Causation as Folk Science

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1. Introduction

Each of the individual sciences seeks to comprehend the processes of the natural world in some narrow domain—chemistry, the chemical processes; biology, living processes; and so on. It is widely held, however, that all the sciences are unified at a deeper level in that natural processes are governed, at least in significant measure, by cause and effect. Their presence is routinely asserted in a law of causation or principle of causality—roughly, that every effect is produced through lawful necessity by a cause—and our accounts of the natural world are expected to conform to it.[1]

My purpose in this paper is to take issue with this view of causation as the underlying principle of all natural processes. I have a negative and a positive thesis.

In the negative thesis I urge that the concepts of cause and effect are not the fundamental concepts of our science and that science is not governed by a law or principle of causality. This is not to say that causal talk is meaningless or useless—far from it. Such talk remains a most helpful way of conceiving the world, and I will shortly try to explain how that is possible. What I do deny is that the task of science is to find the particular expressions of some fundamental causal principle in the domain of each of the sciences. My argument will be that centuries of failed attempts to formulate a principle of causality, robustly true under the introduc-

[1]Some versions are: Kant (1933, p.218) "All alterations take place in conformity with the law of the connection of cause and effect"; "Everything that happens, that is, begins to be, presupposes something upon which it follows according to a rule." Mill (1872, Bk. III, Ch. V, §2): "The law of causation, the recognition of which is the main pillar of inductive science, is but the familiar truth that invariability of succession is found by observation to obtain between every fact in nature and some other fact which has preceded it, independently of all considerations respecting the ultimate mode of production of phenomena and of every other question regarding the nature of 'things in themselves'." For a short survey, see Nagel (1961, Ch. 10, Sect. V).

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tion of new scientific theories, have left the notion of causation so plastic that virtually any new science can be made to conform to it. Such a plastic notion fails to restrict possibility and is physically empty. This form of causal skepticism is not the traditional Humean or positivistic variety. It is not motivated by an austere epistemology that balks at any inference to metaphysics. It is motivated by taking the content of our mature scientific theories seriously.

Mature sciences, I maintain, are adequate to account for their realms without need of supplement by causal notions and principles. The latter belong to earlier efforts to understand our natural world, or to simplified reformulations of our mature theories, intended to trade precision for intelligibility. In this sense I will characterize causal notions as belonging to a kind of folk science, a crude and poorly grounded imitation of more developed sciences. More precisely, there are many folk sciences of causation corresponding to different views of causation over time and across the present discipline. While these folk sciences are something less than our best science, I by no means intend to portray them as pure fiction. Rather I will seek to establish how their content can be licensed by our best science, without the causal notions' becoming fundamental.

In the positive thesis, I will urge that ordinary scientific theories can conform to a folk science of causation when they are restricted to appropriate, hospitable processes; and the way they do this exploits the generative power of reduction relations, a power usually used to recover older theories from newer ones in special cases. This generative power is important and familiar. It allows Einstein's general theory of relativity to return gravity to us as a Newtonian force in our solar system, even though Einstein's theory assures us that gravity is fundamentally not a force at all. And it explains why, as long as no processes interchange heat and work, heat will behave like a conserved fluid, as caloric theorists urged. In both domains it can be heuristically enormously helpful to treat gravity as a force or heat as a fluid, and we can do so on the authority of our best sciences. My positive thesis is that causes and causal principles are recovered from science in the same way and have the same status: they are heuristically useful notions, licensed by our best sciences, but we should not mistake them for the fundamental principles of nature. Indeed we may say that causes are real to the same degree that we are willing to say that caloric or gravitational forces are real.

The view developed here is not an unalloyed causal skepticism. It has a negative (skeptical) and a positive (constructive) thesis, and I urge readers to consider them in concert. They are motivated by the same idea. If the world is causal, that is a physical fact to be recovered from our science. So far our science has failed to support the idea of a principle of causality at the fundamental level (negative thesis); but a causal character can be recovered from the science as looser, folk sciences that obtain in restricted domains (positive thesis).

In Section 2, I will describe the causal skepticism I call "anti-fundamentalism" and lay out the case for the negative thesis in the form of a dilemma. In Section 3, in support of the arguments of Section 2, I will give an illustration of how even our simplest physical theories can prove hostile to causation. In Section 4, I will begin development of the positive thesis by outlining the generative power of reduction relations. In Section 5, I will describe one type of the possible folk theories of causation in order to illustrate the sorts of causal structure that can be recovered from the generative power of reduction relations. Section 6 has examples of this folk theory used to identify first and final causes and to display the domain dependence of the recovery. Section 7 has a brief conclusion.

2. The Causal Fundamentalist's Dilemma

The dispensability of causes

Russell (1917, p. 132) got it right in his much celebrated riposte:

> All philosophers, of every school, imagine that causation is one of the fundamental axioms or postulates of science, yet, oddly enough, in advanced sciences such as gravitational astronomy, the word 'cause' never occurs… . 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.

When they need to be precise, fundamental sciences do not talk of causes, but of gravitational forces, or voltages, or temperature differences, or electrochemical potentials, or a myriad of other carefully devised, central terms. Nonetheless they are still supposed to be all about causes. Perhaps the analogy is to an account of a bank robbery. It can be described in the most minute detail—the picking of the lock, the bagging of the cash—without ever actually mentioning "theft" or "robbery." If one thinks cause might have a similar surreptitious role in science, it is sobering to compare the case of causation with that of energy. Many sciences deal with a common entity, energy, which manifests itself quite directly throughout the science. Sometimes it appears by name—kinetic energy, potential energy, field energy, elastic energy—and other times it appears as a synonym: heat, work, or the Hamiltonian. However, there is little doubt that each of the sciences is dealing with the very same thing. In each science, the energies can be measured on the same scale, so many Joules, for example, and there are innumerable processes that convert the energy of one science into the energy of another, affirming that it is all the same stuff. The term is not decorative; it is central to each theory.

Causal fundamentalism

If one believes that the notions of cause and effect serve more than a decorative function in science, one must find some manifest basis for their importance. It is clearly too severe to demand that causes all be measurable on some common scale, like energies. We can afford to be a little more forgiving. However, we must find some basis; taking cash is theft because of an identifiable body of criminal law. What should that basis be in the case of causes? In it, the notion of cause must betoken some factual property of natural processes; otherwise its use is no more than an exercise in labeling. And the notion must be the same or similar in the various sciences; otherwise the use of the same term in many places would be no more than a pun. I believe this basis to be broadly accepted and to energize much of the philosophical literature on causation. I shall call it:

> *Causal fundamentalism*: Nature is governed by cause and effect; and the burden of individual sciences is to find the particular expressions of the general notion in the realm of their specialized subject matter.

My goal in this section is to refute this view. In brief, I regard causal fundamentalism as a kind of *a priori* science that tries to legislate in advance how the world must be. These efforts have failed so far. Our present theories have proven hard enough to find and their content is quite surprising. They have not obliged us by conforming to causal stereotypes that were set out in advance, and there is little reason to expect present causal stereotypes to fare any better.

The difficulty for causal fundamentalism is made precise in:

> *Causal fundamentalist's dilemma*: EITHER conforming a science to cause and effect places a restriction on the factual content of a science;

> OR it does not. In either case, we face problems that defeat the notion of cause as fundamental to science. In the first horn, we must find some restriction on factual content that can be properly applied to all sciences; but no appropriate restriction is forthcoming. In the second horn, since the imposition of the causal framework makes no difference to the factual content of the sciences, it is revealed as an empty honorific.

