# What a Structuralist Theory of Properties Could Not Be

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## Introduction

*Causal structuralism* is the view that, for each natural, non-mathematical, non-Cambridge property, there is a causal profile that exhausts its individual essence. A property’s causal profile is the collection of conditional powers it bestows on its instances as well as its “backward-looking” causal features regarding what can cause its instantiation. Having a property’s causal profile is both necessary and sufficient for being that property. It is generally contrasted with the *Humean* or *quidditistic view* of properties, which states that having a property’s causal profile is neither necessary nor sufficient for being that property, and with the *double-aspect view*, which states that causal profile is necessary but not sufficient.[[1]](#footnote-1) Motivated by a distaste for the metaphysical baggage of quiddities, the proponents of causal structuralism have detailed a number of convincing arguments against the Humean and double-aspect views. What these arguments get right is that our theory of properties ought not appeal to quiddities but must rather be a structuralist view. But appealing to the *causal* relations that physical properties bear to one another as determining their essence is crucially misguided. I offer several counterexamples from physics where the nature of a property seems to be determined in part by its higher-order mathematical features.

I conclude by suggesting that what is needed is a structuralist view of properties that is neither merely causal nor wholly dispositional,[[2]](#footnote-2) but that incorporates a physical property’s higher-order mathematical properties into its identity conditions. These structural mathematical features of properties can do the same work as quiddities without the problematic metaphysical and epistemic commitments.

## Metaphysical accounts of properties

There are three main positions on the natures of physical properties:

**Humean/neo-Humean view**: The causal powers a property confers are not part of the property’s essence. Though every property may have a causal profile, having the causal profile that it does is neither necessary nor sufficient for a property’s being the property it is.

**Double-aspect view**: Some or all of a property’s causal powers are essential to it. Having a certain causal profile is necessary but not sufficient to determine a property’s identity.

**Causal structuralism**: For each fundamental (natural, non-mathematical, non-Cambridge) property, there is a causal profile that exhausts its individual essence. Having a property’s causal profile is necessary and sufficient for being that property.

The Humean view, most prominently defended by Lewis (2009), entails that properties can play very different causal roles across possible worlds. The property of being negatively charged, for instance, could have failed to confer the power to attract positively charged things. Since different properties can share causal profiles on this view, the Humean must accept that there is something else that determines a property’s nature, namely, an unobservable quiddity or primitive “thisness.” Quiddities are by nature unobservable, as any observable features of a property are part of its causal profile, which the Humean takes to change across possible worlds. Notably, the Humean denies the existence of natural necessity, and it is this compatibility with Humeanism about causation and laws of nature that primarily motivates the quidditistic view.

On the less popular double-aspect view, two properties may have the same causal profile, so a property’s causal profile does not exhaust its individual essence. Since having the causal profile that it does is essential to a property’s being the property that it is, properties cannot change their causal profiles across possible worlds. But since two or more properties can share a causal profile, the double-aspect theorist must still appeal to something else in order to individuate properties. So she too is committed to the existence of quiddities and to the metaphysical baggage that accompanies them. As the view is committed to necessary connections between properties and their causal profiles, it is incompatible with Humeanism about causation.

Causal structuralism, on the other hand, entails that the powers a property confers on its instances do not change across possible worlds. Defended by Shoemaker (1998) and explored by Hawthorne (2001), the view is generally seen as an empiricist approach to property-individuation and essence. Nothing more than a property’s causal profile is required to fix its transworld identity. On this view, two or more distinct properties cannot share causal profiles. The causal structuralist takes causation to be a fundamental part of the world. She is committed to a robust account of causation and thus to the existence of natural necessity. Still, her commitments remain less epistemically objectionable than the quidditist’s, as there is at least some opportunity to observe causal relations in the world, while there is in principle no chance of observing quiddities.[[3]](#footnote-3)

## Against Quiddities

Arguments in favor of causal structuralism tend to focus on the unappealing consequences of the Humean and double-aspect views’ commitments to quiddities. Two of the arguments for causal structuralism – the epistemological argument and the semantic argument – turn on the claim that causal structuralism is the only view that allows us to refer to and recognize physical properties. The epistemological argument is that if two properties, A and B, share a causal profile, we can never identify which property is the cause of some physical event. We do not have access to anything regarding a property’s quiddity; all we can observe is its causal profile. Thus, if two properties share one, we have no way to distinguish between instances of one and instances of the other.

The semantic argument further draws out the consequences of profile sharing. If this possibility is allowed, not only will many statements we take to be true turn out to be false, but some of our statements will be threatened by semantic indeterminacy. Consider the following case. We notice that every instance of some phenomenon P seems to be preceded by an instance of C. Our controlled experiments seem to vindicate the claim that “All instances of P are caused by C,” and we then use C in statements of laws. However, not all instances of P are preceded by an instance of C. Some are preceded by an instance of B. Since we cannot distinguish between instances of C and instances of B, our claims about what causes P will be false. But the problem extends beyond many of our beliefs turning out to be false. Given our belief in the lawlike claim, we may make statements that involve the phrase “*the* cause of C.” Since these sentences have the false presupposition that there is a single cause of C, they will fail to refer to anything, and our science will be compromised by semantic indeterminacy. This undermines the project of science in that it significantly limits the extent to which science can discover facts about the world, including those that are normally considered to be within its domain.

