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CHAPTER 10

CAUSAL PROCESS THEORIES

PHIL DOWE

1. Introduction

If the core idea of process theories of causation is that causation can be understood in terms of causal processes and interactions, then the approach should be attributed primarily to Wesley Salmon (1925–2001). Salmon takes causal processes and interactions as more fundamental than causal relations between events. To express this Salmon liked to quote John Venn: 'Substitute for the time honoured "chain of causation", so often introduced into discussions upon this subject, the phrase a "rope of causation", and see what a very different aspect the question will wear' (Venn 1866: 320). According to the process theory, any facts about causation as a relation between events obtain only on account of more basic facts about causal processes and interactions. Causal processes are the world-lines of objects, exhibiting some characteristic essential for causation.

There are other approaches to causation that seek to respect the idea of a continuous process in terms of chains of events linked by the appropriate relations (e.g. Sober 1988; Menzies 1989; Hitchcock 2001; Schaffer 2001; Thalos 2002). Since the 'appropriate relations' tend to be counterfactual dependence, chance raising, or lawful sequence, these accounts are best viewed as instances of other theories of causation dealt with in this volume (Ch. 7 on regularity theories, Ch. 8 on counterfactual theories, Ch. 9 on probabilistic theories, and Ch. 14 on causal modelling).

A closer relative to process theories is the class of theories that takes causation to be the transfer or persistence of properties of a specific sort (e.g. Fair 1979; Ehring 1997). Some examples of this important class of theories are summarized in the final section. Another close relative is the approach that focuses on mechanisms (e.g. Machamer, Darden, and Craver 2000). Accounts of mechanisms are discussed in Ch. 15 of this volume.

2. The Salmon Programme

While many of Salmon's ideas on causation carry some debt or other to his Ph.D. supervisor Hans Reichenbach (we will not trace those debts in this chapter), the theory of causal processes and interactions is itself original to Salmon.

Salmon's interest in causation arose from his work on scientific explanation where, in response to Hempel, Salmon argued for a causal theory of explanation (e.g. Salmon 1978). This of course begs a theory of causation. However, Salmon wanted to avoid the shortcomings of other popular theories of causation. First, there are general problems with basing causation on events. Further, Salmon felt the modal commitments of counterfactual theories were a violation of actualist requirements of empiricism, that the probabilistic theories of Reichenbach and Good faced unsurmountable technical difficulties (Salmon 1998: ch. 14), and that any account that ultimately appeals to agency misrepresents the fundamental objective and 'ontic' nature of causation. Salmon's views were further shaped by his work on space and time where he was impressed by the idea that relativity could be formulated in terms of processes rather than events, and by his interest in the causal theory of time.

3. Problems with Events

The problem with events was raised by Bertrand Russell in his paper 'On the Notion of "Cause"'. Famously, Russell observes 'The law of causality, I believe, like much that passes muster among philosophers, is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm' (Russell [1913] 1957: 174). Russell argued that the philosopher's concept of causation involving, as it does, the law of universal determinism that every event has a cause and the associated concept of causation as a relation between events, is 'otiose' and replaced in modern science by the concept of causal laws understood in terms of functional relations, where these causal laws are not necessarily deterministic. Russell (ibid. 177) was concerned with the law of causality in the form: 'Given any event e_1, there is an event e_2 and a time interval τ such that, whenever e_1 occurs, e_2 follows after an interval τ'. First, Russell felt that because the time series is dense, no two times are contiguous, and τ must be of finite duration. Second, events may be defined more or less 'narrowly': 'Jenny's drinking arsenic' is fairly widely defined, 'Jenny's drinking arsenic together with her already having certain stomach contents together with her being on a hillside miles from civilization' is more narrowly defined.

A dilemma then arises. On the one hand, for an event to recur 'it must not be defined too narrowly' (ibid. 180). For example, the event must be something short of the whole state of the universe because it is very probable that such an event e_1 will never recur, in which case it becomes trivially true that event e_1 is the cause of an event e_2 which follows it by the suitable time interval τ, since the relevant regularity has just the one instance. On the other hand, if we define the cause 'sufficiently widely' to allow significant recurrence, then since the time interval between the cause and the effect is of finite duration it is possible that in the intervening interval something will happen that prevents the effect.

For example, Jenny's drinking arsenic caused her death. However, drinking arsenic will only be followed by death if one does not have a stomach full of alkaline, and if there is no stomach pump on hand, and so on. But if we define the cause of death as 'drinking arsenic in the absence of large amounts of alkaline and stomach pumps, etc.' then given the likely extent of the 'etc.' this narrowly defined event is unlikely to recur.

There's another problem with going narrow (which, because his interest focuses on the law of causality, Russell doesn't mention): in the case that intuitively, and on a wide definition event e_3 (not e_1) is the cause of e_2, then the theory may wrongly say that e_1 is the cause of e_2, if the narrow definition of e_1 includes e_3, and so defined e_1 is always followed by e_2. If Jenny takes chocolate with the arsenic then her chocolate eating is the cause of her death if all cases of chocolate plus arsenic consumption are followed by deaths.

