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CAUSATION AS SIMULTANEOUS AND CONTINUOUS

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ABSTRACT

We propose that all actual causes are simultaneous with their direct effects, as illustrated by both everyday examples and the laws of physics. We contrast this view with the sequential *conception of causation, according to which causes must occur prior to their effects. We find that the key difference between the two views of causation lies in differing assumptions about the mathematical structure of time.*

1. INTRODUCTION

The *sequential theory of causation* holds that causes always precede their effects. This idea fits naturally with a certain conception of laws of nature, according to which these laws typically take the form:

> Events of type *C* are followed by events of type *E*.[1]

But in many everyday cases and in many laws of physics, causes and effects seem to occur at the same time. The *simultaneous theory of causation* holds that causes always occur simultaneously with their *immediate* effects. This coheres with the view that causal laws typically take the form:

> Temporally extended action *E* occurs simultaneously with temporally extended cause *C*.

Many of these laws are differential equations in which rates of change are related to simultaneously existing causal factors.

Grasping the theory of simultaneous causation requires some cognitive shifts from the sequential view. We will give a few examples of simultaneous causation and then examine some arguments against it and the conception of time that makes these arguments seem plausible. This will root out some of the deeper aspects of time and change that underlie simultaneous causation.

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[1]This view of causation and laws derives from Hume (1992, p. 170; although Hume does not use the terminology of *laws*) and has been assumed, with modifications immaterial to our present point, by such thinkers as Mill (1973, pp. 327, 344), Mackie (1974, pp. 61ff.), and Horwich (1987, pp. 134-5); but note that Mackie and Horwich go on to make room for at least some cases of simultaneous causation. Tooley (1997, chap. 9) provides a different form of the sequential theory of causation, analyzing temporal priority in terms of causal priority.

2. SIMULTANEOUS CAUSATION IN EVERYDAY LIFE

There seem to be a number of everyday examples of simultaneous causation:[2]

1. A lead ball is resting on a cushion. The presence of the ball causes an indentation in the cushion.
2. A train engine is pulling a caboose (it's a very short train). The movement of the engine is responsible for the movement of the caboose.
3. An iron bar is glowing because of its high temperature.
4. The lowering of one end of a seesaw causes the other end to go up.
5. Moving one end of a pencil causes the other end to move.

In all of these cases, it seems that the cause and the effect exist simultaneously.

Proponents of the sequential conception of causation argue that this appearance is an illusion—that when we examine the cases on a more detailed, scientific level, we realize that there is a slight time delay involved in all of these cases. Take case 3: "on the atomic level we know there are lags between the absorption of energy by an electron and its radiation which provide for a lag between the heating and the glowing of an iron bar."[3] Or take case 2: because no real-world materials are perfectly rigid, there will be some amount of stretching of the couple between the engine and the caboose when the engine first begins to move, so that the caboose will begin to move slightly later than the engine. Similarly, when the engine stops, there will be a slight compression of the couple, so that the caboose will

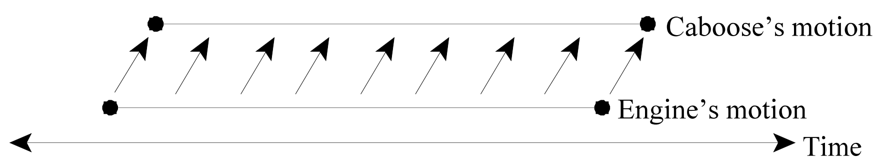

Figure 1. Staggered view of causation. Diagonal arrows represent causal relations.

stop slightly later than the engine.[4] Thus, the engine's motion and the caboose's motion are temporally staggered as in figure 1. This makes it plausible to hold that each stage of the engine's motion causes a slightly later stage of the caboose's motion. A further argument favoring this interpretation of the case is that the special theory of relativity forbids instantaneous action at a distance; no causal influence can be transmitted faster than the

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[2]These examples derive, respectively, from Kant (1965, A203); Taylor (1973, p. 35); Gasking (1955, p. 479); Brand (1980, p. 138); and Tooley (1987, pp. 107-8).

[3]Rosenberg (1975, p. 253).

[4]This objection is discussed in Taylor (1973, pp. 35-6) and Brand (1980, p. 138). Relevantly similar objections to similar examples appear in Rosenberg (1975, p. 253) and Tooley (1987, p. 208).

speed of light.[5] Since the train engine and the caboose are at some distance from one another, there must also be a time delay for the one to act on the other.