The metaphysical argument against quiddities is that they commit one to indistinguishable possible worlds, or “differences that don’t make a difference.” Quidditism entails that two worlds can share all of their functional and behavioral features yet differ only in terms of their quiddities. Needless to say, once we narrow our world down to some set of observationally indistinguishable possible worlds, it is impossible for us to find out which member is our actual world. Since multiple worlds will satisfy the Ramsey sentence describing the laws of our world, we can never know which of these worlds is our own.[[4]](#footnote-4)

Note that all of these arguments have to do with the ramifications of profile sharing. They support causal structuralism only insofar as it is the best view of properties that precludes this possibility. It is standardly assumed that causal structuralism is the only view – and therefore the best views – that prohibit profile sharing. I will, however, suggest another view that prohibits profile sharing while avoiding the problems faced by causal structuralism.

The problems facing causal structuralism include the lack of a unified notion of causation across the sciences, the likelihood that causation is not a fundamental feature of the world, and the fact that there are a number of physical properties whose causal profiles seem not exhaust their essences. Many of the problems that arise for the causal structuralist result from what seems to be a conflation of the *causal* with the *nomological*.

While Shoemaker seems to think that these two things completely coincide, the examples I discuss show that the nomological actually subsumes the causal. One suggestion, then, is for the causal structuralist to broaden her view of what should be included in the profile that determines a property’s essence. We ought to understand a property’s essence in terms of its nomological profile rather than in terms of its narrower causal profile. This proposed change accommodates the problematic cases that constitute counterexamples to the view as it is and avoids the obstacles created by prematurely assuming causation is a fundamental feature of the world.[[5]](#footnote-5)

## Causal vs. Nomological

What is the difference between the causal and the nomological? It is true that everything that is causal is also nomological. For the non-Humean about causation, anything that is causal involves natural necessity. But not everything that involves natural necessity must also be causal. Broadly, I take the nomological to include any empirically detectable[[6]](#footnote-6) features or relations among properties whether causal or not. More specifically, we can take the nomological to include all laws of nature and all aspects of the world that are governed by laws of nature. Not all laws of nature govern causal phenomena. In some cases, higher-order laws of nature govern first-order laws of nature that are not themselves properly understood as causal phenomena.

Lange’s (2007) work on laws and meta-laws helpfully illuminates the need to broaden our understanding of what is empirically and physically relevant beyond the causal by distinguishing between laws and accidents at the meta-level. He offers a distinction with respect to symmetry principles. A symmetry principle can be understood either as a *requirement* or as a *byproduct* of a corresponding conservation law. “If a given symmetry principle is a meta-law, then the first-order laws not only do as a matter of fact exhibit this symmetry, but also *must* exhibit it, just as in consideration of the law that all copper objects are electrically conductive, the regularity that all copper objects are electrically conductive not only does obtain, but also *has* to obtain” (458). The analogy then is that symmetry principles that act as requirements restrict what first-order laws could hold as laws in our world whereas symmetry principles that are byproducts are merely implied by the dynamical laws that happen to hold in our world. Symmetry principles that are byproducts of the first-order laws would not be considered meta-laws that govern the first-order laws but would more appropriately be thought of as meta-accidents.

One way the causal structuralist picture is inadequate is that it is only capable of including first-order relations among physical properties, since it is within first-order laws of nature that causal relations among properties appear. I suggest that we develop a structuralist picture of properties that is not limited to the merely causal but that can also incorporate higher-order nomological relations that physical properties bear to one another as described by meta-laws at higher levels of nomic necessity.

A picture that incorporates higher orders of nomological necessity is well-suited to account for the prevalence of non-causal explanation within the sciences. Much of the work that has been done on non-causal explanation in the sciences focuses on cases that involve higher-order nomic necessity[[7]](#footnote-7) and non-causal mathematical structure.[[8]](#footnote-8) These examples, which contain physical properties whose essence is constituted in part by higher-order structural and mathematical laws, indicate that we ought to have a broader understanding of the empirically detectable features of the world that is not limited to the merely causal.

It is worth noting that many dispositionalists about properties do not accept the existence of higher-order necessities. Bird (2007) rejects the idea that meta-laws can have a necessity that is distinct from first-order laws, as his view entails that laws derive their necessity from the essentially dispositional nature of properties. The fundamentality of dispositions on this view leaves no room for nested modalities, and the necessity of all laws of nature collapses into the necessity of first-order laws, which derives from the fundamentally dispositional natures of properties. The issues raised in section 10.3 are problems not just for causal structuralism but also for dispositional essentialism.[[9]](#footnote-9) Given that on this view the natures of properties entail the laws, dispositional essentialism has difficulty making sense of properties whose dispositions seem to derive from higher-order mathematical or nomological structures, such as those described in 10.3.1 and 10.3.2. In 10.3.3, I address why dispositional essentialism’s inability to countenance a hierarchy of modalities should be seen as a cost of the view given the differential roles that laws and meta-laws play in actual scientific practice.

