Action at a distance

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1. What is 'action at a distance'?

In the broadest sense of the phrase, there is action at a distance whenever there is a spatial or temporal gap (or both) between a cause and its effect. In this sense, it is not at all controversial that there is action at a distance. To cite a few instances: the page a few inches in front of you is impinging on your senses; the Sun is now warming the Earth; we are still living with the consequences of the Second World War. What *is* controversial is the idea of *unmediated* action at a distance, where there is both a gap between cause and effect and no intermediate causes and effects to fill it. The three examples just mentioned are cases of action at a distance, certainly, but not, surely, unmediated action at a distance. What we expect to find, in each case, is a spatially and temporally continuous causal series stretching across time and space.

Why has the possibility of unmediated action at a distance been taken seriously? According to the mechanistic world-view prevalent in the 17th century, and championed by Descartes, among others, the behaviour of matter was taken to be explicable entirely in terms of motion and collision. The paradigm instances of causal interaction (in the material world, at least) were therefore influence by contact, defined precisely by the absence of a gap. Newton's introduction of gravitational forces did not fit this rather rigid mechanical mould, and so appeared to illustrate instantaneous and unmediated causal influence across space. Newton himself made no such claim for gravitation, rejecting the idea of unmediated action at a distance as absurd. As he put it:

> That one body may act upon another at a Distance thro' a Vacuum, without the Mediation of anything else, by and through which their Action and Force may be conveyed from one to another, is to me so great and Absurdity, that I believe no Man who has in philosophical Matters a competent Faculty of thinking can ever fall into it. (Cohen (1978), 302–3)

He nevertheless declined to postulate any mechanism for gravitation, famously declaring 'Hypotheses non fingo'.[1] Later, magnetic forces presented the same conundrum. The development of field theory in the nineteenth century showed how even gravitational and magnetic forces could be treated as mediated action at a distance.[2]

Unmediated action at a distance (hereafter simply 'action at a distance') is a violation of the *Principle of Locality*, the insistence that effects are local to their immediate cause, a principle supposedly threatened by certain implications of quantum physics. Perception of such a threat arose originally from reflection on a famous paper by Einstein, Podolsky and Rosen (1935), which raised the following problem. According to the 'standard' interpretation of quantum mechanics, the position and momentum of a particle are indeterminate until you measure them, and you cannot measure both position and momentum at the same time. But now consider a pair of particles, A and B, that are allowed to interact, and which then move apart. Suppose we then measure the momentum of one of the particles, A. Given information concerning the state of A and B during the period of their interaction, we can, from the value of A's momentum, infer B's momentum. *At that very moment*, then, B's momentum is determinate, even though we have not measured it directly, or interfered with it in any way. If instead we have chosen to measure A's position, we could have inferred B's position. So, if quantum mechanics is complete—if, in the words of the paper, 'every element of the physical reality must have a counterpart in the physical theory'—then both the momentum *and* position of B are determinate, independently of any direct measurement, contrary to the standard interpretation of quantum theory (Einstein et al. (1935), 779–80). Now, it is an assumption of this argument that measuring one particle cannot instantaneously affect the state of the other: that there is no instantaneous action at a spatial distance. But defenders of the standard interpretation may question that assumption: maybe measuring A does instantaneously affect B in a way not mediated by anything in the intervening space.

[1] 'I frame no hypotheses.' This remark occurs in the General Scholium Newton added to the 2nd edition of his *Principia*. A translation is provided in H.G. Alexander (1956), 164–71.

[2] For a historical survey of arguments concerning action at a distance, and its theoretical development, see Hesse (1961).

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So what should the philosophical attitude to Locality be? Is the principle a necessary truth, a contingent but universal truth, or a largely true generalization with some admittedly bizarre exceptions? Perhaps, given its fragile status in contemporary physics, the proper attitude should be one of agnosticism. Here perhaps is yet another example of an entrenched view posing as an *a priori* truth, which must, like so many other metaphysical sayings before it, be surrendered to the fickle ways of scientific fortune. But perhaps it is possible to take a rather more robust position. Philosophers should certainly be concerned about the principle's status, since it is bound up with other important concepts. Let me give two examples.

