# EPILOGUE

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This volume brings together two different, almost disjoint ways of thinking about causation in physics; and that, to my mind, is its special virtue. In describing these two modes of thought it will help to use a conventional philosophical device: a diagrammatic contrast between Kant and Hume. For Kant causality involves order under the universal rule of law. For Hume the concept is intimately connected with our sense that we can make things happen and a projection from that to the presumption that causes in the world outside ourselves similarly make these effects occur. The first point of view has dominated discussions about causality in modern physics throughout the century, both in the general and special theories of relativity and in the various quantum theories. The second has only really entered with the serious discussion of action at a distance in quantum mechanics following the discovery of the Bell inequalities, and that in a piecemeal and not obviously consistent way, for the two traditions sit uneasily together.

Causality in the 'making it happen' sense requires, on the one hand, more than the necessity prescribed by Kant but, on the other, falls far short of it. Yet it is clear that the two brands of causation must be brought together not only in order to understand the real structure of our fundamental theories but also to explain how -or why- they can be put to use to produce the effects that are taken to argue so powerfully for the truth of those theories. That is why the kinds of careful studies we find in this volume showing how the two fit together (or not) are of such importance.

We can see these two separate traditions in more detail in the papers themselves. No one denies that operators for quantities at space-like separated events do not commute, as Pauli showed; nor the related facts about Green's function propagators between the events. That is part of the order under universal law precious in the Kantian tradition. But, Jordi Cat argues these facts merely constrain the possibilities for causal connections between

measurements at the two; they do not by themselves dictate a story about the causal structure of a world governed by quantum field theory. Clearly Cat starts out from a notion of causation that is more demanding and more detailed than mere Kantian order.

Similarly no one denies the probabilistic order described in Bell's inequalities, but, as Joseph Berkovitz shows, different versions of quantum theory fill in different accounts of whether and how events in one wing of the experiment can make specific outcomes in the other wing occur. These causal accounts are based on claims made by the theories: that is what Berkovitz points out. But they are, at least prima facie, stronger claims than those rooted in *just* the fundamental equations of the basic theory.

Curiel explicitly discusses the kind of distinction I point to, but he thinks that the Humean style concept must, if it is legitimate at all, be reducible to facts about universal order dictated by fundamental theory; and he argues that there is no basis in the general theory for generating a notion with the right kind of characteristics to serve as Hume-style causality. This is exactly the opposite starting point from that of Cat, who takes the Hume-style notion to be legitimate on its own and shows that the microcausality principle is not in that sense a causality principle at all. Berkovitz seems to start from Cat's position, counting 'influence' as a concept that we would not expect to piggy back just on the fundamental equations. At any rate, all three studies focus on how the two ideas of causation fit together in different theories in modern physics. We will come to the question of how Dowe's paper relates to this project in a moment.

Why do I say that Humean causality involves something both more and less 'Kantian' necessity? The more is a standard topic; we can most readily find it in discussions of spurious correlation. A factor $C$ is the sole cause of two effects, $E_1$ and $E_2$. If $C$ is lawfully connected with each of its effects, this induces a lawful connection between $E_1$ and $E_2$; and this connection between the two effects is dictated by law every bit as much, or as little, as that between $C$ and each of its effects. There are three standard ways in the current philosophical literature to deal with this problem: 1) accounts that deny the universal rule of law; 2) counterfactual accounts; and 3) process theories. Many argue that process theories require counterfactuals to function correctly and in my view the right kind of counterfactuals require limitations on the rule of law. That is why I claim that the concept of 'making something happen' demands a world in which Kantian necessity fails. But both steps in the move to collapse 3) into 2) into 1) are controversial, so I will lay out all three views separately.

The first is crucial in the literature on probabilistic causality. The most carefully worked out theories are those employing directed acyclic graphs (DAGs) developed by groups working with Judea Pearl[1] at UCLA and with Clark Glymour and Peter Spirtes[2] at Carnegie Mellon University. DAG methods provide powerful procedures for inferring causal laws from facts about probabilistic dependencies given general constraints connecting the causal structures for a given set of quantities with the admissable probability measures over those quantities, constraints like Reichenbach's principle of the common cause (R-PCC described here by Joseph Berkovitz). But the methods are only useful when applied to *causally sufficient* structures: structures in which all common causes of variables in the structure are in the structure as well. In addition it is necessary that all omitted causes of factors represented in the structure be both functionally and probabilistically independent of each other. A similar restriction is imposed in Wolfgang Spohn's theory of probabilistic causality as well[3].

The root idea behind the *independent variability* solution to the problem of spurious correlation is an old and familiar one. To determine if $E_1$ causes $E_2$ compare situations for which the values (or for indeterministic theories, the probabilities) of C and of all other causes of $E_2$ are the same but where the value (or the probability) of $E_1$ varies; then $E_1$ causes $E_2$ just in case $E_2$ varies concomitantly. Clearly this test requires that both $E_1$ and $E_2$ have causes they do not hold in common (contrary to my original description of the relations among C, $E_1$ and $E_2$) and that the causes of $E_1$ vary independently of the causes of $E_2$. So the system cannot be fully deterministic since then all the values would be fixed by the initial conditions and the requisite independent variation would not occur. Thus we see here an odd trade-off on necessity: we wanted to explain how the lawful connections between C and $E_1$ and between C and $E_2$ are 'more necessary' than the lawful connection between $E_1$ and $E_2$. We do so, though, not by directly promoting the connections between C and its effects over that between the effects, but rather by denying that the rule of law holds for every quantity that figures in the causal network.