Of course one might hope that there is some middle ground, a definition of the cause sufficiently wide that it recurs but sufficiently narrow that it will always be followed by its effect. Russell simply makes the point that mature science is not concerned with identifying such, but rather focuses on functional relations between variables, a focus far removed from the kind of common-sense events that we take to be causes and effects. Salmon, however, felt that these problems could be circumvented by focusing on spatio-temporally continuous processes.

4. Causal Lines and Pseudo Processes

An important forerunner of Salmon's account of causal processes is Bertrand Russell's account of causal lines in his *Human Knowledge* (1948). There Russell elaborates the view that 'causal lines' replace the primitive notion of causation in the scientific view of the world, and not only replace but also explain the extent to which the primitive notion, causation, is correct. He writes, 'When two events belong to one causal line the earlier may be said to "cause" the later. In this way laws of the form "A causes" may preserve a certain validity' (1948: 334). And

> I call a series of events a 'causal line' if, given some of them, we can infer something about the others without having to know anything about the environment. (ibid. 333)

> A causal line may always be regarded as a persistence of something, a person, a table, a photon, or what not. Throughout a given causal line, there may be constancy of quality, constancy of structure, or gradual changes in either, but not sudden change of any considerable magnitude. (ibid. 475–7)

So the trajectory through time of something is a causal line if it doesn't change too much, and if it persists in isolation from other things. A series of events with this kind of similarity displays what Russell calls 'quasi-permanence'.

Although this retains a focus on relations between events, Salmon was nevertheless interested in the idea of a causal line with its 'constancy of structure'. However Salmon felt that Russell's theory of a causal line does not enable an important distinction between pseudo and causal processes to be made. As Reichenbach (1958: 147–9) argued, as he reflected on the implications of Einstein's special theory of relativity, science requires that we distinguish between causal and pseudo processes. Reichenbach noticed that the central principle that nothing travels faster than the speed of light is 'violated' by certain processes. For example, a spot of light moving along a wall is capable of moving faster than the speed of light. (One needs just a powerful enough light and a wall sufficiently large and sufficiently distant.) Other examples include shadows and the point of intersection of two rulers (see Salmon's clear exposition in his 1984: 141–4). Such pseudo processes, as we shall call them (Reichenbach called them 'unreal sequences', 1958: 147–9), do not violate special relativity, Reichenbach argued, simply because they are not causal processes, and the principle that nothing travels faster than the speed of light applies only to causal processes. Thus special relativity demands a distinction between causal and pseudo processes. But Russell's theory doesn't explain this distinction, because both causal processes and pseudo processes display constancy of structure and quality; and both licence inferences of the sort Russell has in mind. For example, the phase velocity of a wave packet is a pseudo process but the group velocity is a causal process; yet both licence reliable predictions.

5. Causal Processes and Interactions: The Mark Criterion

We now turn to Salmon's positive account of causation proposed systematically in Salmon (1984). For Salmon the causal structure of the world consists in the nexus of causal processes and interactions. A process is anything with constancy of structure over time. These may be either causal or psuedo; a causal process is a process capable of transmitting a mark. A 'mark' is any local modification of a characteristic, while 'transmission' is understood in terms of the 'at-at' theory. The latter is expressed in the principle of mark transmission (MT), which states:

> MT: Let P be a process that, in the absence of interactions with other processes would remain uniform with respect to a characteristic Q, which it would manifest consistently over an interval that includes both of the spacetime points A and B ($A \neq B$). Then, a mark (consisting of a modification of Q into Q*), which has been introduced into process P by means of a single local interaction at a point A, is transmitted to point B if [and only if] P manifests the modification Q* at B and at all stages of the process between A and B without additional interactions. (ibid. 148)

Salmon himself omits the 'only if' condition; reasons to include it have been given by Sober (1987: 253) and Dowe (1992: 198).

For example, a ball moving through the air is a causal process, since it can be marked, for example by making a small cut with a knife; and this mark would be transmitted since the cut would continue to exist at later times on the ball's trajectory provided there is no further interaction. On the other hand, a spot of light moving across a wall does not transmit a mark due to a single local modification. For example a change in the shape of the light spot caused by distorting the surface is not subsequently transmitted and so doesn't count as a mark transmission.

A causal interaction involves the mutual modification of two intersecting processes:

> *CI*: Let P_1 and P_2 be two processes that intersect with one another at the spacetime point *S*, which belongs to the histories of both. Let *Q* be a characteristic of that process P_1 would exhibit throughout an interval (which includes subintervals on both sides of *S* in the history of P_1) if the intersection with P_2 did not occur; let *R* be a characteristic that process P_2 would exhibit throughout an interval (which includes subintervals on both sides of *S* in the history of P_2) if the intersection with P_1 did not occur. Then, the intersection of P_1 and P_2 at *S* constitutes a causal interaction if (1) P_1 exhibits the characteristic *Q* before *S*, but it exhibits a modified characteristic *Q'* throughout an interval immediately following *S*; and (2) P_2 exhibits *R* before *S* but it exhibits a modified characteristic *R'* throughout an interval immediately following *S*. (Salmon 1984: 171)

For example, the collision of two balls is a causal interaction when both balls undergo a change in momentum, since both balls would have continued with their original momenta had the collision not occurred.

