Synthese (2022) 200:308
https://doi.org/10.1007/s11229-022-03752-5

ORIGINAL RESEARCH

A causal ontology of objects, causal relations, and various kinds of action

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Received: 6 November 2020 / Accepted: 21 May 2022

Abstract
The basic kinds of physical causality that are foundational for other kinds of causality involve objects and the causal relations between them. These interactions do not involve events. If events were ontologically significant entities for causality in general, then they would play a role in simple mechanical interactions. But arguments about simple collisions looked at from different frames of reference show that events cannot play a role in simple mechanical interactions, and neither can the entirely hypothetical causal relations between events. These arguments show that physics, which should be authoritative when it comes to the metaphysics of causality, gives no reasons to believe that events are causal agents. Force relations and some cases of energy-momentum transfer are examples of causal relations, with forces being paradigmatic in the macroscopic world, though it is conceivable that there are other kinds of causal relation. A relation between two objects is a causal relation if and only if when it is instantiated by the two objects there is a possibility that the objects that are the terms of the relation could change. The basic metaphysics of causality is about objects, causal relations, changes in objects, and a causal primitive. The paper also includes a discussion of the metaphysics of forces and a discussion of the metaphysics of energy and momentum exchanges.

1 Introduction

The position defended in this paper is that the basic kinds of physical causality that are foundational for other kinds of causality involve objects and the causal rela-

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Published online: 20 July 2022

tions between them.[1] The objects, or substances, that are the subject of this paper are mostly macroscopic, though a few things will be said about microscopic objects. Force relations and some cases of energy-momentum transfer are examples of causal relations, with forces being paradigmatic in the macroscopic world, though it is conceivable that there are other kinds of causal relation. Causal relations between objects are "the objective, physical, causal connections that Hume sought in vain" that drive the world (Salmon, 1994). Some of the metaphysical problems associated with forces and with exchanges of energy and momentum will be discussed in some detail.

These basic kinds of physical causality do not involve events. If events were ontologically significant entities for causality in general, then they would have to play a role in simple mechanical interactions. But it will be seen that they cannot play a role in simple mechanical interactions. One of the reasons is that the cause event and the effect event identified in one frame of reference are not the same as the cause event and effect event identified other frames of reference. In fact, what is the cause event and effect event in one frame could be reversed in another frame, so that original cause event becomes the effect event, and the original effect event becomes the cause event, contrary to the usual philosophical understanding of causality. The case I have in mind is where in one frame of reference a billiard ball strikes one at rest, and in another frame of reference the ball that was moving is at rest and the ball that was at rest is moving.

If events were causes and effects, then we would expect there to be causal relations between them.[2] But an examination of simple mechanical situations will show no signs of interaction between events. It is also difficult physically to identify causal relations between events, whereas it is easy to find causally significant relations between objects. Causal relations can be explained as follows: a relation between two objects is a causal relation if and only if when it is instantiated by two objects there is a possibility that the objects that are the terms of the relation could change as a consequence. It is only a possibility because it is also possible that change could be prevented.

Even though the basic kinds of causal interaction between objects are symmetrical, there are situations in which there is asymmetry in causality. One example is the development through time of a complex system composed of parts that interact via symmetric causal relations, where earlier states of the complex system give rise to later states. There are two different kinds of action here: the symmetric interaction of the parts are examples of transitive action, whereas the asymmetric evolution of the complex system is an example of developmental action. In *transitive action*, two different objects act on each other by means of a causal relation in such a way that both

[1] Norton 2003 expands on Russell's idea that science is not about causality (see Sect. 4 of this paper). Nevertheless, he thinks better of the theories of Salmon and Dowe (see Sect. 4). Although my distinctions are in a sense *a priori*, I see what I am doing as an example of basic philosophy of physics, and I also think that the making of distinctions is one of the more important things that philosophy does. Though *a priori*, I do not think it is armchair philosophy in Norton's sense.

[2] Event theorists take both causes and effects to be events. There is a tendency for philosophers to think that causes and effects are ontologically the same kind of thing. On the other hand, someone could conceivably take the activity of the sculptor to be the cause and an event and the sculpture to be the effect and an object.

objects are changed. In *developmental action*, a system evolves through time, where the changes are not due to things outside of the system, but due to the interactions of the parts of the system.[3] The traditional example of developmental action was that of an organism, which, though not isolated, changes in a way that is generated from within the organism.[4] The interaction between two planets via forces is an example of transitive action whereas the development of the solar system as a whole on account of the interaction of the parts is an example of developmental action.

Causal chains are another example of asymmetry in causality. They include designed mechanisms, such as the mechanism that relates a trigger in a rifle to the movement of the firing pin. Such mechanisms consist of objects that interact with one another via symmetric causal relations and other forms of causal action. They are typically designed such that when the mechanism is used, it only works in one direction to achieve one result, which introduces the asymmetry. Designed causal chains are discussed in Sect. 11.

2 Recent causal ontologies and symmetry

A number of things have been suggested as causally significant entities. They include: events, facts (states of affairs), processes, substances (objects), properties, property instances, tropes, and powers.[5] Event causation and substance causation appear to be connected since events will have substances as components so that it is conceivable that the causal action of substances could be understood in terms of events. Whittle 2016, for example, defends substance causation but thinks that substances cannot act alone, and that causation also requires events, so that both substances and events are causes. It appears that one of the things that she is trying to do is to make use of events to introduce the expected asymmetry into causation: the expected direction of causation is from cause to effect and not the other way round. She does not, however,

[3] A counterfactual account of causality might regard both developmental action and transitive action as forms of causality. But if it did, that would be of no significance.

[4] Aquinas talks about *actio immanens* or *operatio immanens* and *actio transiens* or *operatio transiens*, see *Summa Contra Gentiles*, III, 1 and *Summa Theologica*, 1a, q. 18, a. 3 ad 1, q. 23, a. 2 ad 1, q. 54, a. 1 ad 3. For Chisholm 1966, transeunt causation refers to an event causing another event; immanent causation refers to an agent causing an event. Dowe 2000, p. 52 ascribes the distinction to Leibniz, who distinguished between intrasubstantial or immanent causation versus intersubstantial or transeunt causation. Spinoza made a distinction between self-causing (*causa sui*), immanent causing (*causa immanens*), which has to do with the persistence of one thing, and transitive causing (*causa transiens*), which involves transference from one thing to another, see Lærke 2010. Cf. Spinoza, *Ethics*, I, def. 1 and prop.8 and Bennett 1984, p. 113.

[5] To take a few examples: Whittle's 2016 defends joint substance-event causation. She thinks that events are the “the front runner”. Weaver 2019 defends event causation in the context of philosophy of physics. He explains the role of causal relations, but they are a new, hypothetical kind of entity. Menzies 2009 defends events within a linguistic approach to metaphysics. Buckareff 2017 in his critique of Whittle, defends the causal powers of substances as causes. Tropes as causal relata have been defended by Ehring 1999 and 2011 and by Garcia-Encinas 2009, and, earlier, notably by Campbell 1990. Lowe 2008, pp. 54 – 5 & 110 distinguishes between fact causation and event causation. Salmon 1984 and Dowe 2000 take causal processes, which are constructed out of events, to be causally significant. Ehring 2009 is a very long discussion of causal relata.

mention causal relations or whether substances are related by one kind of causal relation and events by some other kind of causal relation, and so does not mention how are those relations are related.[6] Heil 2012 recognizes the causal importance of substances over events, and, significantly, takes causation to be symmetrical and reciprocal. For him, “causings” are the mutual manifestings of powers (or dispositions), though in addition to “causings”, there are also causes and effects. Apart from powers or dispositions, it is difficult to know exactly what the other metaphysical categories are that he is appealing to.[7]

In contrast, Menzies 2009 believes that events alone are causes and effects, but again makes no mention of what relates them.[8] He recognizes that events may have substances, which what I call objects, as components, but for him the action of substances is completely submerged in the events that they are components of. He rejects substances as causes because ordinary language sentences involving substances can always be translated into sentences about events. He appears to be inferring things about the world from how ordinary language is used, though he does also make use of the notion of truth makers.

The aim of Massin 2009 is to defend the reality of forces, where he takes forces to be dyadic, symmetric relations between objects. Although he recognizes that forces are causally significant, as I think he must, he denies that they are themselves causal relations, and the reason he gives is that forces are symmetric. Since he expects causal relations to be asymmetric, he must develop a more complex way of explaining the role of forces in causality. He does this by means of causal relations that are additional to the force relation and which assist the force relation, though he does not appear to want to make use of events. Likewise, Wilson 2007 defends the reality and symmetry of forces and also has to find a way to explain how they figure in causal interactions, again not making use of events. Weaver 2019 assumes the reality of forces and events and has an even more complex way of explaining the role of forces in causality, where Massin adds two causal relations to an interaction between two objects, Weaver adds four. However, the causal relations of Massin and Weaver are entirely hypothetical. The attempts of Massin, Wilson, and Weaver to explain of the role of forces in interaction can be regarded as attempts to explain the fundamental causal connection.[9]

[6] She makes a number of interesting points about causation to help justify her claims. She believes that causes can be collective, so that a substance and an event can both be among the causes of some effect.

