Causal necessity, causal sufficiency, and the implications of causative verbs

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Comments welcome!

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

Like many other languages, English has an array of periphrastic causative verbs. Some examples are in (1a-d):

(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.

The sentences in (1) are similar in that they all say that John 'brought about' the dancing of the children. At the same time, (1a-d) are not paraphrases:

each of the sentences triggers (or at least invites) further inferences. (1d) suggests that John acted intentionally, but had difficulty, in bringing about the dancing; (1c) is most naturally interpreted as saying that John directed the children to dance; (1b) that John exerted force, or invoked his authority over the children; and (1a) invites the inference that John's involvement in bringing about the dancing was somewhat indirect (e.g., he may have played their favorite song and thereby motivated them to dance on their own accord).

A plausible first hypothesis would be that the lexical meanings of the verbs in (1) share a common core, call it CAUSE, which captures the basic relation of (causal) 'bringing about'. This core would then be enriched by each causative verb with additional entailments (e.g., indirectness for (1a)).

In this paper, we will argue against this view. We claim that there are different basic relations of (causal) 'bringing about' at play in the semantics of different causative verbs. In particular, we claim that a distinction has to be drawn between those verbs that predicate *causal necessity* and those that predicate *causal sufficiency*, which are two notions that are not reducible to one another. To argue this point, we will focus on the English verb *make* and compare it to the verb *cause* and the German causative verb *lassen*.

1 The implications of causative *make*

It is striking that a sentence with *make* triggers a range of inferences that the corresponding sentence with *cause* lacks. On hearing (1b), but not (1a), a hearer will likely conclude …

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)).

It is not hard to see, however, that none of these implications can be a proper entailment of a univocal verb *make*.[1] For (i) and (iv), this follows

[1] We 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

directly from the fact that *make* is compatible with adverbs like *accidentally*, *inadvertently* and *unintentionally*:[2]

(2) $^{\gamma}$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.

(3) $^{\gamma}$Instead of motivating him to improve, you've inadvertently made him tune you out.

(4) $^{\gamma}$Jackie Hoffman on How Jessica Lange Unintentionally Made Her Cry

These examples also constitute a fairly direct argument against (iii) and (v) as an entailment of a monosemous causative verb *make*. We also note that neither (iii) nor (v) necessarily arise if the embedded VP denotes an intentional action. To see this, it suffices to observe that *make* allows for inanimate and eventive subjects with such complements:

(5) a. $^{\gamma}$this book made me get a divorce.
b. My husband's arrest (finally) made me get a divorce.

Finally, (ii) cannot be an entailment of (univocal) *make*, because it is easy to find examples with unambiguously desirable effects, such as (6).

(6) $^{\gamma}$I was scared, but they made me feel confident!

These observations create a puzzle, especially on the view that *cause* and *make* predicate the same kind of causal 'bringing about' relationship. On the one hand, exchanging *make* for *cause* can induce a variety of rather specific implications, but on the other, none of these implications can be proper entailments coded in the lexical meaning of *make*. This situation led Wierzbicka (1998) and Stefanowitsch (2001) to claim that we need to recognize a number of '*make* constructions', each of which carries an irreducible meaning. In essence, this amounts to claiming that *make* is ambiguous between various causative meanings.[3]

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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*).

[2] We use the diacritic $^{\gamma}$ 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.

[3] Neither Wierzbicka nor Stefanowitsch would put it this way, however. Their work is grounded in construction grammar frameworks, where the meanings in question are not

1.1 The coercive implication

An alternative is to hold on to the claim that *make* makes a uniform semantic contribution, but assume that it is more general than any of the induced implications. The specific implications must then arise through inference and pragmatic reasoning, triggered by properties of the context of use.

Generalizing over the examples we have seen so far, we can isolate what we call the *coercive implication* of *make*:

(7) **Coercive implication of *make***:
NP_S made NP_O VP implies that that $[\![\text{NP}_O]\!]$ did not make a free decision to $[\![\text{VP}]\!]$.

If the coercive implication were a separate entailment of *make*, a sentence like (1b) would have the entailments in (8a) and (8b).

(8) John made the children dance.
a. John brought about the dancing of the children.
b. The children did not make a free decision to dance.

What ‘making a free decision’ amounts to will have to be spelled out in more detail. However, it is not hard to see how the more specific implications of (1b) (i.e., i-v) could come about on the basis of these two entailments, e.g., as inferences as to how it came about that the children did not make a free decision to dance. (1a) would lack these implications, as it only has the entailment in (8a).

But it is doubtful that even the coercive implication is a lexical entailment of *make*. Again, we find occurrences where it does not seem to arise:

(9) [status message on a social networking site]
I have freaking awesome friends. freaking awesome. But some of them make me smoke too much.

With (9), the speaker does not claim that her friends coerce her to smoke in any strong sense. Minimally, this shows that the coercive implication, if it is to be an entailment, must be spelled out in a very weak way.

In addition, if the coercive implication were a lexical entailment of *make*, we would expect the verb to be restricted to verbal complements that denote volitional actions. This is not the case:

attributed to an ambiguous lexical item *make*, but directly attributed to a complex syntactic/semantic configuration in which *make* occurs.

(10) His attention made her feel giddy.

Further, since ‘making a free decision’, clearly must make reference to the volitional state of the referent of the object NP (the ‘causee’), we would expect *make* to be restricted to agentive causees. This is also not the case: examples with non-volitional (indeed, inanimate) causees abound.

(11) The sun made the flowers wilt.

As we have seen, we have good reason to believe that the coercive implication is not a lexical entailment of *make*, since (a) it fails to arise in some cases, and (b) *make* does not show the expected selectional restrictions. But the implication arises fairly regularly in case the embedded VP denotes a volitional action (and hence the causee is a volitional entity).

The puzzle now is this: we want a semantics for *make* that predicts the coercive implication when we observe it (*viz.*, when the embedded VP denotes a volitional action). At the same time, the lexical meaning of *make* should not reference the volitional state of the causee.

1.2 *Cause, make,* and causal necessity

A prominent approach to the semantics of *cause*, building on Lewis (1973), takes the view that the ‘bringing-about’ relation involved in *cause*-statements is closely related to a counterfactual statement which asserts that the effect would not have taken place if the cause had not occurred.

(12) 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, (12b) was in fact (partially) constitutive of the causal relation that (12a) asserts. Although the precise nature of the relationship between (12a) and (12b) is a matter of some debate in the literature, the intuition that there is a tight connection between the two statements – and between *cause* and counterfactuals more generally – is widely attested. This lends credence to the idea that *cause* expresses a type of causal necessity; that is, that the causing event is claimed to be necessary for the effect.[4]

[4] It 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 (12b). 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

Prima facie, it is tempting to analyze the 'bringing-about' component of *make* in terms of causal necessity as well – for instance, by treating *make* as a hyponym of *cause*, as per Shibatani (1976). Similarly, while Wierzbicka (1998) argues for the existence of a handful of irreducible *make* constructions, each of these constructions asserts, centrally, a statement of counterfactual necessity. Examples (13a)-(15a) appear in Wierzbicka (labels hers); (13b)-(15b) give the counterfactual relations she associates with each, by construction type.

(13) *Make* of 'coercion'
  a. She [Anand's mother]…made Anand pump the tires [of the bicycle] every morning.
  b. Anand would not have pumped the bicycle's tires without some action taken by his mother.

(14) *Make* of 'subjective necessity'
  a. A sharp hiss made her [Alice] draw back in a hurry.
  b. Alice would not have drawn back if the hiss had not occurred.

(15) *Make* of 'surprise'
  a. The wind made the door slam shut.
  b. The door would not have slammed shut if it had not been affected by the wind.

This accords with intuition in that the counterfactuals in (13b)-(15b) do seem, to some degree, to be licensed by the corresponding *make*-statements. We want to suggest, however, that a central way in which causative *make* is distinguished from *cause* is with respect to the necessity invoked in the counterfactual formulations given here: we argue that *make* never asserts causal necessity between a cause and an effect.