Daniel Hausman[4] also has nice results linking causes and probabilities and he makes a similar assumption: every effect has a special cause of its own that is independent of the special causes of every other effect. He defends this on the grounds that a factor must be *manipulable* if it is to count as a cause at all. The call for a tight connection between manipulability and causation also appears in the causal theories of Kevin Hoover[5], Huw Price[6], Herbert Simmon[7], James Woodward[8] and others. On the face of it,

manipulability requires an even stronger violation of the universal rule of law than mere independent variation since it demands that values be assignable *at will.*

Other theories demand not that the values of causal factors or handles for manipulation vary independently of each other, but rather that the laws themselves are variable. Sometimes authors slip back and forth between the two views as if they were essentially the same. Kevin Hoover and Herbert Simon require just this. Both define causal structure -'causal' in the Hume sense, over and above lawful functional or probabilistic connection- by reference to what happens when parameters are changed in the functional laws; i.e. by reference to what happens when laws themselves are varied. The possibility of varying causal laws, in fact of eliminating some altogether and replacing them by others, is also central to Pearl's interpretation of causality as well as to Woodward's. My own views depict an even stronger violation of Kantian necessity. All laws, I argue, whether causal or not, are epiphenomenal. They emerge as a consequence of repetition of outcomes from a stable, well-shielded and appropriately ordered arrangements -i.e. as a consequence of the repeated operation of what I call a *nomological machine.*[9]

Turn now to the counterfactual approach and again consider the problem of spurious correlation as a quick way to look at the 'more' and the 'less' of 'Humean' causality vis-à-vis'Kantian' order. If $E_1$ had been different, would $E_2$ have been different as well? Advocates of Humean Causality want to say 'no'; but to do so we know what we must have an account of counterfactuals that rules out what David Lewis called 'backtracking': if $E_1$ had been different, C would have been as well, and thus so too would $E_2$ have been different. Lewis has offered the conventional semantics; recent work of Judea Pearl[10] provides an alternative. In one sense Pearl's framework is more narrow: he deals with systems where the laws can be expressed as linear equations. But in another it is richer, for Pearl distinguishes a number of distinct causal concepts and offers separate counterfactual analyses for each one. But his account explicitly requires that there be factors *exogenous* to the causal network (factors that cause those in the network but are not caused by them) and that these factors vary independently of one another.

Does Lewis's account require genuine independent variation or not? His anti-backtracking semantics picturesquely talks of 'big miracles', 'little miracles' and the like[11]. But that is just a shorthand device for telling us which possible world to direct our attention to; and what happens in alternative possible worlds depends entirely, although in an elaborate way, on

what *actually* happens in the 'real' world. So in one sense physical necessity is cut out altogether. But it enters again through 'laws of nature': roughly, the most-efficient summaries of the largest body of facts.

Now we can ask the question again: does the singling out of some connection over others, all of which are necessary in this sense -that they follow from the laws of nature- turn out after all to be at odds with the assumption of universal necessity? To answer the question I think we need to provide ourselves with an explicit statement of exactly what facts about the real world make the relevant counterfactuals true. But more than that. We need also to see why the facts *matter*: why is this concept -the concept called 'causation' in this scheme, that is, the concept made true by just these kinds of facts- worth bothering about among all the possible concepts we might choose to invent? In particular, can the facts that must obtain when a causal claim is true justify the kinds of influences we make from causal knowledge or the kinds of uses to which we wish to put it? I think it is just not clear yet whether Lewis's account can avoid the need for independent variability that is central to a semantics like that of Pearl, and hence whether it is or is not consistent with the universal rule of law.

By contrast with the other two programmes for Humean causality I have described, the process theory does not demand that putative causes be open to manipulation, it makes no call for quantities to vary without relation to each other and it is not couched in terms of counterfactuals as is patent from the opening paragraph of Phil Dowe's paper here. That is probably why it is popular with philosophers of physics who like to see the fundamental theories of physics as universal, in charge of all that happens in the universe. It is concomitantly the only account whose formal details play a role in the discussions here.

It is controversial whether the process theory can live up to the promise of compatibility with the universal rule of order; can it, for instance, really do without counterfactuals?[12] But these general questions are not at issue in this volume. Rather both Dowe's defense and Curiel's attack on the process theory, just like Cat's discussion of microcausality and Berkovitz's of causal models for E.P.R., look to the details of how we might really fit causal interactions -interactions in which one event makes another happen or at least contributes to that- into our current fundamental theories in physics. As I mentioned in my opening paragraph, this kind of close attention to the details of the fit is why the studies in this volume are of particular importance in understanding physics and how we can make it work to make things happen.

## *Notes*

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10 Pearl, J.: forthcoming, *Causality*, Cambridge, Cambridge University Press.

11 Lewis, D.:1979, 'Counterfactual Dependence and Time's Arrow', *Nous* 13, 455-76.

12 Kitcher, P.: 1989, 'Explanatory Unification and the Causal Structure of the World', in W. Salmon and P. Kitcher (eds.): *Minnesota Studies in the Philosophy of Science*, Vol. 13, Minneapolis, University of Minnesota Press, pp. 410-505.

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