The first horn

Discerning how causation restricts the possibilities has been the subject of a long tradition of accounts of the nature of cause and effect and of the law or principle of causality. One clear lesson is learned from the history of these traditions. Any substantial restriction that they try to place on a science eventually fails. There is no shortage of candidates for the factual restriction of the first horn. The trouble is, none work. Let us take a brief tour.

Aristotle described four notions of cause: the material, efficient, final, and formal; with the efficient and final conforming most closely to the sorts of things we would now count as a cause. The final cause, the goal towards which a process moves, was clearly modeled on the analogy between animate processes and the process of interest. In the seventeenth century, with the rise of the mechanical philosophy, it was deemed that final causes simply did not have the fundamental status of efficient causes and that all science was to be reconstructed using efficient causes alone (De Angelis, 1973). Although talk of final causes lingers on, this is a blow from which final causes have never properly recovered.

The efficient cause, the agent that brings about the process, provided its share of befuddlement. Newton (1692/93, third letter) pulled no punches in his denunciation of gravity as causal action at a distance:

> [T]hat one body may act upon another at a distance through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man, who has in philosophical matters a competent faculty of thinking, can ever fall into it. Gravity must be caused by an agent acting constantly according to certain laws... .

Causes cannot act where they are not. Nonetheless several centuries of failed attempts to find a mechanism or even finite speed for the propagation of gravity brought a grudging acceptance in the nineteenth century that this particular cause could indeed act where it was not.

In the same century, causes were pressed to the forefront as science came to be characterized as the systematic search for causes, as in Mill's, *System of Logic*. At the same time, an enlightened, skeptical view sought to strip the notion of causation of its unnecessary metaphysical and scholastic decorations. While it might be customary to distinguish in causal processes between agent and patient, that which acts and that which is acted upon, Mill (1872, Bk. III, Ch.V, §4) urged that the distinction is merely a convenience. Or, he urged, the continued existence of the cause is not needed after all for the persistence of the effect (§7). All that remained was the notion that the cause is simply the unconditional, invariant antecedent: "For every event there exists some combination of objects or events, some given concurrence of circumstances, positive and negative, the occurrence of which is always followed by that phenomenon" (§2).

Causation had been reduced to determinism: fix the present conditions sufficiently expansively and the future course is thereby fixed. Thus the nineteenth century brought us the enduring image of Laplace's famous calculating intelligence, who could compute the entire past and future history of the universe from the forces prevailing and the present state of things. This great feat was derived directly from the notion that cause implied determinism, as the opening sentence of Laplace's (1825, p. 2) passage avows: "We ought then to consider the present state of the universe as the effect of its previous state and the cause of that which is to follow."

This lean and purified notion of causation was ripe for catastrophe, for it inhered in just one fragile notion, determinism. The advent of modern quantum theory in the 1920's brought its downfall. For in the standard approach, the best quantum theory could often deliver were *probabilities* for future occurrences. The most complete specification of the state of the universe now cannot determine whether some particular Radium-221 atom will decay over the next 30 seconds (its half life); the best we can say is that there is a chance of 1/2 of decay. A lament for the loss of the law of causality became a fixture in modern physics texts (e.g., Born 1935, p.102).

While the refutation seemed complete, causation survived, weakly. If causes could not compel their effects, then at least they might raise the probabilities. A new notion of causation was born, probabilistic causation.[2] Quantum theory brought other, profound difficulties for causation. Through its non-separability, quantum theory allows that two particles that once interacted may remain entangled, even though they might travel light years away from each other, so that the behavior of one might still be affected instantly by that of the other. This places severe obstacles in the way of any account of causality that tries to represent causes locally in space and time and seeks to prohibit superluminal causal propagation.

One could be excused for hoping that this enfeebled notion of probabilistic causation might just be weak enough to conform peacefully with our physics. But the much neglected fact is that it never was! All our standard physical theories exhibit one or other form of indeterminism.[3] (See Earman 1986; Alper *et al.* 2000.) That means that we can always find circumstances in which the full specification of the present fails to fix the future. In failing to fix the future, the theories do not restrict the range of possibilities probabilistically, designating some as more likely than others. They offer no probabilities at all. This failure of determinism is a commonplace for general relativity that derives directly from its complicated spacetime geometries, in which different parts of spacetime may be thoroughly isolated from others. For determinism to succeed, it must be possible to select a spatial slice of spacetime that can function as the "now" and is sufficiently well connected with all future times that all future processes are already manifest in some trace form on it. Very commonly spacetimes of general relativity do not admit such spatial slices. What is less well known is that indeterminism can arise in ordinary Newtonian physics. Sometimes it arises in exotic ways, with "space invaders" materializing with unbounded speed from infinity and with no trace in earlier times; or it may arise in the interactions of infinitely many masses. In other cases, it arises in such prosaic circumstances that one wonders how it could be overlooked and the myth of determinism in classical physics sustained. A simple example is described in the next section.

With this catalog of failure, it surely requires a little more than naïve optimism to hope that we still might find some contingent principle of causality that can be demanded of all future sciences. In this regard, the most promising of all present views of causation is the process view of Dowe, Salmon, and others (Dowe 1997). In identifying a causal process as one that transmits a conserved quantity through

[2]"This quantum indeterminacy is, in fact, the most compelling reason for insisting upon the need for probabilistic causation" (Salmon 1980, p.73, n.19).

[3]Curiously, the most likely exception is a no-collapse version of quantum theory, since it is governed fully by the Schroedinger equation, which is deterministic.

a continuous spatiotemporal pathway, it seeks to answer most responsibly to the content of our mature sciences. In so far as the theory merely seeks to identify which processes in present science ought to be labeled causal and which are not, it succeeds better than any other account I know. If, however, it is intended to provide a factual basis for a universal principle of causality, then it is an attempt at *a priori* science, made all the more fragile by its strong content. If the world is causal according to its strictures, then it must rule out *a priori* the possibility of action at a distance, in contradiction with the standard view of gravitation in science in the nineteenth century and the non-local processes that seem to be emerging from present quantum theory. Similar problems arise in the selection of the conserved quantity. If we restrict the conserved quantity to a few favored ones, such as energy and momentum, we risk refutation by developments in theory. Certain Newtonian systems are already known to violate energy and momentum conservation (Alper *et al.* 2000), and in general relativity we often cannot define the energy and momentum of an extended system. But 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.

Or do we ask too much in seeking a single, universal principle? Perhaps we should not seek a *universal* principle but just one that holds in some subdomain of science that is fenced off from the pathologically acausal parts of science. The first problem with this proposal is that we do not know where to put the fence. The common wisdom has been that the fence should lie between the pathologically acausal quantum theory and the causally well-behaved classical physics. Yet some dispute whether quantum theory has shrunk the domain in which the causal principle holds (Bunge 1979, pp. 346-51; Margenau 1950, pp. 96, 414). And the example of the next section shows that even the simplest classical physics still admits acausal pathologies. The second problem is, if we did find where to put the fence, what confidence can we have of finding a single principle that applies in the causal domain? The proliferation of different accounts of causation and the flourishing literature of counterexamples suggests no general agreement even on what it means to say that something is a cause. So perhaps we should also give up the search for a *single* principle and allow each causally well-behaved science to come with its own, distinct principle of causality.[4] Now the real danger is that we eviscerate the notion of causation of any factual content. For now we can go to each science and find some comfortable sense in which it satisfies its own principle of causality. Since, with only a little creativity, that can be done with essentially any science, real or imagined, the demand of conformity to cause and effect places no restriction on factual content—and we have left the realm of the first horn.