If this analysis of case 2 is correct, then it seems that similar analyses can be given of cases 1, 4, and 5, showing that we have temporal overlap between cause and effect, but not complete temporal coincidence. The theory of simultaneous causation, on this view, is only an approximation to a more precise, staggered view of causation.

Is this correct? Let us turn to a more explicit examination of the treatment of causal relations in physics.

3. SIMULTANEOUS CAUSATION IN CLASSICAL PHYSICS

The prototypical example of simultaneous causation is Newton's second law of motion:

$$\vec{F} = m\vec{a} \qquad \text{or} \qquad \vec{F} = m\frac{d^2\vec{x}}{dt^2}$$

In words: a body's acceleration at any time is proportional to the force exerted on it at that time and inversely proportional to the body's mass.[6]

Collisions are especially simple and intuitive examples of bodies exerting forces on each other. Consider two balls moving toward each other. When they make contact, each begins to push against the other. During the collision, the balls each deform slightly, the magnitude of the repulsive force increasing as the amount of deformation increases. As the deformation reaches its peak, the force between the balls also peaks. Finally, as the balls are returning to their original shape and moving away from each other, the force between them decreases back to zero.

Notice that as the force acting on either body increases and decreases, the body's acceleration changes simultaneously. There is no time delay between one body's pressing against the other and the latter undergoing the resulting acceleration and compression. Notice also that the forces change continuously because the relative positions and velocities of the particles in the two balls are changing continuously—and that those changes are themselves caused by the forces being exerted—which are themselves just a way of describing the influence of the bodies on each other by virtue of their relative velocities and positions.[7]

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[5]Tooley (1987, p. 208) deploys this argument. The main reason for believing special relativity to forbid faster-than-light influences is that, in special relativity, a pair of spacelike separated events have no objective time order: different reference frames disagree on which event precedes the other. But note that this argument fails if one accepts the possibility of backwards causation (Maudlin 2002, pp. 154-5).

[6]Dummett (1954, p. 29) too deploys this example in support of the existence of simultaneous causation. However, he seems to view the relationship as holding between two instantaneous events, as in the interpretation we disclaim below.

[7]In using this example, we imply that forces cause accelerations—these forces being, in turn, caused by the aspects of a physical system's configuration identified by the force laws (e.g., the masses, electric charges, and distances of particles from each other). One

The Lorentz equation in the theory of electromagnetism provides another example of simultaneous causation. According to the Lorentz equation, a body with charge *q* moving at velocity *v* through electric and magnetic fields experiences a force given by

$$\vec{F} = q\vec{E} + q\vec{v}\times\vec{B}$$

where *E* and *B* are the electric and magnetic field vectors at the body's current location in space. The vectors *E*, *v*, and *B* will typically vary over time, along with *F*, and the value of *F* at any given time is determined by the values of *E*, *v*, and *B* *at that time*. Bodies always experience the effect of the electromagnetic field at their location in space and time.

Similar points hold for all the equations of classical physics: one never posits a force, acceleration, or other effect resulting *after* some causally relevant factor exists. Rather, these equations posit forces determined by the present configuration and properties of physical objects. The configurations of physical objects are, in turn, continuously changing at a rate determined by those forces.

4. HOW ARE EXTENDED CAUSAL PROCESSES POSSIBLE?

Hume and others have argued that if causes and effects were simultaneous, then there could be no temporally extended causal chains. This seems very plausible. Suppose e_1 causes e_2, which causes e_3, and so on. If e_1 is simultaneous with e_2, and e_2 is simultaneous with e_3, and so on, then every event in the series must occur at the same time. So no event could be causally connected to any event at any other time.[8]

This argument is valid within the structure of time that Hume assumed. Elsewhere in the *Treatise*, Hume had argued:

> 'Tis a property inseparable from time, and which in a manner constitutes its essence, that each of its parts succeeds another, and that none of them, however contiguous, can ever be co-existent. … 'Tis certain then, that time, as it exists, must be compos'd of indivisible moments.[9]

There seem to be two important aspects of Hume's view of time here, namely: (a) that any time interval can be divided into some smallest parts, and (b) that for any such indivisible part, there is a *next* one following it. If we accept this picture of the structure of time, then we can, and indeed must if we are to recognize extended causal processes, embrace the

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might question this interpretation of Newton's Second Law, either by proposing instead that force is simply *defined* in terms of mass and acceleration, or by taking an instrumentalist view of forces. In this case, one would say that a body's rate of acceleration at a given time is causally determined simply by the configuration, at that time, of the physical system of which it is a part.