Both MT and CI involve counterfactuals. The former defines a causal process in terms of possible marks, and further, the definition of mark transmission requires that the changed characteristic would otherwise have remained constant. Salmon was uncomfortable with the use of counterfactuals, fearing that their context dependence was problematic for an 'ontic' account. He noted, however, that the truth of these counterfactuals should be determinable from scientific experiments, and would, one may speculate, have found support for this idea in the account of Woodward (2003). However, as Kitcher notes, this undermines the idea that the process theory is a distinct approach to causation:

> I suggest that we can have causation without linking causal processes. What is critical to the causal claims seems to be the truth of the counterfactuals, not the existence of the processes and the interactions. If this is correct then it is not just that Salmon's account of the causal structure of the world needs supplementing through the introduction of more counterfactuals. The counterfactuals are the heart of the theory, while the claims about the existence of processes and interactions are, in principle, dispensable. Perhaps these notions may prove useful in protecting a basically counterfactual theory of causation against certain familiar forms of difficulty (problems of pre-emption, overdetermination, epiphenomena, and so forth). But, instead of viewing Salmon's account as based on his explications of process and interaction, it might be more revealing to see him as developing a particular kind of counterfactual theory of causation, one that has some extra machinery for avoiding the usual difficulties that beset such proposals. (Kitcher 1989: 472; see also Psillos 2002: 112–18)

The MT account has other problems that ultimately led Salmon himself to abandon it. Criticism focused on the notion of a characteristic, which would seem to be underspecified. For example, the definition MT allows pseudo processes such as shadows to count as causal. A shadow having the property of 'occurring after a certain time' (Sober 1987: 254), of 'being the shadow of a scratched car' (Kitcher 1989: 638) or of 'being closer to the Harbour Bridge than to the Opera House' (Dowe 1992: 201) will qualify as a causal process under MT.

Further, there are cases of 'derivative marks' (Kitcher 1989: 463) where a pseudo process displays a modification in a characteristic on account of a change in the causal processes on which it depends, either in the source or in the causal background. A change at the source would include cases where the spotlight spot is 'marked' by a coloured filter at the source (Salmon 1984: 142) or a car's shadow is marked when a passenger's arm holds up a flag (Kitcher 1989: 463). Salmon's clause 'by means of a *single* local interaction' (MT) is intended to exclude this type of case. But this will not always work: take the case where a stationary car throws its shadow on a fence. Suddenly the fence falls over, producing a permanent modification in the shadow. Then the shadow has been marked by the single local action of the falling fence (Dowe 1992: 201–2).

Criticisms such as these, together with his discomfort with counterfactuals led Salmon to abandon the mark criterion in favour of the conserved quantity theory, to which we now turn.

6. Conserved Quantity Theory

If causal processes are causal in virtue of *actual* features, rather than counterfactual features, what would those features be? They should be general features common to all causal processes, but lacking in pseudo processes. The result in relativity theory that only time-like world-lines transmit energy suggests the answer might be the transmission of energy. The link between energy and causation is not new. It was suggested by Quine (1973: 5); and Fair and Aronson both formulated theories of causation in terms of energy transfer. And in any case the idea was common enough in the eighteenth and nineteenth centuries. (Krajewski (1997: 194–5) traces the history from Mayer through Lorenz.) The idea of the conserved quantity theory is to generalize this notion to all types of physical interactions. (Brian Skyrms (1980: 111) first suggested 'conserved quantities' and Dowe (1992) formulated this as a Salmon-style process theory.) Dowe (1992; 1995; 2000) and Salmon (1994; 1997) have offered various versions; the most recent are:

> CQ1. A *causal interaction* is an intersection of world lines that involves exchange of a conserved quantity.
>
> CQ2. A *causal process* is a world line of an object that possesses a conserved quantity. (Dowe 1995: 323)

> Definition 1. A causal interaction is an intersection of world-lines that involves exchange of a conserved quantity.
>
> Definition 2. A causal process is a world-line of an object that transmits a nonzero amount of a conserved quantity at each moment of its history (each spacetime point of its trajectory).
>
> Definition 3. A process transmits a conserved quantity between A and B ($A \neq B$) if it possesses [a fixed amount of] this quantity at A and at B and at every stage of the process between A and B without any interactions in the open interval (A, B) that involve an exchange of that particular conserved quantity. (Salmon 1997: 462, 468)

A conserved quantity is any quantity governed by a conservation law. To state the obvious, current scientific theory is our best guide as to what these are: quantities such as mass-energy, linear momentum, and charge. Concerns have been raised about the appeal here to conservation laws. It is common to define conservation in terms of constancy within a closed system. As Hitchcock (1995: 315–16) points out, it would be circular to define a 'closed system' as one that is not involved in causal interactions with anything external. Dowe (2000: 95) suggests 'we need to explicate the notion of a closed system in terms only of the quantities concerned. For example, energy is conserved in chemical reactions, on the assumption that there is no net flow of energy into or out of the system.' Schaffer (2001: 810) comments that this 'looks to invoke the very notion of "flow" that the process account is supposed to analyze'. McDaniel (2002: 261) suggests two possible responses to this. First, the theory could simply list the quantities held to be relevant to causation, Second, the theory could appeal directly to universally conserved quantities, in other words, doing away with appeal to any closed system besides the universe itself. This may run up against the objection of Reuger discussed below.