The second horn

Let us presume that conforming a science to cause and effect places no restriction on the factual content of the science. The immediate outcome is that any candidate science, no matter how odd, may be conformed to cause and effect; the notion of causation is sufficiently plastic to conform to whatever science may arise. Causal talk now amounts to little more than an earnest hymn of praise to some imaginary idol; it gives great comfort to the believers, but it calls up no forces or powers.

Or is this just too quick and too clever? Even if there is no factual principle of causality in science to underwrite it, might not the concept of cause be somehow indispensable to

[4] Or we may purchase broad scope by formulating a principle so impoverished that it no longer resembles causation but contradicts no present science. Margenau (1950, §19.5) proposes that causality is the "temporal invariability of laws": "Causality holds if the laws of nature (differential equations) governing closed systems do not contain the time variable in explicit form."

our science? Perhaps the most familiar and longest lived version of this idea is drawn from the Kantian tradition. It asserts that we must supply a conception of causation if we are to organize our experiences into intelligible coherence. A variant of this is Nagel's (1961, p. 324) proposal that the principle of causality even in vague formulation

> is an *analytic consequence* of what is commonly meant by "theoretical science." …[I]t is difficult to understand how it would be possible for modern theoretical science to surrender the general ideal expressed by the principle without becoming thereby transformed into something incomparably different from what that enterprise actually is.

Nagel (1961, p. 320) formulates the principle as a methodological rule of heuristic value, which "bids us to analyze physical processes in such a way that their evolution can be shown to be independent of the particular times and places at which those processes occur." This version conforms to the second horn since Nagel (1961, p. 320) insists this principle of causality is a "*maxim* for inquiry rather than a statement with definite empirical content."

Appealing as these approaches may be, they do not defeat this second horn of the dilemma. One could well imagine that a concept of causation might be indispensable—or an injunction to find causes, heuristically useful—if the conception of causation reflected some factual properties of the world. Then something like causation must arise when we conform our concepts to the world. Or an heuristic principle could exploit those facts to assist discovery. But that is the province of the first horn, where I have already described my reasons for doubting that there are such facts. The presumption of this second horn is that there are no such factual properties of the world. In the context of this second horn, conceptual indispensability or heuristic fertility must derive not from facts in the world but from facts about us, our psychology, and our methods. So a supposed indispensability or fertility of the notion of causation is at most telling us something about us and does not establish that the would is governed at some fundamental level by a principle of causality.

Varieties of Causal Skepticism

The form of causal skepticism advocated here is not the more traditional Humean and positivistic skepticism that is based on an austere epistemology and aversion to metaphysics. My anti-fundamentalism is based on an aversion to *a priori* science; it requires that a metaphysics of causation that pertains to the physical character of the world must be recovered from our science. It is worthwhile distinguishing a few varieties of causal skepticism in more detail.

Humean/Positivist skepticism. This dominant tradition of causal skepticism in philosophical analysis depends upon an austere epistemology that denies we can infer to entities, causal or otherwise, beyond direct experience. What passes as causation is really just constant conjunction or functional dependence within actual experiences. Hume (1777, Section VII, Parts I-II) initiated the tradition when he urged that the necessity of causal connection cannot be discerned in the appearances; the latter supply only constant conjunctions. The critique was sustained by the positivists of the late nineteenth and early twentieth centuries as part of their program of eliminating metaphysics. Mach (1960, p. 580) concluded, "There is no cause nor effect in nature; nature has but an individual existence; nature simply *is*." Where Hume saw constant conjunction, Mach saw functional dependence: "The concept of cause is replaced … by the concept of function: the determining of the dependence of phenomena on one another, the economic exposition of actual facts…" (Mach 1960, p. 325). Very similar themes are found in Pearson (1911, p. vi, Ch. IV, V). Russell (1903, p. 478; 1917, pp. 142, 150-51) also endorsed a functionalist view akin to Mach's.

Anti-fundamentalism. The skepticism of this paper is grounded in the content of our mature sciences and the history of their development. Skepticism about causal fundamentalism is derived from the failure of that content and history to support a stable, factual notion of causation. In so far as it is able to take the content of our mature sciences seriously, with that content extending well beyond direct experience, it relies on a fertile epistemology rather than the barren epistemology of Humean and positivist skepticism. I believe this anti-fundamentalist form of causal skepticism is quite broadly spread. What did the most to promote the view was the advent of quantum theory and the resulting demise of determinism. On the basis of the content of the latest science, a generation of physicists and philosophers of science lamented the failure of causation. However, I have found it hard to locate expositions in which that lament is systematically developed into a strongly argued version of anti-fundamentalism. It appears to be the position of Campbell (1957, Ch. III). He noted that the relations expressed by many laws of nature cannot be causal, since they do not conform to the characteristic properties of causal relations, which are temporal, asymmetric, and binary. "So," he concluded (p. 56), "far from all laws asserting causal relations, it is doubtful whether any assert them."

These two forms of skepticism should be distinguished from:

Eliminativism.[5] In this view causal skepticism is derived from the possibility of formulating our sciences without explicitly causal terms, like cause and effect. Bunge (1979, p. 345) correctly protested that this is a simple verbal trap and not strong enough to support a robust skepticism. However, there is a converse trap. Most forms of causal skepticism, including mine, lead to the view that the notion of cause is dispensable. Mach (1894, p. 254) "hope[d] that the science of the future will discard the idea of cause and effect, as being formally obscure… ." But that should not then be mistaken as the basis of their skepticism.

[5]I borrow the term from Schaffer (2003, Section 2.1), although I am not sure that we define the term in the same way.

3. Acausality in Classical Physics

While exotic theories like quantum mechanics and general relativity violate our common expectations of causation and determinism, one routinely assumes that ordinary Newtonian mechanics will violate these expectations only in extreme circumstances if at all. That is not so. Even quite simple Newtonian systems can harbor uncaused events and ones for which the theory cannot even supply probabilities. Because of such systems, ordinary Newtonian mechanics cannot license a principle or law of causality. Here is an example of such a system fully in accord with Newtonian mechanics. It is a mass that remains at rest in a physical environment that is completely unchanging for an arbitrary amount of time—a day, a month, an eon. Then, without any external intervention or any change in the physical environment, the mass spontaneously moves off in an arbitrary direction, with the theory supplying no probabilities for the time or direction of the motion.

The mass on the dome

The dome of Figure 1a sits in a downward directed gravitational field, with acceleration due to gravity g. The dome has a radial coordinate r inscribed on its surface and is rotationally symmetric about the origin r=0, which is also the highest point of the dome. The shape of the dome is given by specifying h, how far the dome surface lies below this highest point, as a function of the radial coordinate in the surface, r. For simplicity of the mathematics, we shall set $h = (2/3g)\, r^{3/2}$. (Many other profiles, though not all, exhibit analogous acausality.)