Lange’s (1999), (2007), (2008), and (2009) provide us with an excellent framework to understand the subsumption hierarchy of the nomological and the causal. Though Lange takes his picture to be a way of delineating how subjunctive and counterfactual truths can be lawmakers (and thus explain where the laws of nature get their lawhood), we need not accept the *subjunctive facts as lawmakers* view in order to make use of Lange’s concept of sub-nomic stability and corresponding framework of nested modalities.[[10]](#footnote-10) Lange’s picture has a number of benefits that do not depend on the view that counterfactual truths are what give laws their lawhood. One of these is that it allows us to make sense of the fact that laws that govern various phenomena may themselves be governed by higher-order laws. Indeed, many of the physical properties that provide counterexamples to causal structuralism do so because they have essential features that flow from the higher-order laws that govern them. This makes Lange’s hierarchical account of nomic necessity a good fit for our purposes.[[11]](#footnote-11)

Using Lange’s framework, we can understand the set of first-order laws of nature to be stable across any counterfactual suppositions that are causally possible. The set of causal laws would be stable under counterfactual invariance but it would be stable under a smaller range of counterfactual suppositions than would a set that contained only higher-order laws. That set is at a higher rung of the nomic hierarchy than the set of causal laws is. We can take the nomological to include the causal *and* the set of nomic facts that are invariant under a wider range of possibilities than the causal. My proposal is that structuralism about properties expand what relations can be included in a property’s essence beyond the merely causal to the nomological.

## Problematic properties

Three classes of properties that provide difficulty for causal structuralism are properties of quantum systems, properties of spacetime, and properties that correspond to conserved quantities that are governed by symmetry principles.[[12]](#footnote-12) I address one example from each group. The three properties I discuss all have one thing in common: part of their essence derives from higher-order structural features that are not themselves properly understood as merely causal even if they do offer partial explanations of why the properties have the causal profiles that they do.

## Quantum Incompatibility

That the mathematics involved in representing or constituting a property tends to be ignored in the canonical debates about quiddities is evinced by Black’s (2000). The examples he covers are from classical physics, so it is not the case that quantum properties are the only sorts of properties that can provide counterexamples to causal structuralism. But the fact that many quantum properties are understood primarily in terms of their formalism provides a helpful starting point for thinking about the insufficiency of causal structuralism to capture all essential aspects of physical properties.

Let us examine the quantum property of incompatibility. Incompatibility is a two-place relation that holds between a pair of quantum observables. Consider the Heisenberg Uncertainty Principle. While its name indicates only an epistemic limitation, it is best understood as a metaphysical principle: no quantum system can simultaneously have a definite location and momentum. The properties of location and momentum form but one pair of incompatible properties. From the quantum formalism, it can be shown that there are infinitely many such pairs. When two observables are incompatible, they cannot both be simultaneously instantiated with determinate values by a single system. What’s more is that the explanation for this, and indeed our explication of the property of incompatibility itself, is at least partly mathematical. In order to get a better understanding of this, let us look at some basic background quantum mechanics.

The quantum formalism deals primarily with vectors in the type of vector space known as Hilbert space. Vectors in Hilbert space are physically interpreted as representing states of a quantum system, and Hermitian operators on these vectors are interpreted as physically possible properties of the system. Every quantum system has a wavefunction, which gives the probability amplitude for all the states that the system might be in with respect to a certain property.[[13]](#footnote-13) Every physical system (i.e. every physical object, and every collection of such objects) is also associated with some particular vector space.[[14]](#footnote-14)

Measurable properties of a physical system are called *observables*, and they are represented by linear operators on the vector spaces associated with that system.[[15]](#footnote-15) States that are definite with respect to the value of a physical quantity are *eigenstates* (this is always relative to some observable).

Not all operators on Hilbert space commute. Operators that do not commute do not share eigenstates, so they represent *incompatible* observables. Thus, a physical system cannot have definite values for both of their corresponding properties simultaneously. Necessarily, for two incompatible observables, if a system is in an eigenstate of one, it will be in a superposition of the other.

This higher-order property of incompatibility of two properties is defined in terms of the non-commutativity of their corresponding operators. The operators corresponding to spin in the x-direction and spin in the y-direction, for example, do not commute, so they represent incompatible observables. The incompatibility of a pair of properties entails that whenever a physical system is in an eigenstate of one it will be in a superposition of the other.

Here we have a higher-order physical property whose essence is not exhausted by a causal profile. The notion of causation is too narrow to interpret the relevant nomological conditions on and implications of the property’s instances. And note that instances of the property of quantum incompatibility are themselves irreducibly higher-order relations between observables.

Causal structuralism says that a property’s essence is exhausted by the set of causal powers it confers on its instances. But the essence of quantum incompatibility is partially mathematical, specifically, linear algebraic. Any explication of incompatibility makes ineliminable reference to the non-commutativity of the operators representing the relevant properties. Commutativity is a mathematical notion that cannot be exhaustively spelled out in causal terms, yet it is at the heart of what it is to for two properties to be incompatible.

Incompatibility clearly has causal consequences, as it governs the conditions that constrain the physical instantiation of the pairs of properties that have it. And pairs of incompatible properties exhibit stable dispositions. No physical system can ever simultaneously be in an eigenstate of two incompatible properties. But incompatibility is not *merely* a causal or dispositional property. The disposition of two incompatible properties to never be simultaneously instantiated with a determinate value *follows* *from* the categorical nature of incompatibility, which is characterized by the mathematical property of non-commutativity.

It would be very odd to think that the causal profile of incompatibility is essential to the property while the mathematical structure that is ascribed to it by the theory is inessential to it. The mathematical structure is more fundamental to the property’s nature than its causal profile is, as the mathematical structure of the property actually allows us to derive certain aspects of its causal profile. Thus, the mathematical structure of the property partially explains the property’s causal behavior, but the causal profile cannot also be said to explain the nature of the mathematical structure.

