Dispositions, causes, persistence as is, and general relativity

Joel Katzav

Department of Philosophy and Ethics

Eindhoven University of Technology

Postbus 513, 5600 MB

Eindhoven, The Netherlands

Email: j.k.katzav@tue.nl

Abstract

I argue that, on a dispositionalist account of causation and indeed on any other view of causation according to which causation is a real relation, general relativity does not give causal principles a role in explaining phenomena. In doing so, I bring out a surprisingly substantial constraint on adequate views about the explanations and ontology of general relativity, namely the requirement that such views show how general relativity can explain motion that is free of disturbing influences.

1. Introduction

Over the last few years, dispositions (capacities, powers, etc.) have acquired quite a few new friends among those working in analytical ontology. According to the (new) friends of dispositions, the Humean thesis that properties are not intrinsically causal is false. The truth, the friends of dispositions hold, is that the dispositions of objects are real properties that are what they are by virtue of what they might cause. On their view, dispositions are real properties which if possessed will, by their very nature and in the appropriate circumstances, bring about certain effects or, at least, make certain effects probable to some degree or another.

The friends of dispositions make more than just ontological claims. They also offer a view about what kinds of correct fundamental explanatory principles there are. Supposedly, there are fundamental explanatory principles which correctly explain phenomena by showing that, in the conditions that obtained when the phenomena

were caused, dispositions caused the phenomena. On this view, d-causal principles – where a d-causal principle is a principle which tells us of some disposition that if it is possessed and certain specified attending conditions obtain, then the disposition will cause, or will cause with some degree of probability, specified effects – play a fundamental role in correctly explaining things around us.[1]

Some friends of dispositions assign d-causal principles a fundamental, but nevertheless limited, explanatory role. They hold that although correct explanations for phenomena will often rest, in the end, on d-causal principles, the correct explanations for some phenomena will not do so (see, e.g., Bigelow et al. (1992) and Chalmers (1999)). A more radical group of friends of dispositions, however, go so far as to claim that where phenomena can be correctly explained, the correct explanation will ultimately be in terms of d-causal principles (see, e.g., Cartwright (1989) and Bird (2008)).[2]

The position of the more radical friends of dispositions has been challenged on the ground that conservation principles are not reducible to d-causal principles. The idea is that if conservation principles are not reducible to d-causal principles, we will need a richer ontology than that of objects and their dispositions to ground our fundamental explanatory principles and we will need to accept that some fundamental explanatory principles are not d-causal principles (see, e.g., Chalmers (1999)). My focus here is on i-conservation principles, a class of principles that conform to an intuitive notion of what it is to be a conservation principle. An i-conservation principle is, roughly, a principle according to which some phenomena will persist as is through change in some types of physical systems. I argue that i-conservation principles explain aspects of cases of persistence as is that d-causal principles cannot explain. Further, I argue that some important i-conservation principles explain cases

of persistence as is in the absence of disturbing influences – i.e., in the absence of actual influences that would, if effective, ensure the non-occurrence of the cases of persistence as is – and that d-causal principles can have no role in explaining such cases of persistence as is. I use these results to examine what role general relativity (GR) gives d-causal principles. GR, we will see, provides one type of explanation and this type of explanation explains cases of persistence as is in the absence of disturbing influences. As a result, GR gives d-causal principles no explanatory role whatsoever. Indeed, I will suggest that my conclusions about GR can be extended to any view that shares the dispositionalist assumption that causation is a real relation. It seems that, on any such view, GR provides no causal explanations. In a more constructive vein, my discussion indicates that showing how GR is able to explain persistence as is in the absence of disturbing influences is a substantive constraint on adequate views about its ontology and the nature of its explanations.

The present investigation matters because uncovering the differences it reveals between what the friends of dispositions tell us about the role of d-causal principles and the role GR gives such principles is a step towards evaluating the views of the friends of dispositions. My investigation also matters because, not surprisingly, the popularity of ontologies in which dispositions play a central role coincides with the growing popularity of the supposition that theories and theorising in one or more of the special sciences, usually including physics, give d-causal principles a fundamental explanatory role.[3] Finally, my discussion furthers our understanding of the explanations provided by GR, and of what is required of adequate views of these explanations and of the ontology behind them.

I begin, in section 2, by clarifying what I mean by 'i-conservation principle' and arguing, starting from this clarification, that i-conservation principles can explain

(some) instances of the absence of inexplicable change. I then, in section 3 and in view of the noted explanatory ability of i-conservation principles, bring out two differences between what i-conservation principles, and principles that can explain i-conservation principles, can explain and what d-causal principles can explain. In sections 4 and 5, I examine some of what the outlined differences between d-causal principles and i-conservation principles imply about the explanatory role of d-causal principles in Newtonian mechanics and in GR. I begin by bringing out implications about what explanatory role Newtonian mechanics might give to d-causal principles and then proceed, against this background, to bring out implications about what explanatory role GR gives them.

