University of Birmingham Research at Birmingham

Isolation, not locality

Hicks, Michael; Demarest, Heather

DOI:
10.1111/phpr.12731

License:
Creative Commons: Attribution-NonCommercial-NoDerivs (CC BY-NC-ND)

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (Harvard):
Hicks, M & Demarest, H 2020, 'Isolation, not locality', *Philosophy and Phenomenological Research*.
https://doi.org/10.1111/phpr.12731

Link to publication on Research at Birmingham portal

General rights
Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of ‘fair dealing’ under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy
While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

Download date: 26. Feb. 2021

DOI: 10.1111/phpr.12731

ORIGINAL ARTICLE

Philosophy and
Phenomenological Research

Isolation, not locality

Heather Demarest[1] | **Michael Townsen Hicks**[2]

[1]University of Colorado

[2]University of Birmingham

Correspondence
Heather Demarest, University of Colorado.
Email: heather.demarest@colorado.edu

Funding information
Michael Townsen Hicks's work on this paper is part of the FraMEPhys project, which received funding from the European Research Council (ERC) under the European Unions Horizon 2020 research and innovation programme [Grant Agreement Number: 757295].

Abstract

There is a long tradition of preferring local theories to ones that posit lawful or causal influence at a spacetime distance. In this paper, we argue against this preference. We argue that nonlocality is scientifically unobjectionable and that nonlocal theories can be known. Scientists can gather evidence for them and confirm them in much the same way that they do for local theories. We think these observations point to a deeper constraint on scientific theorizing and experimentation: the (quasi-) isolation of causal or lawful influence. We argue that this requirement ought to replace the locality desideratum in science. We then explore the possibility that the order of explanation has been reversed: perhaps it is isolatable influence that determines what counts as local in the first place.

1 | INTRODUCTION

There is a long tradition of preferring local theories to ones that posit lawful or causal influence at a spacetime distance. In this paper, we examine the reasons philosophers and physicists give in favor of locality.[1] These reasons range from conceptual reasons (e.g., found in Newton) to methodological ones (e.g., found in Einstein). Here we argue against this preference. Nonlocality is scientifically unobjectionable and nonlocal theories can be known. Scientists can gather evidence for them and confirm them in much the same way that they do for local theories. We argue for a deeper constraint on scientific theorizing and experimentation: isolation. A system is isolated (in our sense) just in case all

---

[1] We use ‘nonlocality’ and ‘action at a distance’ interchangeably, though see Tim Maudlin (1994) and Wayne Myrvold (2016) for arguments that nonlocality in quantum mechanics is distinct from action at a distance.

of the features that have causal influence on the suitably specified 'output' state of the system go through the 'input' states. Consequently, scientific observations and experiments are possible so long as scientists must have epistemic (observational, inferential, or manipulable) access to the input and output states of causally (quasi-) isolated systems—regardless of whether they are local or not. We then explore the possibility that the order of explanation has been reversed: perhaps it is isolatable influence that determines what counts as local in the first place.

2 | ARGUMENTS FOR LOCALITY

It is not entirely clear to us how many philosophers would explicitly endorse locality as a desideratum for science. Nevertheless, the assumption of locality, or at least the strong preference for local theories, seems to be in the background of many discussions, ranging from the debate concerning realism about a high-dimensional phase space,[2] to quantum entanglement,[3] to the metaphysical underpinnings of the laws of nature.[4] The arguments we consider, clarify, and develop below largely represent our own interpretation of the motivations for assuming (or hoping for) the truth of locality. We begin with those we find weakest and end with those we find most powerful.

2.1 | Intuitive and experiential arguments for locality

First, consider the argument from metaphysical intuition. As P. W. Evans et al. note (2013, 305), there is a "[long-cherished] intuition that causation acts 'locally' and 'continuously'." The intuitive plausibility of locality may arise from the fact that most of our ordinary macroscopic interactions seem local: if we want to, say, open a door or transport some middle-sized dry goods, we have to actually touch the door and we must move the goods along some path. Famously, even though Hume doubts the reality of causation, he maintains that our idea of causation, which arises from habit or custom, requires 'contiguity.'[5]

However, by attending to the details of these kinds of experiences, we see that while many of our quotidian interactions with the world go along an obvious path, not all do. Smells seem to permeate an area and are (often unfortunately) unaffected by barriers. Electrical circuits transfer information far faster than we can detect and thus give us no experiential evidence of their local influence. And magnets—at least at the level of ordinary experience—seem to attract and repel one another without affecting or being affected by anything between them. Thus, while some of our ordinary experiences seem to support locality, some, by contrast, do not.

2.2 | Conceptual argument for locality

There is evidence that Albert Einstein takes locality to be a conceptual or metaphysical requirement on reality. Einstein, Podolsky, and Rosen (1935, 780) claim, "No reasonable definition of reality

---

[2] See, for instance, David Albert (2013), Valia Allori (2013), Tim Maudlin (1994), and Alyssa Ney (2013).

[3] See, for instance, John Bell (1987), P. W. Evans et al. (2013), and Huw Price (1996).

[4] See, for instance, Tim Maudlin (2007), Craig Callender (2017) as well as several of the chapters in Walter Ott and Lydia Patton's *Laws of Nature* (2018).

