VIII

PROBABILISTIC CAUSALITY*

WESLEY C. SALMON

Although many philosophers would be likely to brand the phrase 'probabilistic causality' as a blatant solecism, embodying serious conceptual confusion, it seems to me that probabilistic causal concepts are used in innumerable contexts of everyday life and science. We hear that various substances are known to cause cancer in laboratory animals—see the label on your favourite diet soft-drink can—even though there is no presumption that every laboratory animal exposed to the substance developed any malignancy. We say that a skid on a patch of ice was the cause of an automobile accident, though many cars passed over the slick spot, some of them skidding upon it, without mishap. We have strong evidence that exposure to even low levels of radiation can cause leukaemia, though only a small percentage of those who are so exposed actually develop leukaemia. I sometimes complain of gastric distress as a result of eating very spicy food, but such discomfort is by no means a universal sequel to well-seasoned Mexican cuisine. It may be maintained, of course, that in all such cases a fully detailed account would furnish invariable cause–effect relations, but this claim would amount to no more than a declaration of faith. As Patrick Suppes has ably argued, it is as pointless as it is unjustified.[1]

There are, in the philosophical literature, three attempts to provide theories of probabilistic causality: Hans Reichenbach, I. J. Good, and Patrick Suppes have offered reasonably systematic treatments.[2] In the vast philosophical literature on causality they are largely ignored. Moreover, Suppes makes no mention of Reichenbach's, later discussion and Good gives it only the

* This material is based upon work supported by the National Science Foundation under Grant No. SOC-7809146. The author wishes to express his gratitude for this support, and to thank I. J. Good, Paul Humphreys, Merrilee H. Salmon, Patrick Suppes, and Philip von Bretzel for valuable comments on an earlier version of this paper.

[1] *A Probabilistic Theory of Causality* (Amsterdam, 1970), 7–8.

[2] Hans Reichenbach, *The Direction of Time* (Berkeley, Calif. and Los Angeles, 1956); I. J. Good, 'A Causal Calculus I', *British Journal for the Philosophy of Science*, 11/44 (1961), 305–18, 'A Causal Calculus II', ibid. 12/45 (1962), 43–51, and 'Errata and Corrigenda', ibid. 13/41 (1963), 88; Suppes, *A Probabilistic Theory*. Both Good and Reichenbach published earlier discussions of probabilistic causality, but both authors regard them as superseded by the works cited here.

slightest note,[3] though both offer brief critical remarks on some of his earlier work. Suppes makes the following passing reference to Good's theory: 'After working out most of the details of the definitions given here in lectures at Stanford, I discovered that a closely related analysis of causality had been given in an interesting series of articles by I. J. Good (1961, 1962), and the reader is urged to look at Good's articles for a development similar to the one given here, although worked out in rather different fashion formally and from a different viewpoint.'[4] Even amongst those who have done constructive work on probabilistic causality, there is no sustained discussion of the three important extant theories.

The aim of the present article is to take a close critical look at the proposals of Good, Reichenbach, and Suppes. Each of the three is, for reasons which I shall attempt to spell out in detail, seriously flawed. We shall find, I believe, that the difficulties arise from certain rather plausible assumptions about probabilistic causality, and that the objections lead to some rather surprising general results. In the concluding section, I shall briefly sketch what seem to me the appropriate ways of circumventing the problems associated with these three theories of probabilistic causality. . . .

2. REICHENBACH'S MACROSTATISTICAL THEORY

Unlike Good and Suppes, who attempt to provide analyses of probabilistic causality for their own sake, Reichenbach develops his analysis as a part of his programme of implementing a causal theory of time. Thus, in contrast to the other two authors, he does not build into his definitions the stipulation that causes are temporally prior to effects. Instead, he attempts to construct a theory of causal relations which will yield a causal asymmetry which can then be used to define a relation of temporal priority. Two of the key causal concepts introduced in this construction are the relation of *causal betweenness* and the structure known as a *conjunctive fork*. The main use of the betweenness relation is to establish a linear time order; the conjunctive fork is employed to impose a direction or asymmetry upon the linear time order. In the present discussion, I shall not attempt to evaluate the temporal ramifications of Reichenbach's theory; instead, I shall confine my attention to the adequacy of the causal concepts as such.

Reichenbach's formal definition of causal betweenness, translated from his notation into a standard notation, reads as follows:[5]

An event B is *causally between* the events A and C if the relations hold:

[3] 'A Causal Calculus II', 45. [4] *A Probabilistic Theory*, 11. [5] *Direction of Time*, 190.

$$1 > P(C|B) > P(C|A) > P(C) > 0 \quad (8)$$

[6]

$$1 > P(A|B) > P(A|C) > P(A) > 0 \quad (9)$$

$$P(C|A.B) = P(C|B) \quad (10)$$

Together with the principle of *local comparability of time order*, the relation of causal betweenness can, according to Reichenbach, be used to construct causal nets and chains similar to those mentioned by Good in his causal calculus. Unlike Good, however, Reichenbach does not attempt a quantitative characterization of the strengths of such chains and nets. It is worth noting that formulas (8) and (9) embody several statistical relevance relations: A is relevant to the occurrence of C, but B is more highly relevant to C; conversely, C is relevant to the occurrence of A, but B is more highly relevant to A. Moreover, according to (10), B screens A off from C and C off from A—that is, B renders A and C statistically irrelevant to one another. A chain of events $A \rightarrow B \rightarrow C$ thus has the Markov property which Good demanded of his causal chains.

