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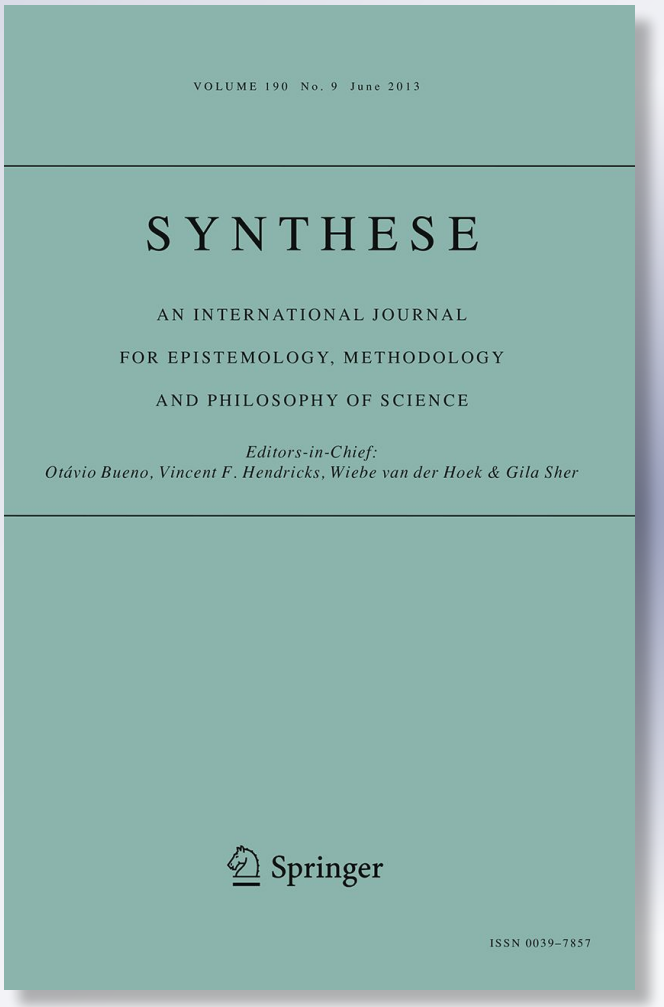

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Inverse functionalism and the individuation of powers

David Yates[1]

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Abstract In the pure powers ontology (PPO), basic physical properties have wholly dispositional essences. PPO has clear advantages over categoricalist ontologies, which suffer from familiar epistemological and metaphysical problems. However, opponents argue that because it contains no qualitative properties, PPO lacks the resources to individuate powers, and generates a regress. The challenge for those who take such arguments seriously is to introduce qualitative properties without reintroducing the problems that PPO was meant to solve. In this paper, I distinguish the core claim of PPO: (i) basic physical properties have dispositional essences, from a hitherto unnoticed assumption: (ii) the dispositional essences of basic physical properties exclusively involve type-causal relations to other basic physical properties. I reject (ii), making room for structuralist ontology in which all basic physical properties are pure powers, individuated by their places in a causal structure that includes not only other powers, but also physically realized qualitative properties such as shapes, patterns and structures. Such qualities individuate pure powers in the way that non-mental input and output properties individuate realized mental properties in functionalist theories of mind, except that here it is the basic physical powers that are individuated by relations to realized non-powers. I distinguish one Platonic and two Aristotelian version of this theory, and argue that the Aristotelian versions require that grounding is not always a relative fundamentality relation, because the powers ground the qualities that individuate them. I argue that symmetric grounding is the best way to make sense of the relational individuation common to all structuralist ontologies, and is therefore no additional commitment of the one proposed here.

✉ David Yates
david.yates@campus.ul.pt

[1] Centro de Filosofia, Faculdade de Letras, Universidade de Lisboa, Alameda da Universidade, 1600-214 Lisbon, Portugal

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Let a *basic physical* property be any simple, unrealized property that features in the laws of ideal completed physics.[1] Perhaps electric charge and mass-energy are such properties. Proponents of powers ontologies[2] think that at least some basic physical properties have at least partially causal or dispositional essences. Powers ontologies are motivated by problems with categoricalism, the view that basic physical properties have no non-trivial essential modal character. There are two main categoricalist positions on the relationship between properties and laws: the Mill–Ramsey–Lewis best systems theory (MRL), and the Dretske–Tooley–Armstrong nomic necessitation theory (DTA), which can be characterised as reductionist and anti-reductionist, respectively.[3] According to MRL, laws of nature reduce by supervenience to local matters of contingent fact. Roughly, the laws of nature are the theorems of the deductive system with the best possible combination of simplicity and strength in relation to the totality of available evidence.[4] On Lewis' version of MRL, basic categorical properties derive their causal roles from the total pattern of instantiation of such properties throughout spacetime, upon which pattern the laws of nature supervene. On DTA, second-order lawmaking relations are introduced to explain why first-order universals have their causal profiles—Fs cause Gs in virtue of N(F,G). Laws are irreducible second-order governing relations, and confer causal roles upon intrinsically inert categorical properties.

There are many well-rehearsed problems with these positions. Given that MRL laws supervene on local matters of fact, how can they also *explain* those matters of fact? How can the laws play a role in bringing about the particular events they subsume, if the laws themselves are metaphysically grounded in the total course of events? Is what counts as the *best* system in part dependent on the quirks of human psychology, and if so, is MRL inconsistent with the objectivity required by robust scientific realism?[5] If the N-relation in DTA's N(F,G) doesn't *essentially* ground the fact that Fs cause Gs, then don't we need a third-order N-relation to explain why it does at our world, which sets us off on a regress? Conversely, if we say that N(F,G) is essential to N, then N itself can't be categorical.[6] Finally, most versions of categoricalism, assuming in addition that categorical properties stand in primitive transworld identity relations, entail that there are possible worlds that differ from actuality solely in terms of which basic physical properties occupy the causal roles specified by completed physics—*merely*

[1] The reason I use 'basic' rather than 'fundamental' will become clear in Sect. 3. I also use 'basic' to describe (putatively) non-composite physical particulars such as electrons and quarks. I likewise apply 'complex' to both properties and particulars.

[2] Shoemaker (1980), Ellis (2002), Heil (2003), Molnar (2003), Mumford (2004), Bird (2007a), and Martin (2007).

[3] For a canonical statement and defence of MRL, see Lewis (1994); for DTA see Armstrong (1983).

[4] Lewis (1994), pp. 478–9.

[5] For both these objections, see Armstrong's (1983) critique of the regularity theory.

[6] Bird (2005a, 2007a, ch. 4).

quiddistic differences, as they are often called. How then can we know which properties occupy those roles at our world,[7] or even whether they are uniquely occupied?[8]

Powers ontologies offer a reductionist alternative to the MRL and DTA accounts of laws, and promise to explain our knowledge of basic physical properties, by closing the gap between the essential natures of such properties and their causal roles. If charge is a power, then nothing explains why negative charges repel—being such as to exert a repulsive force on other negatively charged bodies is part of *what it is* to be negatively charged. Laws of nature, on this view, do not govern anything, but merely describe the dynamic causal essences of the properties they refer to. As is commonplace, we can flesh out the idea that powers have causal essences by saying that they are at least partially individuated by the manifestation types they produce when their instances are subject to certain types of stimulus, where the stimulus and manifestation types may or may not be further powers.[9] For the purposes of this paper, I'll express this claim by saying that powers are at least partially individuated by their places in a *causal structure*—a type-causal structure of powers primitively related in specific ways to their stimulus and manifestation properties. *Pure* powers are *wholly* individuated by their places in such a structure. The pure powers ontology (PPO) is the thesis that *all* basic physical properties are pure powers and it—specifically, its coherence—is the subject of the present work.

Proponents of powers ontologies in general assume that the individuative stimulus and manifestation types of a power are other basic physical properties—whether or not these are also powers. The individuation of powers, it is assumed, is a thoroughly basic physical affair. However, the claim that basic physical properties are pure powers, fully individuated by their places in a causal structure, doesn't settle the issue of what *else* is in the structure. The tacit commitment to basic physical individuation provides the answer: other pure powers. We should therefore state PPO as the conjunction of *two* theses:

(S) All basic physical properties are pure powers, fully individuated by their places in a causal structure of powers and their stimulus and manifestation properties.
(B) The properties that individuate a basic physical power—the other constituents of the causal structure—are always further basic physical properties.