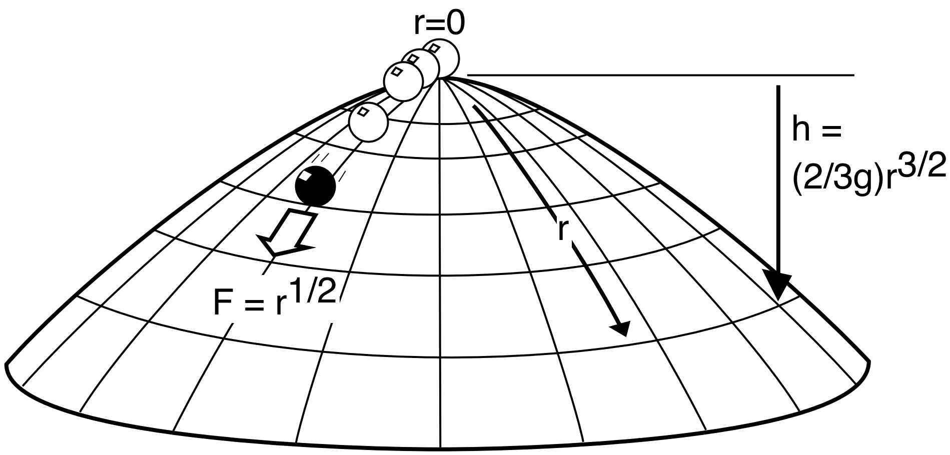

Figure 1a. Mass sliding on a dome

A point-like unit mass slides frictionlessly over the surface under the action of gravity. The gravitational force can only accelerate the mass along the surface. At any point, the magnitude of the gravitational force tangential to the surface is $F = d(gh)/dr = r^{1/2}$ and is directed radially outward. There is no tangential force at r=0. That is, on the surface the mass experiences a net outward directed force field of magnitude $r^{1/2}$. Newton's second law, F=ma, applied to the mass on the surface, sets the radial acceleration d^2r/dt^2 equal to the magnitude of the force field:

$$(1)\ d^2r/dt^2 = r^{1/2}$$

If the mass is initially located at rest at the apex r = 0, then there is one obvious solution of Newton's second law for all times t:

$$(2)\ r(t) = 0$$

The mass simply remains at rest at the apex for all time. However, there is another large class of unexpected solutions. For any radial direction:

$$(3)\ r(t) = (1/144)\,(t-T)^4 \text{ for } t \geq T$$
$$= 0 \text{ for } t \leq T$$

where $T \geq 0$ is an arbitrarily chosen constant. One readily confirms that the motion of (3) solves Newton's second law (1).[6]

If we describe the solutions of (3) in words, we see they amount to a violation of the natural expectation that some cause must set the mass in motion. Equation (3) describes a point mass sitting at rest at the apex of the dome, whereupon at an arbitrary time t=T it spontaneously moves off in some arbitrary radial direction.

Properties

Two distinct features of this spontaneous excitation require mention.

No cause. No cause determines when the mass will spontaneously accelerate or the direction of its motion. The physical conditions on the dome are the same for all times t prior to the moment of excitation, t=T, and are the same in all directions on the surface.

No probabilities. One might think that at least some probabilistic notion of causation can be preserved in so far as we can assign probabilities to the various possible outcomes. Nothing in the Newtonian physics requires us to assign the probabilities, but we might choose to try to add them for our own conceptual comfort. It can be done as far as the *direction* of the spontaneous motion is concerned. The symmetry of the surface about the apex makes it quite natural for us to add a probability distribution that assigns equal probability to all directions. The complication is that there is no comparable way for us to assign probabilities for the *time*

[6] By direct computation, $d^2r/dt^2 = (1/12)\ (t-T)^2 = [(1/144)\ (t-T)^4]^{1/2}$ for $t \geq T$ and 0 otherwise; so that $d^2r/dt^2 = r^{1/2}$.

of the spontaneous excitation that respect the physical symmetries of solutions (3). Those solutions treat all candidate excitation times T equally. A probability distribution that tries to make each candidate time equally likely cannot be proper—that is, it cannot assign unit probability to the union of all disjoint outcomes.[7] Or one that is proper can only be defined by inventing extra physical properties, not given by the physical description of the dome and mass, Newton's laws and the laws of gravitation, and grafting them unnaturally onto the physical system.[8]

What about Newton's First Law?

The solutions (3) are fully in accord with Newtonian mechanics in that they satisfy Newton's requirement that the net applied force equals mass x acceleration at all times. But one may still worry that spontaneous acceleration somehow violates Newton's First Law:

> In the absence of a net external force, a body remains at rest or in a state of uniform motion in a straight line.

It is natural to visualize "uniform motion in a straight line" over some time interval, but we will need to apply the law at an instant. At just one instant, the law corresponds to motion with zero acceleration. So the instantaneous form of Newton's First Law is:

> In the absence of a net external force, a body is unaccelerated.

Returning to the concern, there is no net force on the mass at t=T, so, by this law, shouldn't the mass remain at rest? A more careful analysis shows the motions of (3) are fully in accord with Newton's First Law.

> *For times $t \le T$*, there is no force applied, since the body is at position r=0, the force-free apex; and the mass is unaccelerated.

> *For times $t > T$*, there is a net force applied, since the body is at positions r>0 *not* at the apex, the only force free point on the dome; and the mass accelerates in accord with F=ma.

But what of the crucial time t=T? The solutions of (3) entail that the acceleration a(t) of the mass is given by

$$
\begin{aligned}
(4)\ a(t) &= (1/12)\,(t-T)^2 \text{ for } t \ge T \\
&= 0 \text{ for } t \le T
\end{aligned}
$$

We confirm by substitution into (3) that at t=T, the mass is still at the force-free apex r=0 and, by substitution into (4), that the mass has an acceleration a(0) of zero. This is just what Newton's first law demands. At t=T, there is no force

[7]Since all excitation times T would have to be equally probable, the probability that the time is in each of the infinitely many time intervals, (0,1), (1,2), (2,3), (3,4), … would have to be the same, so that zero probability must be assigned to each of these intervals. Summing over all intervals, this distribution entails a zero probability of excitation ever happening.

[8]For example, consider the natural condition that, at any time t, we always have the same probability of *no* excitation occurring over the next (arbitrarily chosen but fixed) time interval Δt, given that no excitation has occurred by the start of that time interval. This condition uniquely picks out the exponential decay rule $P(t) = \exp(-t/\tau)$ where P(t) is the probability of no excitation over the time interval (0,t) and τ is some positive time constant. (At any time t, the probability of excitation in the ensuing time interval Δt is just $\exp(-(t+\Delta t)/\tau) / \exp(-t/\tau) = \exp(-\Delta t/\tau)$, which is independent of t as required.) The problem is that the dynamics of excitation is governed by the magnitude of the time constant τ, which is the mean time to excitation. A small τ means that we likely will have rapid excitation; a large τ means we will not. Nothing in the physical setup of the dome and mass enables us to fix a value for τ. We must fix its value by arbitrary stipulation, thereby inventing the new physical property of rate of decay, which is not inherent in the original physical system.

and the mass is unaccelerated. At any t>T, there is a non-zero force and the mass is accelerated accordingly.

No first instant of motion—no initiating cause

Why is it so easy to be confused by this application of Newtonian mechanics? Our natural causal instinct is to seek the first instant at which the mass moves and then look for the cause of the motion at that instant. We are tempted to think of the instant t=T as the first instant at which the mass moves. But that is not so. It is the *last* instant at which the mass does *not* move. There is no first instant at which the mass moves. The mass moves during the interval t>T only and this time interval has no first instant. (Any candidate first instant in t>T, say t=T+ε for any ε>0, will be preceded by an earlier one, t=T+ε/2, still in t>T.) So there is no first instant of motion and thus no first instant at which to seek the initiating cause.

Still not happy?