The first example is persistence through time. What is it that underlies our ordinary judgement that a given object remains the *same object* through time? One influential answer to this is that it is *spatio-temporal continuity*: a life history should contain no spatial and temporal gaps.[3] Another answer is in terms of *causal continuity*: each stage in a life history should be intimately causally connected to its previous stages.[4] Locality shows that these are not actually competing criteria, for causal continuity implies spatio-temporal continuity.

The second example is the intrinsic/extrinsic property distinction. The intrinsic properties of a thing are often defined as the properties it has which do not logically (or perhaps, better, metaphysically) depend on the existence or properties of any other object. Being 100 cm^3 in volume, composed of carbon compounds, and having a temperature of 65° thus count as intrinsic. Being my niece's favourite pet, on top of the Matterhorn, and in the path of a beam of ultra-violet light do not. This characterisation has its limitations, however. Suppose substantivalism is true: space exists as an object in its own right, independently of its contents.[5] Then even being 100 cm^3 in volume depends metaphysically on a quite distinct object, namely a region of space. Indeed, any property of a spatial object would then count as extrinsic. Our intuitive grasp of intrinsicness is, in fact, a spatial one, and it seems better to build this into the definition: the intrinsic properties of an object are

[3] See, e.g., Locke's discussion of the persistence of organisms: Locke (1700), II, xxvii, 3–4.

[4] This is implicit in Locke's analysis of personal identity over time in terms of the continuity of memory: *op. cit.*, II, xxvii, 9.

[5] For a detailed characterisation and defence of substantivalism, see Nerlich (1994).

those that do not depend metaphysically on the existence or properties of anything outside the spatial boundaries of that object. That there is a genuine distinction to be made is confirmed by the thought that, if Locality is true, then the spatial conception of intrinsicness articulated above leads to a causal criterion:

> A causally active property F is *intrinsic* to x if and only if the immediate effects of F are in x's immediate spatio-temporal vicinity

Of course, the criterion is inapplicable to acausal properties, which is why this is a described as a criterion, rather than an analysis of intrinsicness. But it does help to put the intrinsic/extrinsic distinction on a securer footing when we reflect that the properties that we intuitively pick out as intrinsic have local effects; those we pick out as extrinsic (typically) do not.

The fate of Locality, then, is philosophically significant. The purpose of this paper is not to assess Locality's compatibility with modern physics, but to explore various reasons, mainly of a philosophical kind, we might offer in favour of it, and how those reasons bear on our understanding of its status. So, for instance, some reasons might support the idea that Locality is a metaphysically necessary truth, others that is simply physically necessary. I am going to suggest that giving up Locality has some anomalous consequences for our understanding of causation (over and above the sheer oddness of action at a distance, of course). But this falls short of establishing Locality as a metaphysically necessary truth. The prospects for establishing the latter do not look good.

First, however, let us address the question of how precisely Locality should be characterised.

2. The Principle of Locality

A simple formulation of Locality is as follows:

(1) There is no spatial or temporal gap between a cause and its immediate effects.

An initial objection is that the notion of 'immediate' effects implies that the causal series exhibits a *discrete* ordering: for any given member of the causal series, there is a unique immediate successor. But what if the causal ordering is *dense*, such that between any two members of the series there is a third? Then we cannot, apparently, talk of the 'immediate effects' of a cause. The causal relation between any two members of a dense causal series will always be mediated.

We can, however, define 'immediate' in such a way that it is applicable to discrete and dense series alike, as follows:

For any cause c, a series (of events, states, facts or whatever) S contains the *immediate effects* of c if and only if S contains some effect x of c, and all causal intermediaries of x and c.