(14) already provides some first evidence for this argument. (14a) is well paraphrased by (16), suggesting that it is not the case that Alice would have failed (ever) to draw back had there been no hiss, but rather that she might have done it later or perhaps in a more leisurely fashion.[5] On this

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 & Pearl (2005); Halpern (2015) for a sophisticated treatment of such cases in a framework similar to the one we employ here.

[5] The use of *prompt* in here, in place of *make*, recalls, for obvious reasons, the PROMPT class of *make*-causative constructions described by Stefanowitsch (2001): the other two classes are TRIGGER and MANIPULATE.

view, it is the hiss that brings about Alice's response, rather than simply making it possible for her reaction to take place.

(16) A sharp hiss prompted Alice to draw back in a hurry.

A prompting relationship emerges even more clearly in the following example, taken from a 2009 installment of the Rachel Maddow show (MSNBC, Monday August 10, 2009; emphasis added).

(17) 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 in any way a necessary condition for his ultimate decision to leave CIGNA. Indeed, he establishes his ongoing dissatisfaction, and thus the clear possibility that he would have quit regardless of the expedition. Rather than representing a necessary step, it was his experience, occurring when it did, that functioned as the 'final straw' in a process that was (to some extent) already underway.

The absence of a necessity entailment is also illustrated well by a constructed example.

(18) a. I was not sure if I should go to band camp last year, but then my mother insisted that I go. I am so happy that she made me go. I had the best summer ever.
b. ($\not\to$) I would not have gone to band camp if my mother had not insisted that I go.

In (18a), the speaker establishes a (contingent) possibility that she will go to band camp, which turned into a certainty at the insistence of her mother. Then she goes on to claim (indeed, presuppose) that her mother's insistence *made* her go to band camp. If *make* asserted counterfactual necessity, paraphrased in (18b), this should result in infelicity, as the prior context explicitly denies the necessity of the cause. But no such infelicity is felt.

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

(19) I was not sure if I should go to band camp last year, but then my mother insisted that I go. ??I am so happy that she caused me to go. I had the best summer ever.

Here, the established possibility of a speaker-propelled decision to go results in a clash with the use of *cause* in the second sentence. The contrast between (18) and (19) can be made sense of if *cause* asserts causal necessity and *make* does not.

1.3 *Make*, *cause*, and causal sufficiency

If not in terms of causal necessity, the question is how the 'bringing about' component of *make* should be analyzed. Recall what we said about example (17): Potter's visit to the the healthcare expedition was the 'final straw' in a process that was already underway. The expedition, then, was not what made his leaving his job possible, but rather, what made it in some sense inevitable (and imminent). Before the expedition, leaving was a possibility; afterwards it was a done deal. Similarly, in the band camp example (18a), the speaker first establishes a (self-directed) possibility that she would go to band camp; after her mother's insistence, this turns into 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.

(20) **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 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 want to anticipate a positive consequence of pursuing the sufficiency thesis: spelled out correctly, causal sufficiency should obviate the need for stipulating *make*'s coercive implication (7) as a separate lexical entailment.

Roughly, the idea is this. If (21) 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.

(21) John made the children dance.

This leaves us with the following explananda for the account we develop in the rest of this paper. 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 of the inevitability that captures the intuitions discussed above, and predicts the coercive implication when (and only when) it arises. Finally, while we have denied – with good evidence – that *make* entails necessity, we do not want to claim that it never gives rise to inferences about the necessity of a cause for its effect. In fact, 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.

2 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 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 & Francez 2016; Nadathur 2016).

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.[6]

We will develop our analysis in several stages. In Section 2.1, 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 & Francez (2016) and Nadathur (2016)'s work on implicatives. In Section 2.2, we illustrate the workings of these notions with examples that tease causal sufficiency and causal necessity apart, and in Section 2.3, we articulate our view of why it is that *make* assertions often invite a necessity inference. In Section 3, we turn to the coercive implication of *make*: while it turns out that sufficiency as developed in Section 2.1 is not enough to predict the coercive implication, it is precisely what it required to account for the puzzling behavior of another causative verb – German *lassen*. In Section 3.3, we present an extension of Schulz's framework that allows us to define a notion of 'strong sufficiency' that implies the coercive implication.

[6] Arguably, 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 & 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 straightfoward system in which to formalize and examine our central claim with respect to sufficiency in causative constructions.

2.1 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 will use 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 $f_X : \{0,1\}^n \to \{0,1\}$. 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 $\mathrm{dom}(s)$ (see Appendix A). Given a situation s, we can check whether the determined variables have any causal consequences; Schulz defines the operator $\mathcal{T}_\mathcal{D}$ which in essence 'runs' the dynamics for one step.[7]

[7] For a proper treatment of overdetermination and pre-emption (cf. footnote 4) clause (b) of Definition 3 must be slightly modified, so as to allow $\mathcal{T}_\mathcal{D}$ to set the the value of an inner

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

(a) if $X \in B$, then $\mathcal{T}_{\mathcal{D}}(s)(X) = s(X)$

(b) if $X \in I$, with $Z_X = \{X_1, \ldots, X_n\}$, then

i. if $s(X) = u$ and $f_X(s(X_1), \ldots, s(X_n))$ is defined, $\mathcal{T}_{\mathcal{D}}(s)(X) = f_X(s(X_1), \ldots, s(X_n))$

ii. if $s(X) \neq u$ or $f_X(s(X_1), \ldots, s(X_n))$ is undefined, $\mathcal{T}_{\mathcal{D}}(s)(X) = s(X)$.

A finite number of iterations of $\mathcal{T}_{\mathcal{D}}$ 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 $\mathcal{T}_{\mathcal{D}}$ relative to s:*

$$s \models_{\mathcal{D}} \phi \textit{ iff } [\![\phi]\!]^{s^*} = 1$$

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 & Francez (2016); 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 $A_X = \left\{Y \in P \;\middle|\; R_F^T(X,Y)\right\}$ be the set of causal ancestors of X.*

*(a) s is **causally necessary** for X iff, for any situation s' with:*

i. $\mathrm{dom}(s) \cap A_X \subseteq \mathrm{dom}(s') \cap A_X$ and

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

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

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.

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. We restrict consideration here to those cases where the causing fact is not determined by the background. 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 $s \not\models_{\mathcal{D}} X$ and $s \not\models_{\mathcal{D}} \neg X$.*

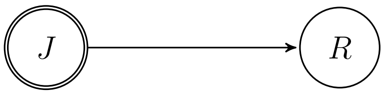
*(a) $X = x$ is **causally necessary** for Y relative to s iff $s[X \mapsto x]$ is causally necessary for Y.*

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

2.2 *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 (22)-(23). 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 (22)-(23), 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').



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

Figure 1: Dynamics for the joke scenario.

(22) $[\![X \text{ cause } Y \text{ to VP }]\!]^{\mathcal{D}} = 1$ iff C is causally necessary for $E = [\![\text{VP}]\!]([\![Y]\!])$ relative to the context situation $s_C \subseteq w_@$, and $w_@(C) = w_@(E) = 1$

(23) $[\![X \text{ make } Y \text{ VP }]\!]^{\mathcal{D}} = 1$ iff C is causally sufficient for $E = [\![\text{VP}]\!]([\![Y]\!])$ relative to the context situation $s_C \subseteq w_@$ and $w_@(C) = 1$.

These proposals are preliminary. In Section 3, we will refine (23) to address several remaining issues. We will leave (22) 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*.

2.2.1 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).

(24) *Context:* Juno was at a comedy show, and the comedian told a particularly risque 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 $R_Z = \{J\}$, 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 $s_0 = \{\langle J, u\rangle, \langle R, u\rangle\}$:

(25) $s_0[J \mapsto 1]$ 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 $[\![R]\!]^{s'} = 0 \neq 1$.

