The Genealogy of Metaphysical Realism

What is metaphysical realism, and where did it come from? This paper distinguishes three types of metaphysical realism, understood broadly as a view of the nature of physical reality in which there is only a loose connection between physical truths and truths related to experience. We trace the history of metaphysical realism from the homespun primary quality realism of early modern realists to the highly rarefied ontic structural realism of contemporary realists. One aim of the paper is to clarify the advantages and disadvantages of metaphysical realism in its various forms; another is to explain why realist thinking has evolved the way it has, and why, despite its persistent popularity, it has always faced intelligent opposition.

1 The Analysis of Matter

In the mid-19th century, Gregor Mendel posited genes to explain observed patterns of biological heredity. Mendel's posit was extremely fruitful (almost literally), even before X-ray crystallography revealed the further underlying nature of genes in the mid-20th century. But all along, people were curious to know what that further underlying nature was, which is why they did the science that eventually led to the discovery of DNA.

The example of genes is typical. Given any explanatory posit, it's natural to wonder about the further underlying nature of the posited phenomenon: the nature it has "in itself," and in virtue of which it explains what it does. Nobody was content to think that the nature of genes was exhausted by their property of explaining observed patterns of biological heredity. Likewise, nobody was content to think that the nature of germs was exhausted by their property of explaining observed epidemiological patterns, or to think that the nature of atoms was exhausted by their property of explaining observed patterns in the behavior of matter. Perhaps we can be driven to think of a particular explanatory posit this way by persistent failure to learn anything more about its nature, or by philosophical arguments purporting to show that we have no good reason to think the posit has a discoverable further nature, or that the posit is best understood as a convenient fiction. But the natural starting assumption is that our explanatory posits do have some nature over and above their explaining what we posit them to explain.

One explanatory posit is the physical world; it is, in a way, the mother of all explanatory posits. We posit it to explain the following facts about experience:

1. Experience is *intrasubjectively orderly,* in the sense that in each of us, experience occurs in prima face non-random ways, that is, differently from how one would expect, if experience occurred at random.

2. Experience is *intersubjectively orderly,* in the sense that different people's experiences often occur in prima facie coordinated ways, that is, in relationships different from what one would expect, if their experiences occurred at random.

3. Experience is *prediction-friendly,* in the sense that we often make accurate predictions about what experiences will occur based on experiences that have occurred.

We can sum up the foregoing facts by saying that experience is *regular*. The regularity of experience is its prediction-friendliness and prima facie intra- and inter-subjective non-randomness.

It's not controversial that experience is regular. Even an external-world skeptic can agree that experience *seems* to occur non-randomly; this is so, even if (implausibly) it actually occurs totally at random. Even an external-world skeptic can agree that we often make successful predictions about experience; this is so, even if (implausibly) our success is due to sheer luck.

Setting aside external-world skeptics, it's also uncontroversial that the regularity of experience has some explanation. There's a metaphysically possible world indistinguishable from ours in regard to the experiences that occur in it, but in which all experience occurs at random. In such a world, the regularity of experience is an inexplicable statistical fluke. But no one believes that this metaphysically possible world is our world. We all believe that the regularity of experience does have some explanation. This belief is so widespread that we have a term for the presumed explanation: we call it "physical reality" or "the physical world."

Acknowledging that the physical world is whatever explains the regularity of experience doesn't commit us to any view on the metaphysical significance of experience in relation to the physical world. In particular, it doesn't commit us to holding that the physical world depends for its existence on the fact that it explains the regularity of experience. Maybe it's a contingent rather than necessary truth that the physical world explains the regularity of experience; maybe the physical world could have existed with all its actual physical features, even if it had lacked the features in virtue of which it explains the regularity of experience. Or maybe not. The platitude that physical reality is what explains the regularity of experience doesn't settle the question.

Different accounts of the ultimate nature of the physical world are different *analyses of matter*. (Here, "matter" refers to physical phenomena in general, not just matter in the narrow sense that contrasts with energy.) The goal of such analyses is to identify the further nature of whatever it is that explains the regularity of experience, by giving substantive and illuminating necessary and sufficient conditions for the existence of physical phenomena, and saying how phenomena satisfying those conditions explain the regularity of experience.

There is a legitimate question as to whether or to what extent this goal is achievable. Some metaphysicians are more optimistic than others on this score. (Kant is famously pessimistic.) In this paper, we set aside Kantian misgivings about the feasibility of a satisfactory analysis of matter, and focus on what has always been the most popular analysis: metaphysical realism.[1]

2 Metaphysical Realism: the Big Picture

Here, in broad strokes, is the Realist picture:[2]

[1]Here's a summary of the rest of the paper: §2 gives a broad overview of realist metaphysics. §3 describes a classic form of metaphysical realism from the early modern era: Primary Quality Realism. §4 explains how pressures on Primary Quality Realism led to a more abstract form of realism that arose in the late modern era; I call this Algebraic Realism. §5 explains how pressures on Algebraic Realism led to an even more abstract form of realism: Ontic Strucural Realism. §6 discusses some challenges to metaphysical realism, and clarifies the relationship between realism and physicalism. §7 concludes. Throughout, I suppress my distaste for the label "realism" and its invidious connotation that opponents of metaphysical realism dispute the reality of physical things.

[2]The label "metaphysical realism" gets applied to a rather wide variety of philosophical views. I use it here in a relatively narrow sense, to mean a view about the nature of physical

> The physical world fundamentally consists of contingently existing entities with various non-mental properties; call these entities and whatever they constitute "Real Things," and the non-mental properties of Real Things "Real Properties." Our conscious perceptual experiences typically arise from causal interactions between our bodies (which are Real Things) and various features of our environment (which are also Real Things). Perhaps it's surprising that conscious experiences arise from these interactions, but given that they do, it's not surprising that interactions between Real Things with similar Real Properties give rise to similar experiences; for example, it's not surprising that similar experiences occur whenever the Real Things that are elm trees interact with the Real Things that are human visual systems. The regularities we find in our experience reflect patterns in the Real Properties of the Real Things that cause our experiences. Though these experiences are our only evidence for the existence of Real Things, it's not essential to Real Things that they cause experiences, or even that they have the power to do so. If God were to strip the Real Things of their experience-causing powers, or replace their existing experience-causing powers with powers to cause very different kinds of experience, that would have no effect on the world's physical contents.

The distinguishing feature of metaphysical realism is the view it takes of the relationship between experience and the physical world. Realists acknowledge that ultimately, experience is our sole source of information about the physical world. But according to them, the physical world does not depend for its existence or physical nature on revealing itself to us in experience, or even on its having the power to do so. If Real Things had no experience-causing powers, we wouldn't know anything about them. But the Real Things of our world could exist and constitute the physical world they actually constitute even if they had no experience-causing powers. Their reality, and the reality of the physical world they constitute, is metaphysically independent of any fact related to experience (or any other mental phenomenon).[3]

What does metaphysical realism exclude? Most obviously, it excludes analyses of matter that reduce physical states of affairs to states of affairs involving actual minds and experiences; this includes the idealist analyses of Leibniz and

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reality. In this sense, metaphysical realism is one species of what Crispin Wright calls realism (Wright, 1986, 2); in the taxonomy of Miller (2022), the kind of metaphysical realism that concerns me here is "local" realism about the physical.

[3]Caveat: any metaphysical realist who accepts physicalism must allow that some physical phenomena metaphysically entail the existence of conscious experience: namely, the brain states that, according to physicalism, are identical with conscious experiences. More on the relationship between physicalism and metaphysical realism in §6.

Berkeley, and the panpsychist analyses of Eddington and his followers. It also excludes a Kantian analysis of matter that reduces the existence of physical phenomena to the existence of things—further natures unknown—with suitable experience-causing powers. Kantians, unlike metaphysical realists, hold that there can't be a physical world where nothing has the power to cause experience.

Metaphysical realists say the physical world is something contingent and non-mental that happens to have (though need not have had) various experience-causing powers. But this is not all they say. There must be something that distinguishes our world from worlds with different physical features. Whatever this distinguishing factor is, it's not anything related to experience, according to realists. So, what is it?

Different metaphysical realists give different answers. The main purpose of this paper is to present these answers clearly and in a way that illuminates the historical development of realist thinking.

I said that metaphysical realism has always has been the most popular analysis of matter. It owes its popularity to three important virtues.

First, metaphysical realism is compatible with, and indeed entails, that physical reality is *mind-independent*. In the realist view, the existence of rocks does not depend on the existence of minds or experiences. This is good, since the proposition that things like rocks can exist independently of minds is one of the most important pre-theoretical platitudes about physical things.

Second, metaphysical realism easily accounts for the *objectivity* of observable physical phenomena, that is, the possibility for more than one observer to observe the same physical thing. This is an important virtue for an analysis of matter to have, since the proposition that physical things are objective in this sense is another important platitude about physical things. In the realist view, for two observers to observe the same physical thing is for the thing to cause perceptual experiences in both observers—or, if that's too simplistic, it's for the thing to cause the observers to have suitable types of experiences, by affecting them along suitable causal pathways. Whatever the details, the outlines of a realist account of objectivity are tolerably clear: observable physical things are objective, in that a single physical thing can be the source of different observers' experiences.

Third, metaphysical realism has no difficulty accommodating *unobservable* physical entities, like quarks and the interiors of black holes. Not all metaphysical realists believe there are such entities (so-called scientific antirealists do not), but there is room for such entities in the metaphysical realist scheme of things, which is at least not obviously the case when it comes to alternative analyses of matter, like idealism and Kantian noumenalism.

Metaphysical realism is not without its problems, some of them quite serious. We'll briefly consider these at the end of the paper. However, my purpose here is not so much to evaluate metaphysical realism as to bring it into clearer focus, and to trace its evolution from a relatively approachable Early Modern era analysis of matter in terms of primary qualities to the highly rarefied analyses advanced by contemporary ontic structural realists. One thing that will emerge from the discussion that follows is that there are fewer differences among these analyses than meet the eye.

3 Primary Quality Realism

The classic version of metaphysical realism is what Robert Adams calls *Primary Quality Realism*. According to Adams,

> Primary Quality Realism presents us with a physical world that is very different from what it appears in sense perception to be. In place of the colors, tastes, smells, and so forth that fill our sensory fields and form so large a part of our ordinary picture of the world, and that certainly do not seem to be only powers, we are offered a world of geometrical properties and motions—little more than a mathematical framework—plus perhaps some powers.[4]

Many early modern thinkers, including Galileo, Descartes, Hobbes, Boyle, Newton, and Locke have views that fit Adams's description. However, like other textbook descriptions of Primary Quality Realism, Adams's leaves it somewhat unclear how to understand Primary Quality Realism as an analysis of matter.[5]

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[4](Adams, 1979, xv).

[5]For classic examples of Primary Quality Realism, see (Galileo, 1623/2008, 185), Descartes (1641/1984a), Hobbes (1655/1839), (Boyle, 1666, 1-16), Newton (1672), and (Locke, 1694/1979, II.iv-viii).

According to classical atomists, like Democritus, macroscopic physical phenomena are combinations of atoms: extremely small objects having various shapes, sizes, and states of motion. Classical atomism is not an analysis of matter. It's an analysis of big chunks of matter into little chunks of matter: a reduction of the macrophysical to the microphysical. If Primary Quality Realism is to be a successful analysis of matter, we must understand the terms of its analysis non-physically; otherwise, it's either a reversion to classical atomism, or an exercise in circularity.

One way for Primary Quality Realism to avoid circularity is by construing physical things as abstract mathematical objects—non-physical, non-mental solids, surfaces, boundaries, etc.—and geometric properties as properties of such objects. Construing kinematic properties like speed and acceleration in abstract terms is more challenging, but maybe we could try to think of them as features of mathematical sequences of abstract objects.