Principle (S)—Structural individuation—is in my view the core tenet of PPO, and indeed PPO is often stated as (S), with (B)—Basic individuation—a tacit assumption. According to (B), any property that plays a role in individuating a basic physical power must itself be basic physical. The conjunction of (S) and (B) entails that basic physical properties are fully individuated by the stimulus and manifestation relations they bear *to each other*, which is how PPO is treated in the literature.[10] In this paper I argue for a powers ontology that preserves (S), but rejects (B). While I think the resulting ontology deserves to be called a pure powers ontology, I'll reserve the label 'PPO' for the conjunction of (S) and (B).

[7] Lewis (2009).

[8] Shoemaker (1980).

[9] I assume for simplicity that both the stimulus and manifestation types of a power are individuative.

[10] See Bird (2007b) for a particularly clear treatment along these lines.

It is often objected to PPO that because it has no qualitative properties in the individuating structure, it generates a regress. If we add qualities to the structure, however, we give up on PPO, because qualities don't have wholly dispositional essences. Now this argument tells against the conjunction of (S) and (B), but crucially, it doesn't tell against (S). I shall defend a powers ontology in which basic physical properties are fully individuated by causal relations to each other and to *complex*, physically realized qualities. All basic physical properties are fully individuated by their places in a causal structure, but a structure that contains complex qualitative properties as well. While part of the causal structure that individuates powers, these qualities are not individuated by their places in it, which helps us to avoid regress. For reasons that will emerge, I shall refer to this theory as *inverse functionalism*. I am not the first proponent of a powers ontology to argue that at least some complex properties are non-powers; George Molnar and Alexander Bird have both endorsed this view.[11] I am, however, the first to suggest that we can appeal to realized non-powers to individuate their basic physical realizers.

A note on terminology: I distinguish powers from *dispositions*, and shall say that causally efficacious properties—powers or not—*bestow* dispositions. An electron is *disposed* to exert a repulsive force $F = e^2/4\pi\varepsilon_0 R^2$ on an electron placed a distance R away from it, in virtue of its charge e; and charge is partially individuated by bestowing this disposition. However, negative charge is not to be *identified* with the disposition to exert Coulomb forces.[12] Charge also bestows the disposition to emit electromagnetic radiation when accelerated. Distinguishing powers from the dispositions they bestow enables us to avoid saying that basic properties such as charge are clusters of powers,[13] which raises the obvious question of why the powers in question are clustered together. On my view, charge is a single, unified power that bestows a wide range of dispositions upon its bearers, which in turn can be explained in terms of the primitive fact that the same powers manifest in different ways when stimulated in different ways.[14] We may then distinguish powers from non-powers as properties that are, versus those that are not, individuated by the dispositions they bestow.

And a note on my aims: powers ontologies offer a distinctive alternative to the MRL and DTA accounts of laws and properties, but my purpose here is not to argue that this alternative is superior. The purpose of this paper is to argue that inverse functionalism is better off than PPO with respect to the individuation of powers, but no worse off as an account of laws of nature, so that anyone committed to a powers ontology as an alternative to Humean accounts of laws and properties ought to be an inverse functionalist. It's crucial to my aims that inverse functionalism doesn't depend on qualitative properties that are epistemically intractable, or whose causal roles stand in need of explanation, for that would be to abandon the key features of powers ontologies that render them distinctive alternatives to MRL and DTA.

[11] Molnar (2003) and Bird (2016).

[12] For more on the distinction between powers and dispositions, see Yates (2013).

[13] As in, for example, Mumford and Anjum (2011).

[14] This is also true on the reciprocal partner powers model defended in Martin (1997) and Heil (2012), but I don't endorse the view that only powers can stimulate powers.

1 Two regress problems for PPO

The intuition that PPO lacks the resources to individuate powers is prevalent, and has been articulated by different authors in different ways.[15] I make no attempt to be comprehensive here, and instead focus on representative examples of the two main regress objections, which I shall refer to as the *causal* and *identity* regresses. The causal regress is memorably stated in D. M. Armstrong 'always packing, never travelling' remark:

> Given purely dispositionalist accounts of properties, particulars would seem to be always re-packing their bags as they change properties, yet never taking a journey from potency to act.[16]

Given PPO, all the changes that individuate basic powers involve some thing or things gaining or losing the power to cause some other thing or things to gain or lose the power to cause…and so on. In order for anything to *happen*, the argument goes, at least one power must manifest as a change in some particular's qualitative properties. Taking the journey from potency to act requires that some power manifest not merely as a change in the pattern of instantiation of powers, but as a change in the qualitative properties of some thing or things.

It's not easy to say exactly what it takes for a property to be qualitative. Armstrong's ontology treats basic physical properties as *thin quiddities*, in the sense that they are primitively individuated properties that don't differ from each other except by being numerically different and (if any are non-monadic) having different adicity.[17] Such quiddities not only raise the familiar epistemological and metaphysical problems outlined above, but also themselves seem to be rather lacking in quality.[18] Bird argues that Armstrong's basic categorical properties are in effect pure powers with the dispositional essences taken away, hence no better off in regards of quality than powers, and significantly worse off in other respects.[19] All there is to Armstrong's basic physical properties is their numerical identity and their adicity, but pure powers have those features too. To my mind, Bird's argument shows that an ontology of basic categorical properties is no less problematic than PPO when it comes to qualitative change, but clearly that doesn't suffice to show that there's no problem of qualitative change in PPO.

Armstrong's worry is that change in PPO consists solely, to borrow Stephen Mumford's phrase, in *passing powers around*.[20] Bird refers to this line of argument as the

[15] See Bird (2007b) for full discussion.

[16] Armstrong (1997), p. 80.

[17] See Jacobs (2011) and Smith (2016) for more on the thin conception of categorical properties. I return to this issue later in this section.

[18] Here is Black on Humean fundamental properties: "Just about all there is to a Humean fundamental quality is its identity with itself and its distinctness from other qualities. A Humean fundamental quality is intrinsically inert and self-contained", (2000), p. 91.

[19] Bird (2007b), pp. 521–2.

[20] Mumford and Anjum (2011), pp. 5–7; note that they endorse a 'passing powers around' conception of qualitative change, and deny Armstrong's intuition that this amounts to no change at all.

insufficient actuality objection, and points out that no proponent of PPO will accept that powers lack actuality. Powers are relationally individuated, but they aren't *relations*; rather they are intrinsic properties of their bearers, and as such there's no reason to suppose that power-instances lack actuality. Perhaps so, but we do seem to have an independent grasp on the notion of the *qualitative*: a property such as having a certain shape, unlike a power, seems to characterise its bearers independently of any dispositions they may have. Proponents of the 'always packing, never travelling' objection can now say that qualitative properties of *this* kind are necessary for there to be genuine change, and—not implausibly—deny that pure powers are qualitative in the relevant sense. Pointing out that powers are intrinsic doesn't seem to address this worry.[21]

By way of illustration of the notion of the qualitative, consider sphericality. Although spheres are disposed to do a range of things in virtue of their shape, there's something that spheres are like, geometrically, which is seemingly a quality *in addition* to those dispositions. Spheres are disposed to roll in virtue of their shape, but sphericality doesn't seem to be *defined* by the dispositions it bestows. It seems that we can fully grasp the shape of a body without thereby thinking of its causal powers; correspondingly, geometric properties can be defined in mathematical terms, without reference to the dispositions of their bearers. Now it may be that shapes are powers in the sense that they too have partially dispositional essences, but it's surely implausible that they have *wholly* dispositional essences, as with *pure* powers. If this is the kind of property needed to end the causal regress, then it seems neither pure powers *nor* Armstrong's basic categorical properties are any use.

Jonathan Lowe raises a different regress objection to PPO, which I refer to as the identity regress, and which doesn't depend on the notion of the qualitative. Lowe argues that in PPO:

> [N]o property can get its identity fixed, because each property owes its identity to another, which, in turn owes its identity to another—and so on, in a way that, very plausibly, generates either a vicious infinite regress or a vicious circle.[22]

As Bird interprets Lowe, the regress (or circle) is problematic to the extent that it entails that identity of properties is *indeterminate*.[23] Bird responds by appealing to graph theory to show that powers can be determinately identified by their places in a causal structure. We can represent powers and the stimulus-manifestation relations between them by means of a graph, with powers as the nodes, and the relations as the edges. A *non-trivial automorphism* is a permutation that maps at least some nodes onto distinct nodes to yield an isomorphic graph. A graph with no non-trivial automorphisms—an *asymmetric graph*—has a structure rich enough that each node occupies a unique place within it. Provided the relevant type-causal structure is asymmetric, it has the resources to determinately identify the powers that compose it.[24]

[21] It's also not obvious that powers are intrinsic; see Tugby (2013) and Yates (2016a).