(26) $s_0[J \mapsto 1]$ 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 $[\![R]\!]^{s_1} = 1$.

Hence, proposals (22)-(25) predict that both *cause* and *make* should be felicitous descriptions of this situation, and this is indeed the case.

2.2.2 Necessary, but insufficient causes: the Titanic scenario

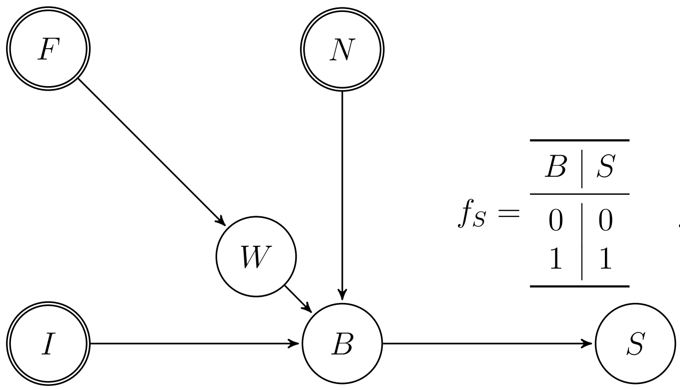
Example (26) demonstrates how a simple dynamics works, but does not allow us to check for the proposed distinction between *cause* and *make*. Next we consider a more complex scenario: the 'event cascade' leading to the sinking of the Titanic.

(27) *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.[8] 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.

[8] Journalist 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)



$$f_S = \begin{array}{c|c} \hline B & S \\ \hline 0 & 0 \\ 1 & 1 \\ \hline \end{array} \qquad f_B = \begin{array}{ccc|c} \hline W & I & N & B \\ \hline 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 \\ \hline \end{array}$$

Figure 2: Dynamics for the sinking of the Titanic.

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 = the 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:

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

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

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

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

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. $\mathrm{dom}(s_I[F \mapsto 1]) \cap A_S = \{I, F\}$, 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 $s' \not\models_{\mathcal{D}} S$.

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

a. $s_1 = \mathcal{T}_{\mathcal{D}}(s_I[F \mapsto 1]) = \begin{bmatrix} I & \mapsto 1 \\ F & \mapsto 1 \\ N & \mapsto u \\ W & \mapsto 1 \\ B & \mapsto u \\ S & \mapsto u \end{bmatrix}$ is the least fixed point of $s_I[F \mapsto 1]$, as in (30c).

b. $s_1 \not\models_{\mathcal{D}} S$, so $s_I[F \mapsto 1] \not\models_{\mathcal{D}} S$.

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 (27).

2.2.3 A sufficient, unnecessary cause: the doctor scenario

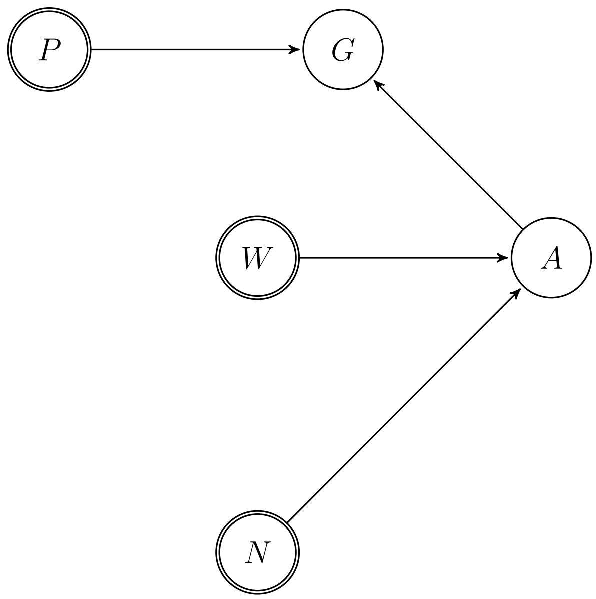
Next, let us consider a toy example involving a sufficient but unnecessary condition.

(31) Context: Alex has been experiencing pain in his back for two days. He is considering going to the doctor if it lasts for another day. His wife sees him wincing, and also sees the doctor's number on the counter. She calls and makes him an appointment, which he goes 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 five variables. The background variables are P = whether back pain lasts for three days, W = whether Alex's wife sees him wince, and N = whether Alex's wife sees the doctor's number at hand. The inner variables are A = whether Alex's wife makes him an appointment and G = whether Alex goes to the doctor. $Z_A = \{W, N\}$, with $f_A = W \wedge N$ and $Z_G = \{P, A\}$. f_G is given in Figure 3.



$$f_B = \begin{array}{cc|c} P & A & G \\ \hline 0 & 0 & 0 \\ 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 1 \end{array}$$

Figure 3: Dynamics for the doctor scenario.

Let the background context be s_{WN}, the situation which verifies W 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, since P is also a sufficient condition for G:

(32) A is sufficient, relative to s_{WN} for G.

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

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

c. s_1 is the least fixed point of $s_{WN}[A \mapsto 1]$, and $[\![G]\!]^{s_1} = 1$

(33) A is not necessary for G, relative to s_{WN}.

a. Consider $s_P = s_{WN}[A \mapsto 1][A \mapsto 0, P \mapsto 1]$. Then dom$(s_{WN}[A \mapsto 1]) \cap A_G \subset$ dom$(s_P) \cap A_G$, and $s_{WN}[A \mapsto 1](A) = 1 \neq s_P(A) = 0$.

b. The smallest fixed point of s_P is $s_2 = \begin{bmatrix} W & \mapsto 1 \\ N & \mapsto 1 \\ P & \mapsto 1 \\ G & \mapsto 1 \\ A & \mapsto 0 \end{bmatrix}$ and $[\![G]\!]^{s_2} = 1$

On the proposals above, this accounts for the felicity of (33b) and the infelicity of (33a).

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 (22) and (23) 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.

2.3 Causal perfection

Examples like the doctor scenario demonstrate that *make*-causatives can be used in contexts in which a designated effect event E was possible prior to the occurrence of the cause C – that is, in which C was not required for a causal pathway to E to be realized. Given these facts, and if the analysis of *make* as asserting sufficiency is correct, we would like to explain why strong necessity inferences are often associated with *make*-statements. Consider (34):

(34) Suzy asks Billy to help her clean a glass vase, telling him to be careful because it is fragile. She leaves the room, leaving the door open behind her. A gust of wind suddenly slams the door shut with a loud bang, which startles Billy into dropping the vase. Suzy

comes back, sees the broken vase and asks what happened. Billy says "The bang from the door made me drop it!"

In this context, it seems clear that Billy is conveying that he would *not* have dropped the vase if the door had not slammed shut. In particular, this inference arises in association with the fact that Billy's utterance not only conveys what happened – the vase was dropped – but also a reason for the error, which is intended to absolve him of clumsiness or carelessness with respect to the undesirable result.

Make-causatives are by no means the only domain in which assertions of a sufficient condition for a particular outcome are interpreted as conveying the necessity of the same condition for the outcome. A well-known instance of sufficiency being strengthened to necessity and sufficiency comes from Geis & Zwicky (1971)'s **conditional perfection**. In this case, a conditional statement such as (35a), which asserts the sufficiency of its antecedent for its consequent, is said to 'invite an inference' to the converse conditional (35b). Taken together, the assertion and inference convey a biconditional statement, which represents the antecedent as a necessary and sufficient condition for the conditional consequent.

(35) a. If you study the material carefully, you will get an A on the test.
b. $\rightsquigarrow$ If you do not study the material carefully, you will not get an A on the test.
c. (35a) + (35b) $\equiv$ If and only if you study the material carefully will you get an A on the test.

Conditional perfection has generated a significant literature, which we do not propose to add to here (see van der Auwera 1997; Horn 2000; von Fintel 2001; Franke 2009: among others). Although analyses differ in details, the perfecting inference is (generally) associated with the contrast between a conditional statement and its associated 'unconditional' consequent:

(36) a. *Conditional:* If you study the material carefully, you will get an A on the test.
$\rightsquigarrow$ *If and only if you study carefully will you get an A on the test.*
b. *Unconditional:* You will get an A on the test.