This approach avoids circularity, but at an unacceptable cost. In effect, it turns Primary Quality Realism into a kind of Pythagoreanism, according to which the physical facts of our world reduce to purely abstract mathematical facts. Adams is aware of this, which is why he includes the "little more than" qualification in "little more than a mathematical framework." If Primary Quality Realists were to hold without qualification that the physical world is a mathematical framework, they'd commit themselves to the untenable view that physical things are mere abstractions.[6]

How can the Primary Quality Realist avoid circularity without lapsing into Pythagoreanism? There are two ways: Descartes's, and Locke's.

3.1 Primary Qualities: the Cartesian Approach

The way of Descartes is simply to *identify* physical things with havers of geometric properties:

> There is no real distinction . . . between space and the corporeal substance contained in it; the only difference lies in the way in which we are accustomed to conceive of them. For in reality the extension of length, breadth, and depth which constitutes a space is exactly the same as that which constitutes a body.[7]

[6]Untenable, but not untendered: see Tegmark (2014).

[7](Descartes, 1641/1984b, 227); see also (Descartes, 1644/1953, Part 2, §4).

There are various problems with this proposal, but the most important, historically, was that it ruled out the possibility of empty space. The problem wasn't (just) that empty space seemed like a coherent possibility; for whatever reason, this didn't impress Descartes.[8] Rather, the problem was that Descartes's whole conception of space was scientifically inadequate even by Descartes's own standards, and that its only rival—Newton's conception of space—clearly *was* compatible with the possibility of empty space.[9]

An area of common ground for Descartes and Newton is the need to distinguish between "true" (or "proper") and "relative" motion.[10] An object moves in the relative sense when its distance from other objects changes over time. For example, after the cue ball hits the seven ball, each ball moves relatively to the other. This motion is equally describable as the seven ball moving away from the cue ball, the cue ball moving away from the seven ball, the seven ball and the cue ball moving away from each other, or both balls accelerating in the same direction, but one of them more slowly than the other.

Descartes and Newton share the scientific goal of explaining empirical observations in terms of intelligible natural laws, and they agree that not all descriptions of bodily motions are on a par, for the purposes of achieving this goal. For example, we can describe a geostationary satellite as persistently at rest relative to a stationary Earth, or as moving in a circular orbit around a rotating Earth. But only the latter description is consistent with explaining the satellite's behavior in terms of an inverse square law of attraction.

According to Descartes, true motion is a special type of relative motion: an object's true state of motion is its motion relative to the things with which it is contiguous. A dolphin sleeping in the Gulf Stream moves relative to Cape Hatteras, as the water in the Gulf Stream moves northward en masse, but this is not true motion, according to Descartes, given that the same water

[8]See (Descartes, 1644/1953, Part II, §§16-19).

[9]Cartesians might try to sidestep the problem by pointing out that in their view, space itself is a physical thing. However, this merely relocates the problem. Now the challenge is to distinguish, e.g., a spherical object that consists of nothing but space from a spherical object that is a physical thing in the everyday sense of "physical thing," and to do so in a way that is consistent with metaphysical realism.

[10]See Rynasiewicz (2000), to which I owe this and related historical observations.

surrounds the sleeping dolphin from one moment to the next. In contrast, a dolphin swimming north does have a true northward motion, since different particles of water surround its body from one moment to the next as it propels itself forward.[11]

Descartes's account of true motion as a species of relative motion is deficient in many ways, and one of Newton's first orders of business in the *Principia* is to point out these deficiencies.[12] To take just one example: imagine a dumbbell located somewhere in outer space, but suspended in the middle of a large air-filled cylindrical container. If this whole system (dumbbell and air-filled container) is rotating, there will be tension in the bar connecting the balls at either end of the dumbbell; otherwise not. But whether or not the system rotates, the dumbbell's "true" state of motion, according to Descartes, in the same: either way, the dumbell is truly at rest, since its position relative to contiguous particles of air doesn't change.[13]

So what *is* an object's true state of motion? According to Newton, it is the motion we describe the object as having when we describe it in terms of an adequate coordinate system; in particular, it's the motion we ascribe to an object when we describe physical phenomena using inertial coordinates.[14]

[11](Descartes, 1644/1953, Part 2, §25).

[12]In the Scholium to the definitions that Newton gives at the very start of the *Principia*: see (Newton, 1687/1999, 408-15); also Newton (c. 1670?/2004).

[13]See (Newton, 1687/1999, 412-15). Mach points out that when the dumbbell spins, the locations of the balls relative to the "fixed stars" change over time, whereas this is not so when the dumbbell is at rest; he suggests that this is enough to explain the tension in the bar. However, this is true only if there would be tension in *any* scenario in which the dumbbell moves relative to the stars as it does when spinning. But it's implausible that we could induce tension in the bar simply by moving the distant stars in circles centered on the dumbbell. Mach, who is a die-hard proponent of the sufficiency of relative motion for all scientific purposes, plaintively observes that there is no experimental proof that the imagined stellar rotation would not produce such an effect: (Mach, 1883/1919, 232-34).

[14]Though Newton never says this explicitly, it is implicit in the structure of the *Principia*. At the beginning of the *Principia,* Newton says that his goal in writing it is "to determine true motions from their causes, effects, and apparent differences." (Newton, 1687/1999, 415) He claims to reach this goal in Book Three, when he concludes that the Solar System's center of gravity is at absolute rest, which it is when motion and rest are defined inertially. (Newton, 1687/1999, 816) The implication is that an object's true state of motion is the one we ascribe to it when we describe things in terms of inertial coordinates. (Newton doesn't make explicit use of coordinate systems, but they are implicit in, and readily recoverable

An "adequate" (or "admissible") coordinate system is one that has the following property: when we describe physical events in terms of that system, we describe them as occurring in accordance with a small number of simple rules (i.e., laws of physics). Not every coordinate system has this property. There are infinitely many ways to assign 4-vectors (quadruples of real numbers $\langle x, y, z, t \rangle$) to events, and it is neither necessary nor *a priori* that any assignment—any "coordinatization of the manifold of events"—is adequate in the relevant sense.

One of Newton's most important discoveries was that there *is* an adequate coordinatization of the manifold of actual physical events (or, more accurately, a class of adequate coordinatizations). He discovered that if we assign 4-vectors to events using a certain method, and interpret those vectors as spacetime coordinates, we unexpectedly describe events as obeying laws like Kepler's Laws and the Universal Law of Gravitation. The method is to assign coordinates to events in such a way that when you describe the events in terms of those coordinates, you describe them as constituting a world in which inertia is homogenous and isotropic—that is, in which it takes the same amount of force to accelerate a body with a given mass by a given amount, regardless of where, when, or in which direction the force gets applied. Surprisingly, it turns out that if we describe physical events in terms of a coordinate system that satisfies this condition, we also describe them as unfolding in conformity with the Universal Law of Gravitation and other laws.

Newton thinks that this surprising fact can't just be an accident. Rather, he takes it as compelling evidence that the motions we attribute to things when we describe them in terms of inertial coordinates are their true motions. That's not to say that Newton *defines* "true motion" as "motion in terms of an inertial coordinate system." He defines true motion as motion within absolute space over absolute time:

> Absolute, true, and mathematical time, in and of itself and of its own nature, without reference to anything external, flows uniformly and by another name is called duration . . .

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from, his geometric presentation.)

> Absolute space, of its own nature without reference to anything external, always remains homogeneous and immovable . . .
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> Absolute motion is the change [over absolute, true, and mathematical time] of position of a body from one absolute place to another . . .[15]

On the most natural interpretation of these remarks, Newton's view is that absolute time and space have a nature that is not exhausted by the fact that changes in them are accurately described by descriptions of phenomena using inertial coordinate systems. Rather, absolute time and space have further natures that *explain why* inertial coordinate systems work so well: a "uniform flow" in the case of absolute time, and, in the case of absolute space, "homogeneousness" and "immovability."

Later, we'll see that this way of thinking about absolute time and space does not sit well with metaphysical realism. For now, the important thing to notice is that Newton's conception of absolute space entails the possibility of empty space.

We've seen that both Descartes and Newton are committed to there being such a thing as an object's true state of motion, and that Descartes's account of true motion fails, while Newton's succeeds. But—and this is the key point—Newton's account comes with a conception of space according to which it's clearly possible for there to be unoccupied regions of space. For there to be such regions, it suffices that not every part of absolute space contains a physical object at every moment; and we have compelling evidence that this is indeed the case, since an inertial coordinatization of events delivers a lawlike description of the world even if in that coordinatization, there are many $\langle x, y, z\rangle$ coordinates that do not get assigned to any physical object or event at all times, or even at any time. For example, to formulate natural laws that account for the motions of the planets around the Sun, we don't have to assign any physical object or event to the center of gravity of the Solar System, which is persistently located at $\langle 0, 0, 0\rangle$ in Newton's inertial coordinate system. This point—"the center of the system of the world," as Newton calls it—is about 700,000 km outside the surface of the Sun.[16]

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[15] (Newton, 1687/1999, 408).

[16] (Newton, 1687/1999, 817).

3.2 Primary Qualities: the Lockean Approach

If Primary Quality Realists can't avoid Pythagoreanism by simply identifying physical things with havers of geometric properties, how can they avoid it?

By adopting John Locke's strategy. According to Locke, the primary qualities include, in addition to geometric and kinematic (motion-related) properties, the property of *solidity* (or impenetrability):

> For division (which is all that a mill or pestle or any other body does upon another, in reducing it to insensible parts) can never take away either solidity, extension, figure, or mobility from any body, but only makes two or more distinct separate masses of matter of what which was but one before; all which distinct masses, reckoned as so many distinct bodies, after division, make a certain number. These I call *original* or *primary* qualities of body, which I think we may observe to produce simple ideas in us, viz., solidity, extension, figure, motion or rest, and number.[17]

In Locke's view, the difference between physical and non-physical instantiators of abstract geometric properties is that the former, unlike the latter, are solid.

At first glance, it might seem circular to analyze physical things in terms of solidity. "Solid" certainly has a very physical ring to it, as in "frozen solid" and "solid gold." If solidity is a physical property, defining physicality in terms of solidity is as hopeless as defining it in terms of weight or viscosity.

However, by calling some things "solid" (or "impenetrable"), Locke means that they obey a certain exclusion principle, which he expresses by saying that a solid body "keeps other bodies out of the space which it possesses."[18] Actually, it's unclear that Locke intends this remark as a definition of solidity, since a few pages later he suggests that the idea of solidity is simple and indefinable.[19] However, I think we can define what Locke has in mind when he speaks of solidity, and do so in a way that's amenable to Primary Quality Realism. We can say that the *solid* objects are those that belong to the class $\boldsymbol{G}$ of geometric objects that satisfies the following condition: it's impossible for two members of $\boldsymbol{G}$ to have proper geometric parts that simultaneously occupy the same region of space.

[17](Locke, 1694/1979, II.viii.9).

[18](Locke, 1694/1979, II.iv).

[19](Locke, 1694/1979, II.iv.6).

Suppose there are two things, $\boldsymbol{A}$ and $\boldsymbol{B}$, that have the abstract geometric property of cubicality (being cube-shaped), and the same abstract geometric size. If $\boldsymbol{A}$ and $\boldsymbol{B}$ are regions of space or abstract objects, then it could be that $\boldsymbol{A}$ and $\boldsymbol{B}$ have parts simultaneously existing at the same spatial location; for example, it could be that $\boldsymbol{A}$ and $\boldsymbol{B}$ spatially overlap (see Fig. 1).

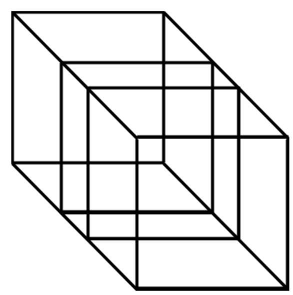

Figure 1: Interpenetrating non-solid objects

However, suppose that it is *not* possible for a $\boldsymbol{A}$ and $\boldsymbol{B}$ to overlap this way. To suppose this is to suppose that $\boldsymbol{A}$ and $\boldsymbol{B}$ are solid, in the intended sense of "solid."