[7] Heil cautions “. . it is important to see that one and the same power is capable of manifesting itself differently with different kinds of reciprocal partner ” (p. 121, cf. p. 133.)

[8] Events theorists have a number of different kinds of event available to them. Kim 1976 defends fine-grained events, see also Bennett 1988, Chap. V, whereas Davidson 1967 defends coarse-grained events, see also Bennett 1988, Chap. IV. Ehring 2009, like Bennett, gives accounts of a number of different kinds of event. Lowe 2002, Chap. 13 is a discussion of the elimination of events. See also Casati & Varzi 2008, pp. 31–54. Fine-grained events can be described in only one way. Two events are the same if and only if they have the same constituents, which are objects, properties, relations, and times. Coarse-grained events can be described in many different ways. Two events are identical if and only they have the same causes and effects. Paul 2000 gives a critique of both fine-grained and coarse grained events.

[9] Heil 2012, Sect. 6.2 talks about the causal nexus, which is the same thing.

3 Metaphysical terms and assumptions

The ontology defended in this paper consists only of objects, properties, and relations. Objects are entities that instantiate properties and are not themselves instantiated by anything else. Among paradigmatic properties are those known to science, such as shape, mass, and charge; hence, objects are things that can instantiate properties like these. Such objects are located in the space-time world, they persist through time, and they persist through changes of properties. Macroscopic objects are taken to be real composite wholes that can be the terms of relations such as forces, though they are not the only things that can be terms of causal relations. This view is defended by Wilson 2007 and Newman 2013.[10] Events and states of affairs, if there were such things, might be particulars, but they would not be objects, though they are closely connected to objects since objects would be among their components.

4 Critique of events in simple interactions: Windows, baseballs, and Billiard Balls

Some conclusions can be drawn about the interaction of objects by considering some simple physical examples, such as how baseballs break windows and how billiard balls collide with each other. It will be seen that all that is needed to account for these examples are objects and the causal relations between them, and that no purpose is served in introducing events as an additional ontological category.

When a baseball breaks a window, it is supposed that the cause is the event of the ball's striking the window, and that the effect is the event of the window's breaking. The event of the ball's striking the window starts when the ball first touches the window and there begins to be a force between them; it ceases when there ceases to be a force on the ball, which I assume is when the breaking ends. The window first bends elastically for a finite period of time and then begins to break. The event of the window's breaking starts when cracks begin to appear, and it ceases when the window has separated into the independent pieces that fall to the ground.[11] The bending and the breaking do not overlap. Hence, there are three different events: a striking, a bending, and a breaking, which can be depicted as follows with time progressing from left to right:[12]

| ———— Striking ———— |

| — Bending — | — Breaking — |

[10] There are causally significant boundaries that separate the matter of the object from other matter; there are emergent properties of solid objects, such as the conduction band in metals; and so on, Newman 2013.

[11] It would still be a breaking even if the cracks remained just cracks, but in the case being considered, it is a breaking that starts with cracks and ends with separate pieces.

[12] The events that would be appropriate here may be the coarse grained events of the early Davidson, see fn.8.

The left-hand boundaries of the events and the boundary in the middle are fairly sharp, whereas the right-hand boundaries are less sharp. These events are not independently existing entities. They are related in that the events have as components two objects: the striking has both objects as components, and the bending and the breaking have just the window as a component. There is a metaphysical clue in that it is the objects, namely, the ball and the window, that are the independently existing entities.

On an events view, the event of the baseball's striking the window must cause the event of the window's bending. In this case the cause overlaps the effect, and continues after the effect event has ceased.[13] The event of the ball's striking the window must also cause the event of the window's breaking. In this case the events also overlap, but in such a way that they both end together. The bending and the breaking do not overlap; they touch. Does the bending also cause the breaking? There is antecedence and contiguity, which are traditional criteria for causality.[14] Another question raised here is the general one of what is the temporal relation between cause events and effect events? And a more specific question is how do the causal relations work in this case?

Unfortunately, there is something wrong with this account from the point of view of physical science. This can be seen by noticing that there is no essential difference between a baseball striking a window and one billiard ball striking another.

Consider the elastic collision of two billiard balls, **A** and **B**, in empty space moving in a straight line that joins their centres. While in contact the billiard balls change shape, which is analogous to the bending of the window. Consider looking at the collision from the point of view of three different frames of reference, labelled 1, 2, and 3, where time is always thought of as going in the same direction. This approach is consistent with Newtonian mechanics and special relativity, and, in effect, originated with Huygens in the 17th century.[15] Technically, the frames of reference are the inertial frames that are common to Newtonian mechanics with absolute space and absolute time, Newtonian mechanics with Galilean space-time, and special relativity. An inertial frame is one that is not accelerating.

The initial states before the collision are on the left of the arrows, and the final states after the collision are on the right of the arrows:

[13] In this case, the supposed cause and the effect start together and are simultaneous for a period of time. Cf. "[It] is presumed that it is metaphysically impossible for an effect to precede, or even to be simultaneous with, one of its causes." Lowe 2002, p. 230. On the other hand, simultaneous causation has been defended by Huemer & Kovitz 2003. They point out that the interaction of billiard balls is continuous, symmetrical, and reciprocal, though they do believe in events.

[14] Hume, *Treatise of Human Nature*, I, III, XV.

[15] See Barbour 1989, Chap. 9.

1. **A** velocity v	**B** velocity 0	→	**A** velocity 0	**B** velocity v
2. **A** velocity 0	**B** velocity $-v$	→	**A** velocity $-v$	**B** velocity 0
3. **A** velocity ½v	**B** velocity −½v	→	**A** velocity −½v	**B** velocity ½v.

According to the first frame of reference, **A** moves to the right with velocity v and strikes **B** causing it to move. The cause as an event is **A**'s striking **B** with velocity v at time t; the effect as an event is **B**'s moving away with velocity v after time t.

According to the second frame of reference the cause and effect are reversed. **B** moves to the left with velocity $-v$ and strikes **A** causing it to move. The cause as an event is **B**'s striking **A** with velocity $-v$ at time t. The effect as an event is **A**'s moving away with velocity $-v$ after time t. If events as causes and effects were to be identified in this way for the third reference frame, there would be two causes and two effects.

The interaction of the two billiard balls is just like the interaction of the baseball and the window in that there is a force that acts between two bodies for a finite period of time. It is easy to construct a situation for billiard balls that is analogous to a baseball breaking a window: just suppose that billiard ball **B** breaks into pieces on contact and **A** does not. From the point of view of the first frame of reference, **A**'s striking **B** causes **B** to shatter. From the point of view of the second frame of reference, **B**'s striking **A** causes **B** to shatter.

The most obvious difficulty in the case of the collision of two billiard balls is that if the cause is to be an event, it should not be interchanged with the effect in another frame of reference.[16] Hence any account of causality in terms of events understood in this fashion must be mistaken. If intuition, common sense, or ordinary language insist that the billiard ball **A**'s striking the billiard ball **B** is *the* cause, then they are mistaken. It might be interesting to discover what view of causality is embedded in ordinary language, but there is no reason to believe that it tells us anything about reality.

Another difficulty with the events account is that there are no known causal relations between such events. Going back to the window, the event of the baseball's striking the window (the supposed cause) and the event of the window's breaking (one supposed effect) overlap temporally, so that there is plenty of opportunity for interaction. But there is no mechanism, and no one has any idea of how they interact. On the other hand, physics is clear that it is the ball and the window that interact. Forces act between physical objects. Energy and momentum are properties that are instantiated by physical objects, and hence they are exchanged between physical

[16] Cf. "[If] an event, e_1, is a cause of another event, e_2, then it is not the case that e_2 is also a cause of e_1." Lowe 2002, p. 329. This appears to be based on a widespread, fundamental intuition about causality. If the sculptor is a cause of the statue, then the statue is not a cause of the sculptor, however you look at the situation. If the ball's striking the window is a cause of the window's breaking, then the window's breaking is not a cause of the ball's striking the window. If the first billiard ball's striking the second billiard ball is a cause of the second billiard's movement, then the second billiard ball's movement is not a cause of the first billiard ball's striking the second billiard ball.

objects.[17] The supposed causal relations between events are entirely hypothetical, unknown to physics, and not subject to investigation. The idea that the two events interact is a pure figment of philosophers' imaginations. Instead, these arguments show that that physics, which should be authoritative when it comes to the metaphysics of causality, gives no reasons to believe that events are causal agents.