[22] Lowe (2006), p. 138. Similar concerns are raised by Howard Robinson; see his (1982), pp. 114–5.

[23] Bird (2007b).

[24] As Bird notes, positing a single symmetric manifestation relation entails that the number of powers is either one, or at least five, which is odd to say the least. Positing an asymmetric manifestation relation can iron out this particular wrinkle, but there are bound to remain purely mathematical constraints on the

In two closely related later works, Lowe responds to Bird, and offers further arguments against PPO.[25] Lowe first draws attention to the fact that principles of individuation specify the essences of the entities in question, and so must hold across possible worlds. It follows that we need the individuating structure to be not only asymmetric, but *necessarily* asymmetric, and this, Lowe argues, is implausible for token powers, because it's easy to imagine token power structures varying across possible worlds, with nothing ruling out symmetric structures. It's not obvious that this argument threatens structuralist conceptions of properties such as PPO, however, because it's not obvious why a proponent of PPO should individuate powers by means of a *token* power structure. Bird clearly conceives the individuating structure in terms of second-order stimulus-manifestation relations obtaining between power types, and Lowe's argument for the contingent asymmetry of token power structures has no clear purchase against this view. The arguments that follow are of greater interest, for they apply equally to the relational individuation of power types by means of second-order structures.

Lowe acknowledges that entities can be determinately *identified* by their places in an asymmetric structure, but argues that this doesn't amount to their *individuation*. A principle of individuation for a given class of entities certainly *entails* an extensionally adequate criterion of identity for the entities in question, but not every such criterion is a principle of individuation. A principle of individuation identifies the target entities by specifying their *essences*, and this, for Lowe, is what's missing from PPO. Where an entity x is (partially or fully) individuated by another entity y, x exhibits a very strong form of ontological dependence, which Lowe calls *identity-dependence*, on y.[26] While asymmetric power structures offer extensionally adequate criteria of identity for powers, they fall short of what's required for the specification of each power's essence, because—Lowe argues—it's incoherent to suppose that each of a plurality of entities of kind K could be identity-dependent solely on other Ks.[27]

Lowe argues for this principle primarily from analogy. The natural numbers are individuated by their predecessors, and sets by their members. Such criteria avoid vicious circularity only because the number 0 and the empty set are self-individuating, so that there's a unique number that's not individuated by another number, and a unique set that's not individuated by another set.[28] By parity of reasoning, Lowe argues, the relational individuation of powers is viciously circular in PPO:

> So, even if there are no relevant symmetries in the power-structure of a world, I still contend that it cannot be the case that every power in that world is indi-

Footnote 24 continued
structures that could serve to determinately identify their nodes. See Bird (2007b), pp. 528–33 for full discussion.

[25] Lowe (2010, 2012). The material presented here occurs in a similar form in both papers.

[26] Lowe (2012), p. 214. I return to the notion of identity-dependence in Sects. 2 and 3, where the distinction between this and weaker forms of ontological dependence will be crucial to the theory I develop.

[27] For the arguments that follow, see Lowe (2012), pp. 228–31.

[28] Numbers with no predecessors trivially have the same predecessor, and sets with no members trivially have the same members, so the proposed individuating principles guarantee the uniqueness of 0 and the empty set.

> viduated *solely by other powers in that world*. Either some power would have to be self-individuating, by analogy with 0 or the empty set, or else some powers would have to be individuated by non-powers. However…no power *could* be self-individuating, given that all powers must have manifestation-types and that every power is individuated by its manifestation-type. For…no power can be *its own* manifestation-type and hence every power's individuator must be an entity that is distinct from itself. The conclusion must therefore be that some powers must have *non*-powers as their manifestation-types.[29]

If Lowe is correct, then no plurality of entities of kind K could be individuated solely by each other. Suppose there are just two Ks, x and y. In order to determine which K x is, it must already be determined which K y is; but if x determines which K y is, it must already be determined which K x is. For any Ks to be structurally individuated, then, we need some non-Ks as the self-individuating primitives of the ontology, which serve to determine the identities of the Ks. Call this *Lowe's principle*. Something like Lowe's principle underpins functionalism in the philosophy of mind, according to which the identities of properties such as pain are determined by their typical causal relations to other mental properties *and to non-mental inputs and outputs*—for instance, being caused by tissue damage, and causing wincing. The identities of the inputs and outputs are not determined by their places in the relevant psychological causal structure, and so can serve to individuate the mental properties whose identities are so determined. Pain, on this theory, is the property of having some property P that occupies a certain causal role R; and for P to occupy R is for it to stand in certain characteristic type-causal relations to other mental properties and to the aforementioned non-mental input and output properties.

Lowe's objections to pure structuralist ontologies have no purchase against the structural individuation of mental properties in functionalist theories, because such theories posit primitive elements—the physical input and output properties—whose identities are not determined by their places in the psychological structure. Although Lowe is no functionalist, I take it functionalism is an application of just the sort of intuition Lowe brings to bear against PPO. The physical input and output properties are individuated independently of their type-causal relations to mental properties, and act as primitive individuators thereof. This should not, however, be taken to imply that the physical properties somehow do all the work of fixing identity in the structure, for that would be to ignore the crucial role that type-causal relations between mental properties play. Functionalist mental properties are individuated *both* by relations to each other, *and* to inputs and outputs. Lowe's principle does not rule out that entities of kind K can be identity-dependent on other entities of kind K, but only that they can be *exclusively* identity-dependent on other Ks. It's the fact that functionalism posits identity-dependence of mental properties on both mental *and* non-mental properties that renders it consistent with Lowe's principle, and immune to the identity regress.

I take no stance on whether either regress discussed in this section is fatal to PPO. My aim is instead to show that we can avoid them both by means of qualitative properties *while preserving principle (S) of PPO*—the claim that basic physical properties are

[29] Lowe (2012), p. 229.

fully individuated by their places in a causal structure—*provided we reject principle (B)*—the assumption that the structure contains only basic physical properties. A tacit endorsement of (B) is common among those who consider qualitative or non-power properties as a means of addressing regress objections. Here, for instance, is Bird, considering a possible response to Lowe's identity regress involving the claim that some basic physical properties are thin quiddities:

> If we trace the chain of dependencies, from the essence of one essentially dispositional property to another, we will eventually come across essentially dispositional properties whose manifestations or stimuli are characterized not in terms of yet further essentially dispositional properties but in categorical terms instead. Since these have their identities primitively, they serve to determine the identities of all the properties in the structure.[30]

With the exception of Lowe—of whom more presently—proponents of powers ontologies who stop short of PPO all propose that at least some basic physical properties are not pure powers. This is to reject principle (S) of PPO, while keeping principle (B), and that, to my mind, is the wrong way around. Before proceeding, let me first spell out some of these proposals.

John Heil and C. B. Martin endorse ontologies in which basic physical properties are both qualitative and powerful, but not in the sense that their quality and their powerfulness are dual aspects of the same property. Heil and Martin claim that the powerful and the qualitative are *identical*, although it's never been entirely clear to me what to make of this claim.[31] As Jon Jacobs understands the proposal, powerful qualities are *thick quiddities*: non-mental qualitative natures that are truthmakers of causal counterfactuals solely in virtue of being the natures they are.[32] The powerfulness of a powerful quality, for Jacobs, is grounded in its being the quality it is. This isn't to say that powerful qualities *have* natures; they simply *are* natures, for Jacobs, and to describe them as thick quiddities is to say they differ from each other by being different natures, rather than merely numerically, as in Armstrong and Lewis. In a similar vein, Deborah Smith argues that the Heil-Martin view can be seen as a version of what she calls *non-recombinatorial quidditism*.[33] According to this theory, basic physical properties are again taken to be qualitative natures, primitively qualitatively distinct from one another. Smith's quidditism is non-recombinatorial in the sense that quiddities can occupy nomic roles solely in virtue of being the qualities they are, and so their existence at a world is sufficient for them to occupy those roles there.

It's not immediately clear whether the powerful qualities ontology is a powers ontology at all, at least as interpreted by Jacobs and Smith. Jacobs interprets the Heil-Martin identity claim as meaning that one and the same property is both a quality and power*ful*, but it isn't clear that a property's being powerful entails its having a causal *essence*. Smith characterises her non-recombinatorial quidditism as a middle ground

[30] Bird (2007b), p. 526.

[31] Heil (2003) and Martin (2007).

[32] Jacobs (2011).