Understood this way, solidity is defined in purely topic-neutral terms. This means that Primary Quality Realists can analyse physical things in terms of solidity without rendering their analysis circular. And since abstract objects are *not* solid in the relevant sense, identifying physical things with solid possessors of abstract geometric qualities does not entail a Pythagorean view of the physical world.

It remains for Primary Quality Realists to provide an account of motion.

Define a *Lockean event* as an instantiation of a geometric property by a solid object. Now consider a totality $\boldsymbol{T}$ that includes (1) a given Lockean event $\boldsymbol{e}$, (2) every Lockean event simultaneous with $\boldsymbol{e}$, and (3) nothing else. Suppose that every event in $\boldsymbol{T}$ stands in some spatial distance relation to every other event in $\boldsymbol{T}$. Call such a totality a *totality of co-existent Lockean events.*

Consider a causal sequence of totalities of co-existent Lockean events that includes all actual totalities of co-existent Lockean events. Call such a sequence a *manifold of Lockean events,* and the totalities that make up this manifold "stages" of the manifold. A Lockean event ***B*** occurs later in time than a Lockean event ***A*** just in case ***A*** occurs in a manifold-stage that is causally prior to the manifold-stage in which ***B*** occurs. For a physical thing to persist is for it to be a solid object that exists in more than one stage of the manifold of Lockean events. For a physical thing to move is for it to be a solid object that does not have the same spatial location in every manifold-stage to which it belongs (i.e., in a Newtonian framework: does not have the same inertial coordinates in every manifold-stage to which it belongs).

Let's call versions of Primary Quality Realism that leverage on a Lockean conception of solidity *Lockean Primary Quality Realism.*[20] According to Lockean Primary Quality Realism, the physical world is a manifold of Lockean events:

> *Lockean Primary Quality Realism:*
>
> The physical world is a Lockean manifold that constitutes the whole of contingent non-mental reality.

How does experience come into the picture, for Primary Quality Realists? The same way it does with all forms of metaphysical realism: as an epistemically indispensable but metaphysically irrelevant add-on. Our bodies are complexes of moving solids embedded in physical environments that are also complexes of moving solids. Certain juxtaposions of human-body complexes with physical-environment complexes give rise to experiences, including the experiences whose regularity is our basis for believing that all these solids exist. But the solids could exist with their geometric properties, standing in their causal relations, even if their juxtapositions never gave rise to any experiences, or gave rise only to experiences radically unlike the experiences we have. The solids constitute what explains the regularity of experience; what explains the regularity of experience is the physical world; therefore, the solids constitute the physical world. But the physical world they constitute exists independent of its propensity to cause experience, regular or otherwise.

[20]In contrast to what we might call the *Cartesian Primary Quality Realism* of Descartes. (From this point on, when I speak of Primary Quality Realism, it's Lockean Primary Quality Realism that I'll have in mind.)

4 Algebraic Realism

In this section, I describe a direct descendant of Primary Quality Realism, which I call Algebraic Realism. Broadly speaking, Algebraic Realism is a more abstract version of Primary Quality Realism. But before diving into the details of Algebraic Realism, I'd like to consider why people moved away from Primary Quality Realism. One reason relates to Primary Quality Realism's reliance on an intuitive conception of geometric properties; another relates to the Primary Quality Realists' concept of solidity.

4.1 Problems with geometric qualities

In order for Primary Quality Realism to be a form of metaphysical realism, it must analyze physical phenomena in terms of properties and relations whose instantiation is metaphysically independent of facts related to experience. Primary Quality Realism is predicated on the assumption that geometric properties and relations are of this sort. But it is not clear that this is true.

The problem is that our ordinary thinking about geometric properties and the things that have them is intimately tied up with the concept of something that we can perceive or imagine by having suitable forms of experience. If you want to explain to a child what sphericality is, a natural way to proceed is by showing him a collection of spherical objects with various sizes and colors, and telling him that sphericality is the perceptually salient feature that the objects have in common.

This might suggest that it's essential to, e.g., sphericality that it stands in appropriate relations to certain types of experience; in that case, one might try to define sphericality as the property in virtue of which things having it are apt to cause experiences with the salient phenomenal property common to experiences like those the child has in the case described above. Like all metaphysical realists, Primary Quality Realists must reject this suggestion. They will say that if we can't think of geometric properties except as properties signified by certain types of experience, this is just a contingent fact about geometric properties. They might concede that we can't think of a spherical object except as something that stands in appropriate relations to certain types of experience, but insist that this merely reflects a cognitive limitation on our part, rather than something about the essential nature of sphericality.

This is not a satisfactory response. It's like conceding that we can't think of a flower except as something that stands in an appropriate relation to certain types of plants, but insisting that this merely reflects a cognitive limitation on our part, rather than something about the essential nature of flowers.[21]

A better response is not to make the concession: to deny that the only way we can think of a spherical object is as something that's appropriately related to appropriate types of experience. And the best way to do this is by providing an alternative way to think of spherical objects, sphericality, and geometric properties in general.

It was Fermat and especially Descartes who provided such a way in the late 1630s: the way of algebraic geometry. This innovation, which made it possible to think about geometric properties in non-visual and, more generally, non-sensory ways, would have a profound influence on metaphysical realist thinking.[22]

Prior to Descartes, people had, of course, used numbers to describe geometric objects and properties. It's even possible that people had begun to think of curves in broadly functional terms as early as Euclid.[23] But prior to Descartes, geometrical thinking was inseparable from visual (and, to a lesser extent, tactual) intuition.

The difference between Euclid and Descartes is the difference between geometric algebra and algebraic geometry. Geometric algebra describes ratios and equalities between various combinations of geometric objects, where these objects are defined using terms like "point," "length," "breadth," "edge," and "meeting." The classic example is Book II of Euclid's *Elements*. Many of Euclid's propositions there are readily translatable into modern algebraic notation. For example, instead of Euclid's Proposition 7:

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[21]Berkeley presses essentially this objection to Primary Quality Realism in (Berkeley, 1710/1901, §§9-17) and (Berkeley, 1713/1979, 23-26); see also (Greene, 1712, I.vi.11-14, I.vii.1-11) and (Greene, 1727, p. 40, §16).

[22]See (Fermat, 1679, 63-73) and Descartes (1637/1925), as well as Viète (1591-1631/1983), which laid the foundations for modern algebra.

[23](Scriba and Schreiber, 2015, 336).

If a straight line is cut at random, then the sum of the square on the whole and that on one of the segments equals twice the rectangle formed by the whole line and the said segment plus the square on the remaining segment.

we can write:

$$x^2 + y^2 = 2xy + (x - y)^2$$

However, Euclid didn't write that. His version of the proposition uses terminology that, absent a modern algebraic interpretation, conveys meaning only by evoking appropriate mental imagery. The reliance on mental imagery also extends to Euclid's proof of this proposition, which, like all of Euclid's proofs, leans heavily on an accompanying diagram.

The ancient Greeks were amazingly good at geometry. But they lacked a language to describe arbitrary geometric states of affairs in purely numerical and functional terms. For them, the language of geometry was primarily a language of pictures. This imposed real limitations on Greek mathematical thinking. For example, an equation like:

$$ax^2 + by + z = 42$$

does not correspond to any state of affairs describable by ancient Greek mathematicians, since by their lights it purports to state the sum of a volume, an area, and a length.[24]

The advent of algebraic geometry gave people a way to think about geometrical properties other than as properties representable by suitable forms of perceptual or imaginative experience. For example, they could now think of a globe as the set of all 3-vectors $\langle x, y, z\rangle$ such that for some positive number r and some 3-vector $\langle a, b, c\rangle$, $(x - a)^2 + (y - b)^2 + (z - c)^2 \leq r^2$, and they could think of globularity as the property that something has if and only if it's a globe, thus defined. In this way, algebraic geometry allows metaphysical realists to deny that the only way we can think of geometric properties is as properties related to appropriate forms of experience.

[24]For this reason, in Greek mathematics all the terms of a sum must have the same dimension. This is the so-called "homogeneity" requirement of Greek mathematics: see (Scriba and Schreiber, 2015, 335). Curiously, Fermat, unlike Descartes, did not discard the homogeneity requirement: see (Coolidge, 1940, 123-26).

Of course, metaphysical realists can't identify any physical object with the set of all 3-vectors $\langle x, y, z\rangle$ such that for some positive number r and some 3-vector $\langle a, b, c\rangle$, $(x-a)^2 + (y-b)^2 + (z-c)^2 \leq r^2$. To do so would be to commit the Pythagorean error of identifying a physical object with a mere abstraction. To avoid the Pythagorean error, Algebraic Realists might try to take a page from the Primary Quality Realists' playbook, and identify physical objects with *solid* or impenetrable entities that satisfy relevant algebraic criteria. However, it's unclear how a set of triples of real numbers could be solid or impenetrable, in the Primary Quality Realists' sense (sets can, after all, intersect). To distinguish physical things from algebraic abstractions, Algebraic Realists must evidently take a different approach.

This is just as well, since the Primary Quality Realists' appeal to solidity faces problems even independent of its failure to combine well with an algebraic conception of geometric properties. Let's consider those problems now.

4.2 Problems with solidity

The first problem with analyzing physicality in terms of solidity is that it doesn't seem necessary for physical things to be solid, in the relevant Lockean sense. John Pollock describes a scenario where there are translucent colored balls that float around in the air. The balls all have the same size and the same mass (though buoyant in air, we can weigh them in a vacuum). They lack any discernible internal structure, but they have different coefficients of elasticity: when you hit a blue ball with a certain force, it zooms away faster than when you hit a yellow ball with the same force. However, the balls do not interact with one another in the way that they interact with other things. In particular, one ball's occupying a given region of space does not prevent any other ball from simultaneously occupying the same region. Thus it's possible to move a blue ball and a yellow ball together so that they coincide, presenting the appearance of a translucent green ball. If you swat the apparent green ball, a blue ball flies away in the same direction as a yellow ball, but at a higher velocity.[25]

[25](Pollock, 1974, 140-41)

The scenario Pollock describes certainly seems like a metaphysically possible one. It also seems like a scenario where there are physical things that are not solid, in Locke's sense.

In fact, according to current scientific orthodoxy, it isn't just non-necessary, but actually false that all physical things are solid, in Locke's sense. The Pauli Exclusion Principle says that no two fermions can simultaneously occupy the same spatial location. But the Pauli Exclusion Principle does not apply to bosons. Different photons, for example, can simultaneously exist at the same point in space. This is what makes lasers possible.

18th century metaphysical realists weren't aware of lasers, so that wasn't what pushed them off of Primary Quality Realism and towards Algebraic Realism. (Historic realists had less excuse for overlooking the *possibility* of things like photons: it takes only imagination, not high-tech lab equipment, to envision a case like Pollock's.) Historically, the biggest factor behind the move away from solidity-based analyses of the physical was probably the rise of atomism in physics and metaphysics.

Atomist realism has its roots in Democritus, but its first clear modern manifestation is in the work of Roger Boscovich. In Boscovich's view, the fundamental constituents of physical reality are pointlike entities. Boscovich thinks of these as pointlike centers of force; alternatively, one might think of them as pointlike force-generators. Either way, the modern atomist sees the physical world as comprising spatially located but spatially dimensionless entities whose motions are dictated by the forces they center or exert, together with their spatial distances from one another.[26]

Boscovich calls such entities "material points." Material points obey Locke's exclusion principle by default: since they have no spatial parts, it's impossible for them to partially overlap. *But the same is true of empty points of space,* as well as abstract geometrical points. It makes no more sense to speak of the interpenetration or partial coincidence of two points in a Cartesian coordinate system, or two pointlike objects in Platonic heaven, or two points of empty space, than to speak of the interpenetration or partial coincidence of two Boscovichian material points.