Any point of view that takes causality to have direction as given uniquely, say, by the first frame of reference in the case of the billiard balls is mistaken. Consider, for example, Quine's view that causality is the same as energy flow, or Aronson and Fair's view that causality is the flow of energy and momentum.[18] According to the first frame of reference, billiard ball **A** transfers all its kinetic energy and momentum to billiard ball **B**, and the energy and momentum flow from left to right. But from the point of view of the second reference frame, billiard ball **B** transfers all its kinetic energy and momentum to billiard

ball **A**, and the flow of kinetic energy and momentum is from right to left. Hence the direction of the "flow" of energy and momentum depends on the frame of reference. It follows that to speak of energy and momentum as flowing is purely metaphorical. Even to speak of energy and momentum as being exchanged is metaphorical. Properties change, but nothing flows. Hence, the suggestion that causality is the same as the flow of energy and momentum is inconsistent with physics.[19] It also follows that interactions of this sort cannot be understood in terms of the transfer of tropes.[20]

The third reference frame is the frame defined by the centre of mass of the two billiard balls, which might be regarded as the preferred reference frame. From the point of view of this frame of reference, the kinetic energy of each billiard ball remains

[17] Cf. Dowe 2000, p. 92. Bennett admits that objects do the "pushing and the shoving and the forcing" but denies that causal relations relate objects, Bennett 1984, pp. 22–3. But he also believes that events are supervenient entities and that all truths about events are reducible to truths not involving events, ibid., p. 12 & chap. VI. It appears, then, that he thinks that causal relations can only be explained linguistically. Trenton Merricks distinguishes object causation from event causation, and maintains that object causation cannot be eliminated, Merricks 2001, pp. 65–6.

[18] Quine 1973, Chap. 2, Aronson 1971, Fair, 1979.

[19] Dowe 2000, pp. 55–59 argues in another way that the energy that is transmitted from one object to another does not possess identity and hence cannot be regarded as a kind of fluid.

[20] If energy does not have identity through time, then an energy trope cannot have identity through time either. It is interesting that when Douglas Ehring, who believes that tropes have identity through time, gives examples of causation involving the transference of tropes that the tropes he considers are charge tropes and structural tropes, which are not obviously subject to this problem, see Ehring 1999, pp. 123-7 and Ehring 2011. Very perceptive perhaps, but in his examples, it is electrons that are exchanged, not charge tropes. See also Ehring 2009 and Campbell 1990, pp. 4, 113, 138–42. Paul 2000 says that her aspects correspond to tropes, but her explanation makes them sound like facts, particularly her use of the gerund, and Bennett says that fine-grained events are rather like tropes (Bennett, 1984, p. 90). Their view makes some sense, since, despite the formal differences between events and tropes: if the property that is a component of a fact is a trope, then the trope is the powerful or business end of the fact. Nevertheless, physically it is objects that interact, not their properties however conceived. When objects interact, they do so on account of their properties and very often on account of several of their properties, not just one. When heat energy is absorbed by a body its temperature increases. The effect, namely the increase in temperature, depends on several properties including the amount of heat added, the mass of the body, and the specific heat of the body. Moreover, if a trope of one object exerted a force on a trope of another object, then the tropes belonging to just one object would have to exert forces on each other. But both kinds of interaction are unknown to physics.

unchanged. Those that believe that energy flows would have to credit energy with some sort of primitive identity through time like a fluid in order to account for the exchange of equal amounts of kinetic energy in either direction. And they would have to believe something similar about momentum so that the quantities of momentum could flow through each other. Neither makes any sense.

Hence, the best that can said about the baseball and the window, and about the two billiard balls, is that two different objects interact, and both are changed as a result, an interaction that is symmetrical and reciprocal.

It might be objected that the ball is the cause and not the window, since the ball is active whereas the window is passive; the thrower of the ball is blamed, not the installer of the window. On the other hand, the window acts on the ball just as much as the ball acts on the window, even though there would be no point in complaining that your baseball had been scratched up. Blaming the thrower involves thinking in terms of human agency, with its attendant notion of intention, and a chain of interactions, whereas our focus is on the temporal neighbourhood of just one physical interaction. To remove human agency (and intention and blame), consider a hailstone breaking a window. According to Newton, the falling of the hailstone is like the falling of an apple, which is like the falling of the moon. In the case of the moon and the earth, it is more obvious that both act, and both are acted upon.

It is possible to look at the collision of the two billiard balls as an example of developmental action. The account of the collision from the point of view of the third frame of reference, where the balls approach each other from opposite directions with the same speed, in fact suggests that the initial state of both balls gives rise to the final state of both balls. If the two balls are taken together and regarded as an isolated system that evolves according to physical laws, it can be represented by a single point in a six-dimensional configuration space. This is described by the Lagrangian formulation of classical mechanics. If this developmental action of a composite system were regarded as what causality is, then the direction of causality would be from past to future, not from left to right. On the other hand, what underlies the temporal evolution of this combined system is the symmetrical, reciprocal interaction of the billiard balls, an example of transitive action.

5 Accounts of physical causation that involve events

Phil Dowe's book on causality is called *Physical Causation*. In fact, Russell, Reichenbach, Salmon, and Dowe form a tradition that can be called the physical causation tradition. It is a tradition that I sympathize with despite its reliance on events.

In "On the Notion of Cause" of 1912, Bertrand Russell concluded that ". . the law of causality, as usually stated by philosophers, is false, and not employed in science".[21] The function that causality was supposed to perform has to do with how the state of a "functionally isolated" system at one time determines the state of the system at a later time.[22] Functionally isolated means sufficiently isolated for all prac-

[21] Russell 1912, p. 207. Cf. Norton 2003 and fn. 1.

[22] Russell 1912, p. 199.

tical purposes, where not enough is coming in from the outside to make a significant difference. Russell was thinking about composite systems, with the universe as an extreme example.[23]

In *Human Knowledge* of 1948, Russell took a different view and defined a causal line as a continuous, temporal sequence of events that displays quasi-permanence, and which is numerically different and separate from other causal lines. Quasi permanence implies that given an event that occurs at a certain time on a causal line, then at any slightly earlier or slightly later time there is on that causal line a closely similar event.[24] He is thinking about a temporal neighbourhood of that point. This time he is prepared to talk about causality:

> When two events belong to one causal line the earlier may be said to 'cause' the latter. In this way laws of the form 'A causes B' may preserve a certain validity.[25]

A causal line for Russell is, in effect, the world line of a physical object. But he does not want to start by talking about the world lines of physical objects because he thinks that events are more fundamental than physical objects, and so he wants to start with events and try to construct what is commonly regarded as the world line of a physical object out of events. Salmon follows Russell in seeing events as fundamental, whereas Dowe sees physical objects as fundamental.

These two passages from Russell discuss two different kinds of developmental action. There is the development through time of a composite system where the evolution of the system through time is due to the interaction of its parts. Russell seems to have had this in mind in 1912. And then there is the development through time of a physical object, understood in terms of events, which may incidentally have parts, but where the focus is not on the interaction of the parts but on the change in its properties. This is what he seems to have had in mind in 1948.

Although in the later account, Russell does actually say that causal lines may always be regarded as the persistence of something,[26] he thinks that events are fundamental and physical objects are to be explained in terms of them, or constructed out of them.[27] In this later account, he is reifying events as fundamental entities, whereas in the earlier discussion of composite systems, he does not appear to want to reify the states of isolated composite systems as events, even though an earlier state of such a system determines a later state of the system.

Russell's accounts of causality only make use of developmental action, even though the physics of his day can be regarded as recognizing the existence of transitive action. The accounts of Wesley Salmon and Phil Dowe are improvements as they make use of both developmental action and transitive action. Wesley Salmon's idea

[23] This paper still exerts it spell, see the collection of papers in Price & Corry 2007.

[24] Russell 1948, pp. 475-7 & 487.

[25] Russell 1948, p. 334.

[26] Russell 1948, p. 477.

[27] Olson 1987 believes that facts are basic, and objects are abstracted out of facts, see pp. 61–64 & 78–81. He ascribes this view to Bradley and Frege.

of a causal process as a series of events is very similar to the idea of a causal line of the later Russell.[28] The fundamental problem with Salmon's account lies in distinguishing the progress of a physical object through time, regarded as constructed out of events, from a pseudo process such as the movement of a spot of light on a surface, also regarded as constructed out of events. This is the issue of the transmission of a mark. According to Salmon, given a structure that could have been transmitted along a process, then a mark is a modification of a structure.[29] Russell's account of a causal line faces the same problem, as was pointed out by Reichenbach.