[33] Smith (2016).

between structuralist ontologies and Lewis' recombinatorial quidditism, but explicitly denies the identity claim.[34] What is clear is that if powerful qualities are taken to have qualitative essences, in the sense that they are essentially the natures they are, then they have their nomic roles *in virtue of* their essences.[35] Now assuming that all nomic roles involve relations between properties—as, for instance, in standard cases such as a repulsive *force* between like *charges* that brings about changes in the bearers' *spatiotemporal relations*—what the powerful qualities ontology really amounts to is the claim that the type-causal causal relations that PPO takes to individuate powers are in fact grounded in the *prior* essences of the qualities related.

There's an interesting parallel here with George Molnar's mixed ontology, in which some basic physical properties are pure powers, but others—specifically, spatiotemporal relations—are both categorical and causally relevant.[36] Molnar needs to explain how the spatiotemporal properties in his ontology get to be causally efficacious without appealing to governing laws or causal essences, and proposes that the roles of categorical properties in a mixed ontology can be seen as built into the causal essences of the powers. By way of illustration, Molnar suggests that properties like electric charge obey inverse square laws because force-carriers are "poor travellers", but offers no further detail.[37] Molnar's proposal is that powers and quiddities of some kind—whether thick or thin, he doesn't say—are type-causally related solely in virtue of the causal essences of the powers. Powerful qualities, by contrast, are so related solely in virtue of being the thick quiddities they are.

In all the cases discussed above, the natures of basic physical properties are fully determined at the basic physical level; and the basic physical non-powers threaten to bring with them at least some of the disadvantages of categoricalism. It's beyond us to know anything about electric charge other than what it does, but if it's a powerful quality, then there must be more to it than that. On Jacobs's view, it must be a nature rich enough to be a counterfactual truthmaker; on Smith's, it must be a rich enough nature to necessitate a nomic role. Furthermore, as Smith explicitly acknowledges, nothing in non-recombinatorial quidditism precludes different basic physical properties having the same nomic roles.[38] The basic physical properties that exist at our world determine the nomic roles occupied here, but the converse determination does not hold. We can't generate a new possibility by permuting the mass and charge quiddities, as we can given the thin quiddities endorsed by Lewis and Armstrong, but nothing precludes

[34] Op. Cit., p. 252; it isn't clear that Smith would deny the identity claim as Jacobs understands it.

[35] In my (2013) account of dispositional essentialism, according to which a property has a (perhaps partially) causal essence iff some causal law is true in virtue of the nature the property, powerful qualities as conceived by Jacobs and Smith do have (at least partially) causal essences. Whether this is the right thing to say—and relatedly, whether my account has the resources to distinguish non-recombinatorial quidditism from standard powers ontologies—is another matter. If causal laws can be true in virtue of the natures of properties that *don't* have causal essences, then note too that this also causes problems for the Finean theory of essence upon which I depend.

[36] Molnar is clear that his ontology doesn't suffer from regress problems, due to the addition of basic categorical properties, although he also doubts that these problems are serious for PPO. See Molnar (2003), pp. 173–81.

[37] Op. Cit. (2003), pp. 164–6.

[38] See Smith (2016), pp. 249–56 for full discussion.

possible worlds with the same nomic structure as actuality but a *different* totality of powerful qualities occupying the basic physical roles, so related in virtue of being the qualities *they* are.

Molnar's proposal is promising, but he offers no account of how it is that the causal essences of powers could involve spatiotemporal quiddities. Suppose, as seems reasonable, that they are thin quiddities; then it seems there should be a possible world that differs from actuality solely in that different quiddities occupy the spacetime roles. But if it doesn't *matter* to the powers which quiddities occupy the spacetime roles, then in what sense can those quiddities be said to be built into their causal essences? Conversely, if the actual spatiotemporal quiddities are somehow built into the essences of powers, then it's difficult to see how they could be thin quiddities, for how could the essence of a power involve a type-causal relation to one, and only one, of a plurality of possible quiddities that differ from each other merely numerically?

There is, I maintain, a dilemma facing those who propose basic physical categorical properties as a means of avoiding the regress problems of PPO. Either the categorical properties in question are thick qualitative natures causally related in virtue of being the natures they are, as in the powerful qualities ontology, or they are thin, primitive properties as in Armstrong's and Lewis's Humean ontologies. If the former, then the qualitative essences of at least some basic physical properties are unknowable. How could we grasp which quality electric charge is, when we can only apprehend it via the dispositions it bestows? If the latter, however, then the properties don't seem rich enough, in and of themselves, to have causal roles *in*essentially without giving rise to a need for external explanation. If we build enough into the natures of basic physical properties to explain their causal roles, then it seems we thereby render those natures epistemically intractable. If we don't build anything into their natures other than primitive identity and difference, then it seems we need to appeal to something else—such as global patterns or reified lawmaking relations—to explain their causal roles, but that just takes us back towards the MRL and DTA accounts. Molnar's proposal seems to offer an alternative, but it's very difficult to conceive of spatiotemporal relations as thick quiddities, and equally difficult to see how they could be built into the causal essences of powers if they are thin.

Lowe's case is interesting: he considers sphericality as an example of a non-power, but doesn't argue that such properties are involved in the individuation of powers. Rather, Lowe appeals to sphericality only as a case of an unproblematic yet causally efficacious non-power, in order to argue that PPO is unmotivated.[39] I don't think this follows: proponents of PPO claim that *basic physical* categorical properties would be causally and epistemically problematic, but needn't take a stand on whether *complex* categorical properties are likewise problematic. Lowe's arguments, if sound, tell only against the motivation for pandispositionalism, the view that *all* properties—basic physical or not—are powers. Lowe is, however, in the vicinity of a solution to both regress problems that preserves what's good about PPO: why not say that all basic physical properties are pure powers, fully individuated by their places in a causal structure involving not only other powers, but also complex, physically realized properties?

[39] Lowe (2010), pp. 18–21.

The resulting ontology keeps principle (S) of PPO, but rejects (B), and I defend it in what follows.

Let's set out some desiderata on the complex properties to be introduced. First, a general constraint: in order that the resulting powers ontology be at least as well motivated as PPO, the properties introduced must not bring with them any of the putative disadvantages of categoricalism. They must therefore be: (1) epistemically tractable, and (2) causally self-contained.[40] In order to solve the causal and identity regresses, respectively, they must also be: (3) qualitative, and (4) not identity-dependent on powers.

2 Inverse functionalism

According to functionalism in the philosophy of mind, as we saw above, complex mental properties are individuated by their places in a structure that also includes physical properties that are not so individuated. Let's refer to that theory as *orthodox functionalism*. According to what I shall refer to as *inverse functionalism*, basic physical properties are individuated by their places in a structure that also includes complex qualitative properties that are not so individuated. In orthodox functionalism, the "inner" mental properties are individuated by their causal relations to each other and to "outer" sensory inputs and behavioural outputs. Inverse functionalism has no corresponding inner/outer distinction, but the principle of individuation is the same. In both cases, we have a structure some of whose nodes are individuated by their places in it, and some of whose nodes are not. The difference is that in orthodox functionalism, we individuate physically realized mental properties by their places in a structure that also includes non-mental properties, whereas in inverse functionalism, we individuate powers by their places in a structure that also includes physically realized non-powers.

Think of the way in which a bar magnet produces a characteristic spatial pattern in iron filings; or the way a spatiotemporal pattern of neural activity propagates throughout the brain; or the way a sphere rolls down an inclined plane. In outline, I propose that complex spatiotemporal properties such as those mentioned here meet all of the desiderata outlined above. If inverse functionalism is to appeal to such properties as partial individuators of pure powers, then they had better not be *functionally realized*. The reason is simple: if they are functional, then all inverse functionalism achieves is the addition of complex pure powers to the causal structure that individuates basic pure powers. This doesn't help with the causal regress, because if basic pure powers aren't qualitative, then neither are realized pure powers; and it doesn't help with the identity regress, because realized pure powers are also fully individuated by their places in the causal structure. Not every way of rejecting principle (B), then, is going to help us—it's no use saying that basic physical properties are partially individuated by relations they bear to complex spatiotemporal properties if these latter properties are just complex pure powers.

[40] I use 'causally self-contained' as a term for properties that have their causal roles in virtue of being the properties they are, like the thick quiddities of the powerful qualities ontology.