However, Sungho Choi (2003) has provided a thorough examination of possible definitions of a closed system, and proposes:

DC: A system is closed with respect to a physical quantity Q at a time t iff

$$(a)\quad dQ_{in}/dt = dQ_{out}/dt = 0 at t or, (b) dQ_{in}/dt = -dQ_{out}/dt = 0 at t$$

where Q_{in} is the amount of Q inside the system and is Q_{out} the amount of Q outside the system. (ibid. 519)

For vector quantities the definition must apply to all components of the vector. This, Choi argues, does not involve any circular appeal to causation.

Alexander Reuger (1998) has argued that since in some general relativistic spacetimes global conservation laws will not hold, it would seem to follow that in such a spacetime there would not be causal processes at all. Dowe's (2000: 97–8) response is that our world is not such a spacetime. (*Ad hominem*, this may be a particular problem for Dowe who argues elsewhere that time travel and hence causation is possible in such spacetimes. See Schaffer 2001: 811.)

John Norton, while endorsing the Salmon–Dowe tack of not tying the theory to any particular conserved quantity since that leaves the theory hostage to scientific developments, nevertheless warns that 'if we are permissive in selection of the conserved quantity, we risk trivialization by the construction of artificial conserved quantities specially tailored to make any chosen process come out as causal' (2007: 18–19).

The differences between Salmon and Dowe indicated above in definitions 1–3 focus attention on the distinction between pseudo and causal processes. For Salmon it is important that the conserved quantity is transmitted, and indeed that a fixed quantity is transmitted in the absence of interactions, in order to rule out cases of 'accidental' process-like energy appearances. Dowe has concerns about the directionality built into 'transmission', and instead attempts to rule out accidental processes via the identity through time of the object in question. So, for Salmon the spotlight spot does not transmit energy in the absence of interactions, but involves a continual string of interactions. For Dowe it is not the spot that possesses energy, but rather the various distinct patches of wall illuminated.

Hitchcock (1995) produces this counterexample: consider an object casting a shadow on the surface of a charged plate. At each point of its trajectory the shadow 'possesses' a fixed charge. But shadows are the archetypical pseudo process. Dowe (2000: 98–9) and Salmon (1997: 472) claim that it is the plate that possesses the charge, and the shadow that moves. Salmon (ibid.), however, suggests that the more problematic 'object' is the series of plate segments currently in shadow, in Dowe's terminology a 'time-wise gerrymander'. Salmon's answer to this is that this object does not transmit charge or else charge in a region would augment when the shadow passes over it, and he proposes to add the corollary explicitly to apply the conservation law to this kind of case (critiqued in detail by Choi 2002: 110–14): 'When two or more processes possessing a given conserved quantity intersect (whether they interact or not), the amount of that quantity in the region of intersection must equal the sum of the separate quantities possessed by the processes thus intersecting' (Salmon 1997: 473). On the other hand, Dowe's answer is that the world-line of the moving shadow is the world-line of an object that does not possess charge, while the world-line of the segments of shadowed plate is not the world-line of an object. (But see McDaniel 2002: 260; Garcia-Encinas 2004.)

Sungho Choi (2002: 114–15) offers a further counterexample to Salmon's version. Suppose the plate contains a boundary such that there is twice as much charge density on one side compared to the other. Suppose the shadow crosses from the lower density to the higher density. Consider the world-lines of (1) the gerrymandered objects which are the segments of plate when crossed by the shadow and (2) the segment of plate just before the boundary. Their intersection will count as a causal interaction on Salmon's account since the world-line in (1) exhibits a change in the conserved quantity.

7. Misconnections: The Problem of Causal Relevance

So far we have focused on the ability of the conserved quantity theory to distinguish causal processes from pseudo processes. But in the words of Chris Hitchcock (2004), *what's this distinction good for?* Salmon and Dowe claim that they are offering a theory of causation, yet each acknowledges one way or another that the definitions above at best gives just a necessary condition for two events to be related as cause and effect. As Woodward (2003: 357) notes, 'we still face the problem that the feature that makes a process causal (transmission of some conserved quantity or other) tells us nothing about which features of the process are causally or explanatorily relevant to the outcome we want to explain'. For example, putting a chalk mark on the white ball is a causal interaction linked by causal processes and interactions to the black ball's sinking (after the white ball strikes the black ball), yet it doesn't cause the black ball's sinking (ibid. 351).