The inadequacy of Reichenbach's definition of causal betweenness was pointed out by Clark Glymour, in conversation, a number of years ago, when he was a graduate student at Indiana University. The cases we discussed at that time were similar in principle to an excellent example, due to Deborah Rosen, reported by Suppes:[7]

> ... suppose a golfer makes a shot that hits a limb of a tree close to the green and is thereby deflected directly into the hole, for a spectacular birdie.... If we know something about Mr. [*sic*] Jones' golf we can estimate the probability of his making a birdie on this particular hole. The probability will be low, but the seemingly disturbing thing is that if we estimate the conditional probability of his making a birdie, given that the ball hit the branch,... we would ordinarily estimate the probability as being still lower. Yet when we see the event happen, we recognize immediately that hitting the branch in exactly the way it did was essential to the ball's going into the cup.

If we let A be the event of Jones teeing off, B the event of the ball striking the tree limb, and C the event of the ball dropping into the cup at one under par for the hole, we have a violation of Reichenbach's condition (8), for

[6] [Ed. note] Throughout this article, Salmon uses 'P' to stand for physical probability, and other italic capital letters to designate classes of individuals or events. Thus '$P(C)$' stands for the physical probability of an occurrence of an event which is a member of class C, while '$P(C|B)$' stands for the physical probability of an occurrence of an event which is a member of class C, given the occurrence of an event which is a member of class B. Salmon construes physical probabilities as relative frequencies, but he points out that those who prefer other concepts of physical probability can easily make any adjustments that seem appropriate. Finally, Salmon also points out that he sometimes speaks of the occurrence of an event A, instead of using the more cumbrous expression, 'occurrence of an event which is a member of the class A'.

[7] *A Probabilistic Theory*, 41.

$P(C|B) < P(C|A)$. The event B is, nevertheless, causally between events A and C.[8] Various retorts can be made to this purported counter-example. One could maintain[9] that sufficiently detailed information about the physical interaction between the ball and the branch might enable us to raise the conditional probability of the ball going into the hole, given these precisely specified physical circumstances, above the conditional probability of Jones making a birdie given only that he [*sic*] tees off. As von Bretzel himself notes, this kind of response seems *ad hoc* and artificial, and there is no good reason to suppose that it would take care of all such counter-examples even if it were adequate for this particular one. Indeed, it seems to me that many examples can be found which are immune to dismissal on these grounds.

Rosen's colourful example involves a near-miraculous occurrence, but we do not need to resort to such unusual happenings in order to find counter-examples to Reichenbach's definition of causal betweenness. The crucial feature of Rosen's example is that Jones makes her birdie 'the hard way'. Since much which goes on in life happens 'the hard way', we should be able to find an abundance of every-day sorts of counter-examples; in fact, we have already considered one. When the game of tetrahedron tossing and card drawing was used in the previous section to raise the second objection to Good's causal calculus, we looked at the case in which the player drew the red card and won the prize 'the hard way'. In that case the tetrahedron came to rest on side 4, forcing the player to draw from the deck with a smaller proportion of red cards. As the original game was set up, the player's initial probability of drawing a red card is 10/16, but if he is required, as a result of his toss, to draw from the less favourable deck, his probability of drawing a red card is only 1/4. Nevertheless, when the player who tosses the tetrahedron fails to show side 4, but succeeds in drawing a red card from the unfavourable deck, the draw from the unfavourable deck is causally between the toss of the tetrahedron and the winning of the prize. Drawing a red card from a deck which contains four red and twelve black cards can hardly be considered a near-miracle.

Once we see the basic feature of such examples, we can find others in profusion. The expression, 'the hard way', is used in the game of craps, and this game provides another obvious example.[10] The shooter wins if he throws

[8] In most cases, of course, the shot from the tee is not the one which strikes the branch, for there are few, if any, par 2 holes. However, the fact that there are other strokes does not alter the import of the example with respect to Reichenbach's definition of causal betweenness.

[9] See Philip von Bretzel, 'Concerning a Probabilistic Theory of Causation Adequate for the Causal Theory of Time', *Synthese*, 35/2 (1977), 173–90, at 182. (This article is repr. in Wesley C. Salmon (ed.), *Hans Reichenbach: Logical Empiricist* (Dordrecht and Boston, 1979), 385–402.)

[10] The basic features of this game are given clearly and succinctly by Irving Copi (*Introduction to Logic*, 4th edn. (New York, 1972), 481–2). A shooter whose point is 4, for example, is

7 or 11 on the first toss; he loses if he throws 2, 3, or 12 on the first toss. If the first toss results in any other number, that is his 'point', and he wins if in subsequent tosses he makes his point before he throws a 7. The probability of the shooter winning in one or another of these ways is just slightly less than 1/2. A player who throws 4 on his initial toss clearly reduces his chances of winning (this conditional probability is 1/3), but nevertheless he can win by making his point. Throwing 4 is, however, causally between the initial toss and the winning of the bet on that play.