[5] See Hume's (1739, 12, 75) *Treatise of Human Nature*.

could be expected to permit [the 'reality' of a second system to] "depend upon the process of measurement carried out on a first system, which does not disturb the second system in any way." It seems plausible that their assumption that the first system does not 'disturb' the second is because they cannot discern a local path of influence. This is supported by Einstein's (1948)[6] claim, "The following idea characterises the relative independence of objects far apart in space (A and B): external influence on A has no direct influence on B; this is known as the 'principle of contiguity'." This statement highlights the conceptual connection between contiguity and influence.

Similarly, Isaac Newton claims,

> That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it. (2004, 136)[7]

One way of arguing for the 'unreasonableness' or 'absurdity' of action at a distance is to look for a contradiction. Samuel Clarke, in his fourth reply to Leibniz, argues, "That one body should attract another without any intermediate means, is not a miracle but a contradiction: for 'tis supposing something to act where it is not." Leibniz and Clarke (1956, 53))

We think Clarke's worry here rests on an ambiguity. On the first disambiguation, the thing acts where it is not because it occurs—as a cause—where it is not. This indeed seems contradictory: trivially everything occurs where it is. But on the second disambiguation, the thing acts where it is not by having effects where it is not. Yet, just as plainly, on any reasonable view, an event can have an effect where it is not. Even purely local causes have effects in places where they do not occur—namely, in spatiotemporally *contiguous* places.[8] Interestingly this observation highlights a way to distinguish local from nonlocal causes: local causes are contiguous (or connected by a string of contiguous processes) to their effects while nonlocal causes are not.

A final, conceptual argument against locality points out that nonlocal causal influences allow for causal loops. If causes could have nonlocal, instantaneous effects, there could be causal loops at a single time. Or, if special relativity is correct, and if causes could have nonlocal, spacelike effects, there could be causal loops between distant, spacelike separated events that would allow for timelike loops. One might worry that such loops would lead to vicious paradoxes. We note, first, that nonlocal

---

[6] The original paper is in *Dialectica*, which Einstein included in his 1948 letter to Born. The english translation is in (1971, 171).

[7] While some authors, e.g., John Henry (2011), have objected to the popular view that Newton wanted to avoid action at a distance, we focus on a straightforward interpretation of this passage (as well as the Clarke passage below) in order to tease out possible arguments in favor of locality. See Gregory Brown (2016) for a recent analysis of some of these interpretive issues in which he says, "I will argue that there is overwhelming evidence that Clarke, at least, was not only strongly committed to the principle of passive matter, but also to the principle of local causation; I will also argue that there is at least some fairly strong evidence that Newton was committed to both principles and that his acceptance of the principle of local causation played a significant role in his rejection of unmediated action at a distance." (2016, 40)

[8] See James Clerk Maxwell (1890) for a similar argument and see the first chapter of Marc Lange (2002) for an extended discussion of this issue. Even in the case of electromagnetic fields—which were (at least partially) posited to preserve locality—Maxwell thinks there is an effect occurring where the cause 'is not': "If, in order to get rid of the idea of action at a distance, we imagine a material medium through which the action is transmitted, all that we have done is to substitute for a single action at a great distance a series of actions at smaller distances between parts of the medium, so that we cannot even thus get rid of action at a distance." (1890, 486).

influence doesn't necessarily involve such loops. But if nonlocal influence did involve causal loops, these loops need not involve contradictions. Just as someone who receives the instructions for a time machine can successfully build it and travel back in time to give a copy of the instructions to her younger self, there are theoretical reasons to think physical systems, more generally, admit of consistent solutions to the boundary conditions required for causal loops.[9]

We conclude that there is no contradiction involved in action at a distance.

2.3 | Relativistic argument for locality

Peter J. Lewis claims, "The reason that causal nonlocality is regarded as problematic is that causal locality is arguably required by special relativity." (2016, 109) Ultimately, the world determines whether locality is true or not, and we are quite happy in deferring to our best physical theories. To be clear, our world may well turn out, as an empirical (and unproblematic) matter, to be purely local. But our aim in this paper is to show that we do not have pre-theoretical, conceptual, or methodological reasons to prefer local theories. Here we argue that special relativity does not straightforwardly entail locality.

First, note that while special relativity famously puts a maximum speed limit, *c*, on all causal influences (or on signaling, depending on the formulation),[10] this, by itself, does not entail that, say, a transmission from *A* to *B*, must be local. There could be a signal from *A* to *B* that does not move along any path, but that affects *B* only after a suitable interval—thereby respecting the universal speed limit. A deeper worry from special relativity is that nonlocal causation might allow for causal influence between spacelike separated events. Not only would this influence move faster than light (violating *c*, above), but worse, it would present us with a dilemma: assuming causes precede their effects, either the causal influence would allow us to discern an objective temporal ordering of spacelike separated events (which would add structure to special relativity), or it would make causation frame-dependent, with different perspectives disagreeing about which way the causal influence traveled.