2. I-conservation principles and some phenomena they explain

A (physical) i-conservation principle is a principle which is part of one or more theoretical systems and which tells us that some quantity, quality or aspect persists as is through change in one or more types of physical system. Each such principle accordingly implies that some quantity, quality or aspect in at least one type of physical system will not inexplicably change. Moreover, that an i-conservation principle implies that some quantity, quality or aspect in at least one type of physical system will not inexplicably change allows the principle to explain why some quantities, qualities or aspects in instances of at least one type of physical system do not inexplicably change.

An inexplicable change is a change that just happens, i.e., a change that is not a result of how (other) things are or should be. Such a change is thus uncaused and not a result of the laws of nature. The friends of dispositions in fact allow, at most, two kinds of fundamental explanatory principles, namely d-causal principles and laws of

nature. So, from their perspective, if a change is uncaused and not a result of the laws of nature, it is inexplicable.

To say that something persists as is in some respect or another is, in the present context, just to say that it does not change in the relevant respect over, at least, part of its trajectory. By implication, cases of persistence as is are cases in which there is an absence of inexplicable change as well as an absence of explicable change.[4] It is for this reason that, since i-conservation principles explain cases of the absence of change, they also explain the absence of inexplicable change.

The principle of the conservation of electric charge, for example, tells us that the net electric charge of an isolated system remains constant through change. It accordingly tells us that we won't find inexplicable increases in the net electrical charges of isolated physical systems. And this information allows us to explain why, in specific isolated physical systems, charge does not inexplicably increase. For example, the principle can explain why the charge of an isolated system comprised solely of a positron and an electron that interact and are annihilated, does not inexplicably increase after the interaction.

Similarly, Newton's principle of inertia tells us that the direction of travel and speed of a massive object upon which no external, unbalanced force is acting will not change over time. So, according to Newton's principle of inertia, we will not find an inexplicable increase or decrease in the speed of such a mass. This allows Newton's principle of inertia to explain, among other things, why the speed of specific, more or less isolated masses does not inexplicably increase.

Notice that I define 'i-conservation principle' in essentially the same way as Belot defines 'conservation principle' (2006, p. 461) and indeed that my definition captures an intuitive notion of what it is to be a conservation principle. But Belot's

definition might be thought to be insufficient as a definition of 'conservation principle'. It is satisfied by Newton's principle of inertia, which is not ordinarily taken to be a conservation principle. Further, we will see below that other principles which are not usually referred to as conservation principles fulfil Belot's definition. I, accordingly, avoid assuming that the concept expressed by 'i-conservation principle' is the same as the concept expressed by 'conservation principle'. My interest here is just with the implications of some of the differences between i-conservation principles and d-causal principles, irrespective of whether i-conservation principles are just conservation principles.

Notice also that, on the present definition of 'i-conservation principle', a principle can be an i-conservation principle even if it is explicable using other, more basic, principles. Newton's principle of inertia, for example, counts as an i-conservation principle even *if* it is thought to be explained by Newton's second law of motion.

As to what it is for an i-conservation principle to explain, this is an issue I need not take a stand on here. My arguments will depend on the above conclusions about what i-conservation principles can explain rather than on any positive view about what it is for them to explain. Still, it is straightforward to offer a view about what it is for them to do so that sits comfortably with the suggestions I will be making about how they differ from d-causal principles. Einstein (1919) distinguished between principle and constructive theories. It is not clear precisely how to interpret this distinction, but van Camp (2011), who I will be following on this matter here, argues that constructive theories are best thought of as explaining by providing a causal-mechanical account of their target phenomena. van Camp further argues that principle theories are best thought of as providing unifying frameworks for understanding

target phenomena, frameworks that apply independently of the possible details of the causal-mechanical processes involved and that explain by virtue of being unifying independently of these details. Now, i-conservation principles do not, on the face of things, provide causal-mechanical explanations of phenomena. Yet they do provide a unified picture of phenomena and their evolution. So such principles can perhaps be viewed as being akin to principle theories in that they explain by unifying and do so irrespective of any possible details regarding relevant causal-mechanical processes.

Finally, I have assumed that the information i-conservation principles give us about individual physical systems explains, just as the information provided by many other principles found in physics does. Two worries arise about this assumption. To begin with, one might worry that, when i-conservation principles explain the absence of inexplicable change, they explain what needs no explanation. The absence of inexplicable change, the thought might be, is just a brute, inexplicable fact about our world. In addition, the assumption that i-conservation principles can explain is correct on the standard way of interpreting i-conservation principles. For example, the principle of the conservation of charge and Newton's inertial principle can, and are used to, answer questions about why things persist as is. Nevertheless, one might be able, and want, to replace the standard way of interpreting i-conservation principles. The suggestion might be that my examples of i-conservation principles can, and should, be reinterpreted in such a way that they *imply* instances of the absence of inexplicable change, but do not explain such instances. Perhaps, then, the conclusion I will draw below about the role d-causal principles have in GR should be taken to be conditional on the standard way of interpreting i-conservation principles.