If the spatiotemporal properties I intend to appeal to in order to address the causal and identity regresses aren't functionally realized, then how is their dependence on the basic ontology to be explained? I'll say that realized properties in general have defining *specifications*, and that their realizers realize them on some occasion by being properties in virtue of which something meets those specifications. I adopt the following general account of realization, which is consistent with, but doesn't require, functional specifications:

> A property-instance $F_\phi\ (x)$ is realized by properties and relations $P_1, \ldots, P_n$; $R_1, \ldots, R_m$ iff (i) x or its proper parts possess $P_1, \ldots, P_n$ and $R_1, \ldots, R_m$ in some combination; and (ii) x meets the specification ϕ definitive of F_ϕ in virtue of (i), but not vice-versa.[41]

This account combines elements of accounts due to Carl Gillett and Andrew Melnyk: I allow that $P_1, \ldots, P_n$; $R_1, \ldots, R_n$ and F_ϕ may be instantiated in different individuals; but I also allow ϕ to be *any* specification—not necessarily *causal*—capable of defining a realizable property.[42] In Cartesian co-ordinates, we may define the property of being a sphere of radius R, centred at (x_0, y_0, z_0), as the property of being an X such that all points (x, y, z) that lie at X's outer boundary satisfy the formula: $(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2 = R^2$. Complex spherical bodies (more or less) satisfy the above formula *in virtue of* the properties and relations of their proper parts.[43] In general, to have a geometric property is to satisfy a certain mathematical formula; things that have the property in question satisfy the defining formula in virtue of the properties and relations of their basic physical proper parts. Now while the basic physical properties of a sphere's proper parts bestow dispositions that realize functional properties such as its rigidity, they do not realize its sphericality by means of their causal roles. Spatiotemporal properties such as sphericality are synchronically realized by their bearers' having basic physical proper parts of *some* kind standing in *some* spatiotemporal relations such that they meet the relevant specification. I shall refer to this kind of realization relation as *qualitative realization*.

Sphericality is defined by a purely mathematical specification, and characterises its bearers independently of their potential causal relations to other things. That isn't to say that spheres don't have various dispositions *in virtue of* their sphericality—of course they do. A massive rigid sphere is disposed to roll down an inclined plane in a gravitational field partly in virtue of its sphericality. However, we know the essential nature of sphericality by knowing its defining mathematical specification, *not* by knowing the various ways in which spheres are disposed to behave and the causal contributions that sphericality makes to those dispositions in each case.[44] It's natural

[41] The 'not vice-versa' clause secures the asymmetry of realization.

[42] Gillett (2003), Melnyk (2003). Gillett's account allows that the realized and realizer property are instantiated by distinct individuals; Melnyk's account allows for non-causal ϕ.

[43] I treat sphericality as mathematically defined, but this is *not* to say that sphericality is an abstract or mathematical *property*. I prefer to think of it as a broadly physical property with a mathematically specifiable essence.

[44] Similar points are made in Lowe (2010).

to say, therefore, that sphericality is power*ful*, but not a power: causally efficacious, but not causally individuated. In a recent paper, Bird makes similar remarks concerning the *prima facie* implausibility of pandispositionalism. Bird argues that while the chemical property aromaticity is a property in virtue of which aromatic chemicals possess a range of dispositions, what *defines* aromaticity is not those dispositions, but the structure of the bonding in the molecule. Such properties are also plausibly construed as defined by qualitative specifications, and qualitatively realized.[45]

I argue elsewhere[46] that some qualitatively realized properties bestow various dispositions not only in virtue of, but *solely* in virtue of, being the qualitative properties they are, hence not in virtue of the basic physical properties that realize them on any given occasion. If this is correct, then such properties are causally novel, in relation to their realizers, in much the same way as is traditionally taken to characterise strong metaphysical emergence.[47] I needn't commit to so controversial a thesis for present purposes. Inverse functionalism requires that complex qualitative properties are part of the causal structure that individuates basic physical properties, and that they are causally self-contained, but it doesn't require that the qualities are causally novel. It's sufficient for present purposes to claim that properties like sphericality stand in certain type-causal relations to powers in virtue of being the qualitative properties they are, leaving open whether they thereby bestow any novel dispositions.

We are now in a position to see how inverse functionalism meets desiderata (1)–(3). Sphericality—and any other properties defined by specifications we can readily grasp—is clearly epistemically tractable. Knowing which property sphericality is requires only that we grasp its defining specification. Appealing to realized spatiotemporal properties that can be explicitly defined has clear epistemological advantages over enriching the basic physical ontology with unknowable thick quiddities. The causal roles of geometric properties can be explained by their qualitative essences, but—unlike the thick quiddities of the powerful qualities ontology—in a fully transparent way. However, such properties have it in common with thick quiddities that their identities aren't primitive, so they don't give rise to merely quiddistic differences between worlds. No governing laws or global patterns are required to explain why spheres roll; it follows from the definition of sphericality that bodies possessing this property are capable of a certain type of motion across a surface.[48] Inverse functionalism therefore preserves what's distinctive about PPO as an account of laws and properties, in relation to MRL and DTA. Being qualitative, realized spatiotemporal properties serve to rebut Armstrong's worry that in PPO, all causation is passing around powers: although they are realized by powers, they are intuitively qualitative

[45] Bird (2016), pp. 354–7; Bird offers several other examples, all of broadly structural or geometric properties that cannot plausibly be construed as causally individuated—nor, it follows right away, as functionally realized.

[46] Yates (2016b).

[47] See Wilson (2015) for a detailed defence of causal conceptions of various forms of emergence.

[48] I omit the mathematics for brevity, but an explanation can be given, in terms of sphericality alone, of why spheres are capable of moving with constant and non-zero linear and angular velocity, while in constant contact with surface, without sliding. The mechanics of rolling of course involves rigid body physics as well, but the possibility of such motion can be explained in purely geometric terms.

in a way their realizers are not, and there's no corresponding concern that causation might turn out to be just passing around *qualities*. Indeed, according to the intuitions behind the causal regress, that's exactly what causation *ought* to be. Hence, inverse functionalism meets desiderata (1)–(3); let's turn now to (4).

If inverse functionalism is to block the identity regress, it's crucial that complex spatiotemporal properties are realized by pure powers, yet not identity-dependent on them. There are two principles one might employ to show that realized spatiotemporal properties *are* identity-dependent on powers: (a) being a power is closed under realization; (b) realized properties inherit their individuating principles from their realizers. Let's refer to these as the closure principle, and the inheritance principle, respectively. Given closure, realized spatiotemporal properties are individuated by their places in the causal structure, just like their basic physical realizers; given inheritance, even if they aren't themselves powers, such properties are still identity-dependent on powers by dint of the fact that their realizers are.

Let's address the closure principle first. I can think of no good reason to suppose that any property that's realized by powers must itself be a power. First, note that it's intuitively implausible to suppose that geometric properties are powers. So, given that they are realized by powers at our world—assuming, that is, that basic physical properties are powers—they are a *prima facie* counterexample to the closure principle. In a recent paper, arguing that PPO fails to support pandispositionalism—the view that *all* properties are powers—Bird provides counterexamples to a closely related closure principle, from which our closure principle would follow a fortiori: the principle that *any* property that can be constructed from powers by means of some property-forming operation is itself a power.[49] Bird considers a substance that's both flammable and soluble—which is disposed to burn when subject to a flame, and disposed to dissolve when immersed in water. These two powers of the substance don't compose under conjunction into a further power, for the substance is not disposed to burn and dissolve when immersed in water and subject to a flame. It follows that not all properties constructible from powers are themselves powers. True, conjunction isn't a realization relation; but if at least some properties that can be constructed from powers are not themselves powers, then anyone who thinks that being a power is closed under qualitative realization needs to supply an additional argument for that claim, and it's less than clear how it would go. Qualitative realization seems more suitable than conjunction for generating properties that are novel in relation to their realizers, and if being a power isn't even closed under conjunction, it seems unlikely that it would be closed under qualitative realization.

The reader may suspect that closure follows, at least for complex spatiotemporal properties, from the claim that the basic spatiotemporal relations are pure powers. In general relativity, spacetime is a dynamic structure, with an intrinsic curvature that's determined by the distribution of matter. The intrinsic geometry of spacetime determines the *inertial paths*, which bodies follow when not acted upon by a force. It's not stretching credibility too much to hold that these roles for spacetime—having its geometry determined by the matter distribution, and constraining inertial motion—are

[49] Bird (2016), pp. 358–60.

causal, and if they are, then a powers conception of the basic spatiotemporal relations is possible.[50] How can I maintain that spatiotemporal properties such as sphericality are non-powers, while leaving open that the spatiotemporal properties that partially realize them *are* powers? To reiterate: complex *broadly* spatiotemporal properties such as shapes and patterns are related by qualitative realization to their (putatively) basic physical spatiotemporal realizers. In the light of Bird's argument, from the claim that the basic spatiotemporal relations are powers, we can't even infer that compounds of such relations formed by conjunction are powers, let alone complex properties formed by realization.