Dowe offers the following account (restricting the causal relata to facts for simplicity):

Causal Connection: There is a causal connection (or thread) between a fact q(a) and a fact q′(b) if and only if there is a set of causal processes and interactions between q(a) and q′(b) such that:

(1) any change of object from a to b and any change of conserved quantity from q to q′ occur at a causal interaction involving the following changes: $\Delta q(a)$, $\Delta q(b)$, $\Delta q'(a)$, and $\Delta q'(a)$; and
(2) for any exchange in (1) involving more than one conserved quantity, the changes in quantities are governed by a single law of nature.

. . . where a and b are objects and q and q′ are conserved quantities possessed by those objects respectively. (Dowe 2000: sect. 7.4; see Hausman 2002: 720–1 for discussion)

The analysis would need to be expressed in a more general form for cases where there are more than two objects involved along the nexus of causal processes and interactions.

Condition (2) in the definition of causal connection states 'for any exchange in (1) involving more than one conserved quantity, the changes in quantities are governed by a single law of nature'. This is an attempt to rule out accidentally coincident causal interactions of the sort identified by Miguel and Paruelo (2002). In one of their examples two billiard balls collide, and at the same instant, one of them emits an alpha particle. Condition (2) would not work for the case also mentioned by Miguel and Paruelo where the same quantity is exchanged in both interactions.

The account, if successful, tells us when two events are related causally, either as cause and effect or vice versa, or as common effects or causes of some event. It will not tell us which of these is the case (Hausman 2002: 719; Ehring 2003: 531–2). To do that, both Salmon and Dowe (2000: ch. 8) appeal to a Reichenbachian fork asymmetry theory (Dowe's particular version of the latter has been subject to serious critique by Hausman (2002: 722–3), which includes the point that his account of priority has nothing to do with the conserved quantity theory).

Suppose a rolling steel ball is charged at a certain point along its trajectory. Suppose its trajectory is unaffected, and the ball subsequently hits another ball. The account should tell us that the fact that the ball gets charged is not causally relevant to the fact that it hits the second ball. It does, since although on the Salmon–Dowe theory the ball's rolling is a causal process and the charging and the collision are causal interactions, and further, a change in the ball's charge and the change in the ball's momentum are both the kinds of changes envisaged in (1), nevertheless there is no causal interaction linking the ball's having charge to the ball's having momentum as required in (1). Hence there is no causal thread as defined in (1) linking the two facts.

The account should also tell us that the tennis ball's heading towards the wall is not the cause of the wall's being stationary after the ball bounces off. It does, because although there is a set of causal processes and interactions linking these

two events, there is a change of object along the 'thread'—ball to wall—yet the wall undergoes no change in momentum, which it needs for the set of causal processes and interactions to count as a causal connection on this definition. (But cf. Hausman 2002: 721; Twardy 2001: 268)

One might hope that the theory also tells us that the fact that a chalk mark is put on the white ball is not causally relevant to the fact that the black ball sinks since there is no causal thread as defined in (1) linking those two facts. However, such a results awaits a translation of 'chalking a ball' to a state involving a conserved quantity. (See the following section for a discussion of this issue.)

To this account Dowe (2000: sect. 7.4) adds the restriction that the facts that enter into causation should not be disjunctive. This is meant to deal with the following type of example. Suppose 'in a cold place, the heater is turned on for an hour, bringing the room to a bearable temperature. But an hour later the temperature is unbearable again, say 2°C. Then . . . the fact that the heater was turned on is the cause of the fact that the temperature is unbearable at the later time'. According to Dowe 'the temperature is unbearable' is a disjunctive fact, meaning 'the temperature is less than *x*' for a certain *x*, which in turn means 'the temperature is *y* or *z* or . . .'. The effect is simply that the room is 2°C. According to Ehring (2003: 532) this result remains counterintuitive.

8. Common Sense, Science, and Reduction

The Conserved Quantity theory is claimed by both Salmon and Dowe to be an *empirical analysis*, by which they mean that it concerns an objective feature of the actual world, and that it draws its primary justification from our best scientific theories. 'Empirical analysis' is to be contrasted with *conceptual analysis*, the approach that says in offering a theory of causation we seek to give an account of the concept as revealed in the way we (i.e. folk) think and speak. Conceptual analysis respects as primary data intuitions about causation; empirical analysis has no such commitment (Dowe 2000: ch. 1).

This construal of the task of delivering an account of causation has drawn criticism from a number of commentators. According to Koons (2003: 244) it threatens 'to turn [the] metaphysical account into a watered-down version of more-or-less contemporary physical theory'. But Hausman (2002: 718) notes that since causation is not a technical concept in science, '[w]ithout some plausible connection to what ordinary people and scientists take to be causation, the conserved quantity theory would float free of both physics and philosophy' (see also Garcia-Encinas 2004: 45). And McDaniel (2002: 259) asks what could justify one in believing a putative 'empirical analysis'. He adds that if an empirical analysis is not at least extensionally equivalent (in the actual world) to the true conceptual analysis, then what would be the point?