[26]See (Boscovich, 1763/1966, 19-23). More on Boscovich below.

The upshot is that as atomistic realism became the dominant form of realism, the Primary Quality Realists' "solidity" lost its capacity to distinguish the elements of the realist ontology from purely abstract entities, or from "objects" consisting of nothing but points of empty space.

4.3 An algebraic analysis of matter

We've seen that Primary Quality Realists face problems related to solidity and geometric properties, and I've suggested that the path forward for metaphysical realists goes by way of an abstract algebraic understanding of geometric properties, and a way of distinguishing physical from non-physical possessors of geometric properties that dispenses with solidity. Let's put on the table a version of metaphysical realism that implements these suggestions.

To begin with, define a *Boscovichian atom* as a partless non-mental contingent existent.[27]

Next, define a *Boscovichian event* as an instantiation by a Boscovichian atom of an elementary non-mental property.[28] (As for what exactly these elementary non-mental properties might be, we'll return to that in the next section, but to foreshadow: they are powers to cause changes in the spatial locations of Boscovichian atoms.)

Let K be a graded or degreed relation that holds between pairs of Boscovichian events and real numbers. To convey that two atomic events a and b stand in K to degree n, we write "$K(ab, n)$."[29]

We stipulate that K satisfies the following conditions:

[27] "[I]n these points of mine, I admit nothing else but the law of forces conjoined with the force of inertia; & hence I intend them to be incapable of thought or will . . . / [T]hese points of mine are material points, and masses of them compose bodies that are far different from spirits." (Boscovich, 1763/1966, 63-64).

[28] Boscovich speaks of "elements" in this connection: "[I]n the threefold class of space, & in the onefold class of time, the point & the instant will be respectively the element, from which, by its progression, motion, space & time will be understood to be generated." (Boscovich, 1763/1966, 199)

[29] A graded or degreed relation is one that things can stand in to varying degrees, like "pricier than": a Learjet is pricier than a Bentley to a greater degree than a Bentley is pricier than a Subaru.

K1 For every two Boscovichian events a and b, there is a non-negative n such that $K(ab, n)$.

K2 $K(ab, n) \leftrightarrow K(ba, n)$.

K3 $\big(K(ab, n) \wedge n > 0\big) \rightarrow a \neq b$.

K4 $\big(K(ab, n) \wedge K(bc, m) \wedge K(ac, j) \wedge j > n \wedge j > m\big) \rightarrow j = n + m$.

K5 $\big(K(ab, n) \wedge n > 0\big) \rightarrow b$ does not cause a or a does not cause b.

K6 The only contingent phenomena that an instantiation of K by Boscovichian events metaphysically depends on are non-mental phenomena.

Call any relation that satisfies these conditions a *chronal relation*.[30]

There may be any number of chronal relations, but consider just those that satisfy the following further conditions:

K7 If $K(ab, 0)$, then a and b have the same location in absolute Newtonian time.

K8 If $\big(K(ab, n) \wedge K(cd, m) \wedge n > m\big)$, then a and b occur farther apart in absolute Newtonian time than c and d.

Call a chronal relation that satisfies these further conditions a *proper chronal relation*. Proper chronal relations among Boscovichian events reflect the distances between the events in absolute Newtonian time.[31]

Let D be a graded relation that holds between pairs of Boscovichian events and real numbers. To convey that two Boscovichian events a and b stand in D

[30] Here are some intuitive glosses of the clauses of the foregoing definition (these aren't part of the definition: I provide them only as "surrounding talk" to help understanding along). K1: all events are temporally related, and the temporal distance between two events can't be less than zero. K2: the temporal distance between two events is the same, regardless of the order in which the events occur. K3: no time elapses between any event and itself. K4: if three events occur in temporal succession, the time elapsed between the first and the last is equal to the sum of the time elapsed between the first and the second and the time elapsed between the second and the third. K5: if two events occur at different times, at most one of them causes the other. K6: temporal relations among non-mental events are metaphysically independent of any mental fact.

[31] Why didn't I just say that in the first place? The answer will become clear in the next section.

to degree n, we write "$D(ab, n)$." We stipulate that D satisfies the following conditions:

D1 $D(ab, n) \rightarrow n$ is non-negative.

D2 If a and b are Boscovichian events, then there is an n such that $D(ab, n)$.

D3 $D(ab, n) \leftrightarrow D(ba, n)$.

D4 $\big(D(ab, n) \wedge D(bc, m)\big) \rightarrow (\exists j)\big(D(ac, j) \wedge j \leq n + m\big)$.

D5 The only contingent phenomena that an instantiation of D by Boscovichian events metaphysically depends on are non-mental phenomena.

Call any relation that satisfies these conditions a *distal relation*.[32]

There may be any number of distal relations, but consider just those that satisfy the following further conditions:

D6 If $D(ab, 0)$, then a and b have the same location in absolute Newtonian space.

D7 If $(D(ab, n) \wedge D(cd, m) \wedge n > m\big)$, then a and b occur farther apart in absolute Newtonian space than c and d.

We now assign $\langle x, y, z, t\rangle$ coordinates to Boscovichian events as follows:

Coordination Protocol

Step 1: choose a proper distal relation D, and a proper chronal relation K.

Step 2: choose at random two Boscovichian events, α and β, such that $D(\alpha\beta, m)$ and $m > 0$; assign each of them different $\langle x, y, z\rangle$ coordinates (which coordinates doesn't matter), and stipulate that $D(\alpha\beta, 1)$. Let $\langle x_\alpha, y_\alpha, z_\alpha\rangle$ be the 3-coordinate we assign to α, and $\langle x_\beta, y_\beta, z_\beta\rangle$ the 3-coordinate we assign to β.

[32] Here are some intuitive glosses of the clauses of the foregoing definition (again, these aren't part of the definition: they're just surrounding talk). D1: the distance between two events can't be less than zero. D2: there's a distance (if only zero) between every two events. D3: the distance between two events is the same whether you measure it from the first event to the second or vice versa. D4: the length of the shortest path from a to c via b cannot exceed the combined lengths of the shortest paths from a to b and b to c. D5: the distances between non-mental events are metaphysically independent of any mental fact.

Step 3: for any two Boscovichian events e_1, e_2, if $D(e_1e_2, n)$, then assign e_1 and e_2 3-coordinates in such a way that, (1) $\sqrt{(x_{e_1} - x_{e_2})^2 + (y_{e_1} - y_{e_2})^2 + (z_{e_1} - z_{e_2})^2}$ $= n\sqrt{(x_\alpha - x_\beta)^2 + (y_\alpha - y_\beta)^2 + (z_\alpha - z_\beta)^2}$, and, (2) once you have assigned a 3-coordinate V to an event e, make all further 3-coordinate assignments in a way that is consistent with assigning V to e.

Step 4: choose at random two Boscovichian events, γ and δ, such that $K(\gamma\delta, m)$ and $m > 0$; assign each of them different t coordinates (which coordinates doesn't matter), and stipulate that $K(\gamma\delta, 1)$. Let t_γ be the t-coordinate we assign to γ, and t_δ the t-coordinate we assign to δ.

Step 5: for any two Boscovichian events e_1, e_2, if $K(e_1e_2, n)$, then assign e_1 and e_2 t-coordinates t_{e_1} and t_{e_2} in such a way that, (1) $|t_{e_1} - t_{e_2}| = n$, and, (2) once you have assigned a t-coordinate S to an event e, make all further t-coordinate assignments in a way that is consistent with assigning S to e.

Step 1 instructs us to choose a proper distal and a proper chronal relation to use in carrying out subsequent steps of the protocol; there is no restriction on which proper relations we choose. Step 2 of the protocol establishes the spatial distance between two randomly chosen events as a standard unit of distance; given this arbitrary choice of unit, we can express all spatial distances between pairs of events as multiples of it. Step 3 tells us to do just that. (The formulae occurring in this step are instances of the Cartesian distance formula for points in an abstract three-dimensional Euclidean space; this formula is just an application of the Pythagorean Theorem.) Step 4 establishes the temporal distance between two randomly chosen events as a standard unit of time; given this arbitrary choice of unit, we can express all temporal distances between pairs of events as multiples of it. Step 5 tells us to do just that.

Assigning coordinates to events using the stated protocol fixes not only the distances between pairs of events (for a given choice of unit), but also the angles by which events relate to one another. Given any three non-colinear events a, b, and c,[33] the Coordination Protocol allows us to express the distances ab, bc, and ca as multiples of the unit distance between α and β, thereby

[33] That is, any three events a, b, and c such that $\Delta ab + \Delta bc \neq \Delta ac$ and $\Delta ac + \Delta cb \neq \Delta ab$ and $\Delta ba + \Delta ac \neq \Delta bc$, where $\Delta\eta\mu = \sqrt{(x_\eta - x_\mu)^2 + (y_\eta - y_\mu)^2 + (z_\eta - z_\mu)^2}$.

determining the angles of the triangle $\boldsymbol{abc}$.[34]

For any distal relation $\boldsymbol{D}$, there are only a limited number of ways that two coordinatizations of the manifold of atomic events by means of the Coordination Protocol can differ, given that both coordinatizations utilize $\boldsymbol{D}$. They can differ (1) by a scaling factor, or (2) by one of them being a rigid translation, rotation, or reflection of the other. Algebraic Realists hold that these differences are ontologically insignificant. In their view, they're just notational differences: differences in how a given manifold gets described, rather than differences in described manifolds. According to Algebraic Realists, a difference with respect to (1) is analogous to the difference between describing an object's dimensions in kilometers versus nanometers; a difference with respect to (2) is analogous to the difference between a compass whose needle always points towards one pole and a compass whose needle always points towards the other pole.[35]

Define a *Boscovichian manifold* as a totality of Boscovichian events such that there is a proper distal relation $\boldsymbol{D}$ and a proper chronal relation $\boldsymbol{K}$ such that every two events in the totality bear $\boldsymbol{D}$ to some number, and every two events in the totality bear $\boldsymbol{K}$ to some number. We now state Algebraic Realism officially, as follows:

> *Algebraic Realism:*
>
> The physical world is a Boscovichian manifold that constitutes the whole of contingent non-mental reality.

According to Algebraic Realists, how does one physical world differ from another? One way is by comprising different numbers of Boscovichian events;

[34]In a scenario where there are only two events, only the first, second, and fourth steps of the protocol apply. In a scenario with only one event, we just assign it a 4-coordinate $\langle x, y, z, t\rangle$ at random; we could add this proviso to the protocol, but the case is of little interest, since by all realist accounts our world contains more than one event.

[35]Treating differences of scale as ontologically insignificant is fairly uncontroversial; likewise for translational and rotational differences. However, it *is* controversial to treat differences of reflection as ontologically insignificant, since doing so implies that there's no difference between a universe consisting only of a left glove and a universe consisting only of a matching right glove: if such worlds are possible, each is a three-dimensional reflection of the other. One of Kant's arguments against metaphysical realism is that such worlds *are* possible: see (Kant, 1783/1997, §§11-13).

intuitively, this corresponds to differences in how much physical stuff there is. The other is by comprising Boscovichian events standing in different patterns of proper distal or chronal relationships; intuitively, this corresponds to differences in how physical stuff is distributed across time and space.

How does experience relate to the physical world, according to Algebraic Realism? The same as in Primary Quality Realism: as an epistemically indispensable but metaphysically irrelevant add-on. Our bodies are complexes of Boscovichian events embedded in physical environments that are also complexes of Boscovichian events. Certain juxtaposions of bodily complexes with environmental complexes give rise to experiences, including the experiences whose regularity is our basis for believing that these complexes of atomic events exist. But the complexes could exist with all their elementary non-mental properties, and all their metrical relations, even if their juxtapositions never gave rise to experience, or gave rise only to experiences radically unlike the experiences we have. The metrically related Boscovichian events constitute what explains the regularity of experience; what explains the regularity of experience is the physical world; therefore, the metrically related Boscovichian events constitute the physical world. But the physical world they constitute exists independent of its propensity to cause experience, regular or otherwise.