The assumption that absences of inexplicable change need explaining is, however, not one I make. My aim is to contrast the explanatory potential of i-

conservation principles and GR with that of d-conservation principles while leaving aside the evaluation of the explanations provided by i-conservations and GR. That said, the price for holding that inexplicable change need not be explained would be high. According to GR, we will see, explaining gravitational phenomena is a matter of explaining the absence of inexplicable change. So denying that the absence of inexplicable change needs explaining means holding either that gravitational phenomena need no explanation or that GR is wrong about gravitational phenomena.

The assumption that i-conservation principles can explain can also be bypassed. My argumentative strategy will rest on picking a candidate fundamental explanatory principle and showing that the principle explains some i-conservation principles and, via these i-conservation principles, certain instances of the absence of inexplicable change. Doing this will allow me, since we will see that d-causal principles cannot explain instances of the absence of inexplicable change, to argue that the selected candidate fundamental explanatory principle explains aspects of cases of absences of change that d-causal principles cannot explain and, when it comes to some of the candidates, that the candidate explains cases of absence of change that d-causal principles can have no role in explaining. However, my argumentative strategy would work just as well if it turned out that although i-conservation principles play a role in deriving conclusions about absences of inexplicable change, the part of the derivation they contribute to is not explanatory.[5]

Nevertheless, I would prefer to discuss what i-conservation principles explain rather than merely what they imply even if my conclusions were conditional on standard interpretations. First, these interpretations fix theories' and i-conservation principles' actual, unreconstructed meanings. And it is of significance to see what role theories give d-causal principles given the standard, unreconstructed understanding of

these theories and of their central implications. Second, rejecting the standard interpretation of i-conservation principles is not something to be done lightly. Doing so would risk reducing the epistemic or, at least, pragmatic virtues of i-conservation principles. For explanatory power is reasonably thought to be an epistemic virtue or, at least, a pragmatic virtue.[6] Doing so would also risk reducing the explanatory and the epistemic, or at least the explanatory and the pragmatic, virtues of GR. I-conservation principles have a central role in GR. Third, an interpretation of i-conservation principles according to which they are not explanatory may not be an option. If, for example, the view that i-conservation principles explain by unifying is correct, the explanatory nature of these principles is one of their essential features.

3. Phenomena that d-causal principles cannot explain

I have argued that each i-conservation principle can explain the absence of inexplicable change in some quantities in some physical systems. I now argue that d-causal principles cannot explain any instances of the absence of inexplicable change. And in light of this, I conclude that each i-conservation principle, and each principle that can explain i-conservation principles, can explain aspects of cases of absence of change that d-causal principles cannot explain and indeed that some i-conservation principles, as well as some principles that can explain i-conservation principles, can explain cases of absence of change that d-causal principles can have no role whatsoever in explaining.

The reason I have for thinking that d-causal principles cannot explain instances of the absence of inexplicable change is that, as I have previously suggested (2005), such principles can only play a role in explaining non-occurrences when these result from the inhibition of some endeavour. Consider a case in which someone is,

entirely unsuccessfully, trying to push a heavy, unlocked door open. Here, we can assume, the solidity of the door along with its mass successfully inhibit the endeavour to move the door and thus play a role in ensuring the absence of movement. Accordingly, d-casual principles describing the relevant dispositions of the door, in combination with an appropriate description of the circumstances, would have a role in explaining the non-occurrence in question.[7] But the non-occurrence of inexplicable change is not the non-occurrence of some change which there is an endeavour to bring about. There is thus, in such cases, no putative cause of the change which the possession of dispositions might inhibit, and thus no prospect that d-causal principles might play a role in explaining the absence of the change.

Why assume that dispositions can only be appealed to in order to explain absences of change when the absences depend on the inhibition of some endeavour or another? The alternative is to suppose that dispositions can cause absences directly and, by virtue of doing so, be appealed to in explaining absences. If, for example, the door's dispositions are to ensure that the door does not budge and do so even though there is no endeavour to move it, the dispositions in question will have to bring about the fact that the door is not moving directly. The problem is that absences are not real physical occurrences. So the physical relation of being directly brought about cannot have absences as relata. To make this more vivid than the case of the door does, note that such direct causation would, for example, allow keeping a conveyor belt going by bringing about the non-occurrence of its slowing down without affecting any of its, or other objects', physical properties.