Though incompatibility is not a wholly causal relation, it is one of the conditions under which the property of superposition is instantiated. This means that the property of superposition creates a further problem for the causal structuralist. Since the causal structuralist includes in a property’s causal profile its “backward-looking” relations (i.e. the conditions that result in its instantiation), the fact that a physical system instantiates the superposition property whenever it is in an eigenstate of an observable that is incompatible with respect to some other observable seems to be just the sort of condition that ought to be included in the essence of superposition.

It is not the case that a physical system’s being in an eigenstate of spin along the x-axis *causes* it to be in a superposition with respect to spin along the y-axis. Nor is it the case that the incompatibility of spin along the x-axis and spin along the y-axis causes it to be in a superposition of spin-y states. But certainly there is a nomological connection between the two, one marked by natural necessity. We might in this case take the nomological necessity to be grounded in a mathematical necessity derived from the linear algebraic structure of the theory.

## Global properties of spacetime

The second type of challenging property concerns the global structure of spacetime. These properties pose a special challenge for causal structuralism in that they are instantiated by spacetime itself rather than at some location within spacetime. Take the property of spacetime’s curvature. It is a property that bears a necessary connection to the distribution of mass-energy in spacetime as well as to the possible paths that light and objects can travel through it. But can we understand the necessary connections among these things to be casual?

Let us consider that light bends in the vicinity of a massive object. Colyvan (1999) suggests that the explanation for this phenomenon is a geometric one. He writes, “It’s not that something causes the light to deviate from its usual path; it’s simply that light travels along space-time geodesics and the curvature of space-time is greater around massive objects.” While being in the vicinity of a massive object is clearly one of the conditions under which a beam of light will bend, it is by no means obvious that being in this condition *causes* light to bend. It seems more appropriate to speak of the relation that massive bodies and mass-energy more generally bears to the curvature of spacetime as one that is governed by nomic necessity deriving from the formalism of General Relativity.[[16]](#footnote-16)

Though the causal structuralist could argue that the mass of the body *causes* spacetime to curve, this route looks unpromising. There is no exchange of energy between the massive body and spacetime itself, nor between spacetime and the bent path that light follows. Further, the relation between the distribution of mass and curvature of spacetime is not asymmetric as we expect causal relations to be; we can derive the distribution of mass from the curvature of spacetime and vice versa.

Colyvan emphasizes that while there is clearly a *covariance* between mass and spacetime curvature, this should not be misconstrued as causation. There are numerous examples of covariance where no causal relation is present. For instance, the behavior of parallel lines co-varies with the type of space in which they are embedded, though it is not the case that one causes the other.

Even if it is true that the curvature of spacetime is in some sense *due to* the presence of massive bodies, we can speak of the massive bodies as *causing* spacetime curvature only loosely and imprecisely. I think that those who insist on calling such a relationship causal are actually operating under the tacit assumption that the notion of what is *causal* incorporates everything that is *nomological* and thus anything that involves lawlike connections.[[17]](#footnote-17) This is a broader conception of the causal than what we usually mean, and I do not think we ought to revise our conception of what is causal to incorporate all that is nomological. One reason for this is addressed at the end of 10.4.

Accounting for the geometry of spacetime is also a problem for the dispositional essentialist. Bird (2007) recognizes the difficulty of giving a purely dispositional account of geometric properties, such as triangularity, and his ultimate response rests on the assumption that a property such as triangularity is unlikely to feature as a fundamental structural property and thus is not something the dispositional essentialist must account for dispositionally. This response may be sufficient for the case study of triangularity, but it cannot be the final word on all geometric properties. The geometric structure of spacetime, whatever it is, may well turn out to be fundamental. The answer to this will depend on features of the final theory of spacetime arrived at through further empirical investigation.

## Symmetry principles and conservation properties

The third kind of property that poses a challenge to causal structuralism is the relation of symmetry principles to conservation laws. Noether showed that every continuous symmetry of a physical theory or isolated system has an associated conserved quantity. The shift symmetry of space corresponds to the conservation of linear momentum, the rotational symmetry of space corresponds to the conservation of angular momentum, and the shift symmetry of time corresponds to the conservation of energy[[18]](#footnote-18).

The challenge that symmetries pose to dispositionalist and causal structuralist views has not gone unrecognized. Bird (2007) considers the objection that certain structural (including geometric) properties seemed to be essentially categorical rather than dispositional. Since he concedes that symmetry properties seem to be mathematical and thus categorical, his response to the challenge from symmetries relies on dismissing them as background conditions that theories should aim to dispense with rather than as foundational structures that are sometimes central to theories. French and Cei (2010) take this response as based on a misunderstanding of the role of background conditions in theories and suggest that, given the significance of symmetry principles and conservation laws in modern physics, it might be seen as a reductio of dispositional essentialism. Livanios (2010) argues that symmetries provide a counterexample to the dispositional essentialist thesis that the identity of physical properties is exhaustively constituted by their dispositional profile.