In a dense ordering, of course, S will contain no first member, but there is no effect of c closer than any member of S. (1) can therefore define Locality for both discrete and dense series. However, there is a further objection. Consider a dense causal series consisting of two parts, A and B, between which there is a spatial or temporal gap. Suppose further that A has no last member and B no first member. Any cause we choose in this series will satisfy (1): because of the peculiar topological properties of the series, there will be no gap between that cause and a set containing its immediate effects. However, the series clearly does not satisfy Locality, as we intuitively grasp it, since the series contains a spatial or temporal gap.[6]

An attempt to exclude this case is the following formulation:

(2) For any non-zero distance or interval d between any cause and effect in a series, there is an intermediate cause that is $d/2$ from the cause.

This condition would not be satisfied by the case we imagined. But it is not a satisfactory formulation. First (although this is perhaps a relatively minor worry), it presupposes that there is an objective division of an interval or distance into two equal halves. It presupposes, in other words, an objective space-time metric. But space and time, intuitively, might lack such a metric, and yet causal series not contain gaps. Second, even if we insist on such a metric, there is still the objection that Locality is a purely topological principle, not a metrical one. Third, suppose space-time to exhibit a discrete structure, with the consequence that causal series exhibit a discrete ordering. And let us suppose further that the distance between any two items is a function of the number of space-time 'atoms', or indivisible, partless minima between them. Now suppose there to be an odd number of such atoms between two items, adding up to distance d. Under these circumstances $d/2$ is not a possible location for any intermediate item. Fourth, if the

[6] I owe this objection, and formulation (2), to Timothy Williamson.

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causal series describes a curved trajectory in space, and we conceive distance *d* between two items to be the shortest route between them, then there is no reason to suppose that there will be intermediate causes at *d*/2 (or indeed anywhere along that shortest route).

There is a further concern. As Lange (2002) has pointed out, spatio-temporal locality is not simply the conjunction of spatial locality and temporal locality. Consider the propagation of causal influence through space (a light sphere, for instance). Here, spatially intermediate causes should also be temporally intermediate. This is spatio-temporal locality. It would be possible for a sufficiently peculiar causal series to satisfy both spatial locality and temporal locality, and yet not to satisfy spatio-temporal locality. Here is his suggested formulation:

> For any event E, any finite temporal interval $\tau>0$, and any finite distance $\delta>0$, there is a complete set of causes of E such that for each event C in this set, there is a location at which it occurs that is separated by a distance no greater than δ from a location at which E occurs, *and* there is a moment at which C occurs *at the former location* that is separated by an interval no greater than τ from a moment at which E occurs *at the latter location*. (Lange (2002), p. 15)

Despite the reference to interval lengths in this characterization, there is no presupposition of an objective metric, because even if there is no fact of the matter as to whether a given spatio-temporal region is as large as any other non-overlapping region, it will still be true that a region will be larger than any region it contains as a proper part, which is all we need for Lange's definition. So we may justly regard it as a purely topological analysis. It is, however, subject to the same counterexample as (1), the causal series with an unusual topology, and the fourth objection to (2): the curved causal trajectory.

To summarise the discussion so far: we are looking for a non-metrical condition, one that is consistent with both dense and discrete causation, and which rules out *relevant* space-time gaps—i.e. ones that disrupt the causal series. The following promises to fit the bill without being over-complex:

(3) If *x* causes *y*, then either (i) *x* and *y* are contiguous in space-time, or (ii) *x* and *y* are linked by a causal chain that follows a continuous spatio-temporal pathway between x and y.

So much, then, for what Locality says. We turn now to the question of its status.

3. Locality as empirical hypothesis: Faraday's criteria for action at a spatial distance

Perhaps the Principle of Locality is no more than an empirical generalization, something which agrees with our ordinary experience of causation. If this is what it is, then we should be able to make sense of observations that would falsify it, evidence of action at a distance. What would constitute such evidence?