Finally, let's consider the inheritance principle, according to which whatever individuates the realizers of a property individuates the realized property as well. Given the inheritance principle, it makes no sense to suppose that the same spatiotemporal property—sphericality, say—could be qualitatively realized both by powers and by non-powers, for it would in each case be differently individuated, and hence a different property. To see this, consider a possible world at which spacetime is a Euclidean, non-dynamic background structure, whose intrinsic geometry is fixed and independent of the matter distribution, and whose curvature is zero—as indeed actuality was thought to be prior to the advent of general relativity. A powers conception of spatiotemporal relations in such a world is untenable, for spacetime is a non-dynamic background upon which the laws of physics play out. Given the inheritance principle, such a world could not contain instances of the same geometric properties as our world, and this, I maintain, is absurd: *of course* sphericality could be realized in a flat Euclidean spacetime—its realizability depends only on the existence of: (i) a space containing spherical proper sub-regions for spherical bodies to occupy, and (ii) basic physical particulars that can be arranged to form complex bodies that meet its defining specification.

I conclude that complex spatiotemporal properties meet all of our desiderata (1)–(4). Inverse functionalism keeps what is distinctive about PPO, but avoids the causal and identity regresses by means of intuitively qualitative complex properties that are causally self-contained, and individuated independently of the powers that realize them. At this point, however, a problem arises. If powers are identity-dependent on complex qualities, it's intuitively clear that they can't be ontologically *prior* to those qualities. It's equally intuitive, however, that realizers are ontologically prior to what they realize—how then can I coherently maintain that powers realize the spatiotemporal qualities upon which their identities depend? In the next section, I consider three versions of inverse functionalism—one Platonic, and two Aristotelian—and show that the two Aristotelian versions do indeed posit *prima facie* problematic ontological dependences, but argue that the problems can be solved provided metaphysical grounding is not always a relative fundamentality relation. In Sect. 4, I'll argue that structuralist ontologies in general are already committed to this claim, and for very similar reasons.

[50] The details needn't concern us here; see Bird (2005b, 2009) for defence, and Livanios (2008) for opposition.

3 Aristotelian versus Platonic inverse functionalism

Suppose we are Platonists about universals, including both basic physical powers and the complex qualities that serve to individuate them. On this view, the entire type-causal structure exists in an abstract realm, and there's no reason to suppose that the powers are prior to the qualities. *Instances* of spatiotemporal qualities are of course realized and *prima facie* posterior to their realizers, but the qualities themselves don't depend on their instances, and are plausibly equifundamental with the powers they individuate. Call the resulting theory Platonic inverse functionalism.[51] Now it may be objected at this point that Platonic spatiotemporal qualities are not only independent of their instances, but also *ontologically basic*, and this raises a problem.[52] Inverse functionalism is supposed to preserve principle (S) of PPO, the claim that all basic physical properties are powers, while rejecting principle (B), the claim that powers are fully individuated by other basic physical properties. Given that Platonic spatiotemporal qualities are basic non-powers, however, it seems that Platonic inverse functionalism instead preserves (B) while rejecting (S), as with the alternative proposals discussed in Sect. 1.

I reply that Platonic sphericality is a complex, mathematically defined property, and not the kind of property that will feature in the ontology of completed physics alongside properties like electric charge. I wrote at the outset that a basic physical property was to be understood as any simple, unrealized property that features in the laws of ideal completed physics. While they are plausibly ontologically basic, Platonic spatiotemporal qualities like sphericality are not *basic physical* properties in this sense, even though the properties themselves are both fundamental and unrealized. They are not simple properties at all, and their complexity is in essence what enables them to be both epistemically tractable and causally self-contained. Simple properties, by contrast, face the dilemma raised in Sect. 2—they are either too thin to explain their causal roles, or thick enough to do so, but therefore intractable. Indeed, that's a major part of the motivation for a powers conception of basic physical properties, which clearly doesn't apply to complex spatiotemporal qualities, whose causal roles follow transparently from their definitions.

There's a further problem with Platonic inverse functionalism. Given that powers are identity-dependent upon ontologically *in*dependent qualities, then even if the qualities are not basic physical, won't they be *more fundamental* than the powers? That would be an odd thing to say, and it would be preferable to avoid saying it. First, note that proponents of structuralist powers ontologies are already committed to the claim that powers are both ontologically dependent and absolutely fundamental, so why shouldn't a Platonic inverse functionalist say the same? From the fact that powers are identity-dependent on qualities, it doesn't follow that powers are less

[51] See Tugby (2013) for a defence of Platonism about powers in standard powers ontologies. Tugby's central argument is that only on Platonic powers ontologies are powers intrinsic to their bearers, and it depends on the fact that Aristotelian powers must satisfy an instantiation condition, so that any given power instance presupposes other concrete particulars as bearers of the powers upon which it is identity-dependent. For further discussion of the intrinsicality of powers in Aristotelian ontologies, see Yates (2016a).

[52] I thank an anonymous referee for drawing my attention both to this problem, and to the one that follows it.

than absolutely fundamental, any more than this follows from the fact that powers are identity-dependent on each other. It may be counterintuitive to suppose that two absolutely fundamental entities could stand in an *asymmetric* identity-dependence relation, but I don't think it's any worse than that. It is, in any case, a consequence of the present theory.

Let's now assume an Aristotelian principle of instantiation that applies to both basic and complex properties. On this view, complex qualities exist at a world, and are able to feature in a type-causal structure there, only if they are *realized* at that world. Given this principle, inverse functionalism entails that our world has, of necessity, a certain degree of complexity, for the individuation of its basic physical properties depends on the existence of complex objects as bearers of the qualities needed to individuate them. On the assumption that basic particulars have only basic physical intrinsic properties, we need complex *particulars* as bearers of the qualities needed to individuate powers. Powers suffice for the existence of the qualities upon which they are identity-dependent by realizing their instances, so our world must minimally include whatever it takes for those qualities to be realized. Some will no doubt see this as a disadvantage, as it places a fairly severe restriction on the range of nomically possible worlds—there could not have been just a lone electron in the void, for instance, for there's no way that such an electron could possess the qualities needed to individuate its basic physical properties. Call this version of inverse functionalism *strongly Aristotelian*.

We can also develop a *weakly Aristotelian* version of inverse functionalism, and one which doesn't require as much concrete structure to individuate powers, simply by weakening the principle of instantiation for complex properties. Aristotle's principle of instantiation, one might suspect, is true only for *basic* properties. In Sect. 2, we saw how to construct geometric property-instances from basic physical properties by qualitative realization. We can use that account to construct *uninstantiated* complex properties, given a suitable existence condition:

> A complex property $F_\phi(x)$ exists at a world W iff $\Diamond_P[\exists X$ at W such that X meets the specification ϕ definitive of $F_\phi]$.

Here '$\Diamond_P$' denotes 'it is physically possible that'. The idea is that a complex property exists at a world iff it is realiz*able* there, given what else there is, and the laws of physics. Sphericality exists at W iff it's physically possible for there to be an X that satisfies the relevant formula.[53] This also places constraints on the basic physical domain: we require a space containing spherical regions, and a domain of basic physical properties and particulars that can be so arranged as to form complex objects that occupy such regions. If complex properties can exist uninstantiated, then there's no reason to suppose they can't feature in a type-causal structure uninstantiated. On weakly Aristotelian inverse functionalism, the world needs significantly less concrete structure for powers to be individuated, depending on what it takes for the necessary qualities to be realizable. Note that despite the fact that we have relaxed the instantiation condition for complex properties, weak Aristotelianism isn't a form of

[53] I'll refer to this as *construction* to distinguish it from token realization, but the reader shouldn't lose sight of the fact that the crucial explanatory relation is qualitative realization, albeit within the scope of a possibility operator.

Platonism: no abstract realm is posited, and complex properties exist uninstantiated because they are constructible from basic properties that do have instances, and for which the instantiation condition holds.