There is a simple way to see that the spontaneous motion of the mass is actually not that strange. Instead of imagining the mass starting at rest at the apex of the dome, we will imagine it starting at the rim and that we give it some initial velocity directed exactly at the apex. If we give it too much initial velocity, it will pass right over the apex to the other side of the dome. So let us give it a smaller initial velocity. We produce the trajectory T_1 of Figure 1b. The mass rises towards the apex, but before it arrives it loses its motion, momentarily halts and then falls back to the rim. So we give it a little more initial velocity to produce trajectory T_2. The mass rises closer to the apex but does not reach it before momentarily halting and falling back. We continue this process until we give the mass just the right initial velocity so that it rises up and momentarily halts exactly at the apex. In this last case, we have ended up with the mass momentarily at rest at the one force free point on the dome, the one point where, if it is at rest, the mass can (but need not) remain at rest. So let us imagine that it does remain at rest once it arrives. We now have a trajectory in which the mass rises up to the apex, halts there and remains there at rest for any arbitrary time period we care to nominate.[9]

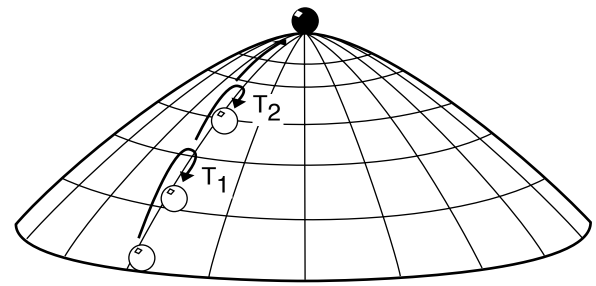

Figure 1b. Projecting the mass towards the apex

An important feature of Newtonian mechanics is that it is time reversible, or at least that the dynamics of gravitational systems invoked here are time reversible. This means that we can take any motion allowed by Newton's theory and generate another just by imagining that motion run in reverse in time. So let us do that with the motion we have just generated. That reversed motion corresponds to a mass that remains at rest at the apex of the dome for some arbitrary time period and then spontaneously moves off towards the rim. And that is just a qualitative description of one of the solutions of (3).

This time-reversal trick is powerful, but we must be cautious not to overrate it. It is best used just to make the acausal behavior plausible, while the proper mathematical

[9] In an analogous analysis, we consider trajectories with too much initial velocity, so that the mass reaches the apex with some non-zero velocity and passes over it. We reduce the initial velocity until the velocity at the apex is zero and then proceed as in the first analysis.

analysis of (1), (3), and (4) proves it. The reason is that there is a loophole. The spontaneous motion can happen only on domes of the right shape, such as those of Figure 1a. It cannot happen on others such as a hemispherical dome. The time-reversal argument fails for these other cases, for a reason that is easy to overlook. As we proceed through the trajectories T_1, T_2, … on a hemispherical dome, the time taken for the mass to rise to its momentary halt increases without bound. The final trajectory we seek, the one that momentarily halts at the apex, turns out to require infinite time. This means that the mass never actually arrives. Its time reverse displays a mass that has been in motion at all past times, without any spontaneous launches. The corresponding time for the dome of Figure 1a, however, is finite, so the analysis does succeed for this case.

4. The Generative Capacity of Reduction Relations and its Utility for Causation

Reduction of gravitational force and particle …

The negative thesis asserts that science is not based fundamentally on cause and effect. That is *not* to say that notions of cause and effect are purely fictions; that would be too severe. There is a sense in which causes are properly a part of our scientific picture of the natural world, and my goal in the positive thesis is to find it. I shall urge that the place of causes in science is closely analogous to the place of superceded theories.

In 1900, our picture of the natural world seemed secure. We concluded that the planet earth orbited the sun because of a gravitational force exerted on it by the sun; and matter consisted of many small charged particles, called ions or electrons. All this was supported by an impressive body of observational and experimental evidence. Three decades later, these conclusions had been overturned. Einstein's general theory of relativity assured us that gravitation was not a force after all but a curvature of spacetime. Quantum theory revealed that our fundamental particles were some mysterious conglomeration of both particle and wavelike properties.

The earlier theories did not disappear; and they could not. The large bodies of evidence amassed by Newton in favor of gravitational forces and by Thomson for electrons as particles needed to be directed to favor the new theories. The simplest way of doing this was to show that the older theories would be returned to us in suitable limiting cases. General relativity tells us that gravitation does behave just like a force, as long as we deal only with very weak gravity; and quantum theory tells us that we can neglect the wavelike properties of electrons as long as we stay away from circumstances in which interference effects arise. In the right conditions, the newer theories revert to the older, so that evidence for the older could be inherited by the newer.

… and the caloric

A simpler and more convenient example is the material theory of heat. In the eighteenth and early nineteenth century, heat was conceived of as a conserved fluid. The temperature measured the density of the fluid, and the natural tendency of the fluid to flow from high to low density was manifested as a tendency to flow from high to low temperature. The theory flourished when Lavoisier (1790) included the matter of heat as the element caloric in his treatise that founded modern chemistry; and Carnot (1824) laid the foundations of modern thermodynamics with an analysis of heat engines that still presumed the caloric theory. Around 1850, through the work of Joule, Clausius, Thomson, and others, this material theory of heat fell with the recognition that heat could be converted into other forms of energy. Heat came to be identified with a disorderly distribution of energy over the very many component subsystems of some body; in the case of gases, the heat energy resided in the kinetic energy of the gas molecules, verifying a kinetic theory of heat. The older, material theory could still be recovered as long as one considered processes in which there was no conversion between heat energy and other forms of energy such as work. An example would be the conduction of heat along a metal bar. Exactly because heat is a form of energy and energy is conserved, the propagating heat will behave like a conserved fluid. In the newer theory, the temperature is measured by the average energy density. It is a matter of overwhelming probability that energy will pass from regions of higher temperature (higher average energy) to those of lower temperature (lower average energy), with the result that the heat energy distribution moves towards the uniform. This once again replicates a basic result of the caloric theory: heat spontaneously moves from hotter to colder.

Generative capacity

I call this feature of reduction relations their "generative capacity." In returning the older theories, the relations revive a defunct ontology. More precisely, they do not show that heat is a fluid, or that gravity is a force, or that electrons are purely particles; rather they show that in the right domain the world behaves just as if they were. The advantages of this generative capacity are great. It is not just that the newer theories could now inherit the evidential base of the old. It was also that the newer theories were conceptually quite difficult to work with, and reverting to the older theories often greatly eases our recovery of important results. Einstein's general relativity does assure as that planets orbit the sun almost exactly in elliptical orbits with the sun at one focus. But a direct demonstration in Einstein's theory is onerous. Since much of the curvature of spacetime plays no significant role in this result, the easiest way to recover it is just to recall that Einstein's theory reverts to Newton's in the weak gravity of the solar system, and that the result is a familiar part of Newton's theory. In many cases it is just conceptually easier and quite adequate to imagine that gravity is a force or heat a fluid.

Applied to causation: are causes real?

The situation is the same, I urge, with causation. We have some idea of what it is to conform to cause and effect, although what that amounts to has changed from epoch to epoch and even person to person. The world does not conform to those causal expectations in the sense that they form the basis of our mature sciences. However, in appropriately restricted circumstances our science entails that nature will conform to one or other form of our causal expectations. The restriction to those domains generates the causal properties in the same way that a restriction to our solar system restored gravity as a force within general relativity, or ignoring conversion processes restored heat as a conserved fluid. The causes are not real in the sense of being elements of our fundamental scientific ontology; rather in these restricted domains the world just behaves as if appropriately identified causes were fundamental.