4.4 Historical Algebraic Realism

I've presented Algebraic Realism as a natural development of realist thinking in response to problems with Primary Quality Realism, but so far I haven't presented any evidence that Algebraic Realism was a position that any historical figure held. To my knowledge, there is no historical figure who held it in exactly the form I've presented. However, as I have heavily signalled, there is one influential figure who took something much like the view I've described: Roger Boscovich.

Though seldom encountered on the philosophy syllabus, Boscovich was an influential figure from the publication of his magnum opus, *A Theory of Natural Philosophy,* in 1763, until the early years of the 20th century. A blend of physics and metaphysics, the stated purpose of *A Theory of Natural Philosophy* is to present "a system that is midway between that of Leibniz & that of

Newton." In it, Boscovich makes a clean break with the Primary Quality Realism of his predecessors. The fundamental constituents of the physical world are no longer solid particles with geometric properties like size and shape. Rather, they are dimensionless "material points" characterized by a single, complex force of attraction and repulsion.[36]

These material points are what I've been calling Boscovichian atoms. They all possess the property of exerting a complex force—the same force in the case of each atom—on other material points. With one caveat, the entire nature of a material point is its possession of a force described by "a single algebraical formula" whose graph is shown in Fig. 2.[37]

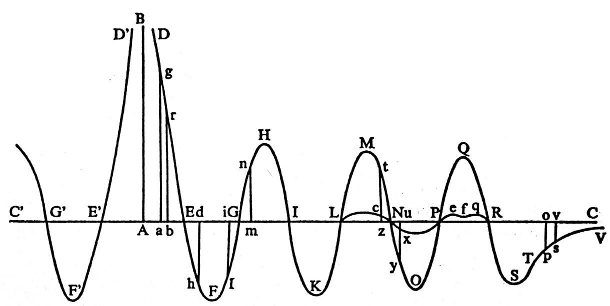

Figure 2: Boscovich's force curve

In the graph, the vertical AB represents a location in space, and the curve extending to the right of AB represents the forces between atoms at various

[36]Boscovich wasn't the first realist to move away from Primary Quality Realism. As noted earlier, Newton's contemporary and critic Robert Greene raised early epistemological objections to Primary Quality Realists' reliance on geometric and sensory intuition, and Gowin Knight rejected extended atoms with different sizes in favor of infinitesimal spherical atoms: precursors to Boscovich's dimensionless centers of force (Knight, 1748, Prop. XXIV & Corol. to Prop. XXIV). While Boscovich's work had little to offer in terms of practical scientific guidance or testable empirical hypotheses, the extreme structural and ontological simplicity of its account of the physical world was long regarded as a theoretical ideal; see, e.g., Nietzsche (1873/2000) (an early unpublished fragment in which Nietzsche develops his own version of Boscovich's theory); Maxwell (1875), Maxwell (1877/2002b), and Maxwell (1877/2002a); (William Thomson, 1904, vi-vii, 125-31,285, 300-301, 495-98, 543, 556, 643-61, 667-68, 674-77); and (Thomson, 1907, 160-64). (For more on Boscovich's influence, see (Thackray, 1970, 151-55).) The non-advent of a prominent Boscovichian school of metaphysics is arguably attributable to the dominance of metaphysical antirealism following the publication (in 1781) of Kant's hugely influential *Critique of Pure Reason.*

[37]See (Boscovich, 1763/1966, 19, 22).

distances from one another. (The curve to the left of AB is simply a reflection of the one to the right.) Points on the rightward curve farther away from AB represent the force-interactions between an atom at AB and atoms located farther away from that atom. Portions of the curve occurring above the horizontal line CC′ represent repulsive force; portions below the horizontal represent attractive force. As the distance between two atoms approaches zero, the strength of the repulsive force between them approaches infinity. As the distance between atoms increases, the repulsive force lessens, then changes to an attractive force, then back to a repulsive force, and so on, until eventually settling into an attractive force whose strength decreases as the square of the distance between the atoms increases; this rightmost portion of the graph corresponds to the inverse square law of gravitational attraction. The various ups and downs the curve displays between AB and the point where gravity kicks in are schematic and largely conjectural: they're place-holders for attractive and repulsive effects that Boscovich hypothesizes to account for a range of observed phenomena, such as fermentation and chemical bonding. The exponential increase in repulsive force represented by the curve's asymptotic approach to AB is something Boscovich considers necessary to accommodate the impossibility (as he argues it to be) for any two spatially dimensionless objects to come into direct contact.

I said that Boscovich's force curve represents the whole essential nature of his material points, with one caveat. The caveat is that material points possess two additional features, which Boscovich calls "local modes of existence" and "temporal modes of existence." While Boscovich's characterization of these "modes" is somewhat opaque, it's clear that they're meant to be relationships between atoms and parts of absolute Newtonian time and space:

> That it is necessary that these modes be admitted, I prove rigorously [elsewhere[38]]. I consider also that they are by their very nature incapable of being displaced; so that, of themselves, such modes of existence lead to the relations of before & after as regards time, far & near as regards space, & also of a given distance & a given position in space. These modes, or one of them, must of necessity be changed, if the distance, or even if only the position in space is

[38]In (Boscovich, 1763/1966, 197). The "proof" is essentially a rehearsal of Newton's arguments against a purely relational conception of time and space, like Descartes's.

> altered. Moreover, for any one mode belonging to any [material] point, taken in conjunction with all the infinite number of possible modes pertaining to any other [material] point, there is in my opinion one which, taken in conjunction with the first mode, leads as far as time is concerned to a relation of coexistence; so that both cannot have existence unless they have it simultaneously, i.e., they coexist. But, as far as space is concerned, if they exist simultaneously, the conjunction leads to a relation of compenetration [(i.e., spatial coincidence)]. All the others lead to a relation of temporal or of local distance, as also of a given local position.[39]

These remarks are somewhat confusing, since Boscovich describes the local and temporal modes of existence in spatial and temporal terms, despite putting them forward as the foundation of spatial and temporal positions and relations. Charitably interpreted, when Boscovich says that a material point "changes modes," he means that it possesses different local modes of existence in scenarios where it possesses different temporal modes of existence, and for a material point to be at rest is for it to possess the same local mode of existence in scenarios where it possesses different temporal modes of existence (or, more precisely, for there to be a continuous sequence of scenarios such that the material point has the same local mode of existence in every scenario in that sequence).

Overall, the picture we get from Boscovich is very much in line with the Algebraic Realism described earlier. Material points are just non-mental mereological simples that exert force on one another (more on this shortly). They instantiate various modes of local and temporal existence, defined by reference to absolute Newtonian time and space, and it's in virtue of instantiating these modes that there are events that stand to one another in proper metrical relations. The physical world is a Boscovichian manifold that includes all these events; other possible physical worlds differ from ours by containing a different number of events, or by containing events that stand in a different pattern of proper metrical relationships.

[39](Boscovich, 1763/1966, 60); see also (Boscovich, 1763/1966, 197-202).

5 Ontic Structural Realism

A main threat to Primary Quality Realism was that it provided no way to think of geometric properties except as the sort of properties signified by various types of experience. This was a threat, because if that really were the only way to think of geometric properties, it would cast doubt on the claim that things having geometric properties is something that can happen independently of any fact about experience, making geometric properties unsuitable as terms of a realist analysis of matter.

Algebraic realists overcome this threat by reducing geometric properties to algebraic properties. This removes the threat, since grasping the relevant algebraic properties does not require thinking of them in geometric terms. But now a new threat emerges.

As a start to seeing where the threat lies, let's take a closer look at the elementary non-mental properties that are supposed to characterize the Algebraic Realists atoms. In Newton's system, one such property is mass. Newton officially defines mass as quantity of matter, where this quantity is a function of volume and density. Thus defined, mass isn't a suitable term for an analysis of the physical, unless we can define density in non-physical terms.[40] If we help ourselves to a distal relation, we can define density as the ratio of the number of atoms that exist within a given region of space to the volume of that region; however, thus defined, density isn't a property that an atom or atomic event can possess. The properties of the atoms themselves remain shrouded in mystery: all we're told is that they're non-mental properties, and that atoms move the ways they do partly in virtue of having them.

More promising is Newton's implicit definition of mass as resistance to change in motion (so-called "inertial mass"). A least, this is more promising if we take for granted a proper distal relation, and understand resistance in terms of how an atom's location in absolute Newtonian space changes over absolute Newtonian time.

This way of understanding mass (and elementary non-mental properties more generally) comes to the fore in Boscovich's theory. According to Boscovich,

[40] As Roger Cotes pointed out to Newton, it's also a definition that has no empirical basis: see (Newton and Cotes, 1712/1850, 65-69).

the elementary properties of atoms are, in addition to local and temporal modes of existence, powers to cause atoms to acquire, lose, or retain local modes of existence. This conception of atoms as loci of powers to affect the spatial locations of other loci of powers is an early glimmer of structural realist thinking. It would be an unqualified example of structural realist thinking, if it were a conception of atoms as powers to bring about further powers. Boscovich doesn't go that far: his material points retain a residue of supra-structural character by having local and temporal modes of existence. He doesn't offer a reductionist account of these modes. In his view, they are inescapable but largely inscrutable posits:

> We have spoken . . . of Space & Time, as they are in themselves; it remains for us to say a few words on matters that pertain to them, in so far as they come within our knowledge. We can in no direct way obtain a knowledge through the senses of those real modes of existence, nor can we discern one of them from another. We do indeed perceive, by a difference of ideas excited in the mind by means of the senses, a determinate relation of distance & position, such as arises from any two local modes of existence; but the same idea may be produced by innumerable pairs of modes or real points of position; these induce the relations of equal distances & like positions, both among themselves & with regard to our organs, & to the rest of the circumjacent bodies.[41]
>
> The consequence of all this is that we are quite unable to obtain direct knowledge of absolute distances; & we cannot compare them with one another by a common standard. We have to estimate magnitudes by the ideas through which we recognize them...[42]

And now the promised threat emerges. Just as it was dubious for Primary Quality Realists to concede that our only grasp of geometric properties is as properties that certain types of experiences signify, but deny that the existence of things with geometric properties has any necessary experience-related implications, it's dubious for Boscovich to concede that our only grasp of proper metrical relations is as relations that certain types of "ideas excited in the mind by means of the senses" signify, but deny that the existence of things standing in those metrical relations has any necessary experience-related implications.

[41](Boscovich, 1763/1966, 203).

[42](Boscovich, 1763/1966, 204).

The shift from Primary Quality Realism to Algebraic Realism was occasioned by a refusal to concede that our grasp of geometric properties comes only through geometrical intuition. The shift from Algebraic Realism to Ontic Structural Realism was occasioned by a refusal to concede that our grasp of proper metrical relations comes only through the sort of experiences that inspire us to posit such relations.

The refusal was slow in coming. More than a hundred and fifty years after Boscovich published his theory, it was still unclear how one could talk about physical phenomena without making at least an implicit reference to experience or the possibility thereof. This, despite the fact that by the early 20th century, actual scientific practice seemed to assume that this was possible.