In response to this, we point out that many philosophers refuse to stipulate that causes must temporally precede their effects. The asymmetry of causation may be better explained in terms of counterfactual or probabilistic asymmetries.[11] Just as instantaneous action in classical gravitation does not allow for a time order between causally related events at an instant, nonlocal causal influence between spacelike separated events need not require one of these events to occur before the other. In such cases, causal influence will seem to flow backwards in time to some observers, forwards in time to others, and instantaneously to yet others. Special relativity tells us that these are equally good perspectives. We conclude that special relativity does not entail locality in any straightforward way.

Neither is special relativity the last word in physics. Even if special relativity required locality, it is not the only highly confirmed theory. Quantum mechanics is also highly confirmed. And, famously, quantum mechanics posits faster-than-light entanglement correlations that exhibit many of the

---

[9] See, for instance, David Lewis (1976) and Frank Arntzenius and Tim Maudlin (2013).

[10] On one way of understanding the theory, special relativity does not rule out *all* kinds of influences between spacelike separated regions; instead, it precludes the transmission of *information*. For instance, in the quantum entanglement case, which we discuss below, Asher Peres and Daniel Terno (2004) argue that since nonlocal quantum interactions cannot transmit signals, they do not contradict special relativity.

[11] See, for instance, David Lewis (1976).

hallmarks of causation.[12] We know this from Einstein, Podolsky and Rosen's (1935) paper, John Bell's proofs (see for example (1964) and (1987)), as well as from countless empirical experiments such as Krister Shalm et al. (2015). A straightforward interpretation of these experiments holds that the measurement of one particle's state instantaneously changes the quantum state of a distant particle without any mediating force or field; this instantaneous change in the quantum state is explicit in some interpretations of quantum mechanics (e.g. Bohmian mechanics and some versions of GRW).

One might wonder then whether the success of quantum mechanics is a straightforward counterexample to strict requirements of locality. We would like to note that nonlocality in quantum entanglement has been resisted by physicists for a very long time. Likely this resistance was emboldened by widespread misunderstandings of John Bell’s (1964) proofs and the corresponding mistaken belief that locality could be preserved by rejecting local variables.

Importantly, there are also ways of preserving locality in light of quantum entanglement. For instance, Huw Price (1996) shows that accepting backwards causation allows one to maintain purely local causal influence in a special relativistic setting.[13] Finally, philosophers who offer high-dimensional interpretations of non-relativistic quantum mechanics often cite locality in 3 N-dimensional space as a reason to prefer those interpretations. Thus, we think it is worthwhile to critically examine pre-theoretic reasons for resisting action at a distance.

2.4 | Methodological argument for locality

We turn now to what we think is the most interesting argument against nonlocality—namely, that successful scientific experimentation requires it. Albert Einstein famously assumes that local action is a prerequisite for the practice of science.

> If [the principle of contiguity] were to be completely abolished, the idea of the existence of (quasi-) enclosed systems, and thereby the postulation of laws which can be checked empirically in the accepted sense, would become impossible. (1948, 321)

In other words, if there were effects that did not travel via a path of contiguous events, it would be impossible to confirm the laws of nature. For instance, a scientist might carefully set up an experiment only to find that unknown factors from a distance had affected the outcome in an unpredictable way. Such a scientist would not be able to uncover the operative laws or causal mechanisms. This can be read this as a kind of skeptical worry: we have to assume we are not in a world that exhibits action at a distance because otherwise we couldn't perform accurate scientific experiments. Or, conversely, insofar as we *can* perform successful experiments, the world must be local. Einstein seems to assume that only local components can appear in quasi-enclosed systems.

---

[12] For arguments that entanglement is better thought of as involving nonseparable states than nonlocal causation, see Jenann Ismael and Jonathan Schaffer (2016). We think that nonseparable states—global states that cannot be reduced to the sum of their parts—are equally subject to the worries raised for nonlocality. For instance, what is done in one spatiotemporal region may yet be affected by—or counterfactually depend upon—what happens elsewhere. We suspect that nonseparability does not pose any distinctive worries for scientific practice, though we do not argue for that here. See also Richard Healey (1991) for a discussion of the connection between nonseparability and holism on different interpretations of the quantum formalism.

[13] John Conway and Simon Kochen (2006) argue for another way out: if the universe is ‘conspiratorial,’ in the sense that it constrains the ‘allowable’ settings of the detectors that register quantum entanglement relations, the correlations can be explained locally.

One reason to think that science requires locality (or that science is easier to the extent that the world is local) is that human scientists, as it happens, are local beings—we are restricted to the here and now. Chris Dorst, for instance, argues that some features of scientists, including their inability to access nonlocal information, ought to explicitly constrain the formulation of the laws of nature. He says, "The spatial and temporal locality desiderata arise because we do not typically have information about spatially and temporally distant events." (2019, 16) Similarly, Craig Callender (2017, 178) argues that nonlocal theories are not as strong—in the Humean best system sense—as local ones, which is, "especially bad if one interprets strength in terms of usable strength for creatures like us."