In fact, since absences of inexplicable change cannot be explained indirectly by appealing to the inhibition of some endeavour, it seems that any view according to which causation is a real relation requires concluding that instances of the absence of

inexplicable change cannot be causally explained. This would seem to follow, for example, if we adopted Dowe's view (1995) that causation involves the exchange or the possession of a conserved quantity. For, if we assume that causation is a real relation, absences cannot be caused directly and hence cannot be explained by appealing to direct causation. Indeed, the source of all the limitations of d-causal principles that I will bring out is these principles' inability to explain the absence of inexplicable change. Accordingly, all the limitations I will bring out seem to be shared, on any view according to which causation is a real relation, by all causal principles. I have not, however, argued that absences of inexplicable change cannot be caused. Moreover, my focus will continue to be on what causal principles can explain if causation is conceived of in terms of disposition manifestations.

The case for denying that absences can be the direct objects of physical action is currently unanswered. Some, including friends of dispositions, argue that absences do not exist (e.g., Molnar, 2004 and Mumford and Anjum, 2011) and thus can never be effects. Others allow that absences exist but argue that they cannot feature as relata of the causal relation (e.g., Kukso, 2006). Yet others argue that absences can be causes/effects but that, either in general or at least in cases of causation involving absences, there is therefore no question of thinking of causation as a real relation (e.g., Schaffer, 2004 and Hall, 2004). The situation of the friends of dispositions is particularly difficult here because they tend to be committed to the idea that dispositions are the mark of the real. Allowing that absences are capable of being affected by physical objects would thus make absences, according to the friends of dispositions, as real as physical objects.

Because i-conservation principles can explain instances of the absence of inexplicable change and d-causal principles cannot do so, i-conservation principles

can explain what d-causal principles cannot explain. More explicitly, i-conservation principles can, while d-causal principles cannot, explain those aspects of cases of absence of change that comprise instances of the absence of inexplicable change. This implies not only that d-causal principles are limited in their ability to explain instances of the absence of change, but also, given that the absence of change in some respect often involves change in another respect, that they are limited in their ability to explain change. They might, for instance, be able to explain why an object continues to accelerate by a given amount but will not be able to explain why it does not inexplicably accelerate further.

Further, if a d-causal principle could explain i-conservation principles, it would indirectly be able to explain instances of the absence of inexplicable change. So d-causal principles cannot explain i-conservation principles, and if some principle can explain i-conservation principles, the principle can explain what d-causal principles cannot explain.[8]

There do appear to be cases in which d-causal principles can partially explain instances of the absence of change that i-conservation principles can explain. In such cases, an i-conservation principle's explanation for a case of the absence of change might be thought of as being equivalent to an explanation that is provided by a conjunction that includes d-causal principles which can explain the inhibition of endeavours which would do away with the absence and a principle according to which no inexplicable change disrupts the absence. We might, for example, say about persistently good natured Chris that he is persistently good natured because he will not just inexplicably turn mean and tends to behave in a way that promotes his good nature. However, explanations resting on inertial principles – that is on principles describing objects' persistence as is (in some respect or another) in the absence of

external, unbalanced forces – are often explanations in which d-causal principles can have no role whatsoever.

What principles of inertia that describe persistence as is in the absence of any disturbing influences explain, and what principles that explain these principles of inertia indirectly explain, cannot even be partly explained by d-causal principles. In the absence of external disturbing influences, there is, by hypothesis, no external influence on any object that might be countered in order to ensure its persistence as is. Nor is any involved object supposed to have a disposition not to persist as is and thus to have a disposition the effects of which might be countered by those of some other disposition. So the only thing that might supposedly be caused and explained in such cases is the absence of inexplicable change. And this absence would accordingly have to be supposed to be caused directly. We have seen, however, that dispositions cannot directly bring about absences.

It is tempting to think that, irrespective of how a physical system evolves, we can think of the dispositions of the objects in it at any given time as causing any later state of the system. If dispositions could do this, d-causal principles could perhaps always fully explain the evolution of physical systems. Thus, one might be tempted to think that Newton's principle of inertia, and other principles of inertia, just describe objects' dispositions to persist as is in the absence of external, unbalanced forces and thus that they are d-causal principles that can fully explain some cases of persistence as is. What we have seen, however, is that since persistence as is involves the absence of inexplicable change, d-causal principles can at most only partially explain persistence as is. Further, while we can perhaps envisage dispositions bringing about any particular path of evolution in some physical systems, we cannot do so in just any such system. When we do envisage dispositions playing a role in bringing about a

particular case of persistence as is, we presuppose that the case of persistence in question involves disturbing influences. We thus limit our consideration to a certain kind of physical system. When evolution involves no disturbing influences and thus nothing dispositions might counter, there is nothing whatsoever that dispositions might cause.