So, are causes real? My best answer is that they are as real as caloric and gravitational forces. And how real are they? That question is the subject of an extensive literature in philosophy of science on the topic of reduction. (For a survey, see Silberstein 2002.) I will leave readers to make up their own minds, but I will map out some options, drawn from the reduction literature, and express an opinion. One could be a fictionalist and insist that causes, caloric, and gravitational forces are ultimately just inventions, since they are not present in the fundamental ontology. Or one could be a realist and insist upon the autonomy of the various levels of science. To withhold reality from an entity, one might say, because it does not fall in the fundamental ontology of our most advanced science is to risk an infinite regress that leaves us with no decision at all about the reality of anything in our extant sciences, unless one is confident that our latest science can never be superceded. My own view is an intermediate one: causes, caloric, and gravitational forces have a derivative reality. They are not fictions in so far as they are not freely invented by us. Our deeper sciences must have quite particular properties so that these entities are generated in the reduction relation. Whatever reality the entities have subsists in those properties, and the properties will persist in some form even if the deeper science is replaced by a yet deeper one. But then they cannot claim the same reality as the fundamental ontology. Heat is, after all, a form of energy and not a conserved fluid. Hence I call the compromise a derivative reality.

Science versus folk science

A major difference between causation and the cases of caloric and gravitational force lies in the precision of the theory governing the entities and processes called up by reduction relations. In the case of caloric and gravitational forces, we call up quite precise theories, such as Newton's theory of gravitation. In the case of causes, what we call up is a collection of causal notions that do not comprise a theory as precise as Newton's theory of gravitation. That no correspondingly precise theory is possible or, at least, presently available is implicit in the continuing proliferation of different accounts of causation in the literature. Yet there is some system and regularity to causal notions called up by reduction relations; hence I have labeled that system a "folk theory" or "folk science."

There are comparable cases in science in which reduction relations call up powers that are not governed by a well worked out but now defunct theory. The simplest example pertains to vacua. We know that in classical physics vacua have no active powers, yet we routinely attribute to them the ability to draw things in—to suck. The appearance of this active power arises in a special but common case: the vacuum is surrounded by a fluid such as air with some positive pressure. The power of the vacuum is really just that of the pressure of the surrounding fluid according to ordinary continuum mechanics. There is no precise account of the active power of the vacuum in the resulting folk theory, which is always employed qualitatively. Any attempt to make it quantitative almost immediately involves replacing the active power of the vacuum by the active power of a pressure differential, whereby we return to the ordinary theory of continuum mechanics. Nonetheless, at a purely qualitative level, it is very convenient to talk of creating the vacuum and to explain resulting processes in terms of a supposed active power of the vacuum.

Causal talk in science has the same status. In many familiar cases, our best sciences tell us that the world behaves as if it were governed by causes obeying some sort of causal principle, with quantitatively measured physical properties such as forces, chemical potentials, and temperature gradients being replaced by qualitative causal powers and tendencies. This proves to be a very convenient way to grasp processes that might otherwise be opaque, just as attributing active powers to a vacuum can greatly simplify explanatory stories. No harm is done as long as we take neither the active powers of the vacuum nor the causal principle too seriously.

The multiplicity of folk notions of causation

There is a second major difference. Newton's theory of gravitational forces or the historical theory of caloric are fixed, so that their recovery from a newer science unequivocally succeeds or fails. Matters are far less clear with causation. The little historical survey of notions of causation in Section 2 and the present literature in philosophy of causation shows considerable variation in views on what counts as causal. Therefore we do not have one unambiguous notion that must be generated by the reduction relations, but many possibilities. Moreover, the notion seems to vary from domain to domain. The sort of causation we recover in physical systems is not quite the same as the sort we recover in biological domains, for example. Finally, our notion of causation evolves in response to developments in the science. May causes act a distance? Is causation anything more than determinism? The answers depend on who you ask and when you ask; and those differences in part result from developments in the relevant science. In crude analogy, seeking causation in nature is akin to seeking images in the clouds. Different people naturally see different images. And different clouds incline us to seek different images. But once an image has been identified, we generally all see it. Moreover, the image is not a pure fiction. It is grounded in the real shape of the cloud; the nose of the face does correspond to a real lobe in the cloud.

5. A Folk Notion of Cause

A sample of the folk theories

When restricting a science to hospitable domains generates cause and effect, just what is it that becomes manifest? We identify a pattern that we label as causal and codify its properties in a folk theory. I have just indicated, however, that there is considerable fluidity in the content of the folk theory and that there are many possible theories appropriate to different times, people, and domains. Nonetheless I do not think that the fitting of causal notions is arbitrary. To illustrate the extent to which this fitting is a systematic activity, in this section, I will try to outline one possible folk theory that I think fairly represents one mainstream view of what it is to be causal. In the znext section, I will illustrate how it is applied. The folk theory will be based on a relation and seven properties that may be attributed to it. I am fairly confident that most causal theorists would not want to endorse all the

properties at once. For this reason the account below really describes a class of folk theories, with the different members of the class arising with different choices of properties. Choosing different subsets of properties, in effect, gives a different folk theory, more amenable to different domains and different views of causation.

My goal is to be distinguished from that of the accounts of causation that are standard fare in the philosophy literature. Their goal is the one, true account of causation that is sufficiently robust to evade the existing repertoire of ingenious counterexamples and the new ones that critics may devise to harass it. My purpose is more modest. I am not trying to enunciate a fundamental principle that must have a definite and unambiguous character. I merely seek to give a compendium of the sorts of things at least some of us look for when we identify a process as causal, without presuming that the compendium is recoverable from a deeper, principled account of the nature of causation. No doubt, the account I offer could be elaborated, but I think little would be gained from the elaboration, because of the imprecision inherent in our current notions of causation. That imprecision supports a multiplicity of distinct theories of causation in the literature, and I have nothing to add to their efforts at capturing the true essence of causation.

In giving folk theories of causation this fragile character I am being a little more pessimistic about the solidity of a folk theory of causation than is evident in the recent philosophical literature on folk psychology, where the notion of a folk theory is most commonly encountered. (See Ravenscroft 1997.) In the spirit of that literature, Menzies (1996) has also sought to characterize causation through what he calls a folk theory of causation. His account is different from mine in that his motivations are not skepticism and his postulates differ from those given below, depending essentially on a probabilistic notion of causation.[10]

The basic notion

It has long been recognized that human action is the prototype of cause and effect. At its simplest, we identify processes as causal if they are sufficiently analogous.[11] We push over a pile of stones and they fall; our action causes the effect of the toppling. We build a tall tower that is too weak and gravity pulls it down; the action of gravity causes the effect of the fall. Using human action as a prototype, *we identify terms in the cause and effect relation whenever we have one that brings about or produces the other; and we identify the process of production as the causal process*.

A popular explication relates causation to manipulability. When a cause brings about the effect, we can manipulate the effect through the cause but not vice versa. This falls short of a fully satisfactory definition, since the notion of manipulation contains residual anthropomorphism and "produces" is little more than a synonym for "causes." However, I do not think it is possible to supply a non-circular definition and, in practice, that does not seem to matter, since, as I shall indicate in a moment, we are able to apply the notion without one.

Applying the notion

It is done as follows. We restrict a science to some hospitable domain. We recover certain processes that are still fully described in the vocabulary of the full science; for example, an acid corrodes holes in a metal foil. We then compare the restricted science to the folk theory of causation and see if we can set up correspondences between terms in the restricted science and in the folk theory. In this case, the acid is the agent that produces or brings about the holes; so we identify the acid as the cause, the holes as the effect, and corrosion as the causal process.

How do we know which terms in the science to associate with the cause and effect? There is no general principle. In practice, however, we have little trouble identifying when some process in science has the relevant productive character that warrants the association. Forces cause the effect of acceleration; or heat causes the effect of thermal expansion; or temperature differences cause the motion of heat by conduction; or concentration gradients cause the diffusion of solutes; or electric currents cause the effect of heating of a resistor; or the cause of a particular electron quantum state produces the effect of a raised probability of a particle detection. The terms in the causal relation may be states at a moment of time; or entities; or properties of entities.

