CAUSALITY IN SCIENCE

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Contents

Summary

This chapter aims to give an overview of the debate on the notion of causality in contemporary science. First, it is argued that today's science requires a probabilistic notion of cause and, moreover, that the mechanistic and manipulative views of causality play a primary role. Consequently, the chapter's main focus is these two notions of causality construed probabilistically. After a sketchy description of the main approaches to causality put forward in the literature, the work of the pioneers of probabilistic causality, namely I.J. Good, H. Reichenbach and P. Suppes, is recollected. Turning to the mechanistic notion of causality, Section 3 addresses the work of W.C. Salmon, whose theory of causality is part of a view of explanation according to which explaining an event means locating it within the mechanism responsible for its occurrence. The alternative views of P. Dowe, P. Machamer, L. Darden, C. Craver and S. Glennan are also outlined. Section 4 deals with the manipulative notion of causality which has long tradition in the fields of econometrics and statistics, and is attracting growing attention on the part of philosophers. After recollecting the approaches taken by econometricians

like H. Simon, H. Wold, and C. Granger, the chapter discusses the theories advanced by two philosophers of science, H. Price and J. Woodward, and contains a succinct account of the notion of causality adopted by the statistician A.P. Dawid and the computer scientist J. Pearl. The chapter ends with some considerations on pluralism, a tendency that is gaining increasing support within the ongoing debate. Many ways of being a causal pluralist are mentioned, and attention is called to the need to take into account the context surrounding causal discourse.

1. Preliminary Remarks

Causality has been part of the history of western thought since its very beginning, but its nature and even its usefulness as a tool for inquiry remain matters of controversy. At the turn of the 20th century, the notion of causality underwent a deep crisis after the new physics had cast doubt on the deterministic paradigm. These developments seemed to suggest good reasons for banning causality from the realm of science as a "relic of a bygone age" not only useless but harmful, as Bertrand Russell claimed in "On the notion of cause" (1913). Causality, however, has survived in the work of many scientists operating in various fields, and after a relatively short period of disgrace the concept was also resurrected within philosophical analysis. An essential component of this resurgence is the combination of causality and probability, giving rise to the notion of probabilistic causality, taken as probable instead of constant conjunction. Without a doubt, the probabilistic approach to causality is today the most popular and for this reason is the focus of this chapter.

A number of different notions of cause are discussed in the literature. The *regularity view* dating back to David Hume's *Treatise on Human Nature* (1739) defines causation in terms of spatiotemporal contiguity, succession and constant conjunction. In other words, the regularity view states that the cause must be contiguous to the effect and must precede it, and that all events of the same kind as the cause have been observed to be followed by events akin to the effect. A similar approach underpins the theory of causation developed one hundred years later by John Stuart Mill in *A System of Logic Ratiocinative and Inductive* (1843). A more recent attempt to analyze causation in terms of necessary and sufficient conditions stems from the work of John Mackie (*The Cement of the Universe*, 1974) whose theory of INUS (Insufficient but Non-redundant part of an Unnecessary but Sufficient) conditions has been well-received. Mackie's theory has the merit of calling attention to the fact that in most circumstances causes do not come in isolation, but in connection with a plurality of other causal factors. Yet, the conceptual machinery using conditions (necessary and/or sufficient, or INUS) is incapable of covering all of those situations whose description rests on statistical correlations.

The same holds for the *counterfactual view*, stating that the effect would not have occurred in the absence of the cause, which is generally expressed in non-probabilistic terms. This approach is often associated with the work of David Lewis, who sets it out in terms of possible word semantics. As clearly seen by Hume, who contemplates the counterfactual view as a sort of corollary to the regularity definition, causes and counterfactuals are strictly intertwined. For this reason the notion of counterfactual, quite apart from Lewis' theory, has a role to play in other approaches too.

Other notions of causation are the *mechanistic*, which associates causation with the idea that effects are due to the productive activity of some mechanism, and the *manipulative*, which revolves around the idea that causal relationships can be utilized for purposes of manipulation and control. These two viewpoints are the object of increasing attention and extensive discussion in recent literature, where both are characterized in probabilistic terms. With respect to the mechanistic and manipulative concepts of causation, notions like "regularity" or "counterfactual" - the ingredients of David Hume's definition of the "causal connection" - can be regarded as transversal, in the sense that they have an important function within both the mechanistic and the manipulative theories. Aware of the primary role played within contemporary science by mechanistic and manipulative causality, this chapter will concentrate on these two views.

2. Probabilistic Causality

Given the impact of the probabilistic notion of causality on the current debate, it seems appropriate to open our survey by recollecting the work of the authors who pioneered the probabilistic approach to causality.