In contexts where the unconditional consequent can be taken to be a (pragmatic) alternative to the conditional statement, use of the more complex and weaker conditional form generates an inference that the unconditional statement does not hold.[9] Further, given the speaker's choice of antecedent, it is only natural to link the negation of the unconditional to the antecedent proposition.

(37) a. If you study the material carefully, you will get an A on the test.
b. $\rightsquigarrow$ You will not unconditionally get an A on the test.
c. $\rightsquigarrow$ If you don't study carefully, you might not get an A on the test.

'Completion' of the perfection process – from (37c) to the full biconditional – can then be taken to be a function of a number of other pragmatic concerns, including the epistemic authority of the speaker, her ability to control one or both of the antecedent and consequent propositions, the desirability of the consequent proposition, and/or the discursive question that the conditional is being given in response to (see, in particular von Fintel 2001; Franke 2009; Nadathur 2013).

The same considerations seem to be in play for what we might call the **causal perfection** inference associated with *make*-causatives. As defined, causal sufficiency of a fact relative to a situation (see Definition 6b) already requires that the background situation leaves the outcome unresolved, which gives us the 'first step' inference (38a) for free.

(38) Cause C made effect E happen.
a. Prior to cause C/in the absence of cause C, E (might or) might not have happened.
b. $\rightsquigarrow$ In the absence of cause C, E would not have happened.

In a sense, there are three parts to the assertion of *make*-causative. First, a statement with the structure of (38) asserts directly that the cause C occurred, and second, that C is causally sufficient for E. From this we get a third entailment, which is that the effect E occurred. This gives us a parallel to conditional statements: in certain contexts, such as (34), we can understand a speaker as choosing between simply asserting the effect, and asserting the effect *as* an effect. This invites the same type of pragmatic reasoning as in conditional perfection, in which we construct a reason for

[9] This type of reasoning – from the use of a more complex, less informative statement to the negation of a simpler and stronger alternative – is widespread. While such inferences can be analyzed as a particular form of scalar implicature, Lauer (2013) suggests that they represent a class of strong, non-optional pragmatic inferences, called "Need-a-Reason" inferences, since they arise from a post-hoc attempt to rationalize the speaker's choice.

the speaker's choice. In both cases, the 'full' perfection inference is easily defeated:

(39) a. If you study the material carefully, you will get an A on the test. But you might still get an A if you don't study.
b. The loud bang made Billy drop the vase. But he might have dropped it in any case.

On the other hand, the 'not-unconditional' inference is difficult to defeat in both cases:

(40) a. If you study the material carefully, you will get an A on the test. ??But you will get an A anyway.
b. The loud bang made Billy drop the vase. ??But he would have dropped it anyway.

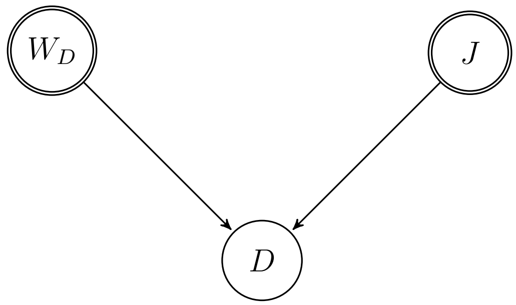
The parallels between conditional perfection and necessity inferences on *make* causatives suggest that they represent instances of the same phenomenon. In particular, then, we would like to attribute the frequency with which *make*-causes are interpreted as necessary causes to a general pattern of pragmatic reasoning which takes place over the (causal) conditional structure which underlies a sufficiency causative. If and when other periphrastic causatives are identified as sufficiency-asserting, we would expect to see inferences of causal perfection arise with these constructions as well.

3 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 the following example.

(41) *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 (42), 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



$f_D =$

W_D	J	D
0	0	0
0	1	0
1	0	0
1	1	1

Figure 4: Dynamics for the scenario in example (41).

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 $s_W = \{\langle W_D, 1\rangle, \langle J, u\rangle, \langle D, u\rangle\}$:

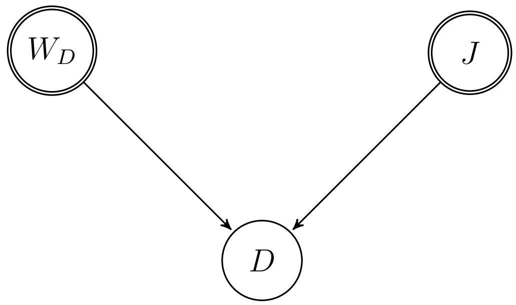
(42) a. $s_W[J \mapsto 1] = \{\langle W_D, 1\rangle, \langle J, 1\rangle, \langle D, u\rangle\}$
b. $s_1 = \mathcal{T}_{\mathcal{D}}(s_W[J \mapsto 1]) = \{\langle W_D, 1\rangle, \langle J, 1\rangle, \langle D, 1\rangle\}$
c. s_1 is a fixed point and $[\![D]\!]^{s_1} = 1$

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:[10,11]

i. W_E is causally irrelevant to E, *i.e.* either W_E is not among the causal ancestors of E, or it is, but in the presence of C, 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.

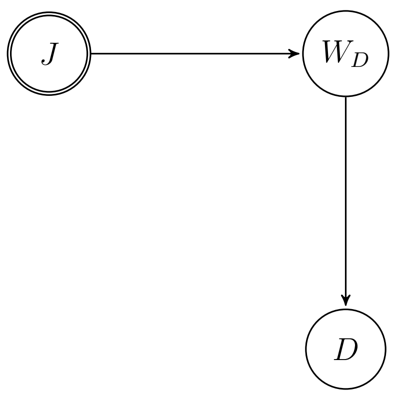
[10] For simplicity, we assume here that, if W_E is causally relevant to E at all, then $W_E = 1$ facilitates E, but $W_E = 0$ does not. If we lift this assumption, there are two alternative options paralleling (ii) and (iii), but the essential picture is unchanged.

[11] It 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), $s[C \mapsto 1]^* \not\models_D E$.



$$f_D = \begin{array}{cc|c} \hline W_D & J & D \\ \hline 0 & 0 & 0 \\ 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 1 \\ \hline \end{array}$$

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 $s_\emptyset = \{\langle W_D, u\rangle, \langle J, u\rangle, \langle D, u\rangle\}$.



$$f_W = \begin{array}{c|c} \hline J & W \\ \hline 0 & u \\ 1 & 1 \\ \hline \end{array}$$

$$f_D = \begin{array}{c|c} \hline W & D \\ \hline 0 & 0 \\ 1 & 1 \\ \hline \end{array}$$

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 $s_\emptyset = \{\langle W_D, u\rangle, \langle J, u\rangle, \langle D, u\rangle\}$.

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*.

3.1 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: (43) 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*).[12,13]

(43) 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) or 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.

[12] The surface form *lassen* has a variety of readings. Superficially most similar to the causative in (43) 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 (43). 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.'

[13] The same 'ambiguity' has been described for Swedish *låta* (Lundin 2003; Rawoens 2013).

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' reading).

3.2 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 2.2. First, (44) is true in the joke scenario:

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

Similarly, (45) is true in the doctor scenario:

(45) Alex' Frau hat ihn zum Arzt gehen lassen.
Alex' wife has him to the doctor go let
'Alex wife made him go to the doctor.'

