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Bi-directionality in causal relationships

(Bidireccionalidad en relaciones causales)

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ABSTRACT: This paper aims to provide an answer to James Woodward's article "Flagpoles anyone? Causal and explanatory asymmetries". It will be conjectured that, when causal directionality depends on the experimental design, it is because the variables involved are capable of producing changes in each other. This will be exemplified using the case of ideal gases as opposed to the flagpole-shadow scenario.

KEYWORDS: causality; directionality; mutually dependent variables.

RESUMEN: *Este artículo tiene el objetivo de responder al artículo "¿Alguien quiere mástiles? Asimetrías causales y explicativas" de James Woodward. Aquí se conjetura que, cuando la direccionalidad causal depende del diseño experimental, se debe a que las variables involucradas son capaces de producir cambios las unas en las otras. Esto se ejemplificará utilizando el caso de los gases ideales, como un escenario opuesto al de las sombras de los mástiles.*

PALABRAS CLAVE: causalidad, direccionalidad, variables mutuamente dependientes.

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1. *Introduction: Basic interventionism notions*

The "Manipulability Theory" or "Interventionism" is not only a theory of causality. It is also a theory of scientific explanations since it provides insight on how causal scientific explanations work, and how good and bad explanations can be compared in terms of the number and variety of (actual or hypothetical) interventions, under which the causal relationships remain *invariant*.

Along this paper we will be using the general notation in Figure 1, where *I* is an intervention producing surgical changes in the values of the variable *C* via the causal relation R_1. In order to study the consequent reaction on the values of *E* and given *C* is the putative cause of the effect *E*, both variables are connected by the relationship R_2. We want to evaluate if R_2 is a putative or a genuine causal relationship.

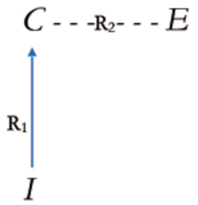

Figure 1

Given a generalization that relates a putative cause *C* and its effect *E*, we say that the generalization remains *invariant/independent* under a range of changes in *C* if it continues to hold when these changes in the values of *C* are generated through the intervention *I* with respect to *E*.

In his most recently published paper (2022), Woodward defines two notions of invariance/independence,[1] **CSI** and **VRI**, as follows.

> **CSI**: Suppose there are distinct random variables $X_1, X_2, X_{3...} X_n$ in the set of relevant variables **V,** such that none of the variables in this set are causes of other variables in the set and none of these variables share common causes (i.e., they are causally independent or exogenous). Satisfaction of **CSI** requires that these variables be, additionally, statistically independent.
>
> **VRI**, in turn, means "Variable Relationship Independence/Invariance" and it refers to the independence between the values of cause variables and the causal relations/laws in which they figure.
>
> (Woodward, 2022, §5)

These two requirements are important for causal assessment, as the interventions must be performed under the best understanding of the relevant variables, the background condi-

[1] This is not the *only* notion of *invariance/independence* at the core of interventionism. Over the years, Woodward and his colleagues have used diverse *invariance/independence* conditions, each differing in the kind of changes performed, or the specific feature that remains unchanged (causal structure, background conditions, values of variables out of the path between *C* and *E*) while those changes occur.

tions, and what specifically may be defining the values of the causal structure under study. If **CSI** and **VRI** are significant in any causal analysis, it is also pertinent to take them on account for the specific issue of *causal directionality*, which will be the main focus of attention here.

The aim of this paper is to discuss causal directionality, contrasting the flagpole example with the ideal gas law. This is a reaction to the paper “Flagpoles Anyone? Causal and Explanatory Asymmetries” published by Woodward in *THEORIA* in 2022.

2. Bi-directionality

Why does causal directionality matter and how is it related to invariance/independence? As it is well known, Hempel and Oppenheim’s Deductive-Nomological Model (1948) states that the phenomena explained in science can be described in a sentence (*explanans)*, which is deduced from a set of premises (*explanandum*) containing laws and particular conditions. According to the model, using the laws of trigonometry and the laws of optics, the following two are perfectly valid scientific explanations:

(i) “The shadow has a length of 20 m because the sunlight hits the 15 m long flagpole when the raising angle of the Sun is 37°.” (see Fig. 1 below).
(ii) “The flagpole has a length of 15 m because a 20m shadow is projected on the sand when the raising angle of the Sun is 37°.”

However, explanation (i) seems far more convincing than explanation (ii) since we know that the flagpole’s specific length may be explained by budget, transport, and so on, but not by its shadow.