Empirical means of determining whether action over a spatial distance is mediated or unmediated are suggested in an 1852 paper by Faraday, entitled 'On the Physical Character of the Lines of Magnetic Force'.[7] His main concern in that paper is with the question 'whether the lines of magnetic force have a physical existence or not' (Faraday (1852), §3297). He compares and contrasts magnetic force with other kinds of force or causal influence: gravitation, radiation (of heat or light), electric current and induction. These other kinds of force seem to fall into three categories:

> Three great distinctions at least may be taken among these cases of the exertion of force at a distance: that of gravitation, where propagation of the force by physical lines through the intermediate space is supposed not to exist; that of radiation, where the propagation does exist, and where the propagating line or ray, once produced, has existence independent either of its source, or termination; and that of electricity, where the propagating process has intermediate existence, like a ray, but at the same time depends upon both extremities of the lines of force, or upon conditions (as in the connected voltaic pile) equivalent to such extremities. (Faraday (1852), §3251)

Gravitation he takes to be the paradigm case of (unmediated) action at a distance, although he is willing to entertain some doubt on the matter:

> There is one question in relation to gravity, which, if we could ascertain or touch it, would greatly enlighten us. It is, whether gravitation takes *time*. If it did, it would show undeniably that a

[7] See Hesse (1961), 198–206.

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> physical agency existed in the course of the line of force. It seems equally impossible to prove or disprove this point; since there is no capability of suspending, changing, or annihilating the power (gravity), or annihilating the matter in which the power resides. (*Ibid*., §3246)

The clearest case of mediated action over a distance is radiation. Here,

> Lines of force have a physical existence independent, in a manner, of the body radiating, or of the body receiving the rays. They may be turned aside in their course ...The lines have no dependence upon a second or reacting body, as in gravitation, and they require time for their propagation. In all these things they are in marked contrast with the lines of gravitating force. (*Ibid*., §3247)

The most important empirical criterion of action at a distance according to Faraday, then, is this:

(a) the transmission of action is instantaneous.

In practice, however, it may be hard to establish whether this obtains or not. The rationale for this criterion is presumably this, that if the transmission of influence requires the existence of an intervening process, this will take time. A second criterion, although this is less prominent, is

(b) the action depends on the simultaneous existence of the source and terminus, or reacting body.

The relevance of this criterion is less clear, but it may be a consequence of the time criterion. For if the transmission were mediated, then it could continue after the destruction of its source, and prior to the existence of a receiving body. Finally, a third criterion:

(c) the direction of influence is unaffected by changes in the intervening space.

The rationale for this is obvious: if the transmission of influence require the existence of states in the intervening states, they will be susceptible to influences in that space.

Having considered in some detail the phenomena associated with magnetism, Faraday comes to the 'speculative' conclusion that, although the propagation of magnetic influence does not appear to take time, magnetic lines of force exist in the intermediate space

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between the objects concerned (for example, between two magnets whose north poles are facing each other).

How satisfactory are these as empirical criteria for action at a distance? Consider the key criterion, (a). The assumption is that spatial action at a distance is instantaneous. But if we are prepared to allow the existence of instantaneous causation across a spatial gap, it is unclear on what grounds we can insist that transmission of action through spatial intermediaries must take time. Why cannot every link be instantaneous? Perhaps, then, the suggestion is not that cause and effect are simultaneous in cases of spatial action at a distance, but simply that there should be no temporal gap between them. But this presupposes *temporal* Locality: there cannot be a temporal gap between cause and immediate effect. What is the justification for this? Why are space and time being treated differently in this respect?

This point also undermines criterion (b). For if violation of temporal Locality were to be allowed, it would no longer be clear why the effect should be co-existent with its source.

As for (c) we might have expected this to be augmented by the requirement that the effect be independent of the *distance* between the two reacting ends. True action at a distance ought not to be so dependent: since the causal influence does not in this case involve causes in the intervening space, it should be, as far as the strength of causal influence is concerned, as if there were *no* intervening space. Yet gravitational force *is* dependent on the distance between the ends, according to the Inverse Square Law. What explains this law, if the propagation of gravitational influence does not involve intervening causes? The answer has to be *nothing*: the Inverse Square law is simply a brute fact if gravitation is true action at a distance. If, however, gravitation is mediated, and we conceive of the field of gravitational influence as a sphere, then the Inverse Square Law follows as a geometrical consequence.[8] We can also deduce that, in a two-dimensional space, gravitational attraction would fall off as a simple inverse of the distance, and in four dimensional space, as the inverse of the cube of the distance.