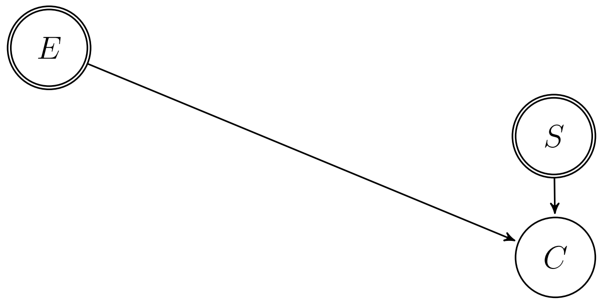
Finally, in lieu of the Titanic scenario, we present a similar but simpler scenario in (46). Like *make*, *lassen* can be used to describe the 'final straw' cause (i.e., the sufficient one), but not a merely necessary one:

(46) 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 in the present analysis: so far, nothing we have said ensures that (46a) comes out false in the given context. Consider the simple dynamics in Figure 7, where E = whether the earthquake happens, S = whether the storm happens and C = whether the



$$f_D = \begin{array}{cc|c} E & S & C \\ \hline 0 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \\ 1 & 1 & 1 \end{array}$$

Figure 7: Dynamics for the lighthouse scenario.

lighthouse collapses. In this dynamics, $E = 1$ in fact *is* sufficient for $C = 1$, relative to the situation $s_S = \{\langle S, 1\rangle, \langle E, u\rangle, \langle C, u\rangle\}$ (the case is actually equivalent, *modulo* variable names, to the scenario in Figure 4).[14]

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

(47) **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.[15]

With this, the contrast in (47) follows: $S = 1$ is sufficient for $C = 1$ relative to situation $s_E = \{\langle E, 1\rangle, \langle S, u\rangle, \langle C, u\rangle\}$, which satisfies (47) as the

[14] Of 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.

[15] It appears that the evaluation time of a causative claim can be shifted (usually forward) by certain kinds of adverbials, in which case more facts can be held constant in the evaluation of a causative claim. Examples of such adverbials are 'in the end' or 'ultimately': (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.

earthquake (E) happens before the storm (S). Conversely, $E = 1$ would be sufficient only relative to the situation s_S, which does not meet the constraint in (47). Hence (46a) comes out false, but (46b) comes out true.

3.3 Strong and weak sufficiency

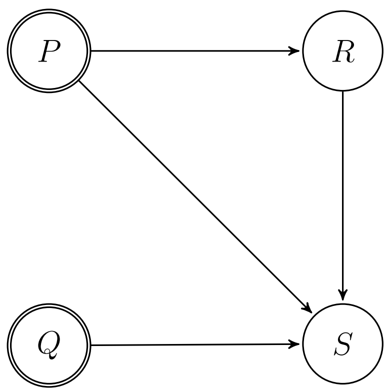
The challenge now is to state what differentiates *make* from *cause*, in such a way that this difference predicts the coercive implication. To recap, this means that we need *make* to assert a kind of sufficiency that excludes that $C = 1$ counts as sufficient cause for $E = 1$ if $W_E = 1$ (the will 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.

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 $\mathbb{V}$. $\mathbb{S}$, 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* $\mathcal{T}_D$ 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.

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



$\mathbb{V} = \{P\}$

$f_R =$

P	R
0	0
1	1

$f_S =$

P	Q	R	S
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	0
1	1	0	1
1	1	1	0

Figure 8: Example dynamics with fickle variables.

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 (48). 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 $S = 1$.

(48)
$$\begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto u \\ S \mapsto u \end{bmatrix} \xrightarrow[\mathcal{T}_{\mathcal{D}}]{} \begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto 1 \\ S \mapsto u \end{bmatrix} \xrightarrow[\mathcal{T}_{\mathcal{D}}]{} \begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto 1 \\ S \mapsto 0 \end{bmatrix} \xrightarrow[\mathcal{T}_{\mathcal{D}}]{} \begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto 1 \\ S \mapsto 0 \end{bmatrix}$$

The sequence in (48) is a valid causal development under the new dynamics, as well. However, since fickle variable potentially change at any iteration step, there are alternative possibilities. In (49), we give one that results in $S = 1$:

(49)
$$\begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto u \\ S \mapsto u \end{bmatrix} \xrightarrow[\mathcal{T}_{\mathcal{D}}]{P \mapsto 0} \begin{bmatrix} P \mapsto 0 \\ Q \mapsto 1 \\ R \mapsto 0 \\ S \mapsto u \end{bmatrix} \xrightarrow[\mathcal{T}_{\mathcal{D}}]{P \mapsto 1} \begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto 0 \\ S \mapsto 1 \end{bmatrix} \xrightarrow[\mathcal{T}_{\mathcal{D}}]{P \mapsto 1} \begin{bmatrix} P \mapsto 1 \\ Q \mapsto 1 \\ R \mapsto 0 \\ S \mapsto 1 \end{bmatrix}$$

$\vec{r_1}$	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	

$\vec{5_1}$	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.

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 (48) is $\vec{r_1}$ in this table, while the one in (49) 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 situations (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):

(50) a. $S^*_{\mathbb{D}}(s)$: The set of *all* causal developments of s.
b. $S^{\downarrow}_{\mathbb{D}}(s)$: The set of those causal developments in which all variables of s (including the fickle ones) maintain their values.

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 $S^{\downarrow}_{\mathbb{D}} = \{\vec{r_1}\}$.[16]

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

(51) Strong causal consequence:
$s \models\!\equiv_{\mathbb{D}} \phi$ if all developments in $S^*_{\mathbb{D}}(s)$ make ϕ true.

(51) Weak causal consequence:
$s \vDash_{\mathbb{D}} \phi$ if all developments in $S^{\downarrow}_{\mathbb{D}}(s)$ make ϕ true.

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

(52) a. A fact $X = x$ is *strongly causally sufficient* for a formula ϕ relative to a situation s_C such that $[\![\phi]\!]^{s_C} \neq 1$ iff

$$s_C[X \mapsto x] \models\!\equiv_{\mathbb{D}} \phi$$

b. A fact $X = x$ is *weakly causally sufficient* for a formula ϕ relative to a situation s_C such that $[\![\phi]\!]^{s_C} \neq 1$

$$s_C[X \mapsto x] \vDash_{\mathbb{D}} \phi$$

Since it is guaranteed that $S^{\downarrow}_{\mathbb{D}} \subseteq S^*_{\mathbb{D}}(s)$, 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 agent 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.[17]

3.3.1 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.

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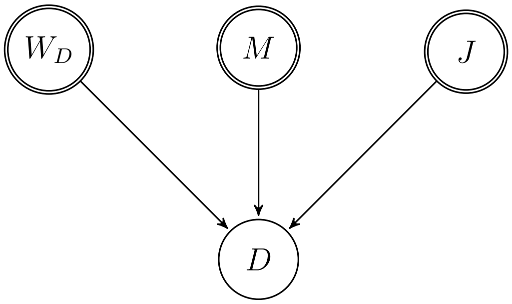
16 Note that $S^{\downarrow}_{\mathbb{D}}(s)$ is not always a singleton. It will only be one if s determines all fickle variables.

17 In 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.



$\mathbb{V} = \{W_D\}$

$f_D =$

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 (41).

$\vec{t_1}$	W_D	M	J	D	
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	

$\vec{r_2}$	W_D	M	J	D	
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	

$\vec{r_3}$	W_D	M	J	D	
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	

$\vec{r_4}$	W_D	M	J	D	
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:

(53) a. $S^*(s_{MW}[J \mapsto 1]) = \left\{\vec{t_1}, \vec{t_2}, \vec{t_3}, \vec{t_4}\right\}$
b. $S^{\downarrow}(s_{MW}[J \mapsto 1]) = \left\{\vec{t_1}\right\}$

Further, we have:

(54) a. $[\![D]\!]^{\vec{t_1}} = [\![D]\!]^{\vec{t_2}} = 1$
b. $[\![D]\!]^{\vec{t_3}} = [\![D]\!]^{\vec{t_4}} = 0$

$\vec{u_1}$	W_D	J	D	
u_{1-1}	1	1	u	$W_D \to 1$
u_{1-2}	1	1	1	$W_D \to 1$
u_{1-3}	1	1	1	

$\vec{u_3}$	W_D	J	D	
u_{3-1}	1	1	u	$W_D \to 0$
u_{3-2}	0	1	1	$W_D \to 1$
u_{3-3}	1	1	1	

$\vec{u_2}$	W_D	J	D	
u_{2-1}	1	1	u	$W_D \to 1$
u_{2-2}	1	1	1	$W_D \to 0$
u_{2-3}	0	1	1	

$\vec{u_4}$	W_D	J	D	
u_{4-1}	1	1	u	$W_D \to 0$
u_{4-2}	0	1	1	$W_D \to 0$
u_{4-3}	0	1	1	

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

And hence:

(55) a. Relative to s, $J = 1$ is *not* strongly sufficient for D, since, e.g. $t_3 \in S^*(s)$ and $[\![D]\!]^{t_3} = 0$[18]
b. Relative to s, $J = 1$ is weakly sufficient for D, since for all $t \in S^{\downarrow} : [\![D]\!]^{t} = 1$

Assuming now that *make* asserts strong sufficiency and *lassen* asserts weak sufficiency, we predict that (56a) is false while (56b) is true in this scenario, as desired.