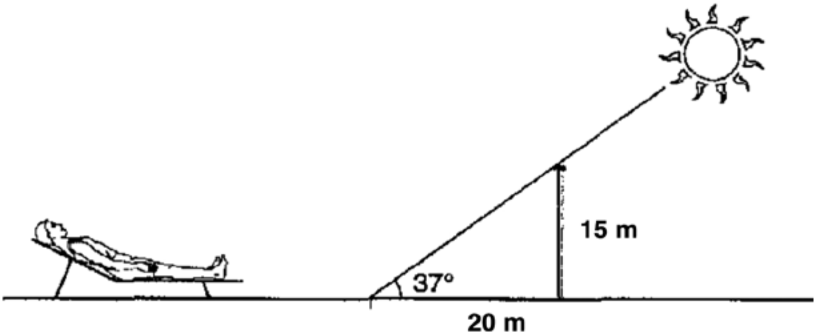

Figure 2[2]

Along with the relevance argument, the flagpole argument is one of the most famous criticisms against the model of Hempel and Oppenheim. It shows that scientific explanations tend to be asymmetrical, in the sense that flagpoles can explain shadows, but not vice

[2] Figure taken from Okasha (2002, p. 66).

versa. Flagpoles *produce* shadows, but not vice versa. Relating this to causality, we are used to explaining effects by finding their causes, but not vice versa.

The scenario is radically different when we leave the flagpole example and turn to assess ideal gases. The ideal gas law states that pressure P, volume V, and temperature T are proportionally related to each other, according to the equation $PV = nRT$. However, in this case, none of the variables "produce" the other two. The values of any of them can be explained in terms of interventions on the values of the other two, because there is no causal hierarchy among them.

In his most recent paper on explanatory asymmetries (2022), Woodward points out that for the ideal gas law, causal directionality depends on the initial conditions. I'd like to additionally argue here that when causal directionality depends on the initial conditions, it is because we are dealing with bidirectional causal relations among variables. By bidirectional I mean that at least two of the variables can cause each other, but also that the causal structure may involve three or more variables connected by a causal arrow of this kind (see Fig. 3 below).

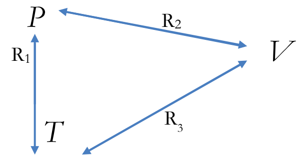

Figure 3

The case of ideal gases is particularly interesting since the variables T, P, and V are neither causally nor statistically independent of each other. However, they can be controlled in pairs, giving us *the impression* of causal directionality. The underlying truth, in my view, is that each pair of variables is capable of causing each other, as shown in Fig. 3.

In Woodward's view, this case is useful to show that causal directionality is not just "*in*" the law considered by itself, it is not fixed or completely determined by the law, but rather has to do with the role played by the initial and boundary conditions and constraints governing the systems. I completely agree with Woodward on his claim that the relevant information about causal directionality is not only "inside" the c-generalizations or scientific laws, but also in the specific values of the initial and boundary conditions. As Woodward himself acknowledges, "this may include information about what is or is not correlated with what, what is fixed and what is not allowed to vary [...] This information is relevant to causal direction since what quantities are correlated or not with others may depend [...] on what is fixed and what can vary in the specific systems we are considering" (see Woodward, 2022, §8).

A consequence of this is that causal directionality is also a matter of how we approach the phenomenon under study, i.e., the experimental design and the interventions we choose to make may change how directionality is perceived. Woodward already recognizes this when he claims: "The asymmetry in the solutions arises in the same way it does in the gas in cylinder example—because of the way in which initial and boundary conditions we impose interact with the laws themselves to yield solutions that are asymmetric" (see 2022, §10).

For instance, we can decide which variable will remain fixed, which one will act as putative cause, and which one as "the effect". This is how we define "by hand" the causal directionality in different experiments, but all this is possible because we already know the equation and we have a high degree of control over the object of study. Before the law was defined, our heroes in physics performed all kinds of interventions to deduce the equation.

But let us come back to the flagpole case. As we do now with gas boxes and pistons, we also have full control over the flagpole-shadow situation. But causal directionality does not change "at our will". Why not? I'd like to argue that this is because—no matter how much we change the initial conditions—shadows will never cause lengths of flagpoles. Flagpoles *produce* shadows, not the other way around. Therefore, those variables are connected with a single causal arrow, not with a double-headed causal arrow.

Temperature produces changes in the volume and the pressure, and vice versa. Exactly the same will happen if we assess the causal relationship between a magnetic field and a flow of electrons, or gravitation forces between a couple of asteroids. In short, causal directionality is reversible only when the variables involved are already symmetrical in the sense of being able to produce changes in each other.

Why is this relevant and who would disagree? In debates about causality, people as important as Bertrand Russell (*On the notion of causation,* 1918[3]) have argued that causes determine their effects, but the set of effects of an event cannot, in turn, determine its causes. This happens in many physical laws. It is also clear in the flagpole example, or in chocolate promoting cognitive abilities in the brain, while the brain does nothing to chocolate (this example will be developed in detail in the next paragraph). However, the fact that *some* causal relationships behave asymmetrically shouldn't lead us to conclude that *none* may behave differently.