But it is unclear to us why science should be constrained by our human limitations. We cannot see very small things or very distant things, yet scientific instruments such as microscopes and telescopes have allowed us to engage in extraordinarily valuable research of the very small and very distant. We argue that scientific inquiry requires *isolated* systems, not local ones. Since most of the isolated systems we encounter are also local, it is easy to see why people have thought locality was so important to scientific investigation. Nevertheless, we do not think action at a distance poses any problem for discovering causal and lawful influence in the world. We conclude that it is a mistake to prefer local theories to nonlocal ones. Locality is not a theoretical virtue. In the next section we present the idea of isolation and explain how it can answer these methodological worries.

3 | ISOLATED SYSTEMS

We argue that the feature of physical systems that is required for science is isolation, not locality.[14] What matters is that scientists have epistemic (observational, inferential, or manipulable) access to the input and output states of causally (quasi-) isolated systems.[15] On our view, a system is causally isolated just in case all of the features that have causal influence on the suitably specified 'output' state of the system go through the 'input' states.[16] A system is causally quasi-isolated just in case all of the *significant* and *non-background* causal influences go through the input states. An insignificant causal influence is one that makes no more than a negligible difference to the outcome (such as the gravitational pull of distant stars when observing the trajectory of a puck on an air hockey table). A background causal influence is one that is uniform throughout an experiment or observation (such as the temperature of the room in the same experiment). When these conditions hold, scientists are able to discover the lawful or causal relationships between different states. The input state can exert nonlocal influences on the output, and as long as scientists are able to account for all of the significant and non-backgrounded components, accurate, scientific predictions can be made (and often, successful interventions can be carried out). We provide examples that illustrate and motivate this account.

---

[14] Of course, there will be many other things that are required for science. For instance, there are additional metaphysical requirements (such as covarying, nontrivial causal influences), social requirements (such as funding for experimental equipment and personnel), etc., etc. Our 'isolation' constraint—meant to take the place of locality—is a necessary, but not sufficient condition for successful science.

[15] Because we are leaving the temporal direction of the experiment open, we use 'input' and 'output' where typical discussions use 'initial' and 'final.' Note that input conditions may include 'non-initial' difference-making boundary conditions. While we focus on the *causal* isolation of systems, some may wish to recast this requirement in terms of lawful dependencies. For a thoroughgoing discussion of the issue see Mathias Frisch (2014)).

[16] One fruitful way of modeling such causal isolation is with Judea Pearl's (2009) causal graphs. See also James Woodward (2003).

3.1 | A fanciful, motivating example

Suppose, contrary to fact, astrology had turned out to be true and the distant positions of the planets exerted nonlocal influences on the people on Earth. If that were true, these influences could be tested and systematized as in any other science. For example, some astrology enthusiasts claim that their moods change when (and because) various planets are in retrograde. There is nothing to prevent testing such an effect on moods. Indeed, according to Paul Thagard (1978, 225–226), “attempts have been made to test the reality of these alleged tendencies [of celestial events to affect human behavior].” He concludes, “through the use of statistical techniques astrology is at least *verifiable*.” If the theory were nuanced enough, we could learn of changes in the relative position of Mars by mood changes in people on Earth. Depending on the time delay, we might learn of those changes on Mars before we saw those changes in our telescopes. Crucially, those correlations would provide scientific support for a nonlocal, causal connection.

Note that an inability to *manipulate* the orbit of Mars does not preclude our ability to scientifically discover causal connections between the orbit of Mars and the behavior of Earthlings. Indeed, much of observational science—ranging from paleontology to astronomy—does not allow for the manipulation of the input states of a system, nevertheless, it is possible to draw scientific conclusions about causal connections based on how observed (or inferred) input states evolve into output states. But, of course, if we developed the technology to causally affect the orbit of Mars, we could use it to produce mood changes via this imagined, astrological nonlocal connection.

3.2 | Quantum entanglement

Consider a case of quantum entanglement, on one of the interpretations that posits a nonlocal causal influence from one photon to its entangled, but distant partner.[17] Scientists prepare a quantum state that consists of two entangled photons. When those photons hit aligned polarized filters, one will pass through and the other will be absorbed. Let us suppose that in this case, the left photon passes through its filter, exerting a nonlocal, causal influence on the right photon, which is absorbed. By assumption, it is the preparation of the entangled state and the left polarizer-and-photon behavior that comprise the input of the experiment. The right polarizer-photon behavior comprises the outcome.[18]

On our view, scientists need epistemic access to these input and output conditions. They achieve this by carefully preparing the entangled state and setting the polarizers (manipulable epistemic access), and by observing the behavior of the photons (observational epistemic access). By isolating this causal process, scientists can be sure that nothing else is relevant in producing the outcome. In fact, improving the degree of isolation is one of the central challenges of the experiment.[19] Crucially, there is nothing scientifically problematic about these experiments, which proceed in much the same way as other kinds of experiments. Even though influence is transmitted nonlocally, the theory is confirmed.

---

[17] This particular interpretation of the experiment is used to show how to apply our account and does not represent our own views about how quantum entanglement actually works.

[18] Different interpretations of the experiment will disagree about which portion of the experiment is properly counted as the ‘input’ condition—one reason to carefully distinguish *input* from *initial*.

[19] Krister Shalm et al. (2015) describe the many ways in which entanglement experiments are able to isolate the relevant variables from other influences.