Both versions of Aristotelian inverse functionalism are *prima facie* problematic, for both token realization and construction are forms of *grounding*, which seems to be a relative fundamentality relation. Grounding is typically treated as an explanatory relation holding between entities: x grounds y iff y exists in virtue of x and it is metaphysically necessary that if x exists then y exists.[54] It's also typical to hold in addition that grounding is a strict partial order: irreflexive, asymmetric and transitive. On this understanding, a chain of grounding relations reflects the relative fundamentality of the entities in the chain, with those lower down being ontologically prior to those higher up. In both versions of Aristotelian inverse functionalism, basic physical properties are identity-dependent on qualities that they ground. In strongly Aristotelian inverse functionalism, powers ground the qualities they depend upon by realizing their instances; in the weak version, powers ground qualities not by realizing them, but by making their realization physically possible. If grounding is indeed a relative fundamentality relation, then the powers must be ontologically prior to the qualities. A complex property, intuitively, cannot be realized by or constructed from basic physical properties unless those properties are in some sense available prior to the property that is realized or constructed.

As I said above, it's difficult to see how powers *could* be ontologically prior to properties upon which they are also identity-dependent. Worse, because identity-dependence is itself plausibly a grounding relation, if grounding is a relative fundamentality relation, then the powers and qualities in Aristotelian inverse functionalism are prior to each other, which is incoherent. Clearly, something has to give. In Sect. 4, I shall first draw attention to some plausible counterexamples to the asymmetry of grounding in the recent literature. I'll then argue that both PPO and ontic structural realism are cases in point, as they both require that entities can be individuated by their places in a structure composed by the entities themselves. The best way to make sense of relational individuation, I shall argue, is to say that the entities and the structure that individuates them are equifundamental and symmetrically grounding.

4 Relational individuation and symmetric grounding

In a recent paper, Naomi Thompson offers several putative examples of symmetric grounding.[55] Let proposition $p_1 = \langle p_2 \text{ is true} \rangle$ and $p_2 = \langle p_1 \text{ is true} \rangle$. Assuming propositions are grounded in their constituents, each of the propositions p_1 and p_2 is

[54] Fine (2012), Sect. 1. Here 'in virtue of' is a *sui generis* relation appropriate to claims of metaphysical explanation. The relation is hyperintensional: Socrates grounds {Socrates}, but not vice versa, despite the fact that necessarily, Socrates exists iff {Socrates} exists. Grounding is therefore not amenable to reductive modal analysis. Grounding is also sometimes treated as holding between facts, but the nature of the relata need not concern us here.

[55] Thompson (2016). Those who endorse symmetric grounding must also, obviously, reject transitivity or irreflexivity or both. I prefer to reject transitivity, but to argue for that here would take us too far afield.

grounded in the other and the property of being true.[56] While this example suggests that grounding isn't *always* a relative fundamentality relation, it doesn't suffice to show that Aristotelian inverse functionalism is unproblematic. For that, we need cases in which entities are identity-dependent on other entities they ground. Thompson offers a further case that's promising in this regard. An organism is partially constituted by its organs, but it's plausible to maintain that the organs derive at least part of their identities *qua* organs from the roles they play within it. Thompson treats both constitution and identity-dependence as grounding relations, and so treats the organs and the organism as symmetrically grounding. The organs are partially individuated by their places in the organism, while the organism is partially constituted by its component organs.

If Thompson is correct about the organs/organism case, then the fact that the xs constitute y doesn't preclude the xs being identity-dependent upon y, so constitution isn't always a relative fundamentality relation. One can bring to bear the same intuitions in the present case as we saw marshalled against Aristotelian inverse functionalism: if the xs constitute y, then the xs must be available prior to y, otherwise the business of constituting y could never get going. To my mind, this intuition stems from a tacit appeal to grounding as a relative fundamentality relation: if the xs are that in virtue of which y exists, then the xs must be prior to y. In both Aristotelian inverse functionalism and in Thompson's case, contrary to intuition, the xs are not only that in virtue of which y exists, but are also identity-dependent on y. Perhaps the reader accepts symmetric grounding in cases such as Thompsons, but objects to it in Aristotelian inverse functionalism; in that case, the burden of proof is squarely on the reader to explain why constitution is different from realization and construction in this crucial respect. If one accepts symmetric grounding between the organs and the organism, then no purely general grounding-theoretic argument against my position will work, and something more must be said about why the specific structures I appeal to are problematic. I shall now argue that PPO and ontic structural realism are further counterexamples, of just the same kind, to the asymmetry of grounding, for each posits xs that are identity-dependent on a y that the xs ground. It follows that no friend of PPO—or any other ontology that posits relational individuation—should be troubled by the symmetric grounding structure Aristotelian inverse functionalism requires.

In PPO, powers are fully individuated by their places in a type-causal structure fully composed of powers and the primitive stimulus and manifestation relations between them. It makes no sense to suppose that the powers are prior to the individuating structure, but intuitively, relata are ontologically prior to relations. This problem isn't new; proponents of ontic structural realism (OSR) have been grappling with it for quite some time. Two electrons orbiting a Helium atom in the singlet state are such that they have net angular momentum zero without having definite spin. Quantum mechanics attributes to them *as a pair* the relation of having opposite spin, but doesn't attribute a definite spin direction to either. Since they may also have the same spatial wavefunction, it's possible for them to have all their intrinsic and relational properties in common. Electrons in this state are *weakly discernible*, in that there's an irreflexive

[56] Gonzalo Rodriguez-Pereyra offers a similar example, but suggests instead that the fact that p_1 is true is grounded in the fact that p_2 is true, and vice-versa. See Rodriguez-Pereyra (2015).

formula free in two variables that is satisfied by the two electrons together: 'x is of opposite spin to y'. Weak discernibility is consistent with the two electrons having all the same intrinsic and spatiotemporal basic physical properties. If anything individuates them, ontic structural realists argue, it must be the primitive modal relation of necessarily having opposite spin. In its most extreme form, OSR is a purely relational ontology without individuals, embracing primitive modal relations while rejecting the need for relata.[57] Having argued that fundamental particles are in some sense *mere abstractions* from the modal structure of physical laws,[58] James Ladyman and Don Ross respond to the obvious objection that there can be no relations without relata as follows:

> [a] core aspect of the claim that relations are logically prior to relata is that the relata of a given relation always turn out to be relational structures themselves on further analysis.[59]

This claim, however, is not obviously consistent with the "mere abstractions" claim, for a relational structure cannot literally *be* an abstraction from relational structure. Suppose the relata turned out to be genuine relational structures, involving their own relata. What do these latter relational structures themselves relate? The claim seems to be that relational structure is all there is, and the sense in which relata "turn out to be relational structures" *just is* that they turn out to be mere abstractions from structure. In that case, however, it seems Ladyman and Ross are squarely committed, ontologically, to relations without relata.[60]

Certain non-eliminativist versions of OSR treat the relata of the primitive modal relations as real but ontologically derived from the relations. As has been suggested,[61] such versions of OSR seem committed to a bundle theory of basic physical particles. According to the bundle theory, properties are ontologically prior to particulars, which seems to provide a natural way for ontic structural realists to understand the claim that fundamental particles are relationally individuated, and ontologically posterior to the individuating relations: they are *bundles of those relations*. So far so good, but if we now ask what it is that the relations relate, we can only answer that it is bundles of themselves. Basic physical particulars are bundles of relations between bundles of relations between bundles of relations between…. What's more, the bundle theory entails some form of the principle of the identity of indiscernibles (PII), which in turn seems to be in tension with the cases that its chief proponents take to motivate OSR, for instance the fact that quantum particles are sometimes only weakly discernible.[62] It's a matter of considerable controversy, however, whether the relational bundle theory

[57] This is arguably the position endorsed in French and Ladyman (2003); many of the claims made in Ladyman and Ross (2007) also suggest an eliminativist approach, but see below.

[58] Ladyman and Ross (2007), pp. 134–7.

[59] Op. cit. p. 154.

[60] See Briceño and Mumford (2016) for a critique of OSR based on the intuitive priority of relata.

[61] Pooley (2006), p. 93; Ainsworth (2010), pp. 51–2; Ainsworth (2011), pp. 77–8.

[62] Esfeld and Lam (2008), p. 33; (2011) pp. 148–9.

entails a version of PII that is falsified by the (mere) weak discernibility of quantum particles.[63]

Michael Esfeld and Vincent Lam defend *moderate* OSR, which keeps the fundamentality of relations but dispenses with the priority of relations over relata, thereby avoiding both the pitfalls of relational bundle theory and the apparent incoherence of relations without relata:

> There are relations as well as objects standing in the relations without there being any ontological priority between them. Relations and objects are both genuine fundamental ontological entities. They are on the same ontological footing, being given "at once" in the sense that they are mutually ontologically dependent on each other.[64]

If we assign priority to objects over relations, they argue, we end up with a form of haecceitism, which is empirically unacceptable.[65] Assigning priority to relations over relata is problematic, as we've seen. A no-priority view would certainly be advantageous, but what exactly does it amount to? Relations are ontologically dependent upon objects, for Esfeld and Lam, in the intuitive sense that concrete instances of relations require objects for them to relate. Objects are ontologically dependent upon relations because they don't have any intrinsic properties, so primitive modal relations are the only natures they get to have. The identities of the objects themselves is *primitive*, and not grounded in or otherwise metaphysically explained by their places in a modal structure. The structure itself is constituted by primitive modal relations between objects whose *identity* is primitive but whose *natures* are exhausted by those relations.

