieved on: 2017-07-05

- (10a) She [Anand's mother]... made Anand pump the tires [of the bicycle] every morning.

Naipaul, V.S. (1969) *A House for Mr. Biswas*. Harmondsworth, England: Penguin.
Cited after: Wierzbicka (1998)

- (11) MADDOW: You worked for [the health insurance company] CIGNA for 15 years, you left last year. What **caused** you to change your mind about what you were doing and leave?

POTTER: Well, two things. One, it was kind of gradually. One instance or in one regard because I was becoming increasingly skeptical of the kinds of insurance policies that the big insurance companies are promoting and marketing these days. [...]

The other thing that really **made** me make this final decision to leave the industry occurred when I was visiting family in Tennessee a couple of summers ago, and [narrates the experience of happening on a 'healthcare expedition' where uninsured patients were treated by volunteer doctors in animal stalls at a fairground.]
The Rachel Maddow Show, MSNBC, Monday August 10, 2009

Transcript available at: http://www.nbcnews.com/id/32372208/ns/msnbc_tv-rachel_maddow_show/

Last retrieved at: 2017-07-05

- (28) Climate change made me do it: activists press the 'Necessity Defense'.

<https://www.forbes.com/sites/legalnewsline/2018/01/10/climate-change-made-me-do-it-activists-press-the-necessity-defense/#721ecb0553e0>

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