The origins of probabilistic causality can be traced back to Hans Reichenbach's work on the direction of time (1956). Other keystones in its development are Irving John Good's "A Causal Calculus" (1961-62) and Patrick Suppes' monograph on probabilistic causality (1970). After these important, albeit isolated, works, causality became the object of increasing attention on the part of both philosophers and scientists, and the literature on the topic has been constantly growing since. As a result, its various aspects have been discussed at length and its relations to strictly connected notions, like explanation, prediction and intervention, have been investigated in detail.

2.1. Suppes' Pluralistic Viewpoint

Let us start with Suppes' theory as it will point to some of the main problems faced by the probabilistic approach to causality. Suppes' main task is to turn Hume's definition of cause as constant conjunction into a probabilistic notion. The basic idea is to say that one event can be taken as the cause of another if the occurrence of the first event is followed with a high probability by the occurrence of the second, and there is no other event that can "absorb" the correlation between the two events. In other words, the occurrence of a cause should be positively relevant to the occurrence of the effect, and should remain so also in the presence of other factors. This calls for a clarification of the concepts of *prima facie* and *spurious cause*. For instance, a barometer falling is usually followed by a storm, but the correlation between the two is not genuinely causal: the barometer falling is only a prima facie cause of the storm, which becomes spurious once the approaching of a low pressure area in the region is considered. Suppes defines *prima facie* and *spurious causes* as follows:

(1) An event $B_{t'}$ is a *prima facie* cause of an event A_t iff

a) $t' < t$

b) $p(B_{t'}) > 0$

c) $p(A_t | B_{t'}) > p(A_t)$.

Spurious causes are defined as follows:

(2) An event $B_{t'}$ is a *spurious cause* of A_t iff $B_{t'}$ is a prima facie cause of A_t and there is a t'' and a partition $\pi_{t''}$ of exhaustive and pairwise disjoint events, such that for all elements $C_{t''}$ of $\pi_{t''}$

a) $p(B_{t'} \cdot C_{t''}) > 0$

b) $p(A_t | B_{t'} \cdot C_{t''}) = p(A_t | C_{t''})$

where "$\cdot$" stands for conjunction.

In other words, a prima facie cause $B_{t'}$ is spurious if it becomes irrelevant to A_t after consideration of the elements of the partition $\pi_{t''}$. On the basis of the notions of prima facie and spurious cause genuine causes can be defined:

(3) A *genuine* cause is a non-spurious prima facie cause.

The limiting case where $p(A_t | B_{t'}) = 1$ represents the case in which $B_{t'}$ is a *sufficient cause* of A_t.

Suppes' theory also contains definitions of probabilistic causes in terms of random variables. As suggested by the plurality of definitions he puts forward, Suppes' aim is not to give a general theory of probabilistic causality, but a flexible account that can adapt to different uses and intuitions of causality occurring in different contexts. In the same pluralistic spirit, he does not give a precise definition of the notion of event, nor does he ground his theory on a particular interpretation of probability.

Furthermore, Suppes requires neither that causal chains be transitive, nor that they have the *Markov property*, which is a fundamental ingredient of other theories of probabilistic causality. In a nutshell, this property states that the probabilities of future events are independent of what past events have occurred, given that the present event is known. Suppes regards the Markovian assumption as too strong to be imposed on the notion of probabilistic cause, and gives various examples of non-Markovian causality. Deeply convinced that there is no ultimate notion of "genuine cause", Suppes regards causality as an irreducibly context-dependent notion and emphasizes the need to relativize causal claims to the conceptual framework in which they occur.

In his 1970 monograph, Suppes allows for a deliberate equivocation in reference between events and kinds of events in the conviction that the scientific analysis of causal relations is concerned with classes of events rather than individual events (Suppes 1970). This attitude goes hand in hand with the idea that probabilistic causality plays a useful role in connection with prediction and manipulation, whereas it is not tied to explanation, a topic that is not investigated by Suppes. However, in subsequent writings Suppes revised his position acknowledging the need to distinguish causal

relations between kinds of events, or *type causality* from relations between individual events, or *token causality*. What follows will go back to this distinction.

2.2. Reichenbach's Theory

Unlike Suppes, Reichenbach embraces a view according to which causality is strictly connected to explanation. In addition, he works out a theory of causality as part of a causal theory of time, on the assumption that time order is reducible to causal order. This obviously requires the causal relation to be defined independently of time. Causal order is defined by means of a relation of "causal betweenness" implemented by a principle of "local comparability of time order", which makes it possible to discriminate counterdirected from equidirected causal chains. Without elaborating these concepts, it can be said that they define causal links as relations of positive relevance between cause and effect, and causal chains as having the Markov property.