Although Dowe's idea of a causal process is similar to that of Salmon, he understands the events that make up a causal process to be constructed out of an object and its properties.[30] Nevertheless, for both Salmon and Dowe causal interactions take place between causal processes rather than between physical objects, and causal processes are things that have events as their components. For Dowe, both causal processes and causal interactions are defined in terms of conserved quantities:

> CQ1. A *causal process* is a world line of an object which possesses a conserved quantity.
> CQ2. A *causal interaction* is an intersection of world lines that involves exchange of a conserved quantity. (Dowe 2000, p.90, cf. Dowe 1995, p. 323)

He is thinking mainly of energy and momentum as conserved quantities, following the causal theories of Quine 1973, Aronson, 1971, and Fair 1979. However, it should be noted that in classical mechanics angular momentum is a conserved quantity, whereas in quantum mechanics orbital angular momentum in conjunction with spin is a conserved quantity. Electric charge is a conserved quantity in classical and quantum mechanics.

Although people who believe that events that have physical objects among their components are causally significant, they may not be so enthusiastic about reifying events involving composite systems. The interesting question here is what sorts of composite whole can be components of events, given so many physical objects are composites? If an event is the sort of thing that can enter into causal relations, then an event should have some sort of natural principle of unity. From Dowe's point of view, it is derived from the object that is one of its components; whereas from Rus-

28 Salmon 1984, pp. 139 & 144.

29 A *causal process* is then one that can transmit a mark, where a mark is transmitted from A to B if the mark is manifested at all points from A to B given no interaction, Salmon 1984, pp. 141-4. Dowe believes Salmon's view should be that a causal process is one that can transmit a mark and a process that cannot is not a causal process, Dowe 1992, p. 198. For Salmon, the dividing of a causal line or the coming together of two causal lines, in other words, generalized interactions, involve the modification of structure. Salmon focusses on structure, Dowe on conserved quantities.

30 Cf. Dowe 2000, p. 107, where he uses the language of endurantism. He also talks about events, facts, and states of affairs, and at one stage appears indifferent to which term is used. He settles on facts as the terms of causal relations, where a fact is an object's possessing a conserved quantity and is an example of what Armstrong calls a state of affairs, Dowe 2000, pp. 168–171. He describes events as thin events. An event in this sense is an object's possessing certain properties at a certain time, though, at one point, he does also say that an event is a change in a property, ibid., p. 169. His events appear to correspond to Kim's fine grained events.

sell's or Salmon's point of view, it is not clear where the principle of unity for events could come from. Although many people would, very reasonably, regard a baseball as a real composite whole and therefore the sort of thing that could be the component of an event,[31] a pair of billiard balls that will interact or have interacted in the past is an unlikely real composite whole because eventually they separate indefinitely and hence lack of any principle of unity. At least, I think our intuition should take us in this direction. Although there are mereologists who believe in unrestricted composition and metaphysical atomists who deny that baseballs are real composite wholes,[32] they usually admit that their views are counterintuitive. But I have no time for either of these theories.

The difficulties associated with finding an answer to the question of what sorts of composite whole can be components of events add to the difficulties in maintaining that events are causally significant. Quantum entanglement may provide a principle of unity for two quantum systems that originate from the same method of preparation. But that does not apply to billiard balls.[33]

As we have seen, philosophers such as Russell and Salmon regard the development through time of what is normally regarded as a physical object as a series of events, which Russell calls a causal line and Salmon a causal process.[34] It follows, I believe, that in the absence of any natural way of dividing a causal process into finite intervals, the events that make up a causal process must be instantaneous. Even with some natural division into finite intervals, there seems to be no way of avoiding the conclusion that those finite intervals are also composed of instantaneous events.

Such instantaneous events appear to be very similar to the temporal parts of perdurantism. Perdurantism is the view that a physical object is a four-dimensional entity that occupies four-dimensional space-time, in which it is divided into temporal parts, where each temporal part corresponds to a time at which the object exists. Hence the temporal parts are sometimes called time slices. Special relativity makes the time slices of a spatially extended object dependent on the frame of reference since they are simultaneity slices. So, the division into temporal parts is frame dependent and the time slices are of no ontological significance.

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[31] See Merricks 2001.

[32] Cf. Quine and the later Davidson's account of what Bennett calls *concrete events*, see Bennett 1984, Chap. VII. "Each [event] comprises the content, however heterogeneous, of some portion of space-time, however disconnected and gerrymandered." from Quine's *Word and Object* quoted in Bennett 1984 p. 103. The difficulty with events of this kind is that they are arbitrary, lacking any principle of unity. The unity of an event could perhaps be explained by the unity of the physical object that was its principal component; but the unity of a physical object cannot be explained by the unity of the event that it is supposed to be abstracted from.

[33] The de Broglie wavelength of a billiard ball moving at a reasonable speed is far too small to be measured and decoherence sets in very quickly for objects of this size.

[34] Armstrong has a causal theory of identity through time, see Armstrong 1980.

6 The Metaphysics of Forces

Accounts of causality where the causal relations are identified include that of Bigelow and Pargetter, who believe that all causes are reducible to the action of forces,[35] and that of Quine, who believed, in effect, that all causal relations were reducible to the exchange of energy. Quine's view was generalized by Aronson and Fair to causal relations being exchanges of energy and momentum. There are also the theories of Campbell and Ehring, who think that causal relations are nothing other than the transfer of tropes.[36]

Forces are well known and part of our common understanding of the world. It appears that forces cause things to happen. They cause bodies to accelerate, to cease to move, to change in shape, to break, and also to be in compression or tension (though these are continuum states), so that forces have several powers. Hence, macroscopic forces have a *prima facie* claim to be real.[37]

In physics forces are introduced by Newton's laws. In particular Newton's third law states that if body A exerts a force **F** on body B, then body B exerts a force –**F** on body A. Hence, a force on a body is not alone: such forces always occur in pairs, where the two forces have the same magnitude and direction but opposite sense.[38] These two forces, though applied to different bodies, are clearly related to each other. Equally clearly, the two bodies are interacting causally and hence there is a causally significant relation between them. Hence, Newton's third law is about forces in a relational situation, and, as we shall see later, does not apply to resultant forces.

In the mathematics of physics, a force is represented by a vector that points towards or away from a body: it has magnitude, direction, and sense. The magnitude is the numerical value of its strength in certain units, and the direction of a force vector is

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[35] Bigelow & Pargetter 1990a, Chap. 6.

[36] See fn. 20.

[37] Bigelow et al., 1988, Newman, 1992, Wilson, 2007, and Massin 2009 among others defend the reality of forces. For further references, see Massin 2009. Wilson 2007 and Newman 2013 defend the reality of forces applied to macroscopic objects. Mach 1883, pp. 242-4 tried to eliminate forces from his system of mechanics. But the forces that he got rid of were forces as introduced and understood by dynamics; his method appears to have no bearing on forces as introduced and understood by statics (for the distinction, see Lange 2009). But perhaps he assimilated the forces of statics to the forces of dynamics on account of his view, following Newton, that the parallelogram law for forces is shown to be true in dynamics: displacements obey the parallelogram law, and therefore velocities do, and accelerations do, and therefore the forces that cause the accelerations also obey the parallelogram law (ibid., p. 40). But this is just not true in special relativity, where the acceleration caused by a force is, in general, not in the same direction as the force vector acting on a particle. The force vector, the acceleration vector, and the velocity vector lie in the same plane but differ in direction (see Sect. 8). So perhaps there is something to be said for the priority of the statical conception of forces. In any event, static forces certainly cannot be eliminated.

[38] The third law was Newton's major innovation according to Sklar 2013, p. 51. Massin 2009, p. 582 thinks that the third law is a metaphysical necessity. Lange 2002, however, does not think that it holds in electromagnetism: "Bodies do not exert forces on fields; bodies alone feel forces." p. 163", cf. pp. 114-5. There are three things to consider here: (1) in a dynamic situation, the field that exerts a force on a body undergoes a change in momentum, so that there is action and reaction, (2) in a static situation, the field exerts a force on a body but the field does not itself change so it does not undergo a change of momentum (do roof trusses stop geodesics?), (3) railguns have recoil, where in a railgun the force on the projectile and the force on the gun itself are mediated by an electromagnetic field. Hence, I suspect that the third law is defensible in electromagnetism, but whether locally is not clear.

the orientation of the straight line associated with it without regard as to whether it is pointing towards the body or away from the body. The two possible senses associated with the direction of a force vector are towards the body or away from the body. The direction and sense of a force vector are the same as the direction and sense of the resulting acceleration, if a body were allowed to accelerate due to just that force in pre-relativistic mechanics.[39]

Let us distinguish between the *force relation*, which is a symmetric, dyadic relation that has magnitude and direction, and is attractive or repulsive, but does not have sense, and the *force vectors*, namely **F** and –**F**, which are monadic, and which have magnitude, direction, and sense. This distinction is made by Newman 1992 and Massin 2009. Although the force vectors are monadic, they are not intrinsic properties of the bodies because monadic intrinsic properties of objects cannot have direction as was pointed out by Massin 2009. When forces occur in pairs like this, each force vector is directed along a line that points it to the other body and its sense is either towards that body or away from it. In other words, the spatial relation between the two bodies is essential to the force vector acting on that body.[40] It is plausible to suggest that because force vectors are not intrinsic properties of objects and are not relations, then they are not real entities.