(56) 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.'

3.3.2 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.

(57) a. $S^*_{\mathbb{D}}(s_W) = \{\vec{u_1}, \vec{u_2}, \vec{u_3}, \vec{u_4}, \}$
b. $S^{\downarrow}_{\mathbb{D}}(s_W) = \{u_1\}$
c. $[\![D]\!]^{\vec{u_1}} = [\![D]\!]^{\vec{u_2}} = [\![D]\!]^{\vec{u_3}} = [\![D]\!]^{\vec{u_4}} = 1$

18 It 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).

Since $J = 1$ is strongly sufficient for D, it is also weakly sufficient and hence both (56a) and (56b) 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 strongly sufficient for D: In this case, W_D is not a background variable (hence not fickle), but rather an internal one.[19]

3.4 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

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

and physically carries or pushes him out the door. (58) is an unexceptional truthful description of this event, while (59) has a ring of ironic understatement. We leave this issue for future research.

(58) Elliot made the troublemaker leave.

(59) ?Elliot hat den Randalierer gehen lassen.
Elliot has the troublemake go let
'Elliot made the troublemaker leave.'

4 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: Some causatives assert *causal necessity*, while others assert *causal sufficiency*. Consequently, a first question to ask about any causative (crosslinguistically) is which kind of causal dependence it asserts. Here, we summarize the relevant diagnostics:

(60) If a verb V is a **strong sufficiency causative** (like *make*), then:
NP$_S$ V NP$_O$ VP …
- 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 scenarios).

Weak sufficiency causatives (like *lassen*) lack the property in (60a), but have (60b) and (60c). By contrast:

(61) If a verb V is a **necessity causative** (like *cause*), then:
NP$_S$ V NP$_O$ VP…
- 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).

Of course, it is not a given that causative verbs can only assert one type of dependence or the other—there well could be causatives that claim that the cause was both sufficient and necessary. In general, we would expect the kind of causation expressed by such a verb to be rather direct (as in the joke scenario). This raises an intriguing possibility: Perhaps *lexical* causatives (such as *kill*), which have often been taken to be restricted to 'direct' causation, assert that the cause was both necessary and sufficient for the effect.

We conjecture that the approach to causative meaning developed can also shed some light on the semantics of standard cases of disposition ascriptions. Like causative statements, these are intimately related to certain counterfactual conditionals: At first blush, (62a) appears to imply (62b), and (63a) appears to imply (63b).

(62) a. This glass is fragile.
b. If this glass were (suitably) struck, it would shatter.

(63) a. This lubricant is water-soluble.
b. If this lubricant were immersed in water, it would dissolve.

As is the case with causatives, these counterfactuals cannot quite be entailments, at least as stated: We can imagine circumstances (involving 'reverse-cycle finks', Martin 1994 or factors 'masking' the disposition, Johnston 1992)[20] in which the dispositional statements are true, but the counterfactual is false.

In a causal-model framework, a disposition can be understood as a hypothetical guarantee: e.g., if a variable for striking the glass is realized, the glass will respond in a predetermined way. This resembles closely the structure underlying the *make*-assertion "Striking the glass made it shatter." In the case of the disposition, however, we do not require that the 'causing' or 'initiating' variable is realized. That is, unlike in the *make*-construction, no one need actually strike the glass for the truth of the sentence to be realizd. Seen from this perspective, the close connection between disposition ascriptions and counterfactual conditionals would, as in the case of causatives,

[20] A reverse-cycle fink is a (often quite outlandish) mechanism that ensures that the consequent state (breaking, dissolving) does not actuate by *removing* the disposition whenever its triggering condition (striking, immersing) is actualized. 'Masking' refers to much less fanciful cases in which the effect is suppressed by other means: A glass that is carefully wrapped in suitable packing material will continue to be fragile ((62a) is true), even though it would no longer shatter if struck ((62b) is false).

not come about because one entails the other, but rather because both are interpreted in terms of the same kind of underlying structure.

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 $w : P \to \{0, 1\}$*
- *A **situation** for $\mathcal{L}_P$ is any function $s : P \to \{0, 1, u\}$*
- *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*

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

- *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*

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

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

i. $[\![p]\!]^s = s(p)$.

ii. $$[\![\neg\phi]\!]^s = \begin{cases} 1 & \textit{if } [\![\phi]\!] = 0 \\ 0 & \textit{if } [\![\phi]\!] = 1 \\ u & \textit{otherwise.} \end{cases}$$

iii. $$[\![\phi \wedge \psi]\!]^s = \begin{cases} 1 & \textit{if } [\![\phi]\!] = [\![\psi]\!] = 1 \\ 0 & \textit{if } [\![\phi]\!] = 0 \textit{ or } [\![\psi]\!] = 0 \\ u & \textit{otherwise.} \end{cases}$$

iv. $[\![\phi \vee \psi]\!]^s = \begin{cases} 1 & \textit{if } [\![\phi]\!] = 1 \textbf{ or } [\![\psi]\!] = 1 \\ 0 & \textit{if } [\![\phi]\!] = [\![\psi]\!] = 0 \\ u & \textit{otherwise.} \end{cases}$

A.2 Dynamics with fickle variables

Definition A.4 (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**.*

Definition A.5 (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 $\vec{\mathbb{V}} \mapsto \vec{v}$ of the fickle variables, such that $\mathcal{T}_{\mathcal{D}}(s_1[\vec{\mathbb{V}} \mapsto \vec{v}]) = s_2$.*

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

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 $k \in \mathbb{N} : s_{n+k}\restriction_X = s_n\restriction_X$.*

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 $\vec{r} = r_1, r_2, r_3 \ldots \in Seq_{\mathbb{D}}(s)$ and any $n \in \mathbb{N}$:*

i. *If $n > 1$, then* $\mathrm{dom}(r_n) \cap \mathbb{V} = \mathbb{V}$
(All situations in all sequences but the first are defined on all fickle variables).

ii. *$\vec{r}$ is $\mathbb{S}$-stable.*

iii. $r_n\restriction_{\mathrm{dom}(r_n)-\mathbb{V}} \subseteq r_{n+1}\restriction_{\mathrm{dom}(r_{n+1})-\mathbb{V}}$.
(The situations in each sequence are increasing on all values except the fickle variables.)

iv. *If* $\mathrm{dom}(r_n) = \mathrm{dom}(r_{n+k})$, *then* $r_n\restriction_{\mathbb{S}\cup I} = r_{n+k}\restriction_{\mathbb{S}\cup I}$

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

ii. By Definition 3 of $\mathcal{T}_{\mathcal{D}}$, 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 $\mathcal{T}_{\mathcal{D}}$: $X \in \mathrm{dom}(r_{n+1})$ iff $Z_X = \{X_1, \ldots, X_k\}$ for some $k \in \mathbb{N}$

and $f_X(r_n(X_1), \ldots r_n(X_k))$ 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* $\vec{r}, \vec{r'} \in Seq_\mathbb{D}(s)$ *and any* $n \in \mathbb{N}$: dom$(r_n) =$ dom(r'_n).