Of course, it could be insisted that it is indeed just a brute law that the strength of interaction varies with the distance. But this undermines criterion (c). If variation with distance can be a brute law, why can variation with the medium not also be the subject of brute law? It seems, then, that all three of Faraday's criteria can be challenged. Are there other *a posteriori* means of determining

[8] See Lange (2002), 96.

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whether a given phenomenon is a case of genuine action at a distance, or simply mediated? Faraday's criteria, note, are indirect. We might instead attempt to discover directly whether, in cases of a gap between cause and effect, there are intermediate causes. But insofar as this involves intervention, we cannot be sure that we have not introduced an intermediate cause (or effect) where there was none before.

This is hardly an exhaustive discussion of the empirical means of discovering action at a distance, but even this brief excursus on Faraday's criteria illustrates the difficulties involved in regarding Locality simply as an empirical, and so falsifiable, hypothesis. So, in the absence of unequivocal *a posteriori* methods, let us turn to *a priori* considerations.

4. Locality as metaphysical truth

Considered as a metaphysically necessary truth—one that *could not* be false, even if not analytically true—Locality poses a puzzle.

Suppose we grant that all causal chains from a particular source must, as a matter of necessity, proceed via effects that are local to the source. Then, in cases where there is both a spatial and a temporal gap between cause C and effect E, we have the following:

(i) There is an *x* that is causally intermediate between C and E, such that
(ii) *x* is spatially intermediate between C and E, and
(iii) *x* is temporally intermediate between C and E.

This is a putative example of something that Hume, for instance, thought impossible: a necessary connection between what he called 'distinct existences' (Hume (1739–40), Appendix, 635). By 'distinct existences' he meant logically distinct objects or states of affairs. That *x* is causally intermediate is logically distinct from its being temporally or spatially intermediate. Locality is not an analytic truth.

But Hume's conception of necessity is a narrow one: he conceives it as logical necessity. And that there could not be logically necessary connections between logically distinct existences is simply a trivial truth. But the last forty years or so has seen growing support for the notion of metaphysical necessity, where this is distinct from logical necessity. To take one of Saul Kripke's examples: any true identity statement, even if not analytic, such as 'Hesperus is Phosphorus', is necessarily true (Kripke (1972),

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102–5). But where we find metaphysical necessities, we should expect to find items that are not ontologically distinct. In this case, the individual named by 'Hesperus' is not ontologically distinct from the individual named by 'Phosphorus': both name the planet Venus (and do so, if Kripke is right, in every possible world: *ibid.*, 102). So we can reframe Hume's injunction as follows: there are no metaphysically necessary connections between ontologically distinct existences. The puzzle, then, is this: if Locality is indeed a necessary truth, then the states of affairs represented by (i)–(iii) above should not be ontologically distinct, yet they appear to be so.

We could, of course, reject the metaphysical version of Hume's injunction. But that leaves us with a connection between causal and spatio-temporal continuity that is simply offered as a brute fact, inexplicable in terms of anything else, and inadequately motivated by empirical reasons. A more satisfying, though controversial, strategy suggests itself: take causal connections to be not entirely distinct from spatial and temporal connections. In other words, pursue a reductionist programme. But in what direction should the reduction go?

Suppose we take causal connections to be constructions from spatio-temporal ones. Then the fact that A and B are causally related is just the fact that they are spatially and temporally related in some way. This is precisely Hume's approach:

> We may define a cause to be 'An object precedent and contiguous to another, and where all the objects resembling the former are plac'd in like relations of precedency and contiguity to those objects, that resemble the latter.' (Hume (1739–40), 170)

Here Locality is built into the very characterization of the causal relation. Causal relations are, on this account, constructions out of the spatio-temporal relations of events. This is not a straightforward identification of causal relations with spatio-temporal ones, since the latter relations obtain between individual events, whereas the causal relation is said by Hume to obtain in virtue of a constant conjunction of event types.