A pool player has an easy direct shot to sink the 9-ball, but he chooses, for the sake of his subsequent position, the much more difficult play of shooting at the 2-ball and using it to put the 9-ball in the pocket. The initial probability of his sinking the 9-ball is much greater than the probability of getting the 9-ball in the pocket if his cue-ball strikes the 2-ball, but the collision with the 2-ball is causally between the initiation of the play and the dropping of the 9-ball into the pocket. Similar examples can obviously be found in an enormous variety of circumstances in which a given result can occur in more than one way, and in which the probabilities of the result differ widely given the various alternative ways of reaching it. The attempt to save Reichenbach's definition of causal betweenness by *ad hoc* devices appears to be a hopeless undertaking. We shall see, however, that Good suggests a method for handling such examples, and that Rosen offers a somewhat different defence on behalf of Suppes.

Reichenbach's definition of *conjunctive fork* does not fare much better. The basic motivation for introducing this concept is to characterize the situation in which an otherwise improbable coincidence is explained by appeal to a common cause. There are many familiar examples—e.g. the explanation of the simultaneous illness of many residents of a particular dormitory in terms of tainted food in a meal they all shared. Reichenbach defines the conjunctive fork in terms of the following formulas[11] which I have renumbered and translated into standard notation:

$$P(A.B|C) = P(A|C) \times P(B|C) \quad (11)$$

$$P(A.B|\bar{C}) = P(A|\bar{C}) \times P(B|\bar{C}) \quad (12)$$

$$P(A|C) > P(A|\bar{C}) \quad (13)$$

$$P(B|C) > P(B|\bar{C}) \quad (14)$$

In order to apply these formulas to the foregoing example, we may let A stand for the illness of Smith on the night in question, B the illness of Jones on the

said to make it 'the hard way' if he does so by getting a double 2, which is less probable than a 3 and a 1.

[11] *Direction of Time*, 159.

same night, and *C* the presence of spoiled food in the dinner served at their dormitory that evening.

The following example, due to Ellis Crasnow, shows the inadequacy of Reichenbach's formulation. Brown usually arrives at his office about 9.00 a.m., fixes himself a cup of coffee, and settles down to read the morning paper for half an hour before beginning any serious business. Upon occasion, however, he arrives at 8.00, and his secretary has already brewed a fresh pot of coffee, which she serves him immediately. On precisely the same occasions, some other person meets him at his office and they begin work quite promptly. This coincidence—the coffee being ready and the other person being at his office—demands explanation in terms of a common cause. As it happens, Brown usually takes the 8.30 bus to work in the morning, but on those mornings when the coffee is prepared for his arrival and the other person shows up, he takes the 7.30 bus. It can plausibly be argued that the three events, *A* (the coffee being ready), *B* (the other person showing up), and *C* (Brown taking the 7.30 bus), satisfy Reichenbach's requirements for a conjunctive fork. Clearly, however, Brown's bus ride is not a cause of either the coffee being made or the other person's arrival. The coincidence does, indeed, require a common cause, but that event is a telephone appointment made by the secretary on the preceding day.

The crucial feature of Crasnow's counter-example is easy to see. Brown arises early and catches the 7.30 bus if and only if he has an early appointment which was previously arranged by his secretary. The conjunctive fork is constructed out of the two associated effects and another effect which is strictly correlated with the bona fide common cause. When we see how this example has been devised, it is easy to find many others of the same general sort. Suppose it is realized before anyone actually becomes ill that spoiled food has been served in the dormitory. The head resident may place a call to the university health service requesting that a stomach pump be dispatched to the scene; however, neither the call to the health service nor the arrival of the stomach pump constitutes a genuine common cause, though either could be used to form a conjunctive fork.[12]

Inasmuch as two of Reichenbach's key concepts—causal betweenness and conjunctive fork—are unacceptably explicated, we must regard his attempt to provide an account of probabilistic causality as unsuccessful.

[12] The day after I wrote this paragraph, an announcement was broadcast on local radio stations informing parents that students who ate lunch at several elementary schools may have been infected with salmonella, which probabilistically causes severe gastric illness. Clearly the consumption of unwholesome food, not the radio announcement, is the common cause of the unusually high incidence of sickness within this particular group of children.

3. SUPPES'S PROBABILISTIC THEORY

In spite of his passing remark about Good's causal calculus, Suppes's theory bears much more striking resemblance to Reichenbach's theory than to Good's. As mentioned earlier, Suppes and Good agree in stipulating that causes must, by definition, precede their effects in time, and in this they oppose Reichenbach's approach. But here the similarities between Good and Suppes end. Like Reichenbach, and unlike Good, Suppes does not attempt to introduce any quantitative measures of causal strength. Like Reichenbach, and unlike Good, Suppes frames his definitions in terms of measures of probability, without introducing any explicit measure of statistical relevance. It is evident, of course, that considerations of statistical relevance play absolutely fundamental roles in all three theories, but as I commented regarding Good's approach, the use of statistical relevance measures instead of probability measures involves a crucial sacrifice of information. In addition, Suppes introduces a number of causal concepts, and in the course of defining them, he deploys the relations of positive statistical relevance and screening off in ways which bear strong resemblance to Reichenbach. A look at several of his most important definitions will exhibit this fact.