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

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

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

ii. dom$(r_{n+1}) \cap \mathbb{S} =$ dom$(r'_{n+1}) \cap \mathbb{S}$ $\quad$ [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, dom$(r_n) =$ dom(r'_n). But then, dom$(r_{n+1}) \cap I =$ dom$(r'_{n+1}) \cap I$.

□

Definition A.10 ($\mathcal{T}_\mathcal{D}$-sequence)**.** *Let* $\mathbb{D}$ *a dynamics with fickles,* 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* $s_1, s_2, s_3 \ldots$ *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* $Seq_\mathbb{D}(s)$ *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* $Seq_\mathbb{D}(s)$ *are* $(\mathbb{S} \cup I)$*-stable at* n*.*

Proof. Let t be an arbitrary $\mathcal{T}_\mathbb{D}$-sequence in $Seq_\mathbb{D}(s)$. 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 dom$(t_z) =$ dom(t_{z+k}). But then, by Fact A.9, for any arbitrary sequence $\vec{r} \in Seq_\mathbb{D}(s)$: dom$(r_z) =$ dom(r_{z+k}). And hence, by Fact A.8 (iv), $r_z\restriction_{\mathbb{S}\cup I} = r_{z+k}\restriction_{\mathbb{S}\cup I}$. 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* $Seq_\mathbb{D}(s)$ *are* $(\mathbb{S}\cup I)$*-stable at* n *and define:* $S^*_\mathbb{D}(s) := \{r_1, r_2, \ldots, r_{k+1} \mid \vec{r} \in Seq_\mathbb{D}(s)\}$ *and* $S^\downarrow_\mathbb{D}(s) := \{\vec{r} \in S^*_\mathbb{D} \mid \vec{r}$ *is* dom(s)*-stable*$\}$

Definition A.14. *We extend the function* $[\![\cdot]\!]$ *to finite sequences of situations as follows:* $[\![\phi]\!]^{\mathbb{D},s_1,\ldots,s_n} = [\![\phi]\!]^{\mathbb{D},s_n}$ *With this, we define:*

$$\Sigma \models_{\mathbb{D}} \phi \textit{ iff } \forall \vec{r} \in S^*_{\mathbb{D}}(s) : [\![\phi]\!]^{D,\vec{r}} = 1$$
$$\Sigma \vDash_{\mathbb{D}} \phi \textit{ iff } \forall \vec{r} \in S^{\downarrow}_{\mathbb{D}}(s) : [\![\phi]\!]^{D,\vec{r}} = 1$$

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

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 fickles 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 fickles and* $\mathcal{D} = \langle \mathbb{S} \cup \mathbb{V}, F \rangle$ *its corresponding classical dynamics and* s *a situation. Then if* $\mathbb{V} = \emptyset$*:*

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

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 $\{s_1, \ldots, s_n\}$ 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 fickles prevent sufficiency)**.** *Let* $\langle \mathbb{S}, \mathbb{V}, F \rangle$ *be a dynamics with fickles such that for some variable* $X \in \mathbb{V}, E \in I$*,* $Z_E = \langle \ldots, X, \ldots \rangle$ *and* f_E *such that* $f_E(\langle \ldots, x, \ldots \rangle) = 1$ *only if* $x = 1$*. Then for no situation* s*,* $C = c$ *is sufficient for* E *relative to* s*.*

Proof. Suppose otherwise and let $\vec{\mathbb{V}} \mapsto \vec{v}$ be an arbitrary setting of fickle variables such that $\vec{v}(X) = 0$. Let $s^{\vec{v}}$ be the $\mathcal{T}_{\mathcal{D}}$-sequence of $s[C \mapsto c]$ for $\vec{v}$. Let k be such that s^v_k be the least fixed point of $\mathcal{T}_{\mathbb{D}}$ relative to $s[C \mapsto c][\vec{\mathbb{V}} \mapsto \vec{v}]$. Since $C = c$ is sufficient for E, it must be that $s^v_k(E) = 1$ and $s(E) = u$. Let i be the smallest n such that $s^v_{n+1}(E) = 1$. It must be that $s^v_i(X) = 1$. But $\mathcal{T}_{\mathcal{D}}$-sequences are $\mathbb{V}$-stable, so $s^v_i(X) = s^v_1(X) = s[C \mapsto c][\vec{\mathbb{V}} \mapsto \vec{v}] = 0$. 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 2 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. DefinitionB.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:*

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

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 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.*

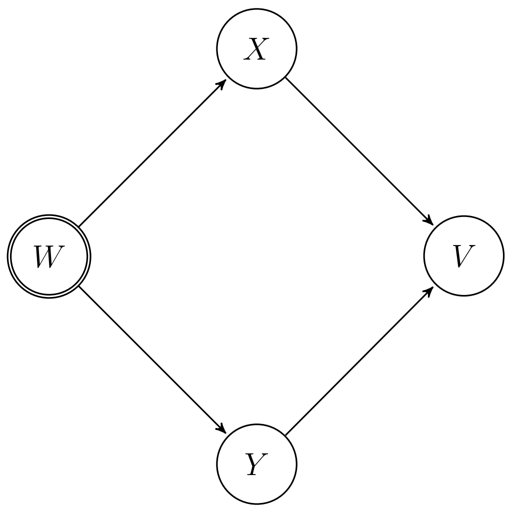
Note that if X is not causally realizable, then D must be defined so that there is no 0-1 assignment $\vec{z}$ to Z_X such that $f_X(\vec{z}) = 1$. In other words, f_X is the constant function at 0. If X is false regardless of the determinations of its causal ancestors, then it does not in any real sense 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 facs 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 & 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.

This definition has several positive consequences:



$f_X =$

W	X
0	0
1	1

$f_Y =$

W	Y
0	1
1	0

$f_X =$

X	Y	V
0	0	0
0	1	0
1	0	0
1	1	1

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

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 $f_Z(\vec{z_1}) = 1$, 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 $s' \models_{\mathcal{D}} X$. □

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:

(64) 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
$s_{X,u} = \{\langle W, u \rangle, \langle X, 1 \rangle, \langle Y, u \rangle, \langle V, u \rangle\}$,
$s_{X,0} = \{\langle W, 0 \rangle, \langle X, 1 \rangle, \langle Y, u \rangle\ \langle V, u \rangle\}$, 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. 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. 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. 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. 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 & Francez's version. Translated into the notation we use, they provide the following:

Definition B.5. *(Baglini & Francez 2016). A situation s is **causally necessary** for a variable $X \in P - B$, iff, for any alternative situation s' such that:*
i. dom$(s) \cap A_X =$ dom$(s') \cap A_X$ *and*
ii. $\exists Y \in$ 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.

(65) 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:

(66) 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: $\text{dom}(s) \cap A_X \subseteq \text{dom}(s') \cap A_X$.

(67) 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.

(2) 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

(3) Instead of motivating him to improve, you've inadvertently made him tune you out.
http://mycrains.crainsnewyork.com/executive_inbox/2009/06/post.

html
Last retrieved on: 2017-06-20

(4) Jackie Hoffman on How Jessica Lange Unintentionally Made Her Cry
http://oianews.com/feuds-jackie-hoffman-on-how-jessica-lange-unintentionally-made-her-cry-exclusive-video
Last retrieved on: 2017-06-20

(5a) this book made me get a divorce.
https://www.amazon.com/Adonis-Selected-Margellos-Republic-Letters/dp/0300181256
Last retrieved on: 2017-07-05

(6) 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

(13a) 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)

(14a) A sharp hiss made her [Alice] draw back in a hurry.
Carroll, Lewis (1929) *Alice's adventures in wonderland*. London: A. & C. Black Ltd.
Cited after: Wierzbicka (1998)

(17) 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

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The authors have no competing interests to declare.