The problem of distinguishing apparent from genuine causal links is handled by Reichenbach through the notion of *conjunctive fork* defined as follows. Take two events A and B which happen simultaneously more frequently than would be expected on the basis of pure chance. Then we have that

$$p(A \cdot B) > p(A) \times p(B)$$

If in the presence of a third event C this correlation is absorbed, so that the two events become reciprocally independent if taken relative to C, we have a *conjunctive fork*. This satisfies the following relations:

1. $p(A \cdot B \mid C) = p(A \mid C) \times p(B \mid C)$
2. $p(A \cdot B \mid \sim C) = p(A \mid \sim C) \times p(B \mid \sim C)$
3. $p(A \mid C) > p(A \mid \sim C)$
4. $p(B \mid C) > p(B \sim C)$

where "~" stands for negation. The common cause C *screens off* irrelevant properties from their effects, allowing us to move from spurious to genuine causes. The strict resemblance between Reichenbach's definition of conjunctive fork and Suppes' definition of spurious cause should not pass unnoticed.

The concept of conjunctive fork supplies the statistical model for a general principle of pivotal importance within Reichenbach's theory, namely the *principle of common cause*. This says that whenever an improbable coincidence has occurred, there must exist a common cause. The example of the barometer falling and the storm is a case in point: the correlation between the two is absorbed by the common cause, namely the approaching low pressure area in the region.

The principle embodies Reichenbach's conviction that causality goes hand in hand with explanation. In fact Reichenbach's principle of common cause is framed in a mechanistic view revolving around the idea that the concept of "probable

determination" provides the key to the comprehension of the causal structure of the world. This idea was subsequently expanded by Wesley Salmon and placed at the core of a theory of scientific explanation largely inspired by Reichenbach's work.

2.3. Good's Quantitative Approach

While Suppes and Reichenbach put forward qualitative theories of probabilistic causality, Good aims at working out a quantitative approach. The point of departure of his analysis is the conviction that a sharp distinction should be made between two kinds of causality, namely "the tendency of one event to cause another one", and "the degree to which one event caused another one", which correspond to what we have called type and token causality. The definition of the first rests on the notion of *weight of evidence*, $W(E:F)$, defined as follows:

$$W(E:F) = \log p(F \mid E) / p(F \mid \sim E).$$

On this basis Good defines $Q(E:F)$, namely the tendency of F to cause E, to mean that "some event F occurs and later an event E either occurs or does not occur". The *tendency to cause* is defined as follows:

$$Q(E:F) = W(\sim E :\sim F) \ .$$

In other words, the tendency of F to cause E is the same as the weight of evidence against E if F does not occur. Good makes clear that both the causal tendency and the weight of evidence should be taken relative to the physical state of affairs U, namely the state of the universe just before F occurred, and to the set H of all true laws of nature. Therefore $Q(E:F)$ is a shorter notation for $Q(E:F \mid U \cdot H)$. The need to make causal tendency conditional on U and H is dictated by that of distinguishing statistical associations from causal associations, or, in other words, apparent from genuine causal links. This is Good's way of handling the problem of spurious causes.

An important aspect of Good's explication of causal tendency amounts to the fact that causal tendency is relative to what we choose to regard as the alternatives to the events considered. Indeed, for Good the very meaning of Q depends on this choice. This introduces a pragmatic element into Good's treatment of probabilistic causality.

A central role within Good's theory is played by the concept of *causal chain*, which can be extended to that of *causal net*. A causal chain has the Markov property and is characterized by relations of positive statistical relevance among its components. Other fundamental notions are those of *strength* and *resistance* of a causal chain. On the basis of these concepts Good defines the *degree of causation* between events. In very general terms, specification of the degree of causation depends on maximally detailed information regarding the causal net connecting the cause to the effect. However, filling all the details required to define the strength of a causal net often proves very difficult, if not impossible. Consequently, the notion of degree of causation is beset with difficulties, and is not so well defined as that of causal tendency.

Remarkably, Good does not establish a strong link between causation and explanation and defines a notion of "explicativity" meant to convey the information on to what extent one proposition explains why another one should be believed to be true. According to his perspective, causality and explanation are related, but not identical.

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Biographical Sketch

Maria Carla Galavotti is Full Professor of Philosophy of Science at the University of Bologna. She is also life member of Clare Hall College, Cambridge, and the Center for the Philosophy of Science of the University of Pittsburgh. Over the years she has been Visiting Fellow at a number of institutions including the Center for the Study of Language and Information (CSLI) of Stanford University and the Department of Philosophy of Princeton University.

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