Despite their denial of a primary need to respect common sense intuitions about the concept of causation, Salmon and Dowe do still want to say their account deals with everyday cases of causation. This again raises the question of translation. As Kim (2001: 242) puts it, there is the 'question of whether the [Dowe–Salmon] theory provides a way to "translate" causality understood in the [Dowe–Salmon] theory into ordinary causal talk and *vice versa*' (and see especially Hausman 1998: 14–17; 2002: 719).

According to Dowe the relata in true 'manifest' (common sense) claims of causation must be translated to physical states of the sort discussed in the previous section ('object *a* has a value *q* of a conserved quantity') such that the manifest causal claim supervenes on some physical causation. Even for purely physical cases such as 'chalking the ball' this is a complicated matter, and it is not obvious that it can be carried through.

Even if this could be made to work in purely physical cases, there remain questions about mental causation, causation in history, and causation in other branches of science besides physics (Woodward 2003: 355–6; Machamer, Darden, and Craver 2000: 7; Cartwright 2004: 812). In any case, to suppose that the conserved quantity theory will deal with causation in other branches of science also requires commitment to a fairly thoroughgoing reductionism, since clearly there is nothing in economics or psychology that could pass for a conservation law.

An alternative to such reductionism is the view developed by Nancy Cartwright, which we might call causal pluralism (see Ch. 16 below). After rejecting the conserved quantity theory (along with a range of major theories of causation) as an account of a 'monolithic' causal concept, on the grounds that it cannot deal with cases in economics, Cartwright (2004: 814) summarizes her position: '1. There is a variety of different kinds of causal laws that operate in a variety of different ways and a variety of different kinds of causal questions that we can ask. 2. Each of these can have its own characteristic markers; but there are no interesting features that they all share in common' (see also Hausman 2002: 723).

9. Disconnections

'I killed the plant by not watering it' (Beebee 2004). If this is a case of causation then process theories are in trouble, because neither my not watering nor whatever

I did instead are connected by a physical process to the plant's death. The same is true for 'my failure to check the oil caused my engine to seize'. Cases of causation by omission, absence, preventing (i.e. causing to not happen) and double prevention (Hall 2004) all raise the same difficulty. If these are cases of causation then the process theory cannot be right (Hausman 1998: 15–16; Schaffer 2000, 2004).

There is a long tradition that asserts that such are indeed cases of causation. Lewis (1986: 189–93; 2004) is adamant and Schaffer (2000; 2004) presents a detailed case. Others have denied these are indeed cases of causation (Aronson 1971; Dowe 1999; 2000; 2001; 2004; Armstrong 2004; Beebee 2004). Some extend their account of causation, in ways that depart from their respective central theses, to include such cases (Fair 1979: 246–7; Ehring 1997: 125, 139; Lewis 2004). According to Hall (2004) and Persson (2002) these cases show that there are two concepts of causation. According to Rieber (2002: 63–4) the account of causation in terms of the transfer of properties can handle these cases by translating negatives into the actual positives that obtain.

Dowe and Armstrong hold that while such cases are not genuine causation, they count as a close relative, which Dowe variously calls causation* (1999; 2000) or 'quasi-causation' (2001; cf. Ehring 1997: 150–1). Persson (2002) coins the term 'fake causation'. This relation is essentially a counterfactual about causation (see also Fair 1979: 246–7). While admitting Schaffer's (2000) point that there are cases of quasi-causation which by intuition clearly count as causation, Dowe asserts that there is also an intuition of difference—other cases of quasi-causation which intuitively are not causation (2001; see also Rieber 2002). For a detailed rebuttal of the intuition of difference see Schaffer (2004: 209–11) and, from a Davidsonian perspective, Hunt (2005). Further, Dowe attempts to explain why we might confuse causation with quasi-causation by appealing to the similar roles they play in explanation, decision-making and inference, and justifies this similarity on the grounds of the relation between causation and quasi-causation (again, quasi-causation is essentially possible causation). Armstrong (2004) points out that another reason we might confuse the two concepts is that in practice it is often difficult to distinguish the two.

Dowe (2001: 221; see also 2000: sect. 6.4) offers this account of quasi-causation:

Prevention: A prevented B if A occurred and B did not, and there occurred an *x* such that

(P1) there is a causal interaction between A and the process due to *x*, and
(P2) if A had not occurred, *x* would have caused B.

where A and B name positive events or facts, and *x* is a variable ranging over events and/or facts.

For example, bumping the table (A) prevented the ball going into the pocket (B) because there is an interaction between bumping the table and the trajectory of the ball (*x*), a causal interaction, and the true counterfactual 'without A, *x* would have caused B'.

One reason that the above is stated only as a sufficient condition is that there is a need to account for alternative preventers, of which there are two types, pre-emptive prevention (cf. pre-emption) and overprevention (cf. overdetermination), since in both cases (P3) fails. To deal with the latter, Dowe (2000 sect. 6.4, adapted) disjoins (P2) with

(P2′) there exists a C such that had neither A nor C occurred, *x* would have caused B or . . .