In definition 1[13] an event B is said to be a *prima-facie cause* of an event A if B occurs before A and B is positively relevant, statistically, to A.[14] Suppes offers two definitions of spurious causes, the second of which is the stronger and is probably preferable.[15] According to this definition (3), an event B is a *spurious cause* of an event A if it is a prima-facie cause of A and it is screened off from A by a partition of events C_i which occur earlier than B. We are told,[16] though not in a numbered definition, that a *genuine cause* is a prima-facie cause which is not spurious. These concepts can easily be applied to *the* most familiar example. The falling barometer is a prima-facie cause of a subsequent storm, but it is also a spurious cause, for it is screened-off from the storm by atmospheric conditions which precede both the storm and the drop in barometric reading.

[13] *A Probabilistic Theory*, 12.

[14] In defining many of his causal concepts, Suppes uses conditional probabilities of the form $P(B|A)$. Since, according to the standard definition of conditional probability $P(B|A) = P(A.B)/P(A)$, this probability would not be well defined if $P(A) = 0$, Suppes explicitly includes in his definitions stipulations that the appropriate probabilities are non-zero. In my discussion I shall, without further explicit statement, assume that all conditional probabilities introduced into the discussion are well defined.

[15] *A Probabilistic Theory*, 23, 25. Suppes refers to these as 'spurious in sense one' and 'spurious in sense two'. Since I shall adopt sense two uniformly in this discussion, I shall not explicitly say 'in sense two' in the text.

[16] Ibid. 24.

There is a close similarity between Suppes's definition of spurious cause and Reichenbach's definition of conjunctive fork. It is to be noted first, as Reichenbach demonstrates,[17] that

$$P(A.B) > P(A) \times P(B) \tag{15}$$

follows from relations (11)–(14) above. Therefore, A and B are positively relevant to one another. If A and B are not simultaneous, then one is a prima-facie cause of the other. Second, Reichenbach's relations (11) and (12) are equivalent to screening-off relations. According to the multiplication axiom,

$$P(A.B|C) = P(A|C) \times P(B|A.C); \tag{16}$$

therefore, it follows from (11) that

$$P(A|C) \times P(B|C) = P(A|C) \times P(B|A.C). \tag{17}$$

Assuming $P(A|C) > 0$, we divide through by that quantity, with the result

$$P(B|C) = P(B|A.C), \tag{18}$$

which says that C screens off A from B. In precisely parallel fashion, it can be shown that (12) says that $\bar{C}$ screens off A from B. But, $\{C, \bar{C}\}$ constitutes a partition, so B is a spurious cause of A or vice versa.[18] Suppes does not define the concept of conjunctive fork. Since he assumes temporal priority relations already given, he does not need conjunctive forks to establish temporal direction, and since he is not concerned with scientific explanation, he does not need them to provide explanations in terms of common causes. Nevertheless, there is a considerable degree of overlap between Reichenbach's conjunctive forks and Suppes's spurious causes.

Although Reichenbach defines conjunctive forks entirely in terms of the relations (11)–(14) above, without imposing any temporal constraints, his informal accompanying remarks[19] strongly suggest that the events A and B occur simultaneously, or nearly so. One might be tempted to suppose that Reichenbach wished to regard A and B as simultaneous to a sufficiently precise degree that a direct causal connection between them would be relativistically precluded. Such a restriction would, however, make no real sense in the kinds of examples he offers. Since the velocity of light is approximately 1 foot per nano-second (1 nsec = 10^{-9} sec), the onsets of vomiting in the case of two room-mates in the tainted food example (above) would presumably have to occur within perhaps a dozen nano-seconds of one another.

[17] *Direction of Time*, 158, 160.

[18] In an easily overlooked remark (ibid. 159), Reichenbach says, 'If there is more than one possible kind of common cause, C may represent the disjunction of these causes.' Hence, Reichenbach recognizes the need for partitions finer than $\{C, \bar{C}\}$, which makes for an even closer parallel between his notion of a conjunctive fork and Suppes's notion of a spurious cause.

[19] Ibid. 158–9.

Reichenbach's basic intent can be more reasonably characterized in the following manner. Suppose events of the types A and B occur on some sort of clearly specified association more frequently than they would if they were statistically independent of one another. Then, if we can rule out a direct causal connection from A to B or from B to A, we look for a common cause C which, along with A and B, constitutes a conjunctive fork. Thus, if Smith and Jones turn in identical term papers for the same class—even if the submissions are far from simultaneous—and if careful investigation assures us that Smith did not copy directly from Jones and also that Jones did not copy directly from Smith, then we look for the common cause C (e.g. the paper in the fraternity file from which both of them plagiarized their papers). It is the absence of a direct causal connection between A and B, not simultaneous occurrence, which is crucial in this context. Thus, in Reichenbach's conjunctive forks A may precede B or vice versa, and hence, one may be a prima-facie cause of the other.