4. D-causal principles in textbook Newtonian mechanics

In order to provide a background to my discussion of the explanatory role of d-causal principles in GR, I will briefly say something about the explanatory role such principles might have in textbook Newtonian mechanics. The emphasis is on textbook Newtonian mechanics because d-causal principles are not implausibly thought of as having an explanatory role in it, a role that allows it nicely to be contrasted with GR. D-causal principles, however, do not appear to have an explanatory role in some of the historical theories that go by the name of Newtonian mechanics. For example, it seems that these principles have no such role in Newton's own version of Newtonian mechanics (Heimann, 1978).

My focus will be on Newton's second law of motion, which is here taken to be one of Newtonian mechanic's fundamental explanatory principles. Equation (1) captures this law as formulated for a single mass:

$$d\mathbf{p}/dt = \mathbf{f} \qquad (1)$$

where $d\mathbf{p}/dt$ is the rate of change of the mass's momentum. According to (1), the rate of change of the momentum is equal to the quantity of force, $\mathbf{f}$, acting on the mass. This allows (1) to explain why, in any system to which it applies, the relationship between the rate of change of the momentum and the quantity of force

acting on the mass in the system will persist as is through change. So (1) explains i-conservation principles.

Among the i-conservation principles that (1) explains we find the already mentioned law of inertia, a standard textbook formulation of which is given by (2):

$$d\mathbf{p}/dt = 0 \qquad (2).$$

(2) tells us that the momentum of a mass upon which no unbalanced force is acting has a rate of change that is equal to zero. A special case of (2) occurs when the mass is one upon which no force whatsoever is acting and thus, in the Newtonian context, one that is not subject to any disturbing influences.

Since (1) explains i-conservation principles, it can explain goings on that d-causal principles cannot fully explain. For example, it can explain, while d-causal principles can at most only partially explain, the fixed relation between the rate of change of a specific mass's momentum and the quantity of force acting on the mass. In the special case of a mass upon which no force whatsoever is acting, (1) explains what d-causal principles can have no role whatsoever in explaining. There is nothing that tends to change the momentum of such a mass, so only by explaining the absence of inexplicable change could the persistence as is of its momentum be explained.

Nevertheless, (1) may give d-causal principles an explanatory role. (1) is naturally thought of as telling us that, at all times at which a force acts on a mass, the force *causes* the mass's momentum to change at a rate that is equal to the force itself. So although (1) explains i-conservation principles, it is also naturally thought of as telling us how certain causes/effects evolve over time. Moreover, the force acting at any given time is supposed to be one that causes an actual deviation from inertial motion in the absence of any forces, so the force is not to be thought of as causing an absence of change (inexplicable or otherwise). This leaves open the door to thinking

of the effects of forces as the effects of dispositions. Thus, perhaps we can think of (1) as describing how certain dispositions and the effects of their being possessed in the circumstances evolve over time, even though, as we have seen, (1) does not allow us to suppose that d-causal principles themselves suffice to explain this evolution. On this construal, (1) would imply d-causal principles. Fully to develop, never mind to assess the viability of the claim that (1) allows d-causal principles a partial explanatory role is not, however, something I intend to do here.

5. General relativity and d-causal principles

(1) implies i-conservation principles and thus has the characteristic explanatory powers of such principles. (1)'s use of the notion of forced motion suggests that it might be able to provide a second type of explanation for phenomena, one that d-causal principles provide. GR, however, offers a single type of explanation for phenomena and this type of explanation is a type that explains i-conservation principles, and indeed that explains i-conservation principles which describe persistence as is in the absence of disturbing influences. Thus, GR gives d-causal principles no fundamental explanatory role.

According to GR's fundamental explanatory equation, that is Einstein's field equation, gravitational effects in a region are not the result of a gravitational force. Rather, they depend on the region's space-time curvature which, in turn, depends on boundary conditions relating to the structure of space-time, the distribution of mass-energy in space-time and the way mass-energy is coupled to the structure of space-time.[9] This means that it is the boundary conditions, the distribution of mass-energy through space-time and the way mass-energy is coupled to the structure of space-time that supposedly explains a region's curvature and thus that supposedly explains the

gravity dependent dynamical properties of the region and of mass-energy in the region. Moreover, as I will illustrate below, the field equation does not make a distinction between different ways in which space-time and mass-energy are coupled. So we can say that GR's explanations are a type of explanation for dynamical properties that is characterised by the assumptions it makes about how space-time structures are coupled to mass-energy, including the assumption that these structures are coupled to mass-energy in a uniform way.[10]

Einstein's field equation tells us how mass-energy is coupled to the structure of space-time. Violations, inexplicable or otherwise, of this particular coupling are excluded. Thus, when Einstein's field equation explains principles that describe change, it explains principles according to which the way in which mass-energy is coupled to the structure of space-time remains constant through change. So when Einstein's field equation explains principles that describe change, it explains i-conservation principles and, through these principles, the kinds of facts that i-conservation principles explain. Einstein's field equation can, accordingly, explain aspects of cases of persistence as is that d-causal principles cannot explain.