The blob- and-arrow diagram

The relation of cause and effect is so often represented by a particular diagram that I believe the diagram itself can be an important part of a folk theory of causation. It is a diagram in which the cause C and effect E are represented by blobs and the asymmetric causal relation between them by an arrow.

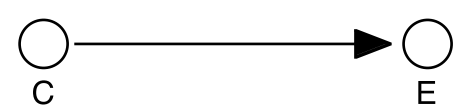

Figure 2. Cause C produces effect E

[10] For comparison, his folk theory is based on three "crucial platitudes": "[T]he causal relation is a relation holding between distinct events"; "[T]he causal relation is an intrinsic relation between events"; "Aside from cases involving pre-emption and overdetermination, one event causes another event just when the two events are distinct and the first event increases the chance of the second event."

[11] That is, I do not mean to offer an account of the nature of causation in terms of human action. I am merely making the weaker point that, in a rough and ready way, we identify causal processes by their analogy to human action. I do not wish to say that anything in this identification is constitutive of causation.

It is common to represent complicated sets of causal interactions by a correspondingly complicated diagram.

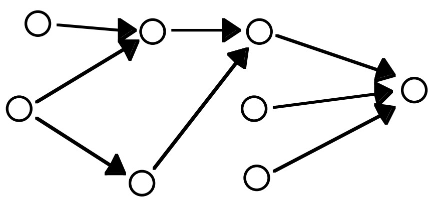

Figure 3. A complicated causal nexus

The particular interpretation of these figures varies by context. In the causal modeling literature, for example, the blobs represent variables that enter into sets of equations (usually linear); the arrows represent the immediate dependencies encoded within the equations (Sprites *et al.* 2000). In other cases, the blobs might represent the presence or absence of some entity or property, and whether the relevant term is present at a blob is determined by some Boolean formula (generally specified separately) from the immediately antecedent blobs.

Properties

The blob-and-arrow diagrams are quite fertile in so far as they suggest properties routinely (though not universally) presumed for causal relations that can be read either directly from the diagram or from simple manipulations of them.

(a) *Principle of Causality*. All states, entities, and properties enter at least as an effect and sometimes also as a cause in causal relations as depicted in Figure 2. Each must enter as an effect, else we would violate the maxim (equivalent to the principle of causality) that *every effect has a cause*. We would have an uncaused state, entity, or property. In terms of the blob-and-arrow diagrams, this means that there can be no blobs that escape connection with arrows; and that a blob-and-arrow diagram is incomplete if it has any blob that is not pointed to by an arrow, that is, one that is not an effect. (See Figure 4.) The cause brings about the effect by necessity; this is expressed in the constancy of causation: *the same causes always bring about the same effects*.

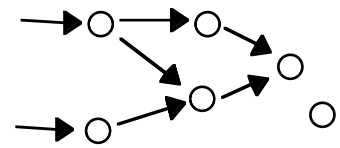

Figure 4. A prohibited uncaused event

(b) *Asymmetry*. The causal relation is asymmetric, as indicated by the arrowhead. Causes bring about effects and not *vice versa*.

(c) *Time Precedence*. The effect cannot precede the cause in time. In so far as times are associated with the blobs, the arrows point from one blob to another that is contemporaneous or later in time.

(d) *Locality*. The blobs indicate that at some level of description, causes can be localized. Most commonly, they are localized in space and time, but they need not be. For example, in medicine we might identify a particular drug as having some causal effect and portray it as a little blob in a diagram, while the drug is actually spatially distributed throughout the body. The action itself is also presumed local, so that both cause and effect are localized in the same place. If the locality is in space and time, then this requirement prohibits action at a distance; causes here can produce effects there only if their action is carried by a medium.[12]

(e) *Dominant Cause*. While many entities and properties may enter into the causal process, it is common to identify just one as the dominant cause and the remainder as having a secondary role. This can be represented diagrammatically by "chunking," the grouping of blobs into bigger blobs or

[12] In his later, far less skeptical treatment of causation, Russell (1948, pp. 491-92) makes this requirement a "postulate of spatio-temporal continuity."

the suppression or absorption of intermediate blobs into the connecting arrow. Chunking allows a complicated causal nexus of the form of Figure 3 to be reduced to the simple diagram of Figure 2 with a single dominant cause.

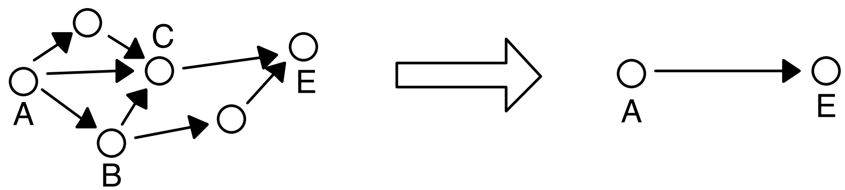

Figure 5. Chunking reveals a dominant cause

(f) *First Cause*. On the model of changes brought about by human action, we expect that every causal process has an initiating first cause. This notion prohibits an infinite causal regress and can be represented by chunking:

Figure 6. Chunking reveals a first cause

(g) *Final Cause*. In cases in which the end state exercises a controlling influence on the course of a process, the process is governed by a final cause. We are used to explaining away apparent cases of final causation as really produced by efficient (initiating) causes. So the modern tendency is to think of final causes as derivative and efficient causes as fundamental. Since I hold neither to be fundamental, there is no reason to deny final causes a place in this list. As we shall see in the next section, invoking the notion of a final cause can supply the same sorts of heuristic advantages as efficient causes. I do not know a simple way of representing final causes in a blob-and-arrow diagram.

While all these properties have been invoked often enough to warrant inclusion here, they are by no means universally accepted. For example, asymmetry might well not be accepted by functionalists about causation, that is, those like Russell and Mach who see causation as residing entirely in functional relations on variables. Time precedence would be denied by someone who thinks time travel or backward causation is physically possible—and a growing consensus holds that whether they are possible is a contingent matter to be decided by our science. Locality must be renounced by someone who judges action-at-a-distance theories or quantum theory to be causal. Someone like Mill who essentially equates causation with determinism may not want to single out any particular element in the present determining state as dominant. The demand for a first cause would not be felt by someone who harbors no fear of infinite causal regresses.

Also, because of their antiquarian feel, I have omitted a number of causal principles that can be found in the literature. Some have been conveniently collected by Russell (1917, pp. 138-39): "Cause and effect must more or less resemble each other"; "Cause is analogous to volition, since there must be an intelligible *nexus* between cause and effect"; "A cause cannot operate when it has ceased to exist, because what has ceased to exist is nothing."

Finally, I do not expect that all the properties will be applied in each case. One may well be disinclined to seek first causes in a domain in which final causes are evident; and conversely, invoking a first cause may lead us to eschew final causes. In choosing the appropriate subsets of properties, we can generate a variant form of the folk theory specifically adapted to the domain at hand.

6. Illustrations

To apply this folk theory to a science, we restrict the science to some suitably hospitable domain. We then associate terms within the restricted science with the central terms of the folk theory; we seek to identify causes and effects such that they are related by a suitable relation of production. Finally, we may seek particular patterns among the causal relations such as those listed in Section 5, above. The way we make the association, just what counts as a relation of production, and the patterns we may find will depend upon the particular content present. If we are interested in weather systems, for example, we would not ask for dominant causes. Because of its chaotic character, the smallest causes in weather systems may have the largest of effects.