Suppes does not introduce the relation of causal betweenness, but he does define the related notions of direct and indirect causes. According to definition 5[20] an event B is a *direct cause* of an event A if it is a prima-facie cause of B and there is no partition C_i temporally between A and B which screens B off from A. A prima-facie cause which is not direct is *indirect*. Use of such terms as 'direct' and 'indirect' strongly suggests betweenness relations. Suppes's definition of indirect cause clearly embodies a condition closely analogous to formula (10) of Reichenbach's definition of causal betweenness, but Suppes does not invoke the troublesome relations (8) and (9) which brought Reichenbach's explication to grief. It appears, however, that Suppes's theory faces similar difficulties.

Let us take another look at Rosen's example of the spectacular birdie. As above, let A stand for Jones teeing off, B for the ball striking the tree limb, and C for the ball going into the cup. If this example is to be at all relevant to the discussion, we must suppose that A is a prima-facie cause of C, which requires that $P(C|A) > P(C)$. We must, therefore, select some general reference class or probability space with respect to which $P(A)$ can be evaluated. The natural choice, I should think, would be to take the class of all cases of teeing off at that particular hole as the universe.[21] We may then suppose that Jones is a better-than-average golfer; when she tees off there is a higher probability of a birdie than there is for golfers in general who play that particular course. We may further assume that A is a genuine cause of C, since there is no plausible partition of earlier events which would screen A

[20] Suppes, *A Probabilistic Theory*, 28.

[21] We cannot let A = the universe, for then $P(C|A) = P(C)$ and A could not be even a prima-facie cause.

off from C. Certainly B cannot render A as a spurious cause of C, for B does not even happen at the right time (prior to A).

There is a more delicate question of whether A is a direct or indirect cause of C. We may reasonably assume that B screens A off from C, for presumably it makes no difference which player's shot from the rough strikes the tree limb. It is less clear, however, that B belongs to a partition, each member of which screens A from C. In other cases, birdies will occur as a result of a splendid shot out of a sand trap, or sinking a long putt, or a fine chip shot from the fairway. In these cases, it seems to me, it would not be irrelevant that Jones, rather than some much less accomplished player, was the person who teed off (A). It might be possible to construct a partition B_i which would accomplish the required screening off by specifying the manner in which the ball approaches the cup, rather than referring merely to where the ball came from on the final shot. But this ploy seems artificial. Just as we rejected the attempt to save Reichenbach's definition of causal betweenness by specifying the physical parameters of the ball and the branch at the moment of collision, so also, I think, must we resist the temptation to resort to similar physical parameters to find a partition which achieves screening off. We are, after all, discussing a golf game, not Newtonian particle physics, as Suppes is eager to insist. The most plausible construal of this example, from the standpoint of Suppes's theory, is to take A to be a direct cause of C, and to deny that the sequence A, B, C has the Markov property. In contrast to Good and Reichenbach. Suppes does not require causal sequences to be Markovian.

The crucial problem about B, it seems to me, is that it appears not to qualify even as a prima-facie cause of C. It seems reasonable to suppose that even the ordinary duffer has a better chance of making a birdie $P(C)$ than Jones has of getting the ball in the hole by bouncing it off the tree limb $P(C|B)$. In Suppes's definitions, however, being a prima-facie cause is a necessary condition of being any kind of cause (other than a negative cause). Surely, as Suppes himself remarks, we must recognize B as a link in the causal chain. The same point applies to the other examples introduced above to show the inadequacy of Reichenbach's definition of causal betweenness. Since the crap-shooter has a better chance of winning at the outset $P(C)$, than he does of winning if he gets 4 on the first toss $P(C|B)$, shooting 4 is not even a prima-facie cause of his winning. Even though Suppes desists from defining causal betweenness, the kinds of examples which lead to difficulty for Reichenbach on that score result in closely related troubles in Suppes's theory.

The fundamental problem at issue here is what Rosen[22] calls 'Suppes' thesis that a cause will always raise the probability of the effect'. Although

[22] Deborah A. Rosen, 'In Defense of a Probabilistic Theory of Causality', *Philosophy of Science*, 45 (1978), 604–13.

both Suppes and Rosen[23] sometimes refer to it as the problem of unlikely or improbable consequences, this latter manner of speaking can be confusing, for it is *not* the small degree of probability of the effect, given the cause, which matters; it is the *negative statistical relevance* of the cause to the occurrence of the effect which gives rise to the basic problem. While there is general agreement that positive statistical relevance is not a sufficient condition of direct causal relevance—we all recognize that the falling barometric reading does not cause a storm—the question is whether it is a necessary condition. Our immediate intuitive response is, I believe, that positive statistical relevance is, indeed, a necessary ingredient in causation, and all three of the theories we are discussing make stipulations to that effect. Reichenbach assumes 'that causal relevance is a special form of positive [statistical] relevance'.[24] Suppes makes positive statistical relevance a defining condition of prima-facie causes, and every genuine cause is a prima-facie cause.[25] Good incorporates the condition of positive statistical relevance into his definition of causal chains.[26]

In a critical note on Suppes's theory, Germund Hesslow challenges this fundamental principle:

> The basic idea in Suppes' theory is of course that a cause raises the probability of its effect, and it is difficult to see how the theory could be modified without upholding this thesis. It is possible however that examples could be found of causes that lower the probability of their effects. Such a situation could come about if a cause could lower the probability of other more efficient causes. It has been claimed, e.g., that contraceptive pills (C) can cause thrombosis (T), and that consequently there are cases where C_t caused T_t'. [The subscripts t and t' are Suppes's temporal indices.] But pregnancy can also cause thrombosis, and C lowers the probability of pregnancy. I do not know the values of $P(T)$ and $P(T|C)$ but it seems possible that $P(T|C) < P(T)$, and in a population which lacked other contraceptives this would appear a likely situation. Be that as it may, the point remains: *it is entirely possible that a cause should lower the probability of its effect.*[27]

Rosen defends Suppes against this challenge by arguing,

> . . . based on the available information represented by the above probability estimates, we would be hesitant, where a person suffers a thrombosis, to blame the person's taking of contraceptive pills. But it does not follow from these epistemic observations that a particular person's use of contraceptive pills lowers the probability that she may suffer

[23] Suppes, *A Probabilistic Theory*, 41, and Rosen, 'In Defense', 607.
[24] *Direction of Time*, 201.
[25] *A Probabilistic Theory*, 12 and 24 respectively.
[26] 'A Causal Calculus II', 45.
[27] 'Two Notes on the Probabilistic Approach to Causality', *Philosophy of Science*, 43 (1976), 290–2, at 291 (Hesslow's italics).

a thrombosis, for, unknown to us, her neurophysiological constitution (N) may be such that the taking of the pills definitely contributes to a thrombosis. Formally,

$$P(T|C.N) > P(T)$$

represents our more complete and accurate causal picture. We wrongly believe that taking the pills always lowers a person's probability of thrombosis because we base our belief on an inadequate and superficial knowledge of the causal structures in this medical domain where unanticipated and unappreciated neurophysiological features are not given sufficient attention or adequate weighting.[28]

Rosen comments upon her own example of the spectacular birdie in a similar spirit: 'Suppes' first observation in untangling the problems of improbable consequences is that it is important not to let the curious event be rendered causally spurious by settling for a superficial or narrow view.'[29] As I have indicated above, I do not believe that this is a correct assessment of the problem. If the causal event in question—e.g. the ball striking the branch—is negatively relevant to the final outcome, it is not even a prima-facie cause. *A fortiori*, it cannot achieve the status of a spurious cause, let alone a genuine cause. She continues:

... it is the angle and the force of the approach shot together with the deflection that forms our revised causal picture. Thus we begin to see that the results are unlikely only from a narrow standpoint. A broader picture is the more instructive one.[30]

As a result of her examination of Hesslow's example, as well as her own, she concludes that it is a virtue of Suppes's probabilistic theory to be able to accommodate 'unanticipated consequences'.[31]

Rosen's manner of dealing with the problem of causes which appear to bear negative statistical relevance relations to their effects (which is similar to that mentioned by von Bretzel) might be called *the method of more detailed specification of events*. If some event C, which is clearly recognized as a cause of E, is nevertheless negatively relevant to the occurrence of E, it is claimed that a more detailed specification of C (or the circumstances in which C occurs) will render it positively relevant to E. I remain sceptical that this approach—though admittedly successful in a vast number of instances—is adequate in general to deal with all challenges to the principle of positive statistical relevance.

Good was clearly aware of the problem of negative statistical relevance, and he provided an explicit way of dealing with it. His approach, which differs from Rosen's, might be called *the method of interpolated causal links*. In an appendix[32] ... he offers an example along with a brief indication of his manner of dealing with it:

[28] 'In Defense', 606. [29] Ibid. 608. [30] Ibid. [31] Ibid.
[32] 'A Causal Calculus I', 318.

Sherlock Holmes is at the foot of a cliff. At the top of the cliff, directly overhead, are Dr Watson, Professor Moriarty, and a loose boulder. Watson, knowing Moriarty's intentions, realizes that the best chance of saving Holmes's life is to push the boulder over the edge of the cliff, doing his best to give it enough horizontal momentum to miss Holmes. If he does not push the boulder, Moriarty will do so in such a way that it will be nearly certain to kill Holmes. Watson then makes the decision (event F) to push the boulder, but his skill fails him and the boulder falls on Holmes and kills him (event E).

This example shows that $Q(E|F)$ [the tendency of F to cause E] and $\chi(E{:}F)$ [the degree to which F caused E] cannot be identified, since F had a tendency to prevent E and yet caused it. We say that F was a cause of E because there was a chain of events connecting F to E, each of which was strongly caused by the preceding one.

This example seems closely related to the remark, later appended to theorem T2, to the effect that a cut chain can be uncut by filling in more of the details. Good could obviously take exception to any of the examples discussed above on the ground that the spatio-temporal gaps between the successive events in these chains are too great. He could, with complete propriety, insist that these gaps be filled with intermediate events, each of which is spatio-temporally small, and each of which is contiguous with its immediate neighbours.[33] I am not convinced, however, that every 'cut chain' which needs to be welded back together can be repaired by this device;[34] on the contrary, it seems to me that size is not an essential feature of the kinds of examples which raise problems for Suppes's and Reichenbach's theories. We can find examples, I believe, which have the same basic features, but which do not appear to be amenable to Good's treatment.