In addition, when Einstein's field equation explains principles that describe motion in the absence of non-gravitational effects, and thus unforced motion, it explains principles according to which not only is such *motion* motion in which mass-energy's coupling to space-time remains unchanged across space-time, it is also motion that is not subject to disturbing influences. So the only thing that GR might be explaining in these cases is what d-causal principles can play no part in explaining, namely the absence of inexplicable change.

The field equation explains the principle that the motion of test particles which are only subject to gravitational effects is geodesic motion, that is motion with no

proper acceleration and, accordingly, along the straightest lines of the geometry of the embedding space-time.[11] An object the motion of which is thus explained will have a variety of properties which will not change, e.g., that of its having zero proper acceleration or of its motion being coupled to space-time in the way specified by Einstein's field equation. Moreover, although the object is supposed to be subject to gravitational effects, it is also supposedly not subject to disturbing influences. Gravitational effects are not here thought of as giving rise to motion that counters objects' pattern of behaviour in the absence of gravity. So the kind of explanation Einstein's field equation provides, in the case of the unforced motion of a test particle, is one in which d-causal principles have no explanatory role. Moreover, the same will be true of the explanations the equation provides in other cases in which only gravitational effects are found. The equation does not bring with it a conceptual distinction between the gravitational influence on test particles and other types of gravitational influence. Indeed, since the field equation always explains through precisely the same type of considerations, it always provides explanations in which d-causal principles have no explanatory role.[12]

It is worth illustrating, in the case of test particles' geodesic motion in the absence of non-gravitational effects, the claim that the appeal to the dispositions of space-time cannot play a part in GR's explanations. Using d-causal principles partly to explain this species of persistence as is would involve assuming that some effects have to be countered if the particles are to move along geodesics.[13] Only then might dispositions have something to inhibit in bringing about geodesic motion, so that d-causal principles could play a role in explaining why such motion occurs. In the present case, one could assume that test particles are in fact disposed to exhibit non-geodesic motion and that the dispositions of space-time ensure that the effects of these

dispositions are entirely cancelled out. Or one could assume the converse and suppose that the dispositions of test particles ensure geodesic motion by countering the non-geodesic effects of the dispositions of space-time. However, even if we accept that a suitable and reasonable d-causal principle friendly story that partly explains geodesic motion can in principle be told, any such story explains motion that is subject to disturbing influences. Such explanations presuppose, just as explanations that appeal to Newtonian forces presuppose, that there are endeavours to disrupt whatever motion it is that is being explained.

The partial explanation of geodesic motion through the countering of effects has the additional feature that it reads like an appeal to a conspiracy in which nature always hides the true natures of test particles and space-time. As a result, such an explanation is, other things being equal, an unlikely explanation. This epistemic feature of a d-causal principle based explanation of geodesic motion further differentiates such an explanation from the ones provided by GR. GR, needless to say, posits no conspiracy between mass-energy and space-time.

It is natural, for friends of dispositions, to suppose that even though GR does not construe gravitation as a force, it does allow construing how space-time and mass-energy interact in terms of dispositions and their effects. Here the thought would be that since GR tells us that space-time and mass-energy are coupled, it allows that the dispositions of space-time affect and are affected by those of mass-energy. Bird, for example, argues on this basis that one can view GR as characterizing the dispositional essence of space-time (2009). The arguments given above show, however, that the fact that GR couples space-time and mass-energy does not suffice to allow construing the interaction between the two in terms of dispositions and their effects.

Nevertheless, even granting my arguments, GR may well still provide causal explanations and, accordingly, be thought of as a constructive theory. For it may still be true that, according to GR, space-time causally interacts with mass-energy. Recall, I have suggested that my arguments about the limited explanatory ability of appeals to causes conceived of as the effects of dispositions would continue to apply on any view according to which causation is a real relation. But I have not suggested that they would apply on just any view of causation. Bartels (2011), for example, may well still be correct that the counterfactual view of causation, a view of causation that does not imply that causation is a real relation, allows us to make sense of the idea that, according to GR, mass-energy and space-time causally interact.

Let me put the argument of this section in a more concrete way. To begin with, we can see what kind of explanation GR yields by taking a look at its fundamental explanatory principle, that is at (3), Einstein's field equation:

$$G^{\mu\nu} = T^{\mu\nu} \qquad (3)$$

$T^{\mu\nu}$ is the stress-energy tensor. It encodes information about energy and momentum due to matter and electromagnetic fields.[14] $G^{\mu\nu}$ is the Einstein tensor. It captures information about the curvature of space-time. Thus, (3) tells us how mass-energy relates to the structure of space-time and vice-versa. Now, we can derive from (3) the conclusion, captured in (4), that the covariant derivative of the stress-energy tensor is 0. (4) is a set of dynamical equations for mass-energy in the form of a local conservation principle.[15]