The dome: a first cause

As an illustration let us return to the dome considered in Section 3, above. This will illustrate both how the patterns of the folk theory may be fitted to the science and how successful fitting requires a restricted domain. We shall see that expanding the domain can defeat the fit by embracing an evident failure of causality.

The failure of causality arises specifically at time t=T, when the system spontaneously accelerates. Before and after, the system is quite causal in so far as we can map the appropriate causal terms onto the system. To see how this works, let us assume for simplicity that T=0, so that the system spontaneously accelerates at t=0, and let us consider the sequence of states at t=0.5, 0.6, …., 1.0 in the causal period. Neglecting intermediate times for convenience, we can say that the state at each time is the effect of the state at the earlier time and the force then acting. If we represent the state at time t by the position r(t) and velocity v(t), and the force at t by F(t), we can portray the causal relations in a blob-and-arrow diagram. By chunking we can identify the first cause:

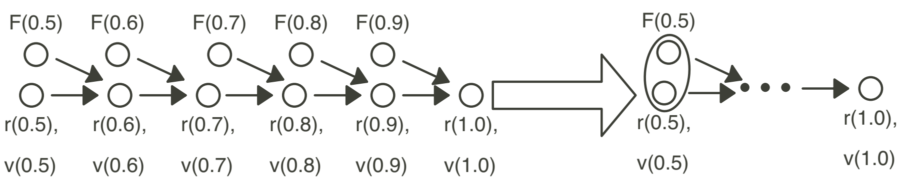

Figure 7. First cause for causal part of motion on the dome

If, however, we extend the time period of interest back towards the moment of spontaneous excitation at t=0, we can

find an infinite sequence of causes at times, say, t=1, 1/2, 1/4, 1/8, … for which there is no first cause:

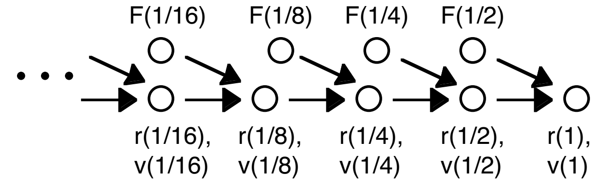

Figure 8. An infinite chain of causes with no first cause

We have already seen the reason for this in Section 3. The mass moves during the time interval t>0 only and there is no first instant of motion in this time interval at which to locate the first cause. (Any candidate first instant t=ε, for ε>0, is preceded by t=ε/2.) Might we locate the first cause at t=0, the last instant at which the mass does not move? As we saw in Section 3, nothing in the state at t=0 is productive of the spontaneous acceleration. One might be tempted to insist nonetheless that there must be something at t=0 that functions as a cause. The result will be the supposition of a cause whose properties violate the maxim that the same cause always brings about the same effect. For the physical state of the system at t=0 is identical with the physical states at earlier times t=-1, t=-2, …, but only the state at t=0 is (by false supposition) causally effective, where the other identical states are not. The folk theory of causation can only be applied in hospitable domains; this difficulty shows that when we add the instant t=0, the domain ceases to be hospitable.

Analogous problems arise in the case of big bang cosmology. The universe exists for all cosmic times t>0, and its state at each time might be represented as the cause of the state at a later time. However there is no state at t=0 (loosely, the moment of the big bang) and the demand that there be a first cause for the process must conjure up causes that lie outside the physics.

Dissipative systems: a final cause

There are many process in physics in which the final state exercises a controlling influence on the course of the process. In thermal physics, processes spontaneously move towards a final state of highest entropy, which is, in microphysical terms, the state of highest probability. Dissipative physical systems are those in which mechanical energy is not conserved; through friction, for example, mechanical energy is lost irreversibly to heat. Such systems can be controlled by their end states in a way that merits the appellation "final cause." Consider, for example, a mass sliding *with friction* in a bowl.

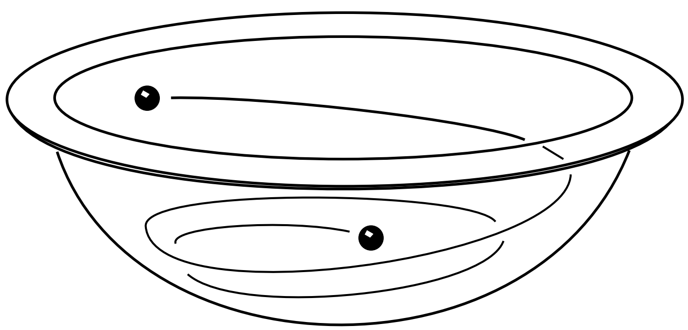

Figure 9. A dissipative system

As long as the initial motion of the mass is not so great as to fling the mass out of the bowl, we know what its ultimate fate will be. The mass may slide around inside the bowl in the most complicated trajectory. Throughout the process it will dissipate energy so that its maximum height in the bowl will lessen until the mass finally comes to rest at the lowest point in the bowl. That ultimate state is the final cause of the process. It seems quite natural to assign that final state the status of final cause. At a coarse-grained level of description, the evolution of the process is largely independent of the initial state, but strongly dependent on the final.

One may want to object that it is somehow improper to assign the term "cause" to this ultimate state; for it exerts no power on the mass in the way, say, that the earth pulls the mass down through a gravitational force. In my view the objection is misplaced. It elevates a gravitational force to the status of a true and fundamental cause, while there are no such things. A gravitational force is a cause in the same way that heat is a material fluid. The generative powers of the reduction relation that confer the character of cause on it can be used equally to confer the character of final cause on the ultimate state of this dissipative process.

Scope

The illustrations above and those earlier in the paper are drawn largely from the physical sciences, for there it is possible for me to give the most precise account of the extent of viability of causal notions. I intend and hope that the account will be applicable in other sciences, although it is beyond this paper to put my hope to the test. I expect that the character of the application may change. In the physical sciences, an important reason for choosing a restricted domain is to fence off processes that are acausal. A second reason to which I gave less attention is that different domains manifest different sorts of causes. In this section, the first illustration manifests efficient causes; the second, final causes. I expect this latter case to be prevalent in chemistry and non-physical sciences—that the restriction to different domains will divide different types of causation, as opposed to fencing off acausal processes. So chemical potentials might appear as efficient causes in one domain of chemistry and, in another, equilibrium states might appear as final causes. Correspondingly in biology, viruses and bacteria might appear as efficient causes of diseases, while adapted forms in evolutionary biology might appear as final causes.

7. Conclusion

The goal of this account of causation in science has been to reconcile two apparently incompatible circumstances. On the one hand, causes play no fundamental role in our mature science. Those sciences are not manifestly about causation and they harbor no universally valid principle of causality. On the other hand, the actual practice of science is thoroughly permeated with causal talk: science is often glossed as the search for causes; and poor science or superstition is condemned because of its supposed failure to conform to a vaguely specified principle of causality. I have argued that we can have causes in the world of science in the same way as we can retain the caloric. There is no caloric in the world; heat is not a material substance. However, in many circumstances heat behaves just as if it were a material fluid, and it can be very useful to think of heat this way. It is the same with cause and effect. At a fundamental level, there are no causes and effects in science and no overarching principle of causality. However, in appropriately restricted domains our science tells us that the world behaves just as if it conformed to some sort of folk theory of causation such as the one outlined above. We should expect these folk theories to be sketchy; we should not expect them to conjure up the exceptionless explication of causation that continues to elude the present philosophical literature. They serve their purpose, however, if they capture what it is we seek when we fit causal conceptions to some process, even if they preserve the vaguenesses of our practice. [13]

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