The objection from symmetries considered here is one that arises from the possibility of symmetry principles as meta-laws. Lange (2007) differentiates cases in which conservation laws are explanatorily prior to symmetry principles from cases in which symmetry principles are explanatorily prior to conservation laws. In the latter cases, these symmetry principles can be understood as meta-laws that govern the conservation laws and explain why they hold. These are cases that causal structuralism and dispositional essentialism are not equipped to handle. In fact, these views have no way of distinguishing the former cases from the latter. As noted earlier, the dispositional essentialist rejects that there is any interesting metaphysical distinction between these cases. Since they take the laws of nature to follow as necessary consequences of the essences of properties, they are committed to collapsing any seeming hierarchy of natural and metaphysical modalities. I take this to be a strike against the theory insofar as actual scientific practice seems to countenance such a distinction. [[19]](#footnote-19)

Let us consider the ways in which the two situations Lange distinguishes differ from one another. A symmetry principle that is a meta-law explains features of force laws. In other words, it explains why out of all the hypothetical force laws there are only those that exhibit a certain invariance. A symmetry principle that is a meta-law has counterfactual stability. The symmetry principle would have held even if certain force laws had been different. And it warrants inductive inference that future force laws will conform to the invariance exhibited by known force laws.

Symmetry principles that are merely byproducts of the force laws and thus accidental at the meta-level have none of these features. They hold in virtue of whatever the first-order force laws happen to be, so they do not explain them. They do not have counterfactual stability, as they are derived from the force laws that actually hold. And they do not warrant inductive inference about undiscovered force laws conforming to the relevant invariance, since “the invariance under a given transformation of the law governing one fundamental force has no explanation in common with the invariance of the law governing another fundamental force.”[[20]](#footnote-20)

How can the causal structuralist understand the higher-order property of being a conserved quantity that is exhibited by various physical properties? What would the causal profile of the property of being a conserved quantity look like? Certainly there are plenty of causal effects exhibited when some property is conserved regarding the consistency of possible measurements of it. That energy has the property of being a conserved quantity under the relevant conditions bears on what possible measurements we could make on any system that instantiates the energy property. When energy is conserved invariance over shifts in time can be construed as conferring causal powers related to possible measurements of systems instantiating the energy property. So it is not the case that being conserved and thus invariant across shifts in time, for instance, confers no causal powers.

However, this does not mean that the causal structuralist can accommodate the difference between symmetry as meta-law and symmetry as byproduct. In both cases, the causal powers conferred on the conserved quantity will be the same. The difference only comes in terms of the strength of necessity of the conservation laws. It is a difference in the range of counterfactual supposition under which the invariance is maintained. This is not a difference that shows itself causally. But it is a physical difference, and it is one that bears on our science. Symmetry principles that are meta-laws warrant inductive inference about what future force laws could be discovered, whereas Symmetry principles that are byproducts do not warrant any such inference. This is an important empirical difference. If it is one that causal structuralism cannot account for, that is a problem for the view.

Since causal structuralists and dispositional essentialists both take laws to follow from the nature of properties, they would simply deny that there is a difference between symmetry principles that are by-products and those that are meta-laws. In other words, they would take there to be no difference in the strength of nomological necessity in the two cases. Given that scientific practice seems to warrant such a distinction, we should consider this to be a cost of these views. Here again, the move from the causal to the nomological is a helpful one. The strength of necessity that a symmetry principle exhibits falls within the nomological, according to our definition.

## Further Motivations

One of the motivations for a broader structuralism about properties that is nomological rather than merely causal is the recognition that many theoretical physical properties derive at least some of their features from the mathematical structures of the theories that describe them. What was once seen as a clear distinction between the mathematical and the physical has been blurred by theoretical physics. Morrison (2007 552) suggests that spin is viewed as a “curious hybrid” of the mathematical and physical, as our physical understanding of it is essentially bound up with the mathematics of group theory. Resnik (2000) notes many of the more fundamental physical objects share at least as many relevant properties with mathematical objects as they do with familiar physical ones. Quantum particles often fail to have definite locations, masses, velocities, and spin. And quantum mechanics lacks the means to tag particles before an interaction and re-identify them after. This has led some such as French (1989) to deny that quantum particles have individuality, which is often taken to be a mark of physical objects. In quantum field theory, the number of particles present in a given region of spacetime fails to be determinate, as particles emerge from excitations of the field, which is itself understood as a distribution of irreducible probabilities. Resnik takes these examples to “break down the epistemic and ontic barriers between mathematics and the rest of science.”

The structural nature, often characterized mathematically, of many theoretical physical properties has been one of the primary motivations for the family of views knows as structural realism. Ontic structural realists, in particular, argue that we should understand physical properties in terms of the relations that theoretically characterize their possible interactions.[[21]](#footnote-21) Esfeld and Lam (2006) argue that we should understand spacetime[[22]](#footnote-22) structurally, as a four-dimensional, differentiable manifold with a Lorentz metric tensor.

Though structural realism aims to capture the important role that structure plays in determining the behavior of physical properties, the relevant structure need not be purely causal. Ladyman and Ross (2007) take OSR to be a view about *modal* physical structure more broadly and explicitly reject that causation is something that could usefully capture structural properties across the sciences. Berenstain and Ladyman (2012) argue that realism about modal structure is a prerequisite to scientific realism in general and offer a range of modal notions frequently employed in the sciences. That causation is only one of these further supports the appeal of moving to the broader conception of the nomological in order to capture all aspects of the natures of physical properties.