Locality emerges from this as a metaphysical truth, though at the price of abandoning the very conception of causation that made Locality interesting. For what the Humean conception does is effectively to eliminate causation as a relation between individual events in favour of regularities. In contrast, a more robustly realist approach to causation treats those regularities as something that emerges from the individual causal relations.[9] According to this approach, it is because there is causation at the level of events that there are large-scale regularities, rather than vice versa. I will not attempt to defend this (surely intuitive) view here, but it is this view that invites a substantive answer to the question: why should the causal chains emanating from a given cause always proceed via the locality of that cause? It is worth considering whether a substantive answer can be given. Hume's analysis gives us the form of a response, but since we are now considering the alternative to the regularity account, let us reverse his analysis and propose that space and time are simply aspects of causation itself.

What would such an account look like? Take time first, as the more straightforward case. We can easily see how temporal precedence could be constituted by causation:

x occurs before *y* if and only if *x* is a cause of *y*

It follows from this that any causal intermediary between *x* and *y* will also be a temporal intermediary. Temporal Locality, however, requires more than this. The immediate effects of *x* must be in *x*'s immediate temporal vicinity. Not all causal theories of temporal precedence will guarantee this. It is consistent with the above analysis that temporal separation is quite independent of causation. Suppose that time exists independently of the events that are located in it, and that times are ordered by betweenness relations. Such a series could exhibit order without any direction: a time series without an 'earlier than' relation. The direction of time could then be entirely a result of the directedness of causation. The temporal separation between *x* and *y* would then be purely a result of their location in time; but the fact that *x* is before *y* would depend on *x*'s being a cause of *y*. In such a world, temporal Locality is not guaranteed. To guarantee temporal Locality, time would have to be completely reducible to causality.[10]

We may be able to reduce time to causality, but can we do the same with space? The connection between space and cause seems less intimate than that between time and cause. A number of objections, in fact, arise for a 'causal theory of space':

(a) causal relations do not entail (non-zero) distance ones: what is happening at one time in the middle of the sun causes in part what happens in exactly the same place at a later time;

[9] See, e.g., Tooley (1987).
[10] For discussion of various versions of a causal theory of time order, and the problems each raise, see Le Poidevin (2003), Chapter 12.

(b) distance relations do not entail causal ones: I can be 4000 light-years from a star without interacting with it;
(c) space, unlike time and causation, is not intrinsically directed;
(d) if we assent to a causal theory of time and space, we necessarily identify time with space.

To (a) we might respond that, although not all causal relations involve distance, some do: the propagation of light from a source, for instance. So perhaps space is a construction from certain kinds of causal processes. If this strategy is to work, however, it must be the case that a different kind of causal relation is involved in those cases that imply distance between cause and effect: the difference cannot simply lie in the *relata*. As for (b), if we accept the strong version of causal theory of time contemplated above, everything has to be causally connected in some way to everything else.

(c) and (d) are rather harder to deal with. An initially promising strategy is to suggest that causality is *multi-dimensional*. In fact, we have to say this if we are to combine the idea that space is reducible to causality whilst preserving the evident fact that space is multi-dimensional. The suggestion that causal relations exhibit more than one dimension is not immediately absurd. We talk, for instance, of the dimensions of sound, meaning simply that there are independent ways in which sounds may differ from each other: in pitch, timbre and volume. If causality, then, were four-dimensional, then we could identify one of these dimensions with time and the other three with space. Thus time would not be identified with space, and could exhibit a direction which the three dimensions of space lack.

The difficulty with this proposal is that, although it can explain both spatial Locality and temporal Locality, it cannot explain spatio-temporal Locality, as we defined it in § 2. In fact, although it can explain spatial Locality with respect to a single spatial dimension, it cannot explain why, where x and y are separated in more than one spatial dimension, any causal intermediary must be between x and y with respect to all those dimensions. The reason for this lies in the fact that variation in one dimension is, by definition, independent of variation in another dimension—this is what makes them different dimensions. If causality is multi-dimensional, then there is no reason to suppose that an ordering in one dimension will match an ordering in any other dimension.