Arthur Eddington thought that the latter fact said something important about the nature of contemporary scientific inquiry. In his view, modern physicists do succeed in using a vocabulary completely divorced from experience, but only at the cost of not really *saying* anything about the world at all. That doesn't mean that the physicists' professional verbalizations are useless, but it does mean that their utility is non-descriptive. According to Eddington, the fact that the language of physics is limited to terms that have no essential relationship to experience implies that the value of physics-talk is that of a symbolic machine for generating reliable predictions.[43]

Eddington arrives at this conclusion by considering how physicists define their basic vocabulary, and arguing that the system of definitions they use is circular. Physicists define their basic vocabulary operationally, in terms of various measurement protocols: essentially, uses of various instruments to get certain outputs ("pointer readings," in Eddington's lingo) for certain inputs (observations or experiments). However, the instruments and their inputs and outputs are themselves typically understood as physical phenomena possessing the very physical features that the operational definitions are meant to define (see Fig. 3, taken from Eddington's *The Nature of the Physical World*).[44]

In the diagram, Mr. X is a conscious observer of physical phenomena. He is appended to the cycle to indicate the standard realist concession that there

[43](Eddington, 1928, 248-49, 252-55, 291-92).

[44](Eddington, 1928, 263).

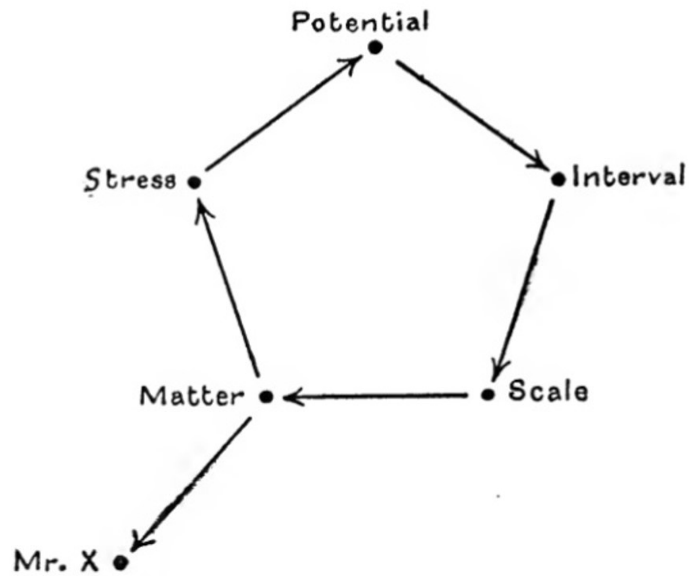

Figure 3: Cyclic definitions of physics + Mr. X

is *some* relationship between experience and the physical world—otherwise, we wouldn't know anything about the physical world—while at the same time denying that this relationship is essential to the physical phenomena themselves, or has any place in scientific definitions of them.

If, as Eddington argues, scientists' definitions of basic scientific vocabulary fail to endow that vocabulary with any meaning, that's bad news for metaphysical realists. Presumably, if a realist analysis of matter is possible, the terms of the analysis will be no stronger than those that scientists use in their definitions: the analysis will employ logical and mathematical language, a predicate for causation or some similar relation of natural dependence, and perhaps some other topic-neutral vocabulary. If the scientists can't provide an intelligible analysis of basic physical phenomena with the semantic and conceptual resources at their disposal, there seems little hope that metaphysical realists can do so. Call this the Gibberish Objection to metaphysical realism.[45]

[45]See (Eddington, 1928, 247-65). The Gibberish Objection to metaphysical realism is a main motivator of currently popular panpsychist metaphysics; see, e.g., (Goff, 2017, 137-38). Berkeley's railings against "abstract general ideas" (Berkeley, 1710/1901, 237-56) are an early version of the Gibberish Objection; see also (Berkeley, 1713/1979, 57).

Eddington's own response to the cyclicality of scientific definitions is a decidedly un-realist metaphysics that identifies all physical phenomena with conscious mental phenomena; this is his famous panpsychism, according to which "the stuff of the world is mind-stuff."[46] Here is not the place to go into that. For our purposes, the important thing to note is that there's another response to the cyclicality of scientific definitions that Eddington does not consider. This response challenges Eddington's assumption that the cycle of definitions he describes fails to endow the defined terms with meaning.

Not all circular systems of definitions are irredeemably circular: some contain the resources to extract perfectly good non-circular definitions of the relevant vocabulary. The extraction protocol is the so-called Ramsey-Lewis method of defining theoretical terms.[47]

The Ramsey-Lewis method takes a body of statements that use the terms to be defined (the "target" terms), conjoins those sentences, replaces all occurrences of the target terms in the resulting conjunction with second-order variables of quantification (assuming the terms we're trying to define are words for properties or relations), and then, for each target term "T" generates a definition of the form:

> x has property T if and only if there are properties $F_1, F_2, F_3, ...F_i$ and relations $R_1, R_2, R_3, ...R_j$ such that for all $y_1, y_2, y_3, ...y_k$ __________ and $F_n(x)$.

—where $1 \leq n \leq i$, and the blank gets filled by a "Ramsey sentence": a conjunction of open-sentences derived from sentences that include the term "T," where this conjunction contains only variables bound by the quantifiers ("there are," "for all") plus other terms whose meanings are already known.[48] Even if the sentences we start out with contain circular cross-references among

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[46](Eddington, 1928, 276).

[47]It would be more appropriate to call it the Ramsey-Carnap-Lewis method; see Ramsey (1929/1978), Carnap (1956), Lewis (1970), and Lewis (1972). Since Ramsey introduced the method the year after Eddington published *The Nature of the Physical World,* Eddington could hardly have been aware of it. It wasn't until the 1970s that Lewis employed the method in the service of realist metaphysics.

[48]If the target term stands for a two-place relation, replace "x has property T" with "x stands in relation T to x'" and replace "$F_n(x)$" with "$R_n(x, x')$" where $1 \leq n \leq j$; similarly for relations of more than two places.

the target terms, the definitions we derive from them need not be circular.

Basically, the Ramsey-Lewis method takes a group of target terms, describes a logical network of relationships among those and other terms, and then assigns each target term a meaning corresponding to its place in that network. A toy example will illustrate.

Suppose you ask an architect what he means by "column," "plinth," and "capital." He replies: "A column is a vertical architectural element that rests on a plinth and supports a capital, a plinth is a level load-bearing architectural element that underlies a column, and a capital is a decorative architectural element that a column supports."

The architect has given you a circular set of definitions, defining "column" in terms of "plinth" and "capital," and each of "plinth" and "capital" in terms of "column." Still, provided that you know what the architect means by "vertical," "architectural element," "rests on," "supports," "level," "load-bearing," "underlies," and "decorative," his circular definitions can enlighten you as to the meanings of "plinth," "capital," and "column." We can use the Ramsey-Lewis method to derive non-circular definitions of these terms from the architect's remarks, as follows:

x is a *plinth* if and only if there are properties F, G, and H, such that
$(\forall y)[Fy \leftrightarrow y \text{ is a level load-bearing architectural element } \wedge \exists z(Gz \wedge y \text{ underlies } z)] \wedge$
$(\forall y)[Gy \leftrightarrow y \text{ is a vertical architectural element} \wedge \exists z_1, z_2(Fz_1 \wedge Hz_2 \wedge y \text{ rests on } z_1 \wedge y \text{ supports } z_2)] \wedge$
$(\forall y)[Hy \leftrightarrow y \text{ is a decorative architectural element } \wedge \exists z(Gz \wedge z \text{ supports } y)] \wedge$
$Fx.$

x is a *column* if and only if there are properties F, G, and H, such that
$(\forall y)[Fy \leftrightarrow y \text{ is a level load-bearing architectural element } \wedge \exists z(Gz \wedge y \text{ underlies } z)] \wedge$
$(\forall y)[Gy \leftrightarrow y \text{ is a vertical architectural element} \wedge \exists z_1, z_2(Fz_1 \wedge Hz_2 \wedge y \text{ rests on } z_1 \wedge y \text{ supports } z_2)] \wedge$
$(\forall y)[Hy \leftrightarrow y \text{ is a decorative architectural element } \wedge \exists z(Gz \wedge z \text{ supports } y)] \wedge$
$Gx.$

x is a *capital* if and only if there are properties F, G, and H, such that
$(\forall y)[Fy \leftrightarrow y \text{ is a level load-bearing architectural element } \wedge \exists z(Gz \wedge y \text{ underlies } z)] \wedge$
$(\forall y)[Gy \leftrightarrow y \text{ is a vertical architectural element} \wedge \exists z_1, z_2(Fz_1 \wedge Hz_2 \wedge y \text{ rests on } z_1 \wedge y \text{ supports } z_2)] \wedge$
$(\forall y)[Hy \leftrightarrow y \text{ is a decorative architectural element } \wedge \exists z(Gz \wedge z \text{ supports } y)] \wedge$
$Hx.$

Applying the Ramsey-Lewis method to the prima facie circular definitions of basic scientific vocabulary yields definitions of that vocabulary in purely *structural* terms, that is, terms that include only logical and mathematical vocabulary plus a primitive (undefined) term for a casual or quasi-causal dependence relation. That's because the relevant Ramsey sentence includes only logical and mathematical vocabulary plus a primitive predicate for causation or some comparable relation; this vocabulary plays a role in Ramsey-Lewis definitions of the scientific vocabulary identical to the role that the terms "vertical," "architectural element," "rests on," "supports," etc. play in the foregoing Ramsey-Lewis definitions of "plinth," "column," and "capital."

I said that Ramsey-Lewis definitions of basic physics vocabulary employ a primitive (undefined) predicate for causation or some comparable relation. Why "or some comparable relation"? And why "primitive"?[49]

The "or some comparable relation" is to acknowledge the reluctance of many contemporary Structural Realists to rely on the concept of causation in their analyses of matter.[50] That said, Structural Realists need *some* form of non-logical, non-metaphysical modality, in order to accommodate the fact that there are non-logical, non-metaphysical dependencies among various physical states of affairs. Structural Realists may disagree among themselves about whether the dependencies are causal; the important thing is that the dependence relation be such that (1) for X to bear it to Y is for X's existence to somehow account for Y's existence, and, (2) X's bearing it to Y doesn't mean that X's existence *metaphysically* entails Y's existence.

The "primitive" is to signal that whatever causal or quasi-causal mode of dependence Structural Realists posit, they can't reduce it to the logical and mathematical properties that constitute the remainder of their reduction base of physical reality. Otherwise, the structural analysis of matter would fall prey to an objection that Max Newman raised against an attempt by Bertrand Russell to analyze physical phenomena purely in terms of contingently existing

[49]That Structural Realism requires some kind of primitive causal or quasi-causal modality is a point that (Ladyman and Ross, 2007b, 128-29) urge in connection with their favored form of Structural Realism.

[50]See Don Ross and Spurrett (2007).

entities (atoms or atomic events) having various logical and mathematical properties and standing in various logical and mathematical relations.[51]

Understood in purely logical or mathematical terms, properties are just sets, and relations sets of ordered *n*-tuples. To define a property in purely logical/mathematical terms is just to specify the set of things that have it; to define an *n*-place relation in purely logical/mathematical terms is just to specify the set of *n*-tuples of things that stand in it. Now, given any possible world W in which there exist exactly the contingently existing things ("atoms," for short) that exist in our world (the actual world), every set of atoms and every set of ordered *n*-tuples of atoms that exists in our world exists in W, and vice versa. Russell's analysis of matter therefore implies that it's metaphysically impossible for a world containing the same atoms as our world to differ from our world physically. Worse yet, Russell's analysis implies that any possible world with the same number of atoms as ours is physically indistinguishable from ours, since any such world contains sets of atoms and sets of ordered *n*-tuples of atoms that differ from those that exist in our world at most in the particular atoms they contain—and in the Russellian analysis, the particularity of the atoms contributes nothing to the physical properties and relations that characterize the world they constitute.

Post-Russellian Structural Realists avoid these problems by supplementing Russell's stock of logical/mathematical properties and relations with a modal relation (e.g., causality, nomic entailment, counterfactual dependence, or conditional probability) that does not reduce to logical/mathematical properties and relations. Since this relation also can't reduce to anything physical (since that would made the structuralist analysis of matter circular) or to anything mental (since that would be to abandon metaphysical realism), it must be a *primitive* modal relation.[52]

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[51]See (Newman, 1928, 144-48). Newman's target is the position Russell takes in *The Analysis of Matter:* see (Russell, 1927, 215, 226-28, 286-89).