Interestingly, these nonlocal effects cannot be used for signaling—they show up as correlations which are only recognizable when experimenters from the two distant experimental apparatus meet up and compare notes using local processes. But we can imagine theories where information is transmitted nonlocally.[20] Newton's theory of gravitation is one such theory, according to which the locations of large, distant masses affect the motion of earthly bodies instantaneously and without any mediating influences.[21] Such an influence could transmit information nonlocally about the locations and sizes of other masses. Indeed, the powerful predictions of Newton's equations, despite the posited nonlocal influence,[22] is a testament to the excellent science that could be done in a nonlocal world.

3.3 | Global nonlocality

The entanglement example involves the nonlocal effects from specific, localized causes that nevertheless act from a distance. Now we turn to an imagined example in which there is a nonlocal effect from a *global* cause that likewise acts from a distance—where the system's input state is distributed across the entire universe and its causal effects do not travel by a continuous path. We argue that if we have inferential epistemic access to these global input conditions, we can make reliable, scientific predictions.

Chris Dorst provides such an example. He asks us to imagine, "Newton's second law were not $F = ma$, but instead $F = m^n a$, where n denotes the total number of particles in the universe. If that were the law, then we'd be out of luck, for there is presumably no way we can reliably figure out the value of n" (2019, 12).

Yet it seems plausible that if the total number of particles appeared in a fundamental force equation, it would be precisely the kind of number we *could* and *would* experimentally determine, in much the same way we actually did for $F = ma$.[23] At first, we might view n as some kind of constant of nature. But a clever scientist might realize that the 'constant,' n, multiplied by the average mass of a particle yielded a number strikingly close to estimates for the total mass of the universe. Furthermore, this estimate might get closer as the equation was properly weighted for different ratios of particles and their masses. Then, it could easily be a live scientific hypothesis that the number n represented the total number of particles. To take the thought experiment further, we can imagine that if the value for n increased at the same rate that particles were being created (perhaps by decay, etc.) it would provide additional confirmation for such a hypothesis.

Even though we are unable to directly observe the total number of particles, we can infer what it is from local observations—and the larger our sample, the more accurate our estimate. In the imagined

---

[20] In fact, many science fiction stories include hypothetical devices that signal faster than light, much as quantum entanglement would if an experimenter could control one of the experimental results. See, for example, the *ansible* in Ursula K. Le Guin's (1974) novel, "The Dispossessed." Setting aside relativity theory, and metaphysical issues that might arise with knowledge of one's own future, there is nothing *scientifically* problematic about these purely fictional devices.

[21] See Earman (1987) for arguments that the lack of a well-defined notion of *same place* leads to a kind of radical nonlocality in Newtonian mechanics, independent of gravity.

[22] While there are (local) field-theoretic formulations of classical gravitation, these formulations were developed long after Newton's presentation of the theory; we are pointing out that the nonlocal Newtonian presentation involved no insurmountable methodological problems.

[23] For similar reasons Ned Hall says, "I imagine, for example, that cosmologists would very much like to know the total mass of the universe—and that even approximate information about this mass would be enormously predictively and explanatorily valuable." (2015, 274)

case, it is the global ratio that matters for the nonlocal influence, so if our sample were *not* representative then such an experiment would miss the connection. But representativeness has nothing to do with locality; it is a feature of any experiment which relies on random sampling.

What makes these cases susceptible to scientific investigation is that, despite involving nonlocal influence, scientists can get an independent epistemic handle on the causally relevant input and output components—by observation, manipulation, or inference. In these cases they are discovered locally, but we think the examples would work equally well if our epistemic access to the input and output conditions were itself nonlocal (via, for instance, wormhole telescopes).

3.4 | Local non-influences

If, as we have argued, causal influences can be unproblematically nonlocal, we won't be able to discover them by looking at spatiotemporally isolated regions—any 'isolated' region will be free of the nonlocal influence by definition.[24] The inverse claim here is that not every cause *within* a region is a component of interest. This is so even for influences that travel locally. Thus, a characterization of isolation that goes beyond spatiotemporal isolation would be needed *even if* all influences were purely local.

This can happen when some degrees of freedom for a system are causally independent of others, and are not coupled by law-governed connections. In these cases we can experiment on them even if they are within the system's local, spatiotemporal region, perhaps even co-located with other parts of the system. This is important because in many cases removing them would be impossible. For example, suppose we want to predict the two-dimensional motion of a puck on an air hockey table. Since classical velocity variables in orthogonal directions can be treated independently, we can ignore the causal influences from gravity. In general, which causal influences can be ignored will depend on how the outcome is specified. For instance, the paint on the puck will be a *local non-influencer* of its two-dimensional motion, but not of its reflective index.