[8]This argument first appears in Hume (1992, p. 76) and is repeated by Ehring (1985) and Taylor (1973, p. 38).

[9]Hume (1992, p. 31).

sequential conception of causation.

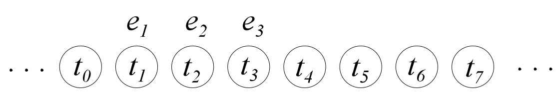

Figure 2. Hume's particulate conception of time. e_1, e_2, and e_3 are atomic events in a causal chain.

The simultaneous conception of causation premises a different structure of time and change. In the simultaneous conception, time and the processes that occupy time are understood as having the mathematical structure of the continuum. There are no smallest events—any temporally extended event has temporally extended parts. Nor does there exist a *next* instant of time following any other instant—for any two points in time, there are other points between them.

In this understanding of time and change, temporally extended events are not conceived as being "built up" from some smallest units. Rather, every event is already a temporally extended whole, which can be divided into indefinitely many parts, each of which is itself a temporally extended event.

Thus, for example, the law "$F = ma$" should not be understood as stating that a discrete force-exerting event, "F", occurs at one moment and causes a discrete accelerating event, "a", to occur at that moment (nor at "the next" moment as in the sequential conception of causation). Instead, the law states a continuous relationship existing between the variables F and a throughout any time interval: a force exerted for any length of time causes a change

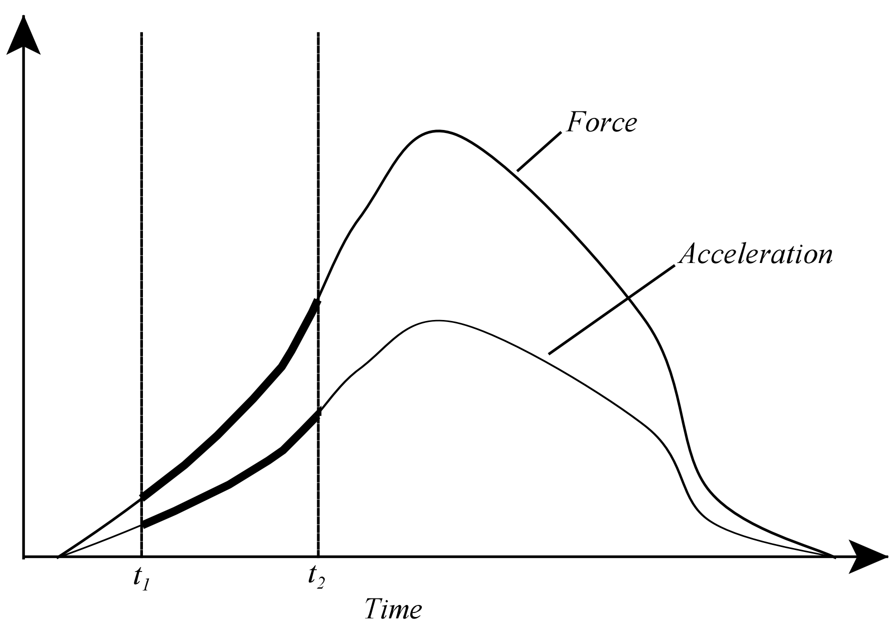

Figure 3. Causation in a temporal continuum. The force-exerting event over any arbitrary interval—say, from t_1 to t_2—causes the corresponding acceleration over that same interval.

in velocity over that interval proportional to the integral of the force over the time interval.

Nor does the law describe a relationship between infinitesimal quantities as Paul Horwich suggests[10]:

> If time were discrete, then we could reduce this law to more basic terms, so that it specified the state at one time in terms of the state at the preceding time
>
> $St(t+1) = g(St(t))$
>
> However, since time is continuous, the most direct cases of [causal] determination are those in which the state at a given time determines the state at an infinitesimally different time, and the most basic laws are the differential equations that describe this form of determination:
>
> $St(t+dt) = g(St(t))$ or $dSt / dt = h$

Here Horwich appeals to a Leibnizian notion of infinitesimal quantities in order to reconcile the sequential conception of causation with the form of the dynamical laws of nature as differential equations.