$$T^{\mu\nu}{}_{;\nu} = 0 \qquad (4)$$

So a statement about how the energy and momentum due to matter and electromagnetic fields is coupled to the structure of space-time allows us to explain dynamical equations governing mass-energy in space-time and, by implication, to

explain specifications of these equations that describe the evolution of physical systems in which gravity plays a role. When the concern is with mass-energy that is only subject to gravitation, for example, the description of the coupling to space-time structure will suffice fully to capture and explain, solely via (4), the evolution of the systems involved.[16] When it comes to systems in which there is no mass-energy, we can derive and explain, again using (4) and what it tells us about how space-time structure is coupled to mass-energy, dynamical equations for space-time in the absence of mass-energy, e.g., for the behaviour of gravitational waves. Further, (3) only specifies one type of coupling between mass-energy and space-time and does not allow for cases in which mass-energy is free of the effects of space-time. Accordingly, Einstein's field equation provides a kind of explanation that is characterised by its explaining on the basis of what it tells us about how space-time structures are coupled to mass-energy, including its assumption that these structures are coupled to mass-energy in a uniform way.[17]

(3) explains, via (4), principles which describe change and imply that this change is change through which the way in which mass-energy is coupled to space-time remains unchanged. So, (3) explains i-conservation principles and, through such principles, particular cases in which things persist as is. Accordingly, the explanations (3) provides are not explanations that could be provided solely by d-causal principles.

In addition, the principles which (3) explains via (4) and which are supposed to describe motion subject solely subject to gravitational effects, are principles according to which the motion they are about is not subject to disturbing influences and is motion through which the way in which mass-energy is coupled to space-time persists through change.[18] So, in these cases, (3) and (4) give d-causal principles no explanatory role whatsoever.

For example, (3) allows us to explain, via (4) and when conjoined with the appropriate stress-energy tensor, an equation of motion for a test particle that is solely subject to gravitational effects. This equation of motion is the geodesic equation (5), in which u^μ is the particle's four-velocity and $u^\mu{}_{;\nu}$ its covariant derivative. According to this equation, the particles' motion is unforced motion along a geodesic.

$$u^\mu{}_{;\nu} u^\nu = 0 \ (5)$$

Now, although this free motion of test particles is supposed to be subject to gravity, it is not contrasted with motion that is not subject to gravity. It is, accordingly, taken to be precisely the kind of motion which Newtonian mechanics tells us the motion of an isolated mass is, that is, motion that is not subject to disturbing influences.

Similarly, consider a standard treatment of an extended object subject only to gravity. We can approximate the motion of an extended object by positing one the size of which is negligible and associating with it a spin. The idea here is that the spin captures part of the effect that arises where an object extends across a curved region of space, and thus across a region with geodesic paths the distance between which is variable. The variable distance between the geodesics means different gravitational constraints on different parts of the object, and thus that the object will deform and rotate (Stephani 2004, p. 180).

According to the approximation being considered, the relevant extended object will exhibit geodesic motion, modified only as a result of how the object's spin affects the object's motion (generally these modifications are in fact negligible). But the supposed deviation of the object from geodesic motion is here explained in the same way in which the geodesic motion itself is explained. The stress energy tensor is modified so as to include a representation of contributions of the objects' spin, and how these contributions are supposed to affect motion is then explained, via (4), by

the same supposed general coupling of mass-energy to space-time that explains the geodesic motion captured by (5). The additional terms introduced to capture the contributions of the objects' spin merely describe relevant, additional features of mass-energy. They do not come with special interpretive assumptions about the nature of the interaction between the spin and space-time, assumptions that would differentiate this interaction from that already assumed in the case of geodesic motion. Here too, then, what is being explained is a principle according to which objects' motion under the sole influence of gravity is not subject to disturbing influences.

But the kind of explanation (3) offers for principles describing motion solely under the influence of gravity, including the kind of explanation offered for (5) and the just described approximation of the motion of an extended body, is the same type of explanation (3) offers in general. In general, the notions concerning the coupling of mass-energy to space-time provided by (3) are the notions that do the explanatory work. So, since (3) gives d-causal principles no role whatsoever in explaining principles describing motion solely under the influence of gravity, (3) gives d-causal principles no explanatory role whatsoever.

6. Conclusion

We have seen that GR does not give d-causal principles an explanatory role. Indeed, I have suggested that, on any view according to which causation is a real relation, GR does not give causal principles an explanatory role. The reason GR thus limits appeals to causation is that the kind of explanation it provides explains persistence as is in the absence of disturbing influences. So a substantial constraint on views about GR's fundamental explanatory principles, and attending views about what ontology GR

brings with it, is whether these views can play a part in showing how GR can explain persistence as is in the absence of disturbing influences.