Force vectors are applied to objects, as though acting from the outside. In fact, it **is** essential to mechanics to understand forces as external to the objects they act on. The idealized objects that are basic to mechanics are made of uniform matter without internal structure. These objects are inert and cannot move themselves, as Descartes pointed out in the Second Meditation. However, there are objects that can move themselves, but they have internal structure associated with a source of potential energy implanted in them, such as a spring or an internal combustion engine. Newton's laws are not in the first place about such objects; they are about the idealized objects made of uniform matter.

The reason there is something acting on one body is that the two objects act on each other, which must be via a relation. Since it is not possible for both the force relation and the two force vectors to be causally effective, the best explanation is that it is the force relation that is causally effective and real, and the force vectors are merely calculating devices or ways of looking at how the force relation acts. A force vector is just a monadic reduction of a force relation (Newman, 1992; Massin, 2009). It also appears to be an important fact of nature that forces are always dyadic so that there are no forces of higher adicity.

[39] Newton's second law is that the resultant force applied to a body is equal to the rate of change of momentum of the body, where both the force and the momentum are vectors. This law, just as it stands, is true both in Newtonian mechanics and special relativity. If **f** is the force vector, then the four-force is $F^{\alpha} = (\gamma d/dt(E/c), \gamma \mathbf{f})$, where $\gamma = (1 - v^2/c^2)^{-1/2}$, the Lorentz factor. In terms of four-vectors, Newton's second law takes the form.$F^{\alpha} = dp^{\alpha}/d\tau = d(m_0 v^{\alpha})/d\tau = m_0 dv^{\alpha}/d\tau = d/d\tau((m_0\gamma c, m_0\gamma \mathbf{v})$, which involves differentiation with respect to proper time.

[40] Cf. the discussion by Massin 2009, pp. 566–572. He points out that if two bodies are at a distance from each other, there is both a dyadic spatial relation with direction only and two spatial vectors with the same direction and opposite sense, and clearly the dyadic relation is real. It could be argued that since forces are not intrinsic, they are not dispositional, though there are those who think that there are dispositional relations.

The parallelogram law for the addition of forces is about how two component forces can be added to give a resultant force. There is a dispute as to whether the component forces are real, or the resultant force is real.[41] The answer is neither. The parallelogram law for the addition of forces, though it is not itself a law of physics, is about the force vectors of the laws of physics, so that both component forces and resultant forces are force vectors and therefore not real.[42]

In general, component forces are associated directly with force relations as, for example, in the attractive force between two planets. Consider planet A and planet B having a force relation between them. We also imagine that there is also a force vector rooted in planet A pointing at planet B, and a force vector rooted in planet B pointing at planet A. If there were another planet C, then it would have a force relation with planet A and a force relation with planet B. Let us focus on planet A. In addition to the two force relations, there is a force vector rooted in A pointing at planet B and a force vector rooted in A pointing at planet C. These two force vectors can then be summed using the parallelogram law of forces. The resultant force vector does not point at planet B or planet C, or anything else for that matter. It is not associated with any force relation; and it does not have a third law pair. But none of this matters if force vectors are not real and just constructions.

It is also possible to resolve a force vector associated with a force relation into components: that force vector, then, becomes the resultant force vector that is the vector sum of the components. This can be done in any number of arbitrary ways. Again, this does not matter if force vectors are not real.

In the case of Newton's law of gravitation, the two force vectors mentioned in the third law appear to be generated equally and symmetrically by both bodies. This can be explained by the single force relation between the bodies being generated equally and symmetrically by both bodies. The same is true of the force relation generated between two bodies when they interact during a collision.[43] As was noted before, it is essential to understand that the force that causes a body to accelerate is external to that body. Each body in itself is inert, but together in combination in an interaction they can generate a force. This is another reason for interpreting the situation metaphysically in terms of a single force relation between two bodies.

But there is something metaphysically paradoxical in something that is essentially inert, and therefore powerless, having the power to generate a force relation, which is not powerless.[44] Suppose that it were suggested that if two objects both lacked a

[41] I believe that the dispute first arose between Cartwright 1980 (and 1983), who believed that only the resultant force was real, and Creary 1981, who believed that only the component forces were real. Newman 1992 and Massin 2009 side with Creary. Wilson 2009 sides with Cartwright. Armstrong 1997, Molnar, 2003, and Bigelow & Pargetter 1990a think forces are monadic, but not Bigelow & Pargetter 1990b.

[42] Lange 2009 has an interesting account of those in the 19th century who had a statical conceptions of forces and tried to derive the parallelogram law from statical considerations, and others, such as Mach, who had a dynamical conception of forces and tried to derive it from dynamical considerations, see fn. 37. Lange did not seem very convinced by these efforts.

[43] It is also true for the force relation between two charged bodies. Bigelow et al., 1988 claim that it is true of a force relation between a particle and a field.

[44] Descartes, Locke, and Leibniz were aware of this paradox. Newton's first law expresses the inertness of matter, though that law was first formulated by Descartes in *The Principles of Philosophy*, Part II. In the

certain property, then the combination must also lack that property. That would be a fallacy, related to the fallacy of composition, and it would also be a denial of the possibility of emergence. Although a basic Newtonian object by itself cannot move itself, the property of mass of one object in combination with the mass of another object can generate a force, a relation, which can cause movement. The inertness of a single body is one thing, the generation of a force by two bodies is another.[45]

7 The fundamental causal connection

Massin 2009 maintains that Newtonian forces are real, symmetric relations that have causal powers. But he denies that force relations are causal relations just because they are symmetric, pp. 582-7. He believes that causal relations should be asymmetric, perhaps on account of some linguistic view as he does not believe in events. Massin's proposal for introducing asymmetry is that there is an asymmetric causal relation between the force relation and one of the accelerations it is responsible for: "Therefore, the causal relation between forces and accelerations seems to be the right place to stop in order to avoid the causal regress: it is a causal relation that has no causal powers, that is not itself a cause." p. 586. This is Massin's account of the fundamental causal connection.

According to Massin's proposal, there is a cause and an effect that are related by a causal relation, a situation that is asymmetric. Hence, Massin's account of the two-body situation is that the force relation between the objects A and B acts on A to cause an acceleration via one causal relation, which is an asymmetric situation, and the same force relation acts on B via another causal relation to cause another acceleration, which is also an asymmetric situation. To his credit Massin is aware that there is the possibility of a regress, and that the regress needs to be stopped. Weaver 2019 pp. 118-9 goes even further. His account of the same situation involves two objects, four events, two forces, and four causal relations. Adding events appears to lead to the further multiplication of entities. It is not clear why Weaver hypothesizes the existence of events. Perhaps he just assumes that causal relations must relate events.

The ordinary language approach to causation and the related events view requires an ontology of causes, effects, and asymmetric causal relations that relate the causes to the effects. One obvious way of applying this requirement to the interaction of two objects is to take the cause to be the event of the two objects' instantiating a force relation for a certain period of time. The effect would then be the changes in the objects understood as an event involving two objects. The causal relation would be some hypothetical relation between the two events. There would be no reason to object to this approach on the ordinary language approach or the events view.

Second Meditation, Descartes explains the inertness of a body by saying that a body is something that can be moved but not by itself.

[45] In some ways the laws about the generation of forces are brute facts: that is just the way things are; though if laws of dynamics were at root relations between universals, then the appropriate relation between universals would be the explanation.

The main problem with this approach is that there is something counterintuitive about a causal relation between events where each event has two independent, separable objects as their components. As was pointed out in the section on physical causation, there is a difficulty with the principle of unity of such events. In the case of the interaction of two billiard balls looked at from the point of view of the third centre of mass frame of reference, there is a sequence of events from time past involving two quite separate objects and a sequence of events receding into time future also involving two quite separate objects. Any of the events in the past could be called a cause and any of the events in the future could be called an effect.

An alternative to the linguistic or events view that recognizes symmetry and reciprocity is to propose that object A and object B interact on account of the force relation between them, which is a real relation, and that force relation is itself the causal relation. That they interact is that they act on each other via the force relation. The object A acts on object B via the force relation to cause it to move in one way, and object B acts on object A via the force relation to cause it to move in another way. Object A and object B interact in virtue of the force relation between them, and "as a result" object A moves in one way and object B moves in another way. This way of looking at it is preferable because there is just one symmetrical, reciprocal act, an act that is an example of transitive action. Here "as a result" is intended to be a causal primitive, so that the causal is not fully explained in terms of the non-causal, though some other form of words, such as 'bring about' could have been used with equal effect.[46] Any account of causation that is non-reductive, will involve at least one causal primitive (obviously). For example, for Massin, his two causal relations and their actions are causal primitives. But there is no reason to suppose that the force relation needs help from other entities, such as additional causal relations, events, powers, or dispositions.