Suppose as well as bumping the table I subsequently knocked the moving ball with my elbow (C), again, preventing it from sinking (overprevention). (P2) is false, but by (P2′) A counts as a quasi-cause of B. So too does C, since substituted for A, it satisfies P(1). Suppose on the other hand C is some completely irrelevant event, and (P1–2) hold for A and B. Then although (P2′) holds for this A–C pair C will not count as a preventer of B because it does not satisfy (P1). (For a contrary view see Koons 2003: 246.)

Although the account in Dowe (2000) is unclear on this point, (P2′) will not handle pre-emptive prevention. Suppose I bumped the table, but didn't hit the ball with my elbow, although I would have had I not bumped the table. We need to add the further alternative:

(P2″) had A not occurred, *C* would have occurred and would have prevented *B*.

The possible prevention here is then analysed by (P1–2) from the perspective of that possible world.

Quasi-causation by omissions or absences are analysed thus:

Omission: not-A quasi-caused B if B occurred and A did not, and there occurred an *x* such that

(O1) *x* caused B, and
(O2) if A had occurred then A would have prevented B by interacting with *x*

where A and B name positive events/facts and *x* is a variable ranging over facts or events, and where prevention is analysed as above. (Dowe 2001: 222; see also 2000: sect. 6.5)

For example, being careful not to bump the table (not-A) quasi-caused the ball to sink (B) because the trajectory of the ball (*x*) causes B and had the table been bumped that would have prevented B. Further cases can be added: prevention by omission, and prevention of prevention, prevention of prevention of prevention, etc. (see Dowe 2000: sect. 6.6). There is indeed a great deal of quasi-causation around, as Beebee (2004) has argued.

Schaffer (2001: 811) offers two criticisms of the counterfactual theory of quasi-causation. First, he argues Salmon's and Dowe's process theory of causation is, ironically, ill equipped to tell us what genuine causation is in these possible worlds (i.e. the worlds one might take to be the truthmakers of the counterfactuals in P2 and O2) since theirs is only an account of causation in the actual world, and worse,

if one follows the semantics of Lewis to deal with the counterfactuals, it will probably turn out that our conservation laws don't hold in those possible worlds At the very least, Dowe's (2001: 221) stated view that 'it's BYO semantics of counterfactuals' is not satisfactory. (For further discussion of this problem see Persson 2002: 139–40.) And second, the account is semantically unstable, since as Dowe asserts quasi-causation plays the same role as causation for explanation, decision theory and inference, that relation is a better deserver of the role of best fitting causation's connotations than Salmon–Dowe's 'genuine causation' (Dowe 2000: 296 n. 13; 2001: 811–12).

10. Related Theories of Causation

There is an increasing number of accounts of causation that are close relatives of the Process Theory but that don't exactly fit the definition of a Process Theory given above. In this section we summarize some important theories that take causation to be the transfer or persistence of properties of a specific property, in particular, energy.

10.1 Aronson's Transference Theory

Aronson's (1971: 422) theory is presented in three propositions:

(1) In 'A causes B', 'B' designates a change in an object, a change which is an *unnatural* one.
(2) In 'A causes B', at the time B occurs, the object that causes B is in contact with the object that undergoes the change.
(3) Prior to the time of the occurrence of B, the body that makes contact with the effect object possesses a *quantity* (e.g. velocity, momentum, kinetic energy, heat, etc.) which is transferred to the effect object (when contact is made) and manifested as B.

Proposition (1) refers to a distinction Aronson draws between natural and causal changes—causal changes are those that result from interactions with other bodies; natural changes are not causal, and come about according to the normal course of events, when things happen without outside interference. Thus internal changes, or developments, are not seen by Aronson as cases of causation. Proposition (2) is Hume's requirement that causation occurs only by contact, which rules out action at a distance. It also means that, strictly speaking, there is no indirect causation, where one thing causes another via some intermediate mechanism. All causation is direct causation.

Proposition (3) is the key notion in Aronson's theory. It appeals to the idea of a quantity, which is possessed by objects, and which may be possessed by different objects in turn, but which is always possessed by some object. The direction of transfer sets the direction of causation. For a critique of this theory see Earman (1976).

10.2 Fair's Transference Theory

David Fair, a student of David Lewis, offers an account of causation similar in many respects to that of Aronson. Fair (1979) makes the claim that physics has discovered the true nature of causation: what causation really is, is a transfer of energy and/or momentum. This discovery is an empirical matter, and the identity is contingent. Fair presents his account as a programme for a physicalist reduction of the everyday concept, and he doesn't claim to be able to offer a detailed account of the way energy transfer makes true the fact that, for example, John's anger caused him to hit Bill. A full account awaits, Fair says, a complete unified science (ibid. 236).

Fair's programme begins with the reduction of the causal relata found in ordinary language. Events, objects, facts, properties, and so forth need to be redescribed in terms of the objects of physics. Fair introduces 'A-objects' and 'B-objects', which manifest the right physical quantities, namely energy and momentum, and where the A-objects underlie the events, facts, or objects identified as causes in everyday talk, while the B-objects underlie those identified as effects. The physical quantities, energy and momentum, underlie the properties that are identified as causes or effects in everyday causal talk.