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What we have, then, is a rather complex and counter-intuitive conception of causality (more than one kind of causal relation, and at least one of these being multi-dimensional) that can explain only limited kinds of Locality.

The prospects, then, for a viable metaphysical picture of causation from which Locality emerges as an *a priori* consequence, seem bleak.

5. Locality as condition of physical law

Locality, we have suggested, is best represented neither as a mere empirical hypothesis, nor as a metaphysical truth. Could it, then, have an intermediate status?

Let us begin by posing this question: what do causes do? In general terms they determine the chances of their effects. If the world is deterministic, then (given background circumstances) they raise the chances of their effects to 1. If the world is indeterministic, then they simply raise the chances of their effects to something less than 1. But *where* and *when* those effects occur is not an arbitrary matter. What, then, determines the chances of the effects occurring at the time and place they do? Here are the possibilities:

(i) cause alone;
(ii) cause plus some feature of the location of the effects;
(iii) cause plus some further principle.

Option (i) is decidedly peculiar. The suggestion is that, in action at a distance, some intrinsic feature of the cause directly determines the gap between cause and effect. Let us suppose, for a moment, that the gravitational force that x exerts on y is an instance of this. According to (i), something intrinsic to x (and therefore logically independent of y) determines that the gravitational effects are felt precisely where and when y is. To see how unlikely this is, suppose further that y is being mechanically moved in an orbit around x by some device that is quite independent of x. The location of the gravitational effects of x is now constantly changing, and this, *ex hypothesi*, is explained by some corresponding change in the intrinsic properties of x. But of course, we know that x itself is not changing in this way, or that, if it is, any correspondence between those changes and the changes in y's location would be quite coincidental. For in the set-up imagined, the cause of y's location (namely, the mechanical device) is quite independent of the cause of the location of x's gravitational effects on y (namely, some intrinsic feature of x).

It is much more natural to suppose that the location of x's effects on y will be determined by y's location. After all, where else could x's effects on y be felt except where y is? Neither x nor y *causally* determine the location of those effects: the location of y is simply a logical constraint on where x's effects can be felt. This takes us to (ii). For gravitational effects to be felt by an object, y, there must another object, x. That is the causal condition. *Where* those effects are felt is logically determined by the spatial location of y. But what explains *when* those gravitational effects are felt? Our instinct here is to point to the temporal location of the *cause*. x's gravitational pull on y is felt at t because x exists at t. But such an appeal presupposes temporal locality: there can be no temporal gap between cause and effect. But if we allowing spatial action at a distance, temporal Locality looks rather less secure. Why should time alone obey Locality?

Since (ii) forces us to appeal to a principle, this response collapses into (iii): what determines the location of the effect is the (location of) the cause plus some other principle. What other principle? The natural candidate, surely, is the one that rules out *any* gap between cause and effect, namely Locality. This, as nineteenth century physicists discovered, has a serious ontological implication, namely the reality of fields. So when we ask why there are gravitational effects only *here*, where y is, the answer is that there are effects in other places too, but they are only manifested in certain ways where there is an object. The gravitational pull on the Earth is the result of the *local* presence of the gravitational field.

Without Locality, then, it would be completely mysterious why the effects of a cause occur at the time and place that they do. And unless there is in action a principle like Locality, making it non-accidental that effects occur when and where they do, there would be no *a priori* reason to suppose that there would be any regularities in nature. But such regularities are a necessary condition of physical law. The natural conclusion to draw is Locality is a condition of there being physical law.

Given that we live in a law-governed, non-chaotic world, that is a reason for thinking Locality is true. What it is not, however, is an *explanation* of the truth of Locality, for such an explanation would show how Locality followed from some more fundamental considerations. In the absence of such an explanation, Locality

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cannot reasonably be presented as a metaphysical truth. Its physical importance, however, is indisputable.

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