This approach can be generalized to give an account of all causal relations:

> A relation between two objects is a causal relation if and only if when it is instantiated by the two objects there is a possibility that the objects that are the terms of the relation could change as a result of that relation between them.[47]

A change in properties of an object is the most obvious form of change, but the creation and annihilation of objects are also changes that can be the result of the action

[46] Characterizations, or elucidations, of this sort can only take us so far. What is meant can then be pinned down by giving examples, which, of course, have already been given. For the notion of elucidation, see Frege 1914, p. 313. Some earlier versions of this work unfortunately use 'illustrative examples' to translate '*erläuterung*'. Cf. Ludwig Wittgenstein, *Tractatus*, 3.263 and 4.112.

[47] Although it is conceivable that one object could act upon another without being acted upon, we are more likely to think that when two objects interact that each acts upon the other and each is acted upon by the other. Perhaps there is a more general metaphysical principle here of mutuality that at least applies to all finite concrete objects: in whatever way they act, they cannot act without being acted upon. Cf. Le Poidevin 1991, pp. 83 & 88 on the principle of reciprocity. Cf. Kant, *Critique of Pure Reason*, B106. He thought that a general metaphysical principle lay behind each of Newton's three laws, in this case the third law.

of causal relations.[48] It has to be said that it is *possible* for changes to occur just because it is possible that changes not occur due to other causal relations preventing change as in static causal situations, such as the eternal ball sitting in the eternal cushion, or indeed in any roof truss.[49]

The basic metaphysics of causality is about objects, causal relations, changes in objects, and a causal primitive such as “results in”. These are the formal metaphysical categories. Obviously, it is possible to talk about causes and effects in an informal sense. It could be said that each of the changes was an effect, or both changes together, or, indeed, some later state of the two objects was the effect. But since it is an informal idea, there is no need to identify just one effect. There is also no need metaphysically to identify just one cause belonging to one specific category. If ordinary language requires the singling out of just one cause, then that is a fault of ordinary language. In an informal sense, the causal relation itself could be called a cause, and of each the objects and the two objects together could also be called causes.[50]

How the force does its work is a question that cannot be answered. It is just part of its nature. If, for example, new hypothetical causal relations were introduced in addition to the force relation relating the force relation to the acceleration, it could be asked of them how do they do their work? The answer would be that it is just part of their nature. Hence the addition of new causal relations does not help with answering questions about how things work. In many cases there is an answer to the question “how does it work?”. But there must come a point where that question cannot be answered, as Hume pointed out long ago.[51]

8 The Metaphysics of Energy and Momentum exchanges

It would be nice if it could be said that forces were an example of causal relations, and that exchanges of energy and momentum were another, different example of causal relations, and that there were yet other, different kinds of causal relation, and

[48] There is no need for causal relations to be associated with exceptionless laws. Consider a machine that is designed to exert a specified force on certain objects that are manufactured to be the same in every way. Suppose that, in fact, as a rule 90% break and 10% do not. In cases where the object breaks, it is the machine and the force that it exerts that make it break. The machine can break objects of that type, which is realized most of the time, but not always.

[49] Kant, *Critique of Pure Reason*, B 248 ff.: eternal ball denting the eternal cushion. Aquinas, *Summa Theologica*, Pt. I, Q. 46, A. 2, ad 1 µm, quoting Augustine: eternal foot in the eternal footprint.

[50] It is interesting that Whittle regards causes as collective. She thinks that there is no need to identify just one cause. “It often makes good sense to single out parts of an event as among the causes because they are particularly important to the occurrence of the effect.” Whittle 2016, pp. 8–9. She does not think that there is a problem of overdetermination if the two entities are related as part and whole or something analogous. She appears to be denying that there is a problem of two-levels overdetermination. She cites Shaffer 2003 who makes a distinction between two-levels overdetermination and two rocks over determination. In the case of the breaking of a window by rocks, the determinate changes that would have been caused by one rock with certain properties are not the same determinate changes that would have been caused by two rocks each with the same properties. Hence the problem of overdetermination does not arise.

[51] Hume, *Enquiry concerning Human Understanding*, Sect. 4.

perhaps there are. Unfortunately, although exchanges of energy and momentum are real, they are metaphysically complicated in a number of different ways.

However, a few conclusions can be drawn quite easily. For example, an exchange of energy and momentum between two macroscopic objects or two microscopic particles is such that both parties are changed, just because of the conservation laws. In the case of the macroscopic billiard balls looked at from different frames of reference, the exchange of energy and momentum can be regarded as symmetrical and reciprocal.

It can also be shown that for macroscopic objects an exchange of energy and momentum is different from a force relation. The reason is based on the fact that in special relativity, if a force is applied to a body, the direction of the resulting acceleration is different from the direction of the force, and the direction of the body's velocity is different again. There are three vectors: the object's velocity, the applied force, and the resulting acceleration of the object. These three vectors have different directions, but all three lie in the same plane.[52] If bodies A and B exert forces on each other, then the force that body A exerts on B should be equal and opposite to the force that B exerts on A, by Newton's third law. The change of momentum of A and the change of momentum of B obey the law of conservation of momentum and as a consequence both lie in the same direction. But the common direction of the changes in momentum is different from the common direction of the two forces since the forces and momenta lie in different directions. Hence the exchange of energy and momentum between two objects is different from the force relation between them, though they are related. It follows that Newton's third law cannot be reduced to the exchange of momentum, as Wilson 2007, pp. 179–80 claims. And it follows that forces cannot be eliminated as Wilson claims.

One of the difficulties with the claim that all causal interactions are nothing other than the exchange of energy and momentum is that it is possible for the exchange of energy and momentum to be the result of the action of another causal relation. This can be seen by considering the collision of two billiard balls as understood by classical mechanics. In Newtonian mechanics the momentum of an object is the mass times the velocity ($\mathbf{p}=m\mathbf{v}$) and the kinetic energy is half the mass times the square of the velocity ($K = ½mv^2$). Consider an elastic collision, which is such that kinetic energy is conserved. During the time of interaction, the force between the objects brings about changes in the velocities of the two objects. Because the velocities of the objects change, their momenta and kinetic energies also change in accordance with the formulas for momentum and kinetic energy. It is possible, though metaphorical, to speak of an exchange of energy and momentum since momentum and energy are conserved. But it is clear that the causal relation is the force relation and cannot be the exchange of energy and momentum. Hence, it is possible for there to be an exchange of energy and momentum where that exchange is not a causal relation.

On the other hand, it is also possible for there to be an exchange of energy and momentum where that exchange is a causal relation. For example, the exchange of

[52] The equations are $\mathbf{f}=d\mathbf{p}/dt=d(m\mathbf{u})/dt=md\mathbf{u}/dt+\mathbf{u}dm/dt=m\mathbf{a}+\mathbf{u}dm/dt=m\mathbf{a}+\{\mathbf{f}.\mathbf{u}/c^2\}\mathbf{u}$. The last term, which requires some work, shows that generally the force, the acceleration, and the velocity lie in different directions in the same plane.

radiant heat between two macroscopic bodies as understood by classical thermodynamics is a good example of such a causal relation, and the interaction is indeed symmetrical and reciprocal.[53] The interaction involves the exchange of radiation, which is a form of electromagnetic radiation. Radiation carries energy and momentum that results in the changes in the objects. Hence, this causal relation is nothing other than an exchange of energy and momentum.

In Newtonian mechanics, kinetic energy and momentum are associated with objects having a velocity.[54] Even though this issue cannot be gone into in any detail here, it should be noted that in the case of fields and waves, including electromagnetic radiation, energy and momentum stand alone and are not associated with objects having a velocity. Therefore, there may be more examples of situations where the exchange of energy and momentum is the causal relation. And in quantum mechanics, exchanges of energy and momentum appear to be of a different kind from those in classical mechanics since standard interpretations of quantum mechanics, at any rate, appear to regard them as involving stand-alone energy and momentum. Bohmian mechanics is a non-standard interpretation of quantum mechanics partly because it does ascribe a velocity to quantum particles.[55]

There are also situations where there are exchanges of energy of momentum that are non-causal, where there are no relevant causal relations. The radioactive decay of a nucleus by the emission of an alpha particle is an example of spontaneous action, where something changes without the change being the result of causal relations of any sort. It follows that an exchange of energy and momentum is not a sufficient condition for a situation being a causal situation. Spontaneous action is discussed in detail in the next section.