[52]Theodore Sider argues for a realist analysis that eschews primitive modality in favor of a primitive second-order property of "carving Nature at the joints" (or "structuring"). (Sider, 2011, 1-9, 266-91) Sider's explication of this property relies heavily on physical and phenomenal examples; see, e.g., (Sider, 2011, 1-5). To the objection that this leaves it unclear how his analysis can avoid circularity or metaphysical antirealism, Sider responds that the meaning of his structure-talk is fixed by the uses he makes of "structure" and

Among contemporary Structural Realists, conditional probability seems to be the favored quasi-causal relation. Instead of defining fundamental physical properties partly in terms of causation, contemporary Structural Realists typically define them partly in terms of conditional probability, that is, in terms of one structural state of affairs giving a certain probability to another structural state of affairs.[53]

To get a structuralist analysis of matter, we proceed as follows.

First, we put together an Eddingtonian cycle of the definitions of the basic terms of our best fundamental science; on standard assumptions, this means the basic terms of our best fundamental physics.

Next, we give explicitly non-circular definitions of these terms using the Ramsey-Lewis method described above. This provides us with a stock of structural predicates, which represent various structural properties and relations.

Now we posit some contingently existing non-mental entities, assuming nothing about their nature besides that they are contingent and non-mental; following John Bell, call these "beables."[54]

Finally, we say that the physical world comprises a totality of beables that have certain structural properties and stand in certain structural relations—those represented by the basic terms of physics, as defined by the Ramsey-Lewis method—where these beables and their structural properties and relations exhaust contingent non-mental reality. Officially:

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related terms: i.e., in effect, by a Ramsey-Lewis definition based on a Ramsey sentence derived from Sider's presentation of his theory. (Sider, 2011, 9-10) Since his theory makes no reference to primitive modality, it's unclear how an analysis of matter in terms of Siderian structure can avoid the Newman objection.

[53]See (Ladyman and Ross, 2013, 139-48).

[54]For Bell's beables, see Bell (1975). Note that we do not assume that the beables exist in spacetime: facts about spacetime and spatiotemporal properties and relations are part of what the Structural Realist aims to analyze: taking such facts as primitive would be a reversion to Algebraic Realism. (Ladyman and Ross, 2007a, 186) suggest that realists can dispense with beables altogether, by "reject[ing] the dichotomy between the abstract and the concrete"; but that way lies Pythagoreanism. (The arguments Ladyman and Ross give "against attributing any significance to the abstract/concrete distinction" are, by their own admission, "not compelling," merely "suggest[ing] the possibility of a rapprochement between the objects of physics and mathematics." (Ladyman and Ross, 2007a, 160). What they have in mind by the suggested "rapprochement" is unclear.)

Ontic Structural Realism:

Physical reality reduces to the fact that

(1) $\Big(\exists x_1, x_2, x_3, \dots x_n\Big)\Big(x_1$ is a beable $\wedge\, x_2$ is a beable $\wedge\, x_3$ is a beable $\wedge \dots\, x_n$ is a beable $\wedge$ ⟦*insert an open sentence containing only structural predicates, logical and mathematical terminology, and variables bound by* $x_1, x_2, x_3, \dots x_n$⟧$\Big)$, and,

(2) the existence of every non-mental state of affairs is a metaphysical consequence of (1).

Strictly speaking, this is not Ontic Structural Realism, but a template for Ontic Structural Realist analyses of matter. To get an actual analysis, we need to replace the square-bracketed part with an actual open sentence of the sort described, derived from a complete description of the physical world in terms of ideal physics, in which all non-logical, non-mathematical vocabulary has been replaced by Ramsey-Lewis definitions thereof. I'm obviously not going to do that here. But, to make it a little more concrete, let's briefly consider a structuralist descendant of the algebraic analysis presented in the previous section.

To "structuralize" the algebraic analysis, we basically redefine proper distal and chronal relations. The Algebraic Realists define a proper chronal relation as one that reflects the true arrangement of contingent non-mental existents in absolute Newtonian time, and a proper distal relation as one that reflects the true arrangement of contingent non-mental existents in absolute Newtonian space. To get Structuralism-friendly definitions, we need to define proper metrical relations in purely mathematical and causal/statistical terms.

Start by replacing the Algebraist's chronal and distal relations with a single class of metrical relations. Call these *interval relations*. (Intuitively, they are meant to capture the spacetime distances among events.)

If we were to take an algebraical approach to this, we'd define a *proper* graded interval relation as a graded interval relation that reflects the distances between events in absolute spacetime, conceived of as an entity whose existence we infer from the utility of certain coordinatizations of events (e.g., those used in General Relativity), but that has a further nature that we can't directly observe, and that explains why certain graded interval relations are proper.

Instead, we define a proper interval relation $\boldsymbol{I}$ as one that satisfies the following condition: if we assign coordinates to events based on their $\boldsymbol{I}$-relationships, and then describe events in terms of those coordinates, we describe them as conforming to a small number of simple laws. In other words, a proper interval relation is one that relates events in a way that generates an adequate or permissible coordination of events. Whatever the relation is, it will have to be defined purely in causal or quasi-causal (e.g., statistical) and mathematical terms, for the reasons explained above. But this isn't a problem for structuralists, since physicists do in fact define interval relations that way: they define them in terms of intersecting worldlines, where worldlines are causal sequences of events, and worldline intersection is causal interaction between events in different worldlines.[55]

Of course, the only way for us to know whether a given relation does, in fact, satisfy the stated condition is through experience. The key difference between the structuralist and algebraical approaches to defining properness is that the Structural Realist defines it in purely causal/statistical and mathematical terms that we can grasp without having to think of them in relation to experience, whereas the Algebraic Realist defines properness in terms of entities (absolute Newtonian time and space) whose only descriptors are words like "homogenous," "immovable," and "flowing uniformly," which we're provided no way of understanding except as explaining various regularities in experience, while at the same time being told that the entities they apply to "make no impression on the senses."[56]

The structuralist approach is the approach that Newton *would* have taken, if, instead of defining proper distal relations as relations that both satisfy clauses D1-D6 on p. 22 and reflect the structure of an independently given absolute space, he had defined them as relations that both satisfy those clauses and induce a lawlike metrical structure on the manifold of events. In theory, he could have done this by turning *The Mathematical Principles of Natural Philosophy* into a gigantic Ramsey sentence, and then using that Ramsey sen-

[55]See (Geroch, 1978, 70-92).

[56](Newton, 1687/1999, 414).

tence to give a Ramsey-Lewis definition of "distance." Such a definition would, in effect, define distance as the relation that plays a certain role (the "distance role") in Newton's theory, namely the role of being a relation whose pattern of instantiations among events in any given "time slice" of the world is a lawlike function of its pattern of instantiations in prior time slices. (Meanwhile, temporal order would get a Ramsey-Lewis definition based on the same gigantic Ramsey sentence.)

A relation might play this law-inducing role, without reflecting anything about an independently given absolute Newtonian space. Such a space need not even exist, for the relation to do its law-inducing work. This is analogous to how a relation among triangular regions of a surface can induce a curvature of that surface, without reflecting anything about an independently given higher-dimensional space that embeds the surface. Such a space need not even exist, for the relation to do its curvature-inducing work.[57]

At bottom, the Structural Realist sees the physical world as a causal or statistical network of beables, where the nature of each beable in the network is exhausted by its place in the network.[58] For example, we might think of the diagram in Fig. 4 as a complete Structuralist representation of an extremely simple physical world comprising just three beables A, B, and C. (Perhaps these beables constitute a single quark.)[59]

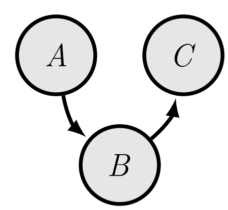

Figure 4: A structuralist world

In causal terms: A is the beable that nothing causes—that's the whole truth about A.[60] B is the beable that some beable causes and that causes some beable—that's the whole truth about B. C is the beable that B causes—that's the whole truth about C. It's causal structure all

[57]This is the main upshot of Gauss (1827/1902).

[58]In terms of graph theory, the physical world is, by this account, a directed graph having beables as nodes and causal or statistical relationships as edges.

[59]Such a quark would be an example of what Donnchadh O'Conaill calls a "concrete structure": see (O'Conaill, 2014, 296-97).

[60]Or perhaps not the *whole* truth: maybe A causes, or has the power to cause, various non-physical conscious experiences, and likewise for B and C. If so, this is a contingent fact about A, B, and C that has no bearing on the physical nature of the world they constitute, according to Structural Realists.

the way down.

In statistical terms: A is the beable whose chance of existing no beable boosts—that's the whole truth about A.[61] B is the beable whose chance of existing some other beable boosts, and that boosts the chance of existing of some other beable—that's the whole truth about B. C is the beable whose chance of existing B boosts—that's the whole truth about C. It's statistical structure all the way down.

The most important difference between Algebraic Realism and Structural Realism is that the latter denies any need to think of the modal, mathematical, and mereological properties and relations that figure in realist analyses of matter as applying to an underlying reality with further properties and relations over and above these. It's not that Structural Realists have to deny that there is such a reality (though many of them would): it's just that according to them, whether such a reality exists is strictly irrelevant to the world's physical nature. According to Structural Realists, the physical truths about our world are truths expressible in a language that uses only generic logical and mathematical vocabulary, supplemented by a term for causation or some comparable modality. If there's a further underlying reality that explains why these truths are true, its relationship to the physical world is explanatory rather than constitutive. Such a reality, if it exists, relates to the physical world in a way analogous to that in which God relates to the physical world in traditional theistic cosmology: it explains why the physical world exists, but it is not itself the physical world. If a different underlying reality had made the relevant structural truths true, or if the truths had been true without being made true by anything, everything would have been just the same, physically.

Other differences between Structural and Algebraic Realism are due to the different scientific milieus in which they arose. The basic terms of the algebraic analysis derive from the conceptual repertoire of 17th and 18th century physicists and mathematicians (basically: causality, Euclidean differential geometry, and elementary algebra). The basic terms of the structuralist analysis derive from the conceptual repertoire of 20th and 21st century physicists and mathematicians (basically: probability theory, non-Euclidean differential geometry,

[61] See preceding footnote.

and linear algebra). So, where a traditional Algebraic Realist construes the physical world as a causally stratified Euclidean manifold of events, a contemporary Structural Realist might construe it as a Markov chain of Cauchy surfaces in a Lorentzian manifold of beables. These are important differences, but their philosophical significance is small compared to the more fundamental difference discussed in the previous paragraph.

6 Challenges and Alternatives to Metaphysical Realism

Realist analyses of matter have important virtues, but they also face important challenges. Some of these are serious enough to have inspired a string of alternatives to metaphysical realism, which we can classify together under the broad rubric of *mentalist metaphysics*.[62]

Broadly speaking, there are four types of mentalist analyses of matter.[63]

The oldest type is classic idealism, which identifies physical phenomena with actually occurring experiences that combine in suitably coherent ways, either due to the experience-causing activities of some powerful mind (as in Berkeley's idealism), or due to the experience-having propensities of a multitude of minds (as in Leibniz's idealism). According to classic idealism, a tree is a combination of experiences with the sort of phenomenal properties and counterfactual interdependencies that normally characterize the experiences that occur in different people when they perceive the same tree; a veridical experience of a tree is one that relates to the totality of all experiences the way your current experiences relate to the rest of the experiences you've had (rather than, e.g., the way that the experiences you have in dreams relate to the rest of your experiences).[64]

[62] Toleration for invidious nomenclature has its limits. The only thing opponents of metaphysical realism deny is the existence of a successful realist analysis of matter. Calling them "metaphysical antirealists" is like calling people who deny that normative facts reduce to physical facts "moral antirealists."