Why not simply take what we have been calling the nomological to encapsulate what the causal structuralist had in mind all along? Elias Okon[[23]](#footnote-23) suggests that one might more charitably interpret “causal profile” in a way that is broad enough to include any empirically detectable features or relations among properties. But the conflation of the causal with the broadly empirically detectable does no favors to naturalistic metaphysics. The notion of causation, while not suited to offer an account of physical properties, is a useful one that should not be jettisoned. If we weaken it so as to include any and all empirically detectable relations, we will lose the useful relation that does extensive work within first-order laws of nature, particularly those found in the special sciences.

Further, our restricted notion of causation helps illuminate the ways in which quantum entanglement is metaphysically unique. Quantum entanglement is an especially mysterious phenomenon, precisely because Bell’s theorem shows the correlation between the states of entangled particles *a* and *b* cannot be understood in terms of *a* causing *b*, *b* causing *a*, or *a* and *b* having a common cause – on any of the standard pictures of causation. Quantum entanglement is thus a special sort of relation particularly because it cannot be understood as causal in the usual sense.[[24]](#footnote-24) If we broaden our notion of causal relation so as to include any empirically detectable necessary relation, we will lose a useful notion that allows us to distinguish between quantum entanglement and standard causally understood information transfers, and thus to explain why entanglement is unique among physical correlations.

## Is causation fundamental?

As causal structuralism aims to characterize all physical properties in terms of their causal profiles, it presupposes that there is some suitable notion of causation that is foundational enough to do this work. While causal structuralism is not necessarily committed to the claim that causation is a fundamental feature of the universe, we might question the prudence of using a non-fundamental feature of the universe to characterize the nature of all physical properties, including fundamental ones. If causation is not fundamental to our physical universe, we ought to expect there to be some physical properties that are more fundamental than causation, and that therefore cannot be understood in terms of causation. Indeed, the cases raised here seem to be just these sorts of properties. But even if the causal structuralist finds a way to accommodate these properties, the question of what account of causation is best suited to the view remains to be settled.

Causal structuralism treats causation as a fundamental, primitive notion. However, other than acknowledging a commitment to natural necessity, defenders of the view fail to offer an explicit account of causation. Perhaps, then, we ought to assume that the notion accepted is one that conforms to our most basic folk and philosophical understanding of causation. While intuitions surrounding causation differ greatly, the two features that are generally part of our basic concept of causation are as follows:

1. Causal relations exist within spacetime (i.e., they hold between objects and events that are located in spacetime).
2. Causality presupposes directionality of time[[25]](#footnote-25) (i.e., there exists a time-asymmetry, and backward causation is likely not possible. A cause must precede its effects.)

Call any concept of causation that respects these two features “folk causation.” While folk causation is a notion that appears throughout the special sciences and is used within them to formulate predictions and generalizations, it is not a notion that plays any scientifically rigorous role in fundamental physics. Many physical properties simply cannot be accounted for within the framework of folk causation. One reason is that many laws of physics and the properties they describe are time-reversal invariant. A concept that presupposes a directionality of time is therefore the wrong sort of thing in terms of which to characterize the properties described in these laws.[[26]](#footnote-26) While it is true that some theories of quantum gravity, most notably causal sets theory, do build causation into the fabric of spacetime at the fundamental level, this should not offer much solace to the causal structuralist. At best, the viability of their view hinges on the small chance that causal sets theory will turn out to be the correct theory of quantum gravity.

Special relativity, for instance, allows us to define the light-cone notion of causation. This notion of causation differs importantly from folk causation, which is not itself a problem. What is a problem for the causal structuralist is that it is not a robust enough notion to do the work that the special sciences require of causation. As such, it does not provide a sufficient framework to define the causal profiles of many of the properties described by the special sciences.[[27]](#footnote-27)

The notion of causation used in spacetime physics is a topological one. It is defined in terms of the light-cone structure of the Lorentzian manifold. A light-cone is a structure that represents the edges of the region of spacetime that can be reached by light traveling away from the point of origin. Since the speed of light is the maximum propagation speed of information in our universe, points outside the light-cone are not reachable from the point of origin and vice versa. Thus, all and only points inside and along the light-cone are considered causally connected to the point of origin. What is important for our purposes is that this concept of causation is too course-grained to do the work of causation in the special sciences. It can offer no interesting distinction between two things that lie inside the observer’s light-cone, and this is exactly the distinction that is needed to accommodate the requirements that the special sciences make on the notion of causation.

Consider the sorts of causal claims that are made within the special sciences: Prolonged UV exposure causes cancer, consuming more calories than you burn causes weight gain, and earthquakes can cause tsunamis. These facts cannot be stated in terms of the notion of causation from spacetime physics. Since all we can appeal to are the spatio-temporal relations among points in the manifold, we cannot even differentiate between co-located properties, where only some of which are causally related to a future event (in the special-sciences sense). There is thus no way to distinguish between, for instance, the causal role that the skin’s exposure to the sun plays in the development of melanoma and the non-causal or causally irrelevant role that the skin’s exposure to the air plays in such a development. The sun and air both fall within the relevant light-cone that determines what things are causally related to my skin, in the special-relativity sense of causation. Since anything that fall’s within my skin’s past light-cone is causally related to my skin, there is no further distinction that the light-cone notion of causality allows us to make in order to distinguish between the factors that cause or partially cause an event (in the special-science sense) and those factors that are spatio-temporally nearby but bear no causal relation to the event.