There are also causal situations where there is no exchange of energy and momentum, which shows that the exchange of energy and momentum is not a necessary condition for a causal interaction.[56] When the string of a crossbow is released driving the bolt forward, the part of the trigger mechanism that is holding the string in place moves forward and downwards due to the circular motion of that part. The movement of this part of the trigger mechanism contributes no force nor energy nor momentum to the string that acts on the bolt. This can be seen more clearly by observing that that part of the trigger mechanism could do its work by moving out of the way at right angles to the string. Because they are at right angles, that moving part can contribute no force nor energy nor momentum to the movement of the string. This is the causal action of a trigger. Something similar is true of the firing mechanism of a bolt action rifle, which involves a chain of objects interacting with each other, from the actual trigger being pulled to the bullet leaving the barrel. At some stage in this chain, the energy in a spring is released to drive the bolt and the firing pin forward, which will

[53] For classical thermodynamics presented as an autonomous subject, see A. B. Pippard, *The Elements Classical Thermodynamics*, Cambridge, 1966.

[54] This is also true of that part of special relativity that deals with objects, otherwise known as bodies.

[55] See Holland 1993 on Bohmian mechanics. The clue is in the title of the book: *The Quantum Theory of Motion*.

[56] For Salmon and Dowe the exchange of a conserved quantity is a necessary condition for a causal interaction: Dowe 2000, p. 90, Salmon 1997, pp. 462 & 468, but not the Salmon of Salmon 1984, see p. 171.

involve the causal action of a trigger.[57] The causal action of triggers is discussed from a more general point of view in Sect. 10.

These conclusions about the rather complicated relations between exchanges of energy and momentum and causality can be summarised as follows:

1. For macroscopic objects, an exchange of energy and momentum is different from a force relation. (From an equation in special relativity)
2. There are situations that are causal where there is an exchange of energy and momentum, and that exchange is not a causal relation. (As in a collision of billiard balls)
3. There are situations that are causal where there is an exchange of energy and momentum, and that exchange is a causal relation. (As in an exchange of radiation)
4. There are situations that are not causal where there is an exchange of energy of momentum. (As in spontaneous action)
5. Therefore, an exchange of energy and momentum is not a sufficient condition for a situation being a causal situation.
6. There are situations that are causal where there is no exchange of energy and momentum. (As in the action of triggers)
7. Therefore, an exchange of energy and momentum is not a necessary condition for a situation being a causal situation.

Although it may be worthwhile to present the conclusions in the abstract, they are difficult to think of in the abstract without thinking of the examples. It is worth noting that the example of the exchange of radiation is likely not to be an isolated example of where the causal relation is an exchange of energy and momentum.

9 Spontaneous action

Transitive action and developmental action are two different kinds of causal action. There are also other kinds of causal action. Spontaneous action is a different kind of action that is not causal. For example, in the alpha decay of a lead atom (Z = 82) to a mercury atom (Z = 80) an alpha particle (helium nucleus) exits the lead nucleus leaving it a mercury nucleus. For these purposes, it is an isolated system that divides into two isolated systems. Something changes but there is no reason for the change to take place. That change is not the result of interactions between the parts of the nucleus, or the result of interactions of any of the parts of the nucleus with something outside the nucleus, and it is not the result of whatever it is that governs the development of the

57 But according to Daniel Dennett: “A fundamental principle of physics is that any change in the trajectory of any physical entity is an acceleration requiring the expenditure of energy, and [if the change is caused by a mental phenomenon] where is this energy to come from?” Dennett 1991, p. 35.

nucleus as an isolated system. This is how alpha emission is understood by standard quantum mechanics.[58]

For Dowe, however, nuclear decay is an example of causality, and he mentions it frequently.[59] The reason is Dowe's view that "A *causal interaction* is an intersection of world lines that involves exchange of a conserved quantity." (2000, p. 90) In nuclear decay, he maintains, the world lines of the alpha particle and the rest of the nucleus exchange energy and momentum, which are conserved quantities, and therefore it is an example of a causal interaction.

The mechanism is the quantum tunnelling that happens when a particle is confined within a finite potential barrier that it does not have the energy to surmount, but nevertheless has a probability of passing through. According to the elementary treatment involving the application of Schrödinger's equation to a particle within a finite potential well, there is no relation of any sort between the particle and anything inside the barrier or anything outside the barrier that is involved in making it leave the barrier. In particular, there is no applied potential. If there were, then it could be regarded as a stand in for a causal relation. But there isn't one.

The mathematical theory of quantum tunnelling shows that as time increases the wave function leaks through the potential barrier, so that the probability of finding the particle outside the barrier increases and the probability of finding the particle inside the barrier decreases. At some point the alpha particle just passes through the potential barrier. There is no reason why it passes through the barrier, or why it happens at that time. It happens *spontaneously*. Hence the laws of physics are consistent with the existence of spontaneous action. Hence, it is possible relative to what we know about the world.

Besides spontaneous action, it is also conceivable that changes could take place on account of the action of free will choice, where the change of the will itself, and therefore the changes that flow from it, are not due to the interaction of objects and not due to whatever it is that governs the development of the mind. The difficulty here would lie in explaining how free will action differs from physical spontaneous action. But the issue of free-will action will be left merely as a suggestion, and the issue of whether there are other kinds of action will not be given any further consideration.

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[58] The discussion in the text concerns the elementary theory of alpha emission according to Schrödinger's equation applied to a particle in a finite potential well (quantum tunnelling) as given by standard quantum mechanics. Sakurai & Napolitano 2017 is a recent textbook of standard quantum mechanics. Their starting point is the powerful algebra of quantum mechanics and in their discussion of Bell's inequality they reject hidden variables. It is like special relativity's rejection of an ether. Bohmian mechanics, which should be regarded as a different theory from standard quantum mechanics (Bricmont, 2016, p. 18), has as its starting point the trajectory of a single particle, which it derives from Schrödinger's equation. It has the resources to give a causal account of the exit of an alpha particle in terms of hidden variables (Holland, 1993, pp. 198–203, based ultimately on the computer modelling of Christopher Dewdney). It affirms what the standard theory denies. The stochastic interpretation is another distinct theory, but I do not know whether it has resources that parallel those of Bohmian mechanics. Standard quantum theory at least shows that causeless action is possible, which is what is needed for metaphysics: a consistent, extremely successful empirical theory is consistent with causeless action. Hence, it is possible relative to what we know about the world. There may be some conceptual difficulties with the standard theory, but so there are with Bohmian mechanics, see Bricmont 2016, p. 181 and Holland 1993, p. 277-8: multi-dimensional configuration spaces and their contents are regarded as real!

[59] Dowe 2000 mentions radioactive decay on pp. 23, 25, 45, 83, and 93.

10 Omission

Given a set of objects and a set of relations between them, causal relations are the relations that can change the objects that are their terms. Nevertheless, with respect to any given object there are two kinds of transitive causal action. The first kind of transitive causal action is where a change is brought about in an object by a causal relation of which it is a term. The second kind of transitive causal action is where a change is brought about in an object by a change in a causal relation of which it is a term. Clearly if there are such things as causal relations between objects, then something could make a causal relation to change, or, indeed, to cease to be instantiated, or to begin to be instantiated. Nevertheless, there is only one fundamental kind of transitive causal action, since the only way a causal relation attached to one object can be changed is by means of other causal relations acting on other objects. On the other hand, relative to a certain object, the two kinds of causal action are metaphysically different. This distinction is helpful in analysing causal situations and could help in dealing with some of the standard difficulties that face theories of causality.

The problem of omission in causality is often introduced by considering the fact that omitting to water a plant can cause it to die. The problem with plants is that the flow of water and nutrients through its vascular system are examples of transport phenomena, not causal relations between objects. The relevant transport phenomenon is the flow of a fluid down a tube due to a pressure difference. Transport phenomena can be regarded as causal but do not involve causal relations between objects, at least at the macroscopic level.[60] However, they should really be looked at from a microscopic perspective, which would involve molecules or atoms (objects) and fields and would be statistical.

It would be better, then, to consider a simpler situation involving forces. Consider a small body resting on a board attached to pegs by means of a number of rubber bands so that it does not move. It is embedded in a network of force relations, one for each rubber band and one for the reaction force of the board that it is sitting on. Each of the rubber bands prevents the others moving the body. “Omit” one of the relations by cutting the rubber band with a pair of scissors and the body will move. There is a sense in which its subsequent movement is due to the forces in the remaining rubber bands: the other forces *produce* the movement (one causal expression), but the cutting of the rubber band *made* the movement happen (another causal expression). The cutting of the rubber band is an example of the causal action of a trigger: the act of cutting does not contribute a force or energy or momentum to the body. Similarly, watering the plant prevents certain factors coming into play. Watering maintains the flow of water through the vascular system of a plant and keeps the plant’s cells in

[60] Other examples include the flow of heat in a piece of copper due to a temperature gradient and the flow of an electrical in a wire due to a potential difference. From a macroscopic point of view, they are all continuous phenomena and the equations that govern them have the same form. Creary’s 1981 discussion of “laws of causal influence” (a little like laws governing causal relations) was criticized by Cartwright 1983, pp. 62–67 by merely presenting a large number of complex transport phenomena, which, she claimed, his approach could not deal with. He was talking about causal relations; she wanted to confuse matters by talking about transport phenomena.

their correct, full shape, and prevents them from collapsing. This steady state can be disrupted by failure to water, which is analogous to cutting a rubber band.