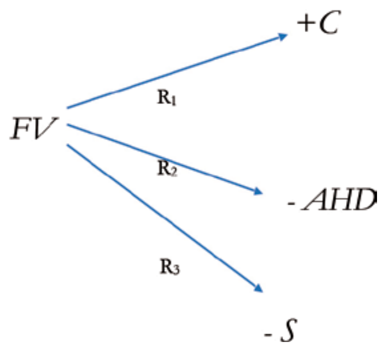

Figure 4

Let us assess a final case, representing Astrid Nehlig's medical explanation of the effects of cocoa and chocolate on brain health and cognitive abilities (2012) in a causal graph (Fig. 4). The variables that will be included in the causal graph have been emphasised in the explanation and the causal graph will follow:

> "Cocoa powder and chocolate contain numerous substances among which there is a quite large percentage of antioxidant molecules, mainly **flavonoids [FV]**, most abundantly found in the

[3] I'm following here the reconstruction of the argument made by Mathias Frisch (2014).

form of epicatechin. These substances display several beneficial actions on the brain. They provoke angiogenesis, neurogenesis and changes in neuron morphology, mainly in regions involved in learning and memory. Epicatechin improves various aspects of **cognition** [**C**] in animals and humans. Chocolate also induces positive effects on mood and is often consumed under emotional stress. In addition, flavonoids preserve cognitive abilities during ageing in rats, lower the risk for developing **Alzheimer's disease** [**AHD**] and decrease the risk of **stroke** [**S**] in humans. In addition to their beneficial effects on the vascular system and on cerebral blood flow, flavonoids interact with signalization cascades involving protein and lipid kinases that lead to the inhibition of neuronal death by apoptosis induced by neurotoxicants such as oxygen radicals, and promote **neuronal survival** [**NS**] and synaptic plasticity." (Nehlig, 2012, p. 716, my emphasis)

The causal structure represented in Fig. 4, works beautifully as an example of indubitable causal direction. No matter how we decide to set up the background conditions, or **CSI** and **VRI** invariances, the case is so neat, that the directionality of causal relations R_1, R_2 and R_3 wont backflip, for it is clear that brain activity or brain health does not alter the amount of substances in chocolates.

3. *Final Remarks*

Causal directionality does not rely *completely* on scientific laws. Woodward argued this in 2020, and here we have agreed with him. Sometimes, for a defined law or a functional relationship, a change in the initial conditions may revert causal directionality. Woodward has exemplified this point with ideal gases.

Causal directionality can also change when we work in the context of intricate relationships among variables that violate statistical independence. As it is suggested here, in those cases it is convenient to redefine the relevant variables or the functions relating them, in order to perform a "clean" causal analysis.

However, when this happens—and it will happen in a wide range of situations—we shouldn't stop ourselves from proposing causal evaluations based on special interventions as "joint interventions", nor conclude that interventionism is problematic for asking too much of causal systems. If I have understood Nancy Cartwright's position in *Hunting Causes and Using Them* (2007), she claims that Hausman's and Woodward's requirements for causation[4] are so strong that they fail to capture causality in nature. I believe, on the

[4] Given the system of equations: $E_1 = aC_1 + C_2$; $E_2 = bC_1 + C_3$, modularity is defined as follows: **MOD**: A system of equations is modular if (i) Each equation is invariant under some range of interventions on its independent variables; And (ii) for each equation, it is possible to intervene on the dependent variable in that equation in such a way that only the equation in which that dependent variable occurs is disrupted while the other equations in the system are left unchanged. Daniel Hausman and James Woodward have claimed that when a system of equations is not modular it will fail to accurately and completely represent the causal relationships it models (see Hausman & Woodward, 1999; Or Woodward 2008, p. 222). Therefore, modularity is a condition to assure that there is at least one way to intervene to change the values of a genuine cause. Nancy Cartwright believes that it is very rare to find cases where **MOD** is actually fulfilled (2007, §8.4). But I am a bit more optimistic. I believe that we can make sense of this kind of causal structures and design interventions in a good number of cases, and that the causal analysis of those cases may result useful for society, as Cartwright herself aims.

contrary, that working with a very flexible attitude and adapting the interventionist conditions—as scientists always do with their own laws—we can still reach a remarkable amount of relevant and interesting causal assertions.

Even when causal directionality may be reversed after some changes in the initial conditions, or after some interventions on statistically dependent variables have been revaluated, there are still some strongly asymmetrical cases, as the flagpole-shadow and the chocolate-brain examples, where the variables involved have a well-defined direction that won't change by any means.

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