A natural step, at this point, is to consider whether the arguments provided here can be extended so as to support the view that, on any plausible view of causation, GR gives causal principles no explanatory role. Another next natural step is to consider whether quantum mechanics, on its Copenhagen or 'standard' interpretation, gives d-causal principles an explanatory role. My suspicion is that it does not. Most notably, although Schrödinger's equation does allow a distinction between forced and unforced quantum mechanical systems, the quantum mechanical notion of force cannot, on the Copenhagen interpretation, be interpreted as referring to a real phenomenon in the way that the classical notion of force can. As a result, I would argue, the principles that Schrödinger's equation explains are principles according to which quantum mechanical systems persist as is (in some respect) and do so in the absence of (real) disturbing influences. D-causal principles could play no part in explaining such persistence as is.

Acknowledgements

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[1] See, among many others, Harré and Madden (1973), Fetzer (1977), Cartwright (1989 & 1999), Bigelow, Ellis and Lierse (1992), Chalmers (1999), Molnar (2003), Mumford (2004), Heil (2005) and Bird (2008).

[2] Another important claim many friends of dispositions make is that one can reduce some or all laws of nature to d-causal principles. I do not elaborate on this claim here as I avoid drawing any conclusions about views of laws of nature from my discussion.

[3] See Cartwright and Alexandrova (2005) for a brief summary of some of the ways in which the special sciences are often supposed to presuppose that d-causal principles are ultimate explanatory principles.

[4] When I write of cases of absences of change or of instances of the absence of change, I refer to instances of the absence of change in some respect in some situation. Thus, that there is some instance of the absence of change does not mean that there is no change in general or in whatever situation the absence is found.

[5] Insisting that candidate fundamental explanatory principles are not explanatory would not help either to identify the candidates with d-causal principles or to equate the candidates with some conjunction of d-causal and other principles. For d-causal principles are supposed to be explanatory. Further, as we will see, such insistence is not plausible in the case of GR.

[6] See Psillos (1999, pp. 171-172) for an overview of the considerations for thinking that explanatory strength is an epistemic virtue, i.e., a virtue that is a guide to truth. See van Fraassen (1983, pp. 166-169) for a case for thinking that explanatory strength is just a pragmatic virtue, i.e., a virtue that is indicative of empirical adequacy.

[7] This is a case in which d-causal principles would explain the absence of a certain caused change and hence the absence of explicable change. My focus is on the inability of d-causal principles to explain the absence of inexplicable change rather than just on explaining the absence of change precisely because d-causal principles can explain the absence of explicable change.

[8] An even stronger conclusion can be drawn here and can be drawn without assuming that if d-conservation principles could explain i-conservation principles, d-conservation principles would also be able to explain instances of the absence of inexplicable change. Insofar as d-causal principles provide information about what will be the case, the information in question is about physical occurrences. It is not information about absences of inexplicable change. So there is no way of deriving, solely from d-causal principles, principles that do provide information about what absences of inexplicable change will be the case.

[9] When I speak of mass-energy here, I exclude the mass-energy of the gravitational field itself.

[10] Some, e.g., Brown (2005), prefer to say that general relativity explains by appealing to the coupling between the gravitational field and mass-energy in space-time. But that the explanations of general relativity are in terms of space-time geometry is not essential to my argument. What is essential to it is just that relativistic explanations are a single kind of explanation that explains what d-causal principles cannot explain.

[11] A test particle is a particle with energy and momentum sufficiently small so that its effect on the curvature of space-time is negligible, and with a size that is such that the inhomogeneities of the gravitational field in its vicinity have a negligible effect on its motion.

[12] The fact that Newtonian mechanics treats inertial motion as motion that is not subject to gravity allows one to argue that it offers no explanation for inertial motion. Since GR treats inertial and non-inertial motion as motion in a gravitational field, however, it does not allow such an argument. Indeed, the case for thinking that GR explains the principle of inertia and, with it, inertial motion is well established in the literature (Brown, 2005).

[13] The explanation would have to be partial, of course, because d-causal principles cannot explain instances of the absence of inexplicable change.

[14] The reference to electromagnetic fields made here is needed because information about these fields sometimes goes into explanations that are based on Einstein's field equation. I am not, however, considering what types of explanations result when Einstein's field equation is combined with equations for non-gravitational phenomena.

[15] Whether (4) really is a local conservation principle is unclear (Hoefer, 2000). I, accordingly, do not assume that it is.

[16] In other cases, (4) will have to be supplemented by additional relevant dynamical equations, e.g., by Maxwell's equations in the case of an electromagnetic field, if the dynamics are fully to be determined.

[17] This argument is nicely put by Ciufolini and Wheeler (1995, pp. 27-28).

[18] Explanations derived from (3) will, even when they purport to be solely about gravitational phenomena, sometimes make use of auxiliary, (arguably) explanatory hypotheses that are not part of a theory of gravity as such. I make no claim about the explanations these hypotheses provide.

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