The physically specifiable relation between the A-objects and the B-objects is the transfer of energy and/or momentum. Fair sees that the key is to be able to identify the same energy and/or momentum manifested in the effect as was manifested in the cause. This is achieved by specifying closed systems associated with the appropriate objects. A system is closed when no gross energy and/or momentum flows into or out of it. Energy and/or momentum transfer occurs when there is a flow of energy from the A-object to the B-object, which will be given by the time rate of change of energy and/or momentum across the spatial surface separating the A-object and the B-object.

Fair's (1979: 236) reduction thus is:

> A causes B iff there are physical redescriptions of A and B as some manifestation of energy or momentum or [as referring to] objects manifesting these, that is transferred, at least in part, from the A-objects to the B-objects.

For one extended critique of Fair's theory see Dowe (2000: ch. 3).

10.3 Ehring's Trope Persistence Theory

Douglas Ehring sets out a highly original theory of causation in his book *Causation and Persistence* (1997). Ehring takes the relata of causation to be tropes—that is, non-repeating property instances. Causal connections involve the persistence of such tropes, and also their fission (partial destruction) and fusion. Trope persistence is endurantist, that is to say, tropes wholly exist at every time they exist, and that a particular trope at one time is strictly identical to itself at other times. Since tropes do not change they avoid the well-known problem for edurantists of temporary intrinsics.

Actually Ehring's theory has two parts. 'Strong causal connection' concerns trope persistence, and this is a symmetric matter. Causal priority on the other hand involves broader considerations including counterfactuals. Here are Ehring's definitions (following the summary in Ehring 2004):

Strong Causal Connection: Tropes P and Q, are strongly causally connected if and only if:

(1) P and Q are lawfully connected, and either
(2) P is identical to Q or some part of Q, or Q is identical to P or some part of P, or
(3) P and Q supervene on tropes P' and Q' which satisfy (1) and (2).

Causal Priority: Ehring employs counterfactuals to define a relation of 'being a condition of a causal connection', and then he uses this relation, together with the symmetrical relation of causal connection, to define causal direction (1997: 145, 146, 148, 149, 151, 179).

Putting these two together, we get:

Causation: Trope P at t causes trope Q at t' iff either
(A) P at t is strongly causally connected to Q at t' and P at t is causally prior to Q at t' *or*
(B) there is a set of properties $(R_1, \ldots, R_n)$ such that P is a cause of R_1, under clause (A), . . . , and R_n is a cause of Q under clause (A).

Clause (B) is to allow for events connected by a chain of indirect causation. For discussion of Ehring's theory see Beebee (1998).

10.4 Other Theories

There are a number of notable and related theories of causation which space unfortunately forbids us to deal with in detail. The reader is encouraged to consult the references for details.

On Castañeda's (1980) transference theory of causation, 'causity', is the transmission of a physical element: energy, movement, charge. According to Bigelow, Ellis, and Pargetter (1988) causation is the action of forces (see also Bigelow and Pargetter 1990), while for Heathcote (1989) causation is an interaction (as defined by a suitable quantum field theory). Collier (1999) develops the notion that causation is the transfer of information. Krajewski (1997) outlines several causal concepts including transfer of energy and the transfer of information. Kistler (1998; 2006) develops the trope persistence view in terms of conserved quantities. Rieber (2002) provides a conceptual analysis of causation in terms of property acquisition and transfer, and also gives references to many historical figures who hold a similar view. Finally, Chakravartty (2005) defines causal processes as systems of continuously manifesting relations between objects with causal properties and concomitant dispositions.

Further Reading

The early views of Salmon on spatio-temporally continuous processes, and interaction are presented in an accessible form in his first book on the topic (1984). His later views are mostly collected in (1998), which should be supplemented by Salmon (1997). The Conserved Quantity version is first offered in Dowe (1992) and in an extended form in (2000). Discussions of the distinction between causal and pseudo processes can be found in Hitchcock (1995; 2004), Choi (2002), McDaniel (2002), and Garcia-Encinas (2004). Discussions of the use of conserved quantities can be found in Hitchcock (1995), Rueger (1998), Schaffer (2001), McDaniel (2002), Choi (2002; 2003), and Norton (2007).

The problem of misconnections and causal relevance in general, as it relates to the Process Theory, is discussed in Twardy (2001), Hausman (2002), Miguel and Paruelo (2002), Ehring (2003), Woodward (2003), and Hitchcock (2004).

Responses to the notion of an empirical analysis are developed in Hausman (1998; 2002), Kim (2001), McDaniel (2002), Koons (2003), and Garcia-Encinas (2004).

Questions about the 'problem of disconnections' or apparent causation involving negatives, and its significance for process theories, are discussed in Ehring (1997), Hausman (1998), Schaffer (2000; 2004), Rieber (2002), Persson (2002), Koons (2003), Beebee (2004), Armstrong (2004), and Hunt (2005). Dowe's account can be found in (2001).

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