The standard modern analysis does not incorporate such quantities. This is the reason for the "delta and epsilon" proofs developed by Cauchy, Weierstrass, and others and found in standard calculus texts today. Briefly, the delta-and-epsilon proofs demonstrate that a rate-of-change quantity such as dv/dt can be understood purely in terms of relationships between finite quantities—finite velocity-differences and finite time-intervals in this case.[11] A causal law containing a derivative with respect to time does not require the existence of instantaneous changes, indivisible intervals, or infinitesimal quantities.

Just as the 'particulate' structure of time envisioned by Hume requires a sequential view of causation, a continuous temporal structure requires a simultaneous view of causation, given one plausible auxiliary assumption. This auxiliary assumption, which Hume himself accepted, is that of the impossibility of action at a temporal distance: "[N]othing can operate in a time or place which is ever so little remov'd from those of its existence."[12] The intuition is that a causal factor cannot exercise a direct influence on anything at a time when that factor does not exist.[13] Within Hume's particulate temporal structure, this generates the requirement

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[10]Horwich (1987, pp. 134-5).

[11]dv/dt may be defined as the real number, a, such that for every $\varepsilon > 0$, there exists a $\delta > 0$ such that, whenever $|\Delta t|$ is less than δ, $|v(t+\Delta t) - v(t) / \Delta t|$ is within ε of a. Notice that this definition only quantifies over real numbers.

[12]Hume (1992, p. 75).

[13]We interpret this to mean that no occurrence can be directly causally relevant to an occurrence at a nonzero temporal distance from it.

that cause and effect should be contiguous. To see why this principle, together with the continuous structure of time, leads to a simultaneous conception of causation, suppose that A is a direct cause of B, and that B follows A. There are four possibilities:

Case 1: A and B are instantaneous (exist at exactly one point in time). The points in time at which A and B occur must have some distance between them: if the distance is 0, then they are the same point, and A and B are simultaneous. But if the distance is nonzero, then we have action at a temporal distance. In Hume's scheme, we would resolve the difficulty by supposing the points to be contiguous. But in the continuous conception of time, a given point in time has no contiguous point, no 'next point' following it.

Case 2: A and B are temporally extended events, with B following A. Is A directly causally relevant to *the second half* of B? If so, then we have action at a temporal distance. If not, then it seems that A does not directly cause B as a whole but at most directly causes the part of B that it borders on (it may cause the rest of B indirectly).[14] Again, there is a solution to this dilemma within the Humean structure of time: Hume could hold B to be an indivisible event. This resolution is not available in the continuous conception of time, wherein all nonzero time intervals are infinitely divisible.

Case 3: A is instantaneous and B is temporally extended. Then the argument from case 2 applies.

Case 4: A is temporally extended and B is instantaneous, with B following A. Is the *first half* of A directly causally relevant to B? If so, then we have action at a temporal distance. If not, then A as a whole does not directly cause B.

In a world with a continuous temporal structure and no action at a temporal distance, then, a cause cannot precede its immediate effect; they must be simultaneous.

5. THE PRINCIPLE OF RECIPROCITY

Robin Le Poidevin discusses a principle he calls "the Principle of Reciprocity," which states that in any interaction, the cause is always altered as a direct result of its bringing about the effect.[15] Le Poidevin argues that this principle conflicts with the idea of simultaneous causation. Consider two examples.

First example: Two billiard balls, A and B, collide, and A causes B to begin moving. The cause here is A's initial momentum, and the effect is B's final momentum. If cause and effect are simultaneous in this case, then at the moment of the collision, A must have its initial (pre-collision) momentum and B must also have its final (post-collision) momentum. But such a state of affairs would violate the law of conservation of momentum.

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[14]See Waterlow (1974, pp. 376-7) for an essentially similar argument.

[15]Le Poidevin (1991, p. 83). He makes further refinements to the principle (p. 88). The two examples following are from Le Poidevin (pp. 88-92).

Second example: A lead ball is placed on a cushion, causing an indentation in the cushion. Focus on what happens when the ball is lowered onto the cushion. When they make contact, the ball exerts a force of magnitude F, say, on the cushion, which causes some small amount of compression of the cushion. Now, once the cushion is (partially) compressed, the cushion will exert a force (in addition to the reaction force against F) on the ball due to that compression. By Newton's third law, this additional force would then induce a reaction force R from the ball. If the causes and effects in this case happen simultaneously, then at the moment when the ball exerts a (total) force of F, it exerts a force of F + R, *because* it exerts a force of F!