References

Baglini, Rebekah & Itamar Francez. 2016. The implications of managing. *Journal of Semantics* 33(3). 541–560. http://dx.doi.org/10.1093/jos/ffv007.

Bennett, Jonathan. 1984. Counterfactuals and temporal direction. *The Philosophical Review* 93. 57–91. http://dx.doi.org/10.2307/2184413.

Briggs, Rachael. 2012. Interventionist counterfactuals. *Philosophical Studies* 160. 139–166. http://dx.doi.org/10.1007/s11098-012-9908-5.

Copley, Bridget & Philip Wolff. 2014. Theories of causation should inform linguistic theories and vice versa. In Bridget Copley & Fabienne Martin (eds.), *Causation in grammatical structures*, 11–57. Oxford: Oxford University Press. http://dx.doi.org/10.1093/acprof:oso/9780199672073.003.0002.

Dixon, Robert M. W. 2005. *A semantic approach to English grammar* (Oxford Textbooks in Linguistics). Oxford: Oxford University Press.

Enzinger, Stefan. 2010. *Kausative und perzeptive Infinitivkonstruktionen: Syntaktische Variation und semantischer Aspekt [Causative and perceptual infinitival constructions: Syntactic variation and semantic aspect]* (Studia Grammatica 70). Berlin: Akademie Verlag. http://dx.doi.org/10.1524/9783050062310.

Franke, Michael. 2009. *Signal to act: Game theory and pragmatics*. Amsterdam: Universiteit van Amsterdam dissertation.

Geis, Michael & Arnold Zwicky. 1971. On invited inferences. *Linguistic Inquiry* 2(4). 561–566.

Gunkel, Lutz. 2003. *Infinitheit, passiv und kausativkonstruktionen im deutschen [infinitivity, the passive and causative constructions in German]* (Studien zur deutschen Grammatik 67). Tübingen: Narr.

Hall, Ned. 2004. Two concepts of causation. In John Collins, Ned Hall & Lauri A. Paul (eds.), *Causation and counterfactuals*, 225–276. Cambridge, MA: MIT Press.

Halpern, Joseph Y. 2015. A modification of the Halpern-Pearl definition of causality. In Qiang Yang & Michael Wooldridge (eds.), *Proceedings of the Twenty-Fourth International Joint Conference on Artificial Intelligence (IJCAI 24)*, 3022–3033. Palo Alto, CA: AAAI Press.

Halpern, Joseph Y. & Judea Pearl. 2005. Causes and explanations: A structural-model approach – Part I: Causes. *British Journal of Philosophy of Science* 56. 843–887. http://dx.doi.org/10.1093/bjps/axi147.

Hiddleston, Eric. 2005. A causal theory of counterfactuals. *Nôus* 39(4). 632–657. http://dx.doi.org/10.1111/j.0029-4624.2005.00542.x.

Horn, Laurence. 2000. From if to iff: conditional perfection as pragmatic strengthening. *Journal of Pragmatics* 32(3). 289–326. http://dx.doi.org/10.1016/s0378-2166(99)00053-3.

Horn, Laurence R. 2010. Scalarity and polarity: What's the point? Talk given at the SCALE workshop, Stanford University, April 2010.

Huber, Walter. 1980. *Infinitivkomplemente im Deutschen: Transformationsgrammatische Untersuchungen zum Verb* lassen *[Infinitival complements in German: A tranformational grammar invegistation of the verb* lassen*]*. Berlin: Freie Universität Berlin dissertation.

Johnston, M. 1992. How to speak of the colors. *Philosophical Studies* 68(3). 221–263. http://dx.doi.org/10.1007/BF00694847.

Karttunen, Lauri. 1971. Implicative verbs. *Language* 47(2). 340–358. http://dx.doi.org/10.2307/412084.

Kaufmann, Stefan. 2013. Causal premise semantics. *Cognitive Science* 37(6). 1136–1170. http://dx.doi.org/10.1111/cogs.12063.

Lauer, Sven. 2013. *Towards a dynamic pragmatics*. Stanford, CA: Stanford University dissertation.

Lewis, David. 1973. Causation. *Journal of Philosophy* 70(17). 556–567. http://dx.doi.org/10.2307/2025310.

Lundin, Katarina. 2003. *Small clauses in swedish : Towards a unified account*: Lund University dissertation.

Mackie, John. 1965. Causes and conditions. *American Philosophical Quarterly* 2(4). 245–265.

Martin, Charles B. 1994. Dispositions and conditionals. *The Philosophical Quarterly* 44. 1–8. http://dx.doi.org/10.2307/2220143.

Nadathur, Prerna. 2013. *If ... (and only if): conditional perfection and completeness*. Oxford: University of Oxford MA thesis.

Nadathur, Prerna. 2016. Causal necessity and sufficiency in implicativity. *Semantics and Linguistic Theory (SALT)* 26. 1002–1021. http://dx.doi.org/10.3765/salt.v26i0.3863.

Paul, Lauri A. 1998. Keeping track of the time: Emending the counterfactual analysis of causation. *Analysis* 58(3). 191–198. http://dx.doi.org/10.1093/analys/58.3.191.

Pearl, Judea. 2000. *Causality*. Cambridge: Cambridge University Press. http://dx.doi.org/10.1017/CBO9780511803161.

Pitteroff, Marcel. 2014. *Non-canonical lassen-middles*. Stuttgart: Universität Stuttgart dissertation.

Rawoens, Gudrun. 2013. The swedish verb *låta* 'let' from a synchronic and diachronic perspective. *Language Sciences* 36. 113–123. http://dx.doi.org/10.1016/j.langsci.2012.04.002.

Schaffer, Jonathan. 2004. Counterfactuals, causal independence, and conceptual circularity. *Analysis* 64(4). 299–309. http://dx.doi.org/10.1093/analys/64.4.299.

Schulz, Katrin. 2007. *Minimal models in semantics and pragmatics. free choice, exhaustivity, and conditionals*. Amsterdam: Universiteit van Amsterdam dissertation.

Schulz, Katrin. 2011. "If you'd wiggled A, then B would've changed": Causality and counterfactual conditionals. *Synthese* 179(2). 239–251. http://dx.doi.org/10.1007/s11229-010-9780-9.

Scriven, Michael. 1971. The logic of cause. *Theory and Decision* 2(1). 49–66. http://dx.doi.org/10.1007/bf00133138.

Shibatani, Masayoshi. 1976. The grammar of causative constructions: A conspectus. In Masayoshi Shibatani (ed.), *The grammar of causative constructions* (Syntax and Semantics 6), 1–40. New York: Academic Press.

Sloman, Steven, Aron Barbey & Jared Hotaling. 2009. A causal model theory of the meaning of *cause*, *enable*, and *prevent*. *Cognitive Science* 33(1). 21–50. http://dx.doi.org/10.1111/j.1551-6709.2008.01002.x.

Stefanowitsch, Anatol. 2001. *Constructing causation: A construction grammar approach to analytic causatives*. Houston, TX: Rice University dissertation.

Talmy, Leonard. 1988. Force dynamics in language and cognition. *Cognitive Science* 12(1). 49–100. http://dx.doi.org/10.1207/s15516709cog1201_2.

van der Auwera, Johan. 1997. Pragmatics in the last quarter century: the case of conditional perfection. *Journal of Pragmatics* 27(3). 261–274. http://dx.doi.org/10.1016/s0378-2166(96)00058-6.

von Fintel, Kai. 2001. Conditional strengthening: a case study in implicature. Manuscript, MIT.

Wierzbicka, Anna. 1998. The semantics of English causative constructions in a universal-typological perspective. In Michael Tomasello (ed.), *The new psychology of language: Cognitive and functional approaches to language structure*, 113–153. Mahwah, NJ: Lawrence Erlbaum.

Wolff, Philip. 2007. Representing causation. *Journal of Experimental Psychology: General* 136(1). 82–111. http://dx.doi.org/10.1037/0096-3445.136.1.82.