3.5 | Quasi-isolation

Typically, only some components of a system are significantly relevant to a suitably specified outcome. Consequently, good scientific experiments cannot require total isolation. Rather, some components have effects small enough to be ignored and others exert uniform effects that can be backgrounded—assuming they cannot be shielded altogether. Our ability to isolate the difference-makers—the causally relevant features—of a system is what allows successful experimentation.[25]

---

[24] Thus, isolation should not be defined in terms of spatially isolated regions. See, for example, Hilary Greaves and David Wallace (2014). Greaves and Wallace focus on the isolation of regions, and give an excellent physical explication of region-isolation. We believe that Greaves and Wallace's region-isolation is a special case of the sort of isolation we discuss. Similarly, Adam Elga (2007, 156) takes macroscopic locality to be an important feature of ordinary folk physics and argues that 'overwhelming macroscopic locality' is required to make fairly simple folk-physical causal models. We disagree on both counts. As we say in Section 2.1, a careful examination of everyday experience suggests that even folk physics is not entirely local and we think that 'overwhelming macroscopic *isolation*' is better suited to play the role Elga identifies in folk physics.

[25] We can use Woodward's (2003) framework to represent a quasi-isolated experiment. The significant and non-background causal influences are represented by *endogenous variables*, the insignificant influences are omitted, and the background influences are represented by *exogenous variables* that are held constant. The relevant causal influences are represented by structural equations between these variables and the outcome.

There are negligible effects in the air-hockey example above. For instance, the orthogonal force of gravity exerts a uniform influence across the table, but it is weakly coupled with the movement of the puck across the table due to friction. The puck on the table does not behave in exactly the same way as it would in the absence of gravity—but, because friction is minimized it's close. And, unless the experiment requires a great deal of precision, we can ignore this influence when we perform experiments on this quasi-isolated system.

We can also ignore a causal influence if it exerts a uniform influence throughout the experiment. In this case, the causal factor can be treated as a fixed part of the uniform background. The air pressure from the table is like this in our air-hockey game. Significant changes to the air pressure can change what happens to the puck, but provided the pressure is roughly constant throughout the experiment, we can ignore it.

We conclude that *quasi-isolated systems* are required for experimental and observational science to work. We must have epistemic access to input and output states of systems which stand in a causal relationship with one another, such that any causal influences on the output states (a) go through the input states, or (b) are insufficient to significantly affect the outcome of our experiment, or (c) are uniform and so appropriately backgrounded. None of these features require that causal relations be local, or require our experiment or observational study to be in a causally isolated spatiotemporal region.

4 | WHAT IS LOCALITY ANYWAY?

Many of the examples above involve local agents discovering nonlocal laws using local methods—for instance, by using local communication to compare the results of distant entanglement experimental apparatus. But scientists operating in a nonlocal world need not be restricted to local methods. Tools to measure nonlocal correlations could themselves be nonlocal. We can imagine integrating such tools into our lives in various science-fictional ways: a nonlocal contact lens to watch concurrent storms on Jupiter; a nonlocal supernova detector for preparing protective shields in advance of harmful radiation; a nonlocal corpora callosa to enable synchronous, bilocational adventures. Thinking in this way makes us wonder what agents would mean by ‘near’ and ‘far’ in such a futuristic world.[26] Scientists with access to thoroughly nonlocal apparatus might have very different notions of distance. If causation between widely separated regions were ubiquitous, in what sense would these regions be widely separated?

Some philosophers argue that our notion of distance is itself dependent on our world's dynamics.[27] Here is one way of spelling this out: the strength of the various interactions of the world are represented by the world's Hamiltonian. In our world, the Hamiltonian can be factored into three independent dimensions, and (most) interactions become weaker along these dimensions. The fact that the Hamiltonian can be factored this way gives rise to the appearance of a four-dimensional world (three spatial dimensions and one temporal dimension), and the fact that the strength of these interactions decreases along these dimensions gives rise to our notion of distance: one object is farther from another just in case the strength of interaction between the two objects is less.

---

[26] We assume externalism about meaning; the features of a world that make it the case that one event is some distance from another may not be transparent to the agent.

[27] See, for instance, David Albert (1996, 282–283), Harvey Brown (2005), and Eleanor Knox (2013; 2019). Some of these ideas were inspired by our conversations with Marco Dees. Cf. Earman (1987, 454) who presents “(L4) *T* is a space-time theory” as a ‘pre-locality’ condition. He argues, “Without L4 it is hard to see how to make precise sense of … locality principles…”

On these views, the geometric structure of spacetime emerges from an underlying dynamical theory.[28] And these views seem to suggest that locality holds by the very nature of the dependence: all interactions must be local, not because locality is a requirement or precondition of science, but because the notion of distance itself is derived from those interactions. However, such a dynamical view of spacetime relies on the fact that *all* physical interactions, including electrodynamic, strong, weak, and gravitational interactions, can be factored into the same four dimensions and that the influence of these interactions decreases in a similar way along those dimensions.

But we can imagine a world where this is not the case. If, for example, all interactions could be factored *except one*, we might think that there was an emergent spacetime, but think of the interaction which did not factor in this way as nonlocal on that spacetime. Provided that most interactions, in some sense of 'most', were susceptible to a unified metrical structure, our ordinary macroscopic interactions and intuitive representations of the world would likely be coupled to this metrical structure; any remaining interaction types would appear to feature causation across arbitrary distances or causal processes without any path within the sensible spacetime associated with the 'normal' interactions.