The difficulty in the first example arises from treating the collision as an instantaneous event. Instead, the collision occupies a finite, albeit brief, interval of time, during which A's momentum is continuously decreasing and B's is continuously increasing. At any given time, the instantaneous rate of change of A's momentum is causally related to the instantaneous rate of change of B's momentum—intuitively, we say that A is transferring its momentum to B. Now, Le Poidevin takes it that *A's having an initial momentum of x* causes *B's having a final momentum of y*. But this is not an instance of direct causation, since there is a causal intermediary between the two states of affairs, namely, the collision event itself. Similarly, if one takes A's momentum at any time during the collision and B's momentum at some later time, there is a causal intermediary between these two states.

Now turn to the second case. Le Poidevin supposes that the ball's exerting a force of magnitude F on the cushion causes some compression in the cushion, resulting in a slightly greater force a little later. But because the force exerted by the ball is continuously changing, it takes on any given magnitude at only one instant. A force exerted at a single instant (for zero duration) cannot produce any deformation in the cushion. So *the ball's exerting a force of magnitude F on the cushion* cannot be taken as the relevant cause. We must let the relevant cause be the ball's exerting a (varying) force on the cushion over some finite time interval. And the corresponding compressing of the cushion will also be occurring during exactly that time interval.

Alternately, we could take *the ball's exerting a force of F on the cushion at time t* as the relevant cause, and take the effect as the instantaneous rate of change in the cushion's shape at *t*.[16]

6. DISTINGUISHING CAUSE AND EFFECT

An interesting question that the theory of simultaneous causation raises is that of how one may determine which factors are causes and which are effects. On the standard interpretation of the causal laws, physical configurations—the spatial arrangements of bodies together with their intrinsic properties, such as mass and charge—cause forces, which cause accelerations. Given that a configuration exists simultaneously with the corresponding set of forces and accelerations, is it possible to reverse the normally accepted causal priority relations? Why not hold that accelerations causes forces, which cause physical configurations?

There are a number of answers to this. One reason why we prefer the standard

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[16]More precisely: the force exerted by the ball is a partial cause of the rate of acceleration of the particles at the surface of the cushion.

interpretation over the alternative interpretation lies in the intuitive notion of a force as a body's pushing another body in a certain direction—this seems intuitively like the right sort of thing to cause a kinematic effect.

A second reason is that the alternative interpretation cannot supply sufficient causes for the effects it identifies. The alternative interpretation would hold that accelerations causally explain configurations. However, from a knowledge of a body's rate of acceleration, together with a knowledge of the physical laws, one cannot recover the configuration of the body, let alone that of the system including the body and its environment; many different configurations are compatible with a given rate of acceleration. In contrast, a given configuration of a physical system is compatible with only one rate of acceleration for each of the bodies in the system. In other words: mathematically, the physical laws determine a function from possible specifications of a system's configuration to specifications of the acceleration of any part of the system, but not vice versa. As a result, the standard interpretation can supply sufficient causes for the events it identifies as effects, while the alternative interpretation cannot.

To illustrate the point, suppose body A is in free fall near the surface of the Earth and is undergoing an acceleration of 9.8 meters per second per second. Another body, B, is also undergoing an acceleration of 9.8 meters per second per second, but B is not in free fall. Instead, B is in a car whose driver is stepping on the gas pedal. According to the standard causal interpretation of the laws, A and B are experiencing qualitatively the same effect, produced by different causes. But in the alternative interpretation, what we have are qualitatively identical *causes* (accelerations of 9.8 meters per second per second), with radically different effects.

7. SUMMARY

A central question, addressed in different ways by the sequential and simultaneous conceptions of causation, is this: given the assumption that a causal factor cannot act over a temporal distance, how is it possible to account for causally connected processes that take place over extended time periods? The sequential conception of causation provides an answer to this question within an atomistic structure of time: temporally extended causal processes consist of series of discrete, contiguous events, one beginning in the moment after another ends, and causation connects one moment to the next. The simultaneous conception of causation provides a different answer, within a continuous temporal structure: rates of change of causally relevant factors vary continuously throughout a given time interval according to a rule relating them to the current values of the causal factors themselves.

The conception of causation as simultaneous and continuous is illustrated by the laws of classical physics. Properly understood, the theory does not require that all events in a causal chain occur simultaneously, it does not conflict with the principle that causal factors are often themselves altered during an interaction, and it does not preclude our ability to distinguish cause from effect.

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