It would be consistent with the ontology developed in this paper to maintain that a change of properties was the joint "result" of all the causal relations that acted on the object: it would be an example of plural causal action that parallels plural reference.[61] If ordinary language demands a single cause for each change, then ordinary language is mistaken. It is unlikely that a metaphysical theory of causality will follow our common sense or ordinary linguistic usage exactly.

The causal action of a trigger is an example of transitive causal action of the second kind where there is no contribution of force or energy or momentum to the change. The cutting of one of the rubber bands is an example of a trigger. When a bolt is shot from a crossbow or when a rifle is fired, there is a causal chain starting at the actual trigger such that at some point in the chain there is an example of the causal action of a trigger, an example of transitive causal action of the second kind. Transitive causal action of the second kind is not a static absence; it involves an intervention.

11 Causal Chains

It is difficult to talk about causality without alluding to causal chains, where the mechanism of the crossbow and the mechanism of the rifle are examples of designed causal chains.[62] Here is a brief account of designed causal chains. Take another more complicated example: if the key is turned in the ignition of a car, then as a result the engine will start. It is an obvious, intuitive example of causality. But it is not just one causal relation: it is a sequence of processes, electrical, chemical, and mechanical, which can be called a causal chain:

> An electrical current flows, the current's potential is increased by some means, there are sparks in the tops of the cylinders in a staggered fashion, gaseous mixtures explode in a staggered fashion in the tops of the cylinders, the piston heads are driven downwards in the cylinders in a staggered fashion, the connecting rods of the pistons are driven downwards in a staggered fashion, the crankshaft rotates. The flow of the electrical current is a transport phenomenon. The explosions are chemical. The interactions of the cylinder heads, connect-

[61] I am grateful to Jonathan Lowe for drawing my attention to this parallel. Whittle 2016 has a different idea of collective causes, see fn. 50.

[62] A conceivable philosophical view of causality is that causal chains (mechanisms or causal processes) are what causality is and hence the starting point for a theory of causality. Such a theory would face a number of philosophical difficulties. Causal chains will have parts and components, and questions can be raised about how they interact. And questions about how they interact will not always be answered by referring to further causal chains but will at some point come down to interactions between objects. But such a theory cannot account for the interactions between two objects, which are obviously causal but are not chains or causal processes.

ing rods, and crank shaft are mechanical and involve forces between extended objects.[63]

Within one causal chain, there will be a number of different causal relations and a number of different kinds of causal action. The causal chain involved in starting a car is objective, although there is intention involved because it was designed to perform a certain task. It is a *single thread* in the sense that the processes are *designed* to lead from the turning of the key to the turning of the crank shaft and nothing else. In this case, there is also some splitting in that the current is "distributed" to the cylinders in turn, which leads to the different actions of the cylinders that act together.[64] It should be recognized that there can be local splitting, providing that overall, there is a single thread. There are also other, extraneous, unintended effects such as the exhaust and the heating that takes place at every stage of the chain, but they are incidental to the design.

My informal account of this kind of a designed causal chain is that it is a sequence of processes, like the starting of a car engine, that overall forms a single thread. A causal chain is not fundamental because is based on fundamental causal relations and other kinds of causal action. The action of a crossbow which starts with the pulling of the trigger, which is all mechanical, and the action of the mechanism of a rifle, which is not all mechanical, are also examples of this type of designed causal chain with a single thread.[65] There are, presumably, other, natural (non-designed), causal chains, but there is no need to go into them here.[66]

12 Conclusion

The position defended in this paper is that the basic kinds of physical causality that are foundational for other kinds of causality involve objects and the causal relations between them. These interactions do not involve events. If events were ontologically significant entities for causality in general, then they would play a role in simple

[63] An enthusiast for events could suggest that turning the ignition key in the lock was an event and the cause, and the turning of the engine's crank shaft was an event and the effect. But there really is no need to reify changes as metaphysical entities. Things change all the time and there is no need to suggest that philosophers' entities come into and out of existence all the time. For one thing it is not even clear what the effect event is. Is it the beginning to turn of the crank shaft, which is a limit point event and problematic ontologically? Is it the temporally extended event during which the crank shaft is undergoing angular acceleration? Or is it the final temporally extended event of the crank shaft having a constant angular velocity, which will be ended by some arbitrary intervention?

[64] Those that remember old-fashioned distributors that had a distributer cap, points, and a rotator arm will find "distribution" easier to understand.

[65] Causal chains like the simple mechanical mechanism found in a rifle are not subject to issues concerning different frames of reference for obvious reasons.

[66] Dowe 2000, pp. 170ff gives a formal account of what he calls causal connections, which are, in effect, natural causal chains. Putnam's theory of meaning of 1975 could make use of natural causal chains, as could theories of reference to past objects in the philosophy of time. For the philosophy of time, causal chains have the virtue that their end points do not exist at the same time. Theories of reference require a single thread.

mechanical interactions. But arguments about simple collisions looked at from different frames of reference show that events cannot play a role in simple mechanical interactions, and neither can the entirely hypothetical causal relations between events. These arguments show that physics, which should be authoritative when it comes to the metaphysics of causality, gives no reasons to believe that events are causally significant.

Force relations and some cases of energy-momentum transfer are examples of causal relations, with forces being paradigmatic in the macroscopic world, though it is conceivable that there are other kinds of causal relation. When there is a force relation between objects A and B, the force relation is the causal relation. Object A and object B interact in virtue of the force relation between them, and "as a result" object A changes in one way and object B changes in another way. There is just one symmetrical, reciprocal act, an act that is an example of transitive action. Generalizing, a relation between two objects is a causal relation if and only if when it is instantiated by the two objects there is a possibility that the objects that are the terms of the relation could change "as a result" of the causal relation. The basic metaphysics of causality is about objects, causal relations, changes in objects, and a causal primitive.

The conclusions drawn from the discussion of forces can be summarized as follows. Newton's third law is about forces that act on bodies, and which always occur in pairs. It follows that the third law is about bodies in a relational situation. Hence, there must be a relation associated with the forces between the bodies. Hence it makes sense to distinguish between a force relation and the force vectors that are specific to each body. The best explanation is that the force relation is real and the force vectors constructions, mere calculating devices. Since the force relation is real and responsible for the changes, it is the causal relation.

The conclusions drawn from the discussion of exchanges of energy and momentum can be summarized as follows. For macroscopic objects, an exchange of energy and momentum is different from a force relation on account of an equation in special relativity. There are situations that are causal where there is an exchange of energy and momentum, and that exchange is not a causal relation, as in a collision of billiard balls. On the other hand, there are situations that are causal where there is an exchange of energy and momentum, and that exchange is a causal relation, as in the exchange of radiation between two bodies. It is important to note that the exchange of radiation, where an exchange of energy and momentum is a causal relation, is likely not to be an isolated example. It was also shown that an exchange of energy and momentum is neither a sufficient condition for a situation to be a causal situation nor a necessary condition for a situation to be a causal situation.

During the course of the previous discussion, a number of different kinds of causal action were described, and one kind of non-causal action, namely spontaneous action as in alpha emission. The examples of causal action are as follows. *Transitive action* is where there is a causal relation between two objects that as a result change their properties, as in a collision of billiard balls. Where the situation is more complicated, a distinction can be made between transitive causal action of the first kind and transitive causal action of the second kind. The first kind of transitive causal action is where a change is brought about in an object by a causal relation of which it is a term. The second kind of transitive causal action is where a change is brought about in an object by a change in a causal relation of which it is a term, as in the cutting of one of the rubber bands. The *action of a trigger* is an example of causal action of the second kind where the action of the trigger contributes no force nor energy nor momentum to the changes that result, as in the trigger of a crossbow. *Developmental action* is where a composite system evolves through time driven by the causal relations between its parts, as in an organism or the solar system. An earlier state of the composite system does indeed determine a later state, but there are no causal relations between earlier states and the later states. *Static causation* is where causal relations are instantiated but there are no changes, such as the eternal ball sitting on the eternal cushion. There are many obvious examples of static causation involving forces, but two bodies exchanging radiation energy can reach equilibrium where energy continues to be exchanged but the bodies do not change their properties.

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