Indeed, if wave function realists are correct about the ontology of (non-relativistic) quantum mechanics, it is plausible that quantum entanglement is just this sort of nonstandard interaction in a world which, fundamentally, is very high dimensional but whose interactions typically can be factored into a four-dimensional spacetime.[29] According to such a picture, our everyday notions of distance are derived from the interaction strengths, and while most interactions turn out to be 'local,' importantly, some—such as the outcomes of quantum entanglement experiments—do not. The open possibility that our world is in fact a wave in a high-dimensional space whose temporal evolution gives rise to a mostly, but not entirely, local three-dimensional sensible world strongly suggests that even if metrical structure is dependent on dynamic structure, nonlocal interaction is possible and discoverable.[30]

A similar program in theoretical physics takes spacetime to emerge due to entanglement relations between nonspatial points.[31] This program takes quantum entanglement to be a pre-spatial notion, and then argues that spacetime emerges from underlying entanglement relations. "Nearby" points are those with which a system is maximally entangled, but some points are also entangled with "distant" points that don't properly fit into a 3- or 4-dimensional mapping.

5 | CONCLUSION

We have argued that nonlocal theories pose no problems for successful scientific practice. Nothing about the metaphysics of interaction, the nature of agents, or the different ways of thinking about distance give us any reason to doubt that science would be possible in a nonlocal world. While many philosophers and scientists have assumed or argued that science is easier if locality is true, we have argued that a more plausible requirement on scientific inquiry is isolation. As long as scientists have

---

[28] On spacetime-emergent views, the 3+1 dimensional spacetime in which we find ourselves arises from a deeper nonspatial geometry (perhaps a string landscape, causal sets, or a quantum mechanical wave function evolving in a high-dimensional space). On spacetime-functionalist views, the geometry of spacetime is determined directly by the dynamics of the theory, without any appeal to a distinct pre-spatial geometry. In both cases, it is the structure of the dynamics of the theory which determines the dimensionality and metric of our macroscopic spacetime.

[29] See, for instance, Albert (1996), Craig Callender (2015), Alyssa Ney (2013), and Jill North (2013).

[30] Thus, wave function realists cannot appeal to arguments from locality, and will have to rely on other arguments, such as an ontological commitment to the wave function and its corresponding high-dimensional space.

[31] See Juan Maldacena and Leonard Susskind (2013) and Cao ChunJun, Sean Carroll, and Michalakis Spyridon (2017).

independent epistemic access to the causally relevant components, they will be able to test scientific predictions.

ACKNOWLEDGMENTS

We would like to thank Thomas Blanchard, Alison Fernandes, Barry Loewer, Andreas Hüttemann, Elizabeth Miller, Caleb Perl, Noelia Iranzo Ribera, Katie Robertson, Jonathan Schaffer, Julia Staffel, Brian Talbot, Alastair Wilson, and the audience at the *Conference on History and Metaphysics of Laws*, Central European University, Budapest.

REFERENCES

Albert, D. (2013). Wave function realism. In A. Ney & D. Albert (Eds.), *The wave function: Essays on the metaphysics of quantum mechanics*. Oxford University Press.

Albert, D. Z. (1996). Elementary quantum metaphysics. In J. T. Cushing, A. Fine, & S. Goldstein (Eds.), *Bohmian mechanics and quantum theory: An appraisal* (pp. 277–84). Dordrecht: Kluwer Academic Publishers.

Allori, V. (2013). Primitive ontology and the structure of fundamental physical theories. In A. Ney & D. Albert (Eds.), *The wave function: Essays on the metaphysics of quantum mechanics*. Oxford University Press.

Arntzenius, F., & Maudlin, T. (2013). Time Travel and Modern Physics, Stanford Encyclopedia of Philosophy. http://plato.stanford.edu/archives/win2013/entries/time-travel-phys/

Bell, J. (1987). *Speakable and unspeakable in quantum mechanics*. Cambridge University Press.

Bell, J. S. (1964). On the Einstein Podolsky Rosen paradox. *Physics Physique Fizika*, *1*(3), 195.

Born, M., Born, H., Born, I., & Einstein, A. (1971). *The Born-Einstein letters: Correspondence between Albert Einstein and Max and Hedwig born from 1916 to 1955*. Walker.

Brown, G. (2016). Did Samuel Clarke really disavow action at a distance in his correspondence with Leibniz?: Newton, Clarke, and Bentley on gravitation and action at a distance. *Studies in History and Philosophy of Science*, *60*, 38–47.

Brown, H. (2005). *Physical relativity: Space-time structure from a dynamical perspective*. Oxford University Press.

Callender, C. (2015). One world, one beable. *Synthese*, *192*(10), 3153–3177.

Callender, C. (2017). *What makes time special?* Oxford University Press.

Cao, C., Carroll, S. M., & Michalakis, S. (2017). Space from Hilbert space: Recovering geometry from bulk entanglement. *Physical Review D*, *95*(2), 024031.

Conway, J., & Kochen, S. (2006). The free will theorem. *Foundations of Physics*, *36*(10), 1441–1473.

Dorst, C. (2019). Toward a best predictive system account of the laws of nature. *British Journal for the Philosophy of Science*, *70*(3), 877–900.