Consider the following fictitious case, which has the same statistical structure as the first tetrahedron-cum-card example. We have an atom in an excited state which we shall refer to as the 4th energy level. It may decay to the ground state (zeroeth level) in several different ways, some of which involve intermediate occupation of the 1st energy level. Let $P(m \rightarrow n)$ stand

[33] Ibid. 307–8; 'A Causal Calculus II', 45.

[34] Paul Humphreys has provided a theorem which has an important bearing upon the question of the mending of cut chains. In any two-state Markov chain, the statistical relevance of the first to the last member is zero if and only if at least one link in the chain exhibits zero relevance, and the statistical relevance of the first to the last member is negative only if an odd number of links exhibit negative relevance. The first member of a two-state Markov chain is positively relevant to the last if and only if no link has zero relevance and an even number (including none) of the links exhibit negative relevance. In other words, the signs of the relevance measures of the links multiply exactly like the signs of real numbers. Thus, it is impossible for a two-state Markov chain whose first member is negatively relevant to its last, or whose first member is irrelevant to its last, to be constructed out of links all of which exhibit positive relevance—just as it is impossible for the product of positive real numbers to be zero or negative. It may, however, be possible to achieve this goal if, in the process of interpolating additional events, the two-state character is destroyed by including new alternatives at one or more stages.

for the probability that an atom in the *m*th level will drop directly to the *n*th level. Suppose we have the following probability values:[35]

$$P(4 \to 3) = 3/4 \qquad P(3 \to 1) = 3/4$$
$$P(4 \to 2) = 1/4 \qquad P(2 \to 1) = 1/4 \tag{19}$$

It follows that the probability that the atom will occupy the 1st energy level in the process of decaying to the ground state is 10/16; if, however, it occupies the 2nd level on its way down, then the probability of its occupying the 1st level is 1/4. Therefore, occupying the 2nd level is negatively relevant to occupation of the 1st level. Nevertheless, if the atom goes from the 4th to the 2nd to the 1st level, that sequence constitutes a causal chain, in spite of the negative statistical relevance of the intermediate stage. Moreover, in view of the fact that we cannot, so to speak, 'track' the atom in its transitions from one energy level to another, it appears that there is no way, even in principle, of filling in intermediate 'links' so as to 'uncut the chain'. Furthermore, it seems unlikely that the Rosen method of more detailed specification of events will help with this example, for when we have specified the type of atom and its energy levels, there are no further facts which are relevant to the events in question. Although this example is admittedly fictitious, one finds cases of this general sort in examining the term schemes of actual atoms.[36]

There is another type of example which seems to me to cause trouble for both Reichenbach and Suppes. In a previous discussion of the principle of the common cause[37] I suggested the need to take account of *interactive forks* as well as conjunctive forks. Consider the following example. Pool balls lie on the table in such a way that the player can put the 8-ball into one corner pocket at the far end of the table if and almost only if his cue-ball goes into the other far corner pocket. Being a relative novice, the player does not realize that fact; moreover, his skill is such that he has only a 50–50 chance of sinking the 8-ball even if he tries. Let us make the further plausible assumption that, if the two balls drop into the respective pockets, the 8-ball will fall before the cue-ball does. Let event A be the player attempting that shot, B the dropping of the 8-ball into the corner pocket, and C the dropping of the cue-ball into the other corner pocket. Among all of the various shots the player may attempt, a small proportion will result in the cue-ball landing in that pocket. Thus, $P(C|B) > P(C)$; consequently, the 8-ball falling into one

[35] We assume that the transition from the 3rd to the 2nd level is prohibited by the selection rules.

[36] See e.g. the cover design on the well-known elementary text, Eyvind H. Wichmann, *Quantum Physics* (Berkeley Physics Course, 4; New York, 1967), which is taken from the term scheme for neutral thallium. This term scheme is given in fig. 34A, p. 199.

[37] Wesley C. Salmon, 'Why Ask "Why?"?—An Inquiry Concerning Scientific Explanation', *Proceedings and Addresses of the American Philosophical Association*, 51/6 (Aug. 1978), 683–705.

corner pocket is a prima-facie cause of the cue-ball falling into the other pocket. This is as it should be, but we must also be able to classify B as a spurious cause of C. It is not quite clear how this is to be accomplished. The event A, which must surely qualify as a direct cause of both B and C, does not screen B off from C, for $P(C|A) = 1/2$ while $P(C|A.B) = 1$.

It may be objected, of course, that we are not entitled to infer, from the fact that A fails to screen off B from C, that there is no event prior to B which does the screening. In fact, there is such an event—namely, the compound event which consists of the state of motion of the 8-ball and the state of motion of the cue-ball shortly after they collide. The need to resort to such artificial compound events does suggest a weakness in the theory, however, for the causal relations among A, B, and C seem to embody the salient features of the situation. An adequate theory of probabilistic causality should, it seems to me, be able to handle the situation in terms of the relations among these events, without having to appeal to such *ad hoc* constructions.

4. A MODEST SUGGESTION

. . . It seems to me that the fundamental source of difficulty in all three of the theories discussed above is that they attempt to carry out the construction of causal relations on the basis of probabilistic relations among discrete events, without taking account of the physical connections among them. This difficulty, I believe, infects many non-probabilistic theories as well. When discrete events bear genuine cause–effect relations to one another—except, perhaps, in some instances in quantum mechanics—there are spatio-temporally continuous causal processes joining them.[38] It is my view that these processes transmit causal influence (which may be probabilistic) from one region of space–time to another. . . .