The causal relation that is defined within special relativity is not fine-grained enough to formulate basic causal claims in sciences like chemistry and biology. Thus, the causation concept from spacetime physics fails to provide a sufficient framework within which to characterize *all* physical properties, since this set includes many special-science properties whose causal profile must be understood in terms of a special-science notion of causation.

I do not claim that no satisfactory account of causation is available to the causal structuralist. However, it does seem clear that simply adopting a naïve understanding of causation will not be sufficient. The causal structuralist must find an account of causation that is foundational enough to characterize all physical properties yet fine-grained enough make the necessary distinctions required of causal relations in the special sciences. Perhaps an account that fits these criteria is possible. More likely is that since there is no unified notion of causation across the sciences, there is no notion of causation fundamental enough to do the work that the causal structuralist demands of it.

## Where to go from here

I have discussed a number of motivations for moving from a merely causal to a nomological understanding of physical properties. What the examples I discuss have in common is that they each point to a physical property whose essence is at least partially constituted by a higher-order nomological property. Some of these higher-order nomological properties are mathematical. What causal structuralism gets right is that the nature of a property should be understood in terms of the (empirically discoverable) necessary relations it bears to other properties. What it gets wrong is the assumption that these relations are always causal. Causal structuralism naively assumes that a property’s *nomological* profile is exhausted by its *causal* profile. This ignoresthe complex mathematical nature of contemporary physics and the nested modality of laws of nature.

What is needed is a structuralist account of properties that is not merely causal, but that incorporates a physical property’s higher-order mathematical properties into its essence. A view of this sort does not fit cleanly into the traditional trichotomy of views, but it maintains many of the original motivations for causal structuralism. It precludes the possibility of a property having different causal profiles across possible worlds, since the property’s causal profile can still be considered part of its essence. It would prevent the problems that come with causal profile sharing. Causal powers can still play a role in determining a property’s essence, as long as we acknowledge that these causal powers do not exhaust its essence. This new picture maintains the empiricist spirit of causal structuralism while avoiding both the pitfalls associated with causal structuralism and dispositional essentialism and with views committed to quiddities.

Would this count as a double-aspect view? In a sense it would, but given that it wouldn't be committed to quiddities it avoids all the traditional problems associated with the double-aspect view. The view I have offered includes everything nomological, and the way we have characterized the nomological expressly rules quiddities out of this realm. This view allows the higher-order mathematical and nomological properties to do the work of quiddities, but unlike quiddities, we already have plenty of reason to be committed to these properties.

I have not said much about the relationship between laws and properties on the view I have suggested. One argument against causal structuralism and dispositional essentialism is that the fact that laws are entailed by properties collapses the metaphysical hierarchy of natural necessity. But if property essences don’t determine laws of nature, what does? My own view is that the modality of the physical world derives from the mathematical structures that underlie physical systems.[[28]](#footnote-28) This accounts for the role that higher-order mathematical structures play in determining the properties considered here, offers an illuminating account of physical modality, and makes sense of the often indispensible role that mathematical structures play in predicting and explaining empirical phenomena.