Earman, J. (1987). Locality, nonlocality, and action at a distance: A skeptical review of some philosophical dogmas. In R. Kargon & P. Achinstein (Eds.), *Kelvin's Baltimore lectures and modern theoretical physics: Historical and philosophical perspectives* (pp. 449–490). MIT Press.

Einstein, A. (1948). Quantum mechanics and reality. *Dialectica*, *2*(3–4), 320–324.

Einstein, A., Podolsky, B., & Rosen, N. (1935). Can quantum-mechanical description of physical reality be considered complete? *Physical Review*, *47*, 777–780.

Elga, A. (2007). Isolation and folk physics. In H. Price & R. Corry (Eds.), *Causation, physics, and the constitution of reality: Russell's republic revisited* (pp. 106–119). Oxford University Press. chapter 5.

Evans, P. W., Price, H., & Wharton, K. B. (2013). New slant on the EPR-Bell experiment. *British Journal for the Philosophy of Science*, *64*, 297–324.

Frisch, M. (2014). *Causal reasoning in physics*. Cambridge University Press.

Greaves, H., & Wallace, D. (2014). Empirical consequences of symmetries. *British Journal for the Philosophy of Science*, *65*(1), 59–89.

Hall, N. (2015). Humean reduction about laws of nature. In B. Loewer & J. Schaffer (Eds.), *A Companion to David Lewis* (pp. 262–277). John Wiley & Sons. chapter 17.

Healey, R. A. (1991). Holism and nonseparability. *The Journal of Philosophy*, *88*(8), 393–421.

Henry, J. (2011). Gravity and de graviatione: The evelopment of newton's ideas on action at a distance. *Studies in History and Philosophy of Science*, *42*, 11–27.

Hume, D. (1739). *A Treatise of Human Nature* (2nd ed.). Clarendon, Oxford. First edition by Selby-Bigge published in 1888.

Ismael, J., & Schaffer, J. (2016). Quantum holism: Nonseparability as common ground. *Synthese*, 1–30.

Knox, E. (2013). Newtonian spacetime structure in light of the equivalence principle. *The British Journal for the Philosophy of Science*, *65*(4), 863–880.

Knox, E. (2019). Physical relativity from a functionalist perspective. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, *67*, 118–124.

Lange, M. (2002). *Introduction to the philosophy of physics*. Blackwell Publishers Oxford.

Le Guin, U. K. (1974). *The dispossessed*. Harper & Row.

Leibniz, G. W., & Clarke, S. (1956). Leibniz-Clarke papers. In H. G. Alexander (Ed.), *The Leibniz-Clarke correspondence*. Manchester University Press.

Lewis, D. (1976). The paradoxes of time travel. *American Philosophical Quarterly*, *13*, 145–52.

Lewis, P. J. (2016). *Quantum ontology*. Oxford University Press.

Maldacena, J., & Susskind, L. (2013). Cool horizons for entangled black holes. *Fortschritte der Physik*, *61*(9), 781–811.

Maudlin, T. (1994). *Quantum Non-locality and relativity*. Blackwell Publishers.

Maudlin, T. (2007). *The metaphysics within physics*. New York: Oxford University Press.

Maxwell, J. C. (1890). Attraction. In W. D. Niven (Ed.), *The scientific papers of James Clerk Maxwell* (Vol. *2*). Cambridge University Press. chapter 74.

Myrvold, W. (2016). Lessons of bell's theorem: Nonlocality, yes; action at a distance, not necessarily. In M. Bell & S. Gao (Eds.), *Quantum nonlocality and reality* (pp. 238–260). Cambridge University Press.

Newton, I. (2004). *Newton: Philosophical writings*, ed. Andrew Janiak. Cambridge University Press.

Ney, A. (2013). Ontological reduction and the wave function ontology. In A. Ney & D. Albert (Eds.), *The wave function: Essays on the metaphysics of quantum mechanics* (pp. 168–183). Oxford University Press.

North, J. (2013). The structure of a quantum world. In A. Ney & D. Albert (Eds.), *The wave function: Essays on the metaphysics of quantum mechanics* (pp. 184–202). Oxford University Press.

Ott, W., & Patton, L. (2018). *Laws of nature*. Oxford University Press.

Pearl, J. (2009). *Causality*. Cambridge University Press.

Peres, A., & Terno, D. R. (2004). Quantum information and relativity theory. *Reviews of Modern Physics*, *76*(1), 93.

Price, H. (1996). *Time's arrow and Archimedes' point*. Oxford University Press.

Shalm, L. K., Meyer-Scott, E., Christensen, B. G., Bierhorst, P., Wayne, M. A., Stevens, M. J., … Nam, S. W. (2015). Strong loophole-free test of local realism. *Physical Review Letters*, *115*(25), 250402.

Thagard, P. R. (1978). Why astrology is a pseudoscience. In *PSA: Proceedings of the biennial meeting of the philosophy of science association* (Vol. *1*, pp. 223–234). Philosophy of Science Association.

Woodward, J. (2003). *Making things happen: A theory of causal explanation*. Oxford University Press.

How to cite this article: Demarest H, & Hicks MT. Isolation, not locality. *Philos Phenomenol Res*. 2020;00:1–13. https://doi.org/10.1111/phpr.12731