[63] Even more broadly speaking, mentalist analyses of matter are just one genus of mentalist metaphysics, another genus being theories in which human conceptual capacities define the limits of metaphysical possibility; see, e.g., Wittgenstein (1922) and Hofweber (2019).

[64] See, e.g., Berkeley (1710/1901), Leibniz (1714/1989), Foster (2008), Smithson (2017), Robinson (2022), and Yetter-Chappell (2025).

A more recent type of mentalist analysis of matter is the causal analysis we find in Kant. According to this, the physical facts about our world metaphysically supervene on facts about the experience-causing powers of whatever in our world has the power to cause experience (so-called "noumena"). According to causal theorists, the existence of a tree reduces to the fact that noumena have the power to cause groups of experiences like those that classic idealists identify with trees; a veridical experience of a tree is one that relates to the totality of all the experiences that the noumena have the power to cause in the way your current experiences relate to the rest of your experiences.[65]

An even more recent type of mentalist analysis of matter is the phenomenalist analysis we find in Mill. This is a streamlined version of the causal analysis; it reduces physical truths to counterfactuals of the form, "if such-and-such experiences occurred, such-and-such other experiences would occur," rather than to truths about an ostensible noumenal reality that grounds such truths.[66]

Finally, there is the currently fashionable panpsychist analysis of matter, also known as Russellian Monism, according to which the world's fundamental microphysical constituents are conscious minds or mental states, of which macrophysical phenomena are causal or spatiotemporal combinations.[67]

Probably the most influential objection to metaphysical realism is what we might call the "incompleteness" objection. (This is the objection that's chiefly responsible for the popularity of panpsychism.) The objection is that realist descriptions of the world are too generic, rarefied, or insubstantial to serve as complete descriptions of any concrete physical entity. This is distinct from the Gibberish Objection discussed earlier, but similar in spirit. Here's how Robert Adams puts it:

> [A] system of spatiotemporal relationships constituted by sizes, shapes, positions, and changes thereof is too incomplete, too hollow, as it were, to constitute an ultimately real thing or substance. It is a framework that, by its very nature, needs to be filled in by something less purely formal. It can only be a structure of something of some not merely structural sort. Formally rich as such a structure may be, it lacks too much of the reality or material of thinghood. By itself, it

[65]See, e.g., Kant (1781/1998), Fumerton (1985), and Langton (1998).

[66]See, e.g., (Mill, 1979/1865, XI), Lewis (1946), Ayer (1946-1947), and Pelczar (2022).

[67]See, e.g., Eddington (1928), Strawson (2006), and Goff (2017).

participates in the incompleteness of abstractions.[68]

Though suggestive, it's hard to turn the incompleteness objection into a persuasive criticism of metaphysical realism. The objection is best construed as an underdetermination argument, but when we try to develop it in detail, we don't get very far.

For example, we might try to press the objection with a thought-experiment where the realist's atoms or beables are replaced by disembodied minds that exist in a causal or statistical network structurally indistinguishable from the network that metaphysical realists identify with actual physical reality.[69] This doesn't work, for two reasons. First, the realist's atoms or beables are explicitly non-mental; so, the thought-experiment doesn't even pose a prima facie threat to metaphysical realism. Second, even if realists were to suspend the requirement that the atoms or beables be non-mental, they could say that the envisioned scenario is physically indistinguishable from our actual scenario: it's just that in the envisioned scenario, physical facts get realized in a non-standard way.[70]

We might try to press the incompleteness objection with a thought-experiment where someone (say God) creates a fully detailed model of our physical world, perhaps a computer model, or perhaps a mechanical model analogous to an orrery. For this to have any hope of threatening metaphysical realism, we have to assume that the model constitutes the whole of contingent non-mental reality in the world where it exists; otherwise, the case won't satisfy the final "completeness" clause of the realist analysis of matter. Given this assumption, however, the realist will once again say that the envisioned scenario is just a non-standard realization of a physical reality indistinguishable from our own. In effect, we've just supplemented the realist analysis of matter with

[68](Adams, 2007, 40); see also (Hartshorne, 1946, 413) and (Goff, 2017, 140). Here, Adams is talking about Primary Quality Realism. The flavor of incompleteness is only stronger in Algebraic and Structural Realism.

[69]See (Foster, 2008, 89-93).

[70]This is analogous to how functionalists respond to thought-experiments in which the population of China instantiates the same functional features as the brain of an ordinary human being: if the Chinese population duplicates my brain's functional features, then, say the functionalists, it also duplicates my phenomenal features.

some additional information about the atoms or beables, namely that they are features of a divinely constructed model. By realist lights, this information has no more bearing on the described world's physical nature than information about the atoms' or beables' experience-causing powers.

A less influential but more serious objection to metaphysical realism is that it underestimates the relevance of experience-related facts to questions about the existence and nature of the physical world. Because I consider this to be the main challenge to metaphysical realism, I'll call it the Central Objection.

According to Structural Realists, the physical world we inhabit is a causal or quasi-causal network of contingent, non-mental existents; any possible world in which this network exists and exhausts contingent non-mental reality is physically indistinguishable from our world. But, as metaphysical realists are bound to acknowledge, there are possible worlds in which this structure exists and exhausts contingent non-mental reality, but in which it does not have the relationship to experience that it has in our world. For example, there are possible worlds where the structure does not cause experiences, does not have the power to cause experiences, does not support non-trivial counterfactuals of the form, "if such-and-such experiences were to occur, such-and-such other experiences would occur," and where there are no non-trivial truths of the form, "the probability of such-and-such mental state of affairs given such-and-such other mental state of affairs = x."

There are also worlds structurally identical to ours in which the relevant structure does have and exercise experience-causing powers, does support non-trivial counterfactual conditionals related to experience, and in which there are non-trivial probabilities of the aforementioned form, but where the relevant powers, counterfacts, and probabilities are radically unlike those that characterize our world. For example, there's a world W with the same network of beables as ours, but characterized by experience-related powers, counterfacts, and probabilities that give the inhabitants of W the same reasons to believe they live in a physical world like Tolkien's Middle Earth that we have to believe that we live in the world that we take ourselves to inhabit.

What should we say about W? That it is physically indistinguishable from our world, and that its inhabitants are mistaken in believing otherwise? Or that, despite being identical to our would in all respects that Structural Realists deem relevant to the physical, it differs from our world physically in the way that Middle Earth differs from our world?

Structural realists are committed to saying the former; mentalist metaphysicians say the latter. Without pretending to settle this debate, let me share three considerations that seem to favor of the mentalist stance.

First, the mentalist stance receives support from the history of science. Over time, there have been many changes of received opinion about the structure of the world that gives us our experiences. People used to think it had the structure of various blends of Earth, Air, Fire, and Water; later, they thought it had the structure of Democritean atoms whizzing around in a void; later yet, they thought it had the structure of Daltonian atoms arranged in successive time-slices of Euclidean space; still later, they thought it had the structure of a relativistic four-dimensional Riemannian manifold of events, or possibly of a high-dimensional Hilbert space populated by quantum mechanical states. These shifts of opinion about the structure of the origins of our experience did not occasion corresponding waves of external world skepticism. All along, people believed that there were trees, rivers, mountains, clouds, stars, etc. This suggests that our belief that there are (e.g.) trees is a belief about the sort of experiences that are apt to occur in our world, rather than about a supposed structure that has no essential relationship to experience. After all, it's the experiential powers or tendencies that have remained the same through all the historic changes of opinion about the world's underlying structure.

Second, we can imagine that our experience arises from a realist structure, but that it's a different realist structure from one moment to the next. We can imagine that although the realist structure constantly changes, there is no change in what experiences the (constantly changing) structure has the power to cause, no change in what experience-related counterfactuals the constantly changing structure supports, no change in experiential probabilities—no change in any fact related to experience. If you were to learn that this is how it actually is, would you conclude that no physical thing persists from one moment to another—e.g., that the teeth you brushed before going to bed last night weren't the teeth you brushed after breakfast this morning? If not, you should consider the possibility that you aren't a metaphysical realist.

Third, it's unclear how we can learn anything about the physical world, if its physical nature depends on features it has metaphysically independently of any fact related to experience. The only information we have about the source of experience comes from experience itself: if you try to look behind experience to see where it's coming from, you're just going to have more experience. Perhaps abduction can tell us that *something* causes experience, and perhaps induction can support judgements about what experience-causing powers this Something has. But it's hard to see how we could ever come to know that the Something possessed specific features that it could have even if it had no tendency to cause experiences, support counterfactuals related to experience, etc. If, as metaphysical realists contend, the existence of a certain physical world just *is* the existence of something with certain features of this type, it follows that we can never know what kind of physical world we inhabit.

Before concluding, I should say something about the relationship between metaphysical realism and physicalism, the view that all mental phenomena are physical phenomena. Physicalism and metaphysical realism might seem like a natural pairing, but the truth is that physicalism has a tendency to blur the distinction between metaphysical realism and mentalist metaphysics.

To begin with, if physicalism is true, some physical phenomena (e.g., various brain states) *are* mental phenomena. It follows that if physicalism is true, at least some physical phenomena metaphysically depend for their existence on mental phenomena, namely the mental phenomena that those physical phenomena are.

If this were all, it wouldn't muddy the water too much. We could just define metaphysical realism as the view that *most* physical phenomena, including all that are not brain states of a certain sort, exist independently of any fact related to experience.

However, some physicalists might hold that it's essential to any physical entity that it has precisely the powers to bring about physical effects that it does; this would be a version of so-called "power essentialism." Since all macroscopic physical entities have the power to cause experiences, a physicalist power essentialist must hold that all macrophysical entities depend for their existence on various facts about experience, namely the fact that they have various experience-causing (i.e., in this view, brain-state-causing) powers.

The combination of physicalism and power essentialism already carries us to the brink of a Kantian powers-based analysis of matter. To take the final step, we need only imagine a physicalist power essentialist who also embraces scientific antirealism, the view that there are no imperceptible physical phenomena (or at least, none that we have any good reason to believe in).

Physicalist power-essentialist scientific antirealism implies a causal analysis of matter along broadly Kantian lines: it's a view in which the physical facts metaphysically supervene on facts about experience-causing powers. Yet it seems somehow wrong to call it mentalist metaphysics. Perhaps we could think of it as a limiting case where realism and mentalism converge.

7 Conclusion

Metaphysical realism has evolved from a relatively naive account of the physical world as a causal sequence of solid objects having various geometrical properties, to a highly sophisticated account of the physical world as a statistical network of beables whose non-mathematical properties are exhausted by their places in the network. Driving this evolution is a need to find a way to characterize the realists' "Real Things" and "Real Properties" in a way that both avoids reducing physical phenomena to mere abstractions and makes good on the realist claim that the physical facts of our world are strictly independent of any fact related to experience. Pursuit of this double objective has yielded increasingly rarefied analyses of matter, culminating in the supremely austere analysis favored by contemporary Structural Realists.

There is another side to this story. Though metaphysical realism has had the upper hand for much of the modern era, it has always faced intelligent opposition, which has evolved in parallel with metaphysical realism. Like Primary Quality Realism, the idealism of Leibniz and Berkeley presents a relatively accessible picture of physical things as combinations of more or less ordinary sense experiences. Perceived extravagances of this picture, such as its implication that physical things couldn't exist in the absence of minds, led to the more spartan and sophisticated noumenalism of Kant and his followers: a natural foil to the Algebraic Realism of the late 18th century. As people came to regard even the noumena as an extravagance, Kantian metaphysics yielded to the highly rarefied phenomenalism of J.S. Mill. As in realist thinking, the trend has been towards ever greater abstraction and ontological frugality. Also as in the realist case, developments in mentalist thinking parallel contemporaneous formal and scientific developments. Exploring those parallels is an adventure for another day.

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