Moderate structural realism is somewhat unstable, as it leaves open the *relationship* between the natures of the primitive objects and their identities. Suppose we ask: could there be just one basic physical object, standing in no relations? Given that there are no intrinsic natures, a lone object would have no nature at all, but since they are primitively individuated, why should this matter? Physical objects depend on primitive modal relations *for their natures*, but if they don't ontologically depend *on their natures*, then they don't ontologically depend on relations either. On this view, it seems most natural to say that basic physical objects are prior to the modal relations between them. If, on the other hand, we say that the relational natures of the physical objects *are* essential to them, then it seems we must also embrace relational individuation, and say that what makes them the objects they are is the modal relations in which they stand. This in turn just leads us back to the apparent ontological priority of relations over objects.[66]

Now suppose we say that objects and structure are equifundamental, as Esfeld and Lam do, but add that they are *mutually grounding*. Physical objects are individuated by

[63] See for instance Ladyman and Bigaj (2009) and Ainsworth (2011).

[64] Esfeld and Lam (2011), p. 146; see also Esfeld and Lam (2008), pp. 31–4.

[65] Esfeld and Lam (2008), p. 34.

[66] Interestingly, in their (2011), Esfeld and Lam claim that weak discernibility is sufficient to ground the numerical distinctness of the primitive objects, meaning they no longer need primitive individuation, but claim in addition that this "does nothing to show how objects could be derived from relations", (p. 149).

their places in a relational structure that is in turn *constituted* by those objects and the relations between them. This brings to mind Thompson's case of mutual grounding between organs and body, with the organs identity-dependent on a body that they partially constitute. Given symmetric grounding, we can have a no-priority version of OSR that avoids both free-floating relational structure *and* primitively individuated objects. Precisely the same lesson applies to PPO, *mutatis mutandis*.

In PPO, pure powers are individuated by their places in a structure fully composed of powers and the relations between them. Which came first, the powers or the structure? Assigning priority to the structure raises the obvious question of what it is supposed to be a structure *of* (and we can't obviously appeal to bundle theory to help us in the case of powers, because they aren't particulars); on the other hand, to assign priority to the powers is to give up on the idea that they are relationally *individuated*. A no-priority view is clearly preferable here too: powers and the primitive stimulus and manifestation relations between them compose into a second-order type-causal structure, which individuates the powers by means of their places in it. Note too that this applies not only in PPO, but also in mixed ontologies such as Molnar's, in which some basic physical properties are powers, and some are categorical. The powers in Molnar's ontology are individuated by their places in a structure that they themselves *partially* compose, so it still doesn't make sense to say that either the powers or the structure is prior to the other.[67] Symmetric grounding is a promising way of making sense of relational individuation, and should be seen as a cornerstone of structuralist ontologies in general, rather than an additional commitment of the particular ontology I have defended here.

5 Conclusion

Pure powers ontologies suffer from an intuitive lack of quality that renders the individuation of powers problematic. Extant responses to the regress problems discussed here either deny the intuition, or posit qualitative properties of some kind in the basic physical ontology, either alongside or in place of pure powers. Inverse functionalism offers a third way: retain the idea that all basic physical properties are pure powers, fully individuated by their places in a causal structure, and use these basic powers to build complex qualitative properties that are also part of the individuating structure, but which are not individuated by their places in it, nor otherwise identity-dependent on powers. According to Aristotelian versions of this theory, powers are identity-dependent on qualitative properties that they ground, so assuming identity-dependence is a grounding relation, this is a case of symmetric grounding. Platonic inverse functionalism doesn't require symmetric grounding, and may therefore be preferable for those who are more strongly committed to the asymmetry of grounding than they are to Aristotelianism.

[67] These remarks also apply to orthodox functionalism, *mutatis mutandis*—we can't assign priority to mental properties over the psychological causal structure, because they are individuated by their places in it; and we can't assign priority to the structure over the properties, because it's partially composed of them.

The symmetric grounding posited by Aristotelian inverse functionalism is not, I have argued, an additional commitment thereof in relation to PPO. Structuralist ontologies in general are unified by a commitment to relational individuation, which is best understood in terms of symmetric grounding relations between the individuating structure and its relata. In PPO, powers are individuated by their places in a type-causal structure fully composed of the powers and the primitive relations between them. Neither the structure nor the powers can plausibly be considered ontologically prior to the other, so the best way to make sense of PPO is to say that they are equifundamental: basic physical properties are pure powers, fully individuated by their places in a type-causal structure that they themselves compose. If rejection of the asymmetry of grounding is indeed built into powers ontologies—and other structuralist ontologies such as OSR—*qua* structuralist, then the fact that Aristotelian inverse functionalism requires symmetric grounding between powers and complex spatiotemporal qualities isn't an additional commitment.

Those who take symmetric grounding to be incoherent will of course want to reject structuralist ontologies, if they agree with me that such ontologies are committed to symmetric grounding *qua* structuralist. However, that takes us back either to familiar categoricalist accounts of properties and laws such as MRL and DTA, which bring with them a host of familiar problems; or to some form of the powerful qualities ontology, which, as we have seen, threatens to bring with it at least some of the epistemic disadvantages of standard categoricalism. In any case, my aim in this paper has not been to defend powers ontologies against their rivals, but to show that we can appeal to complex spatiotemporal qualities to individuate powers, thereby solving two serious regress problems for PPO, without abandoning its commitment to the claim that all basic physical properties are pure powers. That makes inverse functionalism an attractive position for anyone committed to the view that a powers ontology of some kind is the best way to understand both the natures of basic physical properties, and the laws of nature.

In closing, let me draw attention to an application of the metaphysical structure defended here to a puzzle raised by recent work in quantum gravity, which seems to suggest that manifest spacetime as we ordinarily conceive it, with three dimensions of space and one of time, emerges from a basic *non*-spatiotemporal quantum reality.[68] The term 'emergent' in this context doesn't typically carry its traditional implications, and is sometimes taken to mean something like 'grounded', or 'not basic physical'; and sometimes something like 'merely phenomenological'. Inverse functionalism offers a promising way of addressing a potential inconsistency between emergent spacetime and powers ontologies, which in turn suggests that a more robustly ontological emergence relation may be involved. The problem with powers ontologies in emergent spacetime is that the causal roles that are taken to individuate powers are spatiotemporally defined—negative charge is (*inter alia*) the power to exert a *repulsive* force on other negative charges whose magnitude depends on their *separation*. This suggests that basic physical properties are individuated in part by means of spatiotemporal relations, because we can't specify their causal essences without them. This is of course

[68] See Huggett and Wüthrich (2013) for discussion of various results, from several independent quantum gravity research programmes, which have been taken by some to suggest that spacetime is not basic physical.

unproblematic if spatiotemporal relations are basic physical, but what should we say if they are not?

If one held, according to principle (B) of PPO, that only basic physical properties can individuate basic physical properties, then emergent spacetime would seem to preclude any kind of powers ontology, for emergent spacetime can't be basic physical. The nature of this emergence relation is mysterious, since quantum gravity is still a work in progress, but suppose that it's a grounding relation. Inverse functionalism allows us to make sense of how spacetime could be both emergent *and* individuative of basic physical properties, by allowing those properties to be partially individuated by means of their roles in an emergent spacetime that is itself grounded in the basic ontology.[69] The idea that spatiotemporal properties and their basic physical grounds are equifundamental and mutually grounding offers a way of understanding how spacetime could be both emergent and metaphysically fundamental, which in turn suggests a more robust notion of emergence than that suggested by the way the physics community typically uses the term. But developing this view is a task I must leave to future work.[70]

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[69] Lam and Esfeld (2013) argue that spacetime must be basic physical in quantum gravity given that entanglement is a defining feature of quantum mechanics, and entanglement is typically defined in terms of spatially separated systems whose dynamics can't be independently specified. On my proposal, a property needn't be basic physical to play a defining or individuative role that suffices for its fundamentality.

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