There is a strong tendency on the part of philosophers to regard causal connections as being composed of chains of intermediate events, as Good brings out explicitly in his theory, rather than spatio-temporally continuous entities which enjoy fundamental physical status, and which do *not* need to be constructed out of anything else. Such a viewpoint can lead to severe frustration, for we are always driven to ask about the connections among *these* events, and interpolating additional events does not seem to mitigate

[38] I do not believe quantum indeterminacy poses any particular problems for a probabilistic theory of causality, or for the notion of continuous causal processes. This quantum indeterminacy is, in fact, the most compelling reason for insisting upon the need for probabilistic causation. The really devastating problems arise in connection with what Reichenbach called 'causal anomalies'—such as the Einstein–Podolsky–Rosen problem—which seem to involve some form of action-at-a-distance. I make no pretence of having an adequate analysis of such cases.

the problem. In his discussion of Locke's concept of power, Hume[39] seems to have perceived this difficulty quite clearly. I am strongly inclined to reverse the position, and to suggest that we accord fundamental status to processes. . . .

It is beyond the scope of this paper to attempt a rigorous construction of a probabilistic theory of causality, but the general strategy should be readily apparent. To begin, we can easily see how to deal with the three basic sorts of counter-examples discussed above. First, regarding Rosen's example, we shall say that the striking of the limb by the golf ball is causally between the teeing-off and the dropping into the hole because there is a spatio-temporally continuous causal process—the history of the golf ball—which connects the teeing-off with the striking of the limb, and connects the striking of the limb with the dropping into the hole. Second, we can handle the pool-ball example by noting that the dropping of the 8-ball into the pocket is not a genuine cause of the cue-ball falling into the other pocket, because there is no causal process leading directly from the one event to the other. Third, we can deal with the Crasnow example by pointing out that the telephone appointment made by Brown's secretary constitutes a common cause for the coffee being ready and for the arrival of the business associate, because there is a causal process which leads from the appointment to the making of the coffee and another causal process which leads from the appointment to the arrival of the other person. However, there are no causal processes leading from Brown's boarding of the early bus to the making of the coffee or to the arrival of the other person. . . .

The most difficult problem, it seems to me, involves the dictum that cause–effect relations must always involve relations of positive statistical relevance. I believe that the examples already discussed show that this dictum cannot be accepted in any simple and unqualified way; at the same time, it seems intuitively compelling to argue that a cause which contributes probabilistically to bringing about a certain effect must at least raise the probability of that effect *vis-à-vis* some other state of affairs. For example, in the tetrahedron-cum-card game, once the tetrahedron has been tossed and has landed on side 4, the initial probability of drawing a red card in the game is irrelevant to the causal process (or sequence[40]) which leads to the draw of a red card from the deck which is poorer in red cards. What matters is that a causal process has been initiated which may eventuate in the drawing of a

[39] *An Enquiry Concerning Human Understanding* (1748), sect. 7. 1.

[40] Actually, in this example as in most others, we have a *sequence of events* joined to one another by a *sequence of causal processes*. The events, so to speak, mark the ends of the segments of processes; they are the points at which one process joins up with another. Events can, in most if not all cases, be regarded as intersections of processes.

red card; it makes no difference that an alternative process might have been initiated which would have held a higher probability of yielding a red card.

Once the tetrahedron has come to rest, one of two alternative processes is selected. There is an important sense in which it possesses an *internal* positive relevance with respect to the draw of a red card. When this example was introduced above, I made the convenient but unrealistic simplifying assumption that a draw would be made from the second deck if and only if the tetrahedron toss failed to show side 4. However, a player who has just made a toss on which the tetrahedron landed on side 4 might simply get up and walk away in disgust, without drawing any card at all. In this case, of course, he is certain not to draw a red card. When we look at the game in this way, we see that, given the result of the tetrahedron toss, the probability of getting a red card by drawing from the second deck is greater than it is by not drawing at all—thus, drawing from the second deck *is* positively relevant to getting a red card. . . .

The essential ingredients in a satisfactory qualitative theory of probabilistic causality are, it seems to me: (1) a fundamental distinction between causal processes and causal interactions, (2) an account of the propagation of causal influence via causal processes, (3) an account of causal interactions in terms of interactive forks, (4) an account of causal directionality in terms of conjunctive forks, and (5) an account of causal betweenness in terms of causal processes and causal directionality. The 'at-at' theory of causal influence[41] gives, at best, a symmetric relation of causal connection. Conjunctive forks are needed to impose the required asymmetry upon connecting processes.

If an adequate theory of probabilistic causality is to be developed, it will borrow heavily from the theories of Reichenbach and Suppes; these theories require supplementation rather than outright rejection. Once we are in possession of a satisfactory qualitative theory, we may be in a position to undertake Good's programme of quantification of probabilistic causal relations. These goals are, I believe, eminently worthy of pursuit.

[41] Wesley C. Salmon, 'An "At-At" Theory of Causal Influence', *Philosophy of Science*, 44/2 (June 1977), 215–24.