1. Of course, there is room in logical space for a view on which having a property’s causal profile is sufficient but not necessary for being that property, but it is unclear what would motivate such a view. [↑](#footnote-ref-1)
2. Dispositional essentialism, which is the view that all fundamental properties are purely dispositional, shares many of the same motivations as causal structuralism. Bird (2007) takes it to be the case that any dispositions must be causal, which would seem to make his version of the view indistinct from causal structuralism and vulnerable to all of the problems that causal structuralism faces. [↑](#footnote-ref-2)
3. The view can also be defended on the purely metaphysical grounds that a commitment to natural necessity is better motivated than a commitment to quiddities. [↑](#footnote-ref-3)
4. Lewis (2009) accepts this consequence of his view and suggests we adopt an attitude of epistemic humility. [↑](#footnote-ref-4)
5. The concern here is not that causation may fail to turn out to be a metaphysically real and robust feature of the physical world; rather it is about the likelihood that causation is not built into the fundamental fabric of spacetime but emerges only at more macroscopic spatio-temporal scales, making it an inappropriately limited framework within which to understand all physical properties. [↑](#footnote-ref-5)
6. Empirically detectable is to be understood broadly enough include features that can be inferred through IBE. [↑](#footnote-ref-6)
7. This is just the kind of necessity exhibited by meta-laws that govern the first-order laws. [↑](#footnote-ref-7)
8. Colyvan (2003) identifies several examples of paradigmatically non-causal scientific explanation. One is the explanation of the fact that, at any time *t*, there are two antipodal points on the surface of the earth that have exactly the same temperature and barometric pressure, which is due to a theorem in algebraic topology. A second is the geometric explanation of the Fitzgerald-Lorentz contraction, which appeals to non-causal, geometric features and entities of Minkowski spacetime, such as the Minkowski metric. The third example is the geometric explanation for the bending of light around massive bodies, which is addressed in section 3.2. While causal entities may figure into parts of the explanation in each of these examples, the explanations do not reference onlycausal entities. [↑](#footnote-ref-8)
9. Yates (2012) argues that it is the view that properties have *causal* essences that is really driving dispositional essentialists. This helps illuminate why dispositional essentialism falls into many of the same traps that causal structuralism does, and thus why it is open to many of the same objections that apply to causal structuralism. [↑](#footnote-ref-9)
10. Lange defines sub-nomic facts as those that laws might govern but that do not explicitly state what is a law. See his (2009), p. 17. For any two sub-nomically stable sets, one must be a subset of the other, and so the sub-nomically stable sets fall into a natural hierarchy. There is no sub-nomically stable set that contains an accident. [↑](#footnote-ref-10)
11. We can retain Lange’s metaphysical commitment to nested modalities as well as his explication of this notion in terms of the useful apparatus of sub-nomically stable sets while dispensing with his metaphysical interpretation that counterfactuals ground laws. [↑](#footnote-ref-11)
12. While all the counterexamples to causal structuralism addressed here are from physics, I do not think the special sciences are free of them. A number of special-science properties will likely pose similar problems, especially those that are essentially probabilistic or related to equilibria. Game theory and economics, for example, might prove to be abundant sites of modal properties derived from mathematical and higher-order nomological structures. [↑](#footnote-ref-12)
13. The wavefunction evolves deterministically in Hilbert space according to the linear dynamics of the Schrodinger equation. [↑](#footnote-ref-13)
14. The various physically possible states of any such system correspond to vectors of length 1 in that system’s associated space. Every such vector is taken to pick out some particular state. The states picked out by all those vectors are taken to comprise the possible physical states of that system. In an *N*-dimensional space, any collection of *N* mutually orthogonal vectors in that space (that have a norm of 1) are said to form an *orthonormal basis* of that *N*-dimensional space. If for some particular operator *O* and for some particular vector |*B*> the vector *O*|*B*> generated by operating on |*B*> with *O* happens to be a vector pointing in the same direction as |*B*> then |*B*> is said to be an *eigenvector* of *O* with *eigenvalue α* (where *α* is the length of the new vector relative to the length of |*B*>). An intuitive way to picture this is to consider the basis made up of mutually orthogonal vectors. Think of these as axes in a coordinate system. A vector that lies along an axis will be an eigenvector of the property associated with the operator that takes vectors to that axis. [↑](#footnote-ref-14)
15. Albert (1994, 33) states the rule that connects those operators (and their properties) and those vectors (and their physical states): “If the vector associated with some particular physical state happens to be an eigenvector, with eigenvalue (say) *α*, of an operator associated with some particular measurable property of the system in question (in such circumstances, the state is said to be an *eigenstate* of the property in question) then that state has the value *α* of that particular measurable property. [↑](#footnote-ref-15)
16. See Katzav (2013) for a far more detailed treatment of the difficulty of accounting for General Relativity’s spacetime structure causally. [↑](#footnote-ref-16)
17. The confusion might also stem from the fact that the curvature of spacetime is counterfactually dependent on the distribution of matter and energy, and counterfactual dependence is often conflated with causation. [↑](#footnote-ref-17)
18. When the symmetry group of the translations is finite-dimensional. [↑](#footnote-ref-18)
19. That actual scientific practice does countenance such as distinction is evinced in the reluctance of early twentieth-century physicists to regard radioactive emission as violating the conservation of energy. Planck, for instance, posited that any new natural phenomenon discovered would follow a law that obeyed the conservation of energy. Lange cites this as evidence that they expected energy conservation to hold as a meta-law rather than a byproduct if at all (2007, 468). [↑](#footnote-ref-19)
20. Lange (2007), p. 469. [↑](#footnote-ref-20)
21. French and Ladyman (2003). [↑](#footnote-ref-21)
22. As characterized in GR. [↑](#footnote-ref-22)
23. In personal communication [↑](#footnote-ref-23)
24. Efforts to understand the entanglement relation causally require accepting either backwards causation or non-locality, as Price (2012) demonstrates. The need to go retrocausal in order to understand entanglement as causal in *some* sense illustrates the point that the phenomenon cannot be understood within the same causal framework as other physical properties. [↑](#footnote-ref-24)
25. Of course, this directionality need not be part of the fundamental structure of spacetime. [↑](#footnote-ref-25)
26. Though this objection is similar to Russell’s (1913), there is an important difference. Russell took causation to be an inherently anthropocentric concept based on a problematic analogy with human volition and dependent on what he called crude uniformities. He thought such a metaphysical notion was not found at all in physics. While there is useful insight to be gleaned from Russell’s rejection of anthropocentric concepts from metaphysics, his claim that no notion of causation could be found in physics seems to have turned out false. Unlike Russell’s, my objection is not that no notion of causation can be developed within physics but that the one that has been cannot be made to do the necessary work that the causal structuralist requires. [↑](#footnote-ref-26)
27. Though it can nonetheless be seen as a necessary constraint on causation. [↑](#footnote-ref-27)
28. In an unpublished manuscript, I consider a range of examples of mathematical structures playing an indispensible role in the explanation and novel prediction of empirical phenomena. I suggest that there is an important parallel between the no-miracles argument for scientific realism and the indispensability argument. Just as unobservable entities are taken to explain the behavior of observable entities when they cause such behavior, mathematical structures can only explanatory if they bear some determination relation to the empirical systems they are taken to explain. I conclude that we must posit a relation of metaphysical dependence between mathematical structure and modal physical structure, and I show how such a view can offer a straightforward response to the applicability problem and account for examples of non-causal scientific explanation. [↑](#footnote-ref-28)