On Perspicuous Representation in Physics

Jill North*

(forthcoming, *Journal for General Philosophy of Science*)

Abstract

There are in general many different ways of representing something. How we represent something seems entirely up to us, a matter of convention or stipulation or unencumbered decision on our part, dictated solely by considerations as to what will be most useful for us given our aims and interests in the context. There are also in general better and worse ways of representing something. Philosophers of physics have generally thought that the quality of representation is likewise only ever a matter of pragmatic or other sorts of extrinsic and subjective factors that are tied to us.

I argue that there is a non-pragmatic, intrinsic, more objective sense in which one representation in physics can be better—more perspicuous—than another, a sense that flows from the nature of things themselves rather than aspects tied to us. One result is that there is a physically significant sense in which representations differing only in their level of perspicuity are not equivalent, where this includes different formulations of a physical theory.

1. Introduction

There are in general many different ways of representing something. Different mathematical devices can be used to represent a space, as different coordinate systems can be used to represent a Euclidean plane. Different languages can be used to express the same content, as the proposition that snow is white can be expressed in English or in French. Different mathematical formalisms can be used to state a physical theory, as quantum mechanics can be formulated in terms of matrix or wave mechanics.

*Department of Philosophy, Rutgers University; j.north@rutgers.edu

How we represent something seems entirely under our stipulative control. We may decide to use any coordinate system we like; we may choose to speak any language; we may equally use matrix or wave mechanics. The only constraints seem to be pragmatic factors concerning which representation will be most useful for us, given the aims we happen to have in the context at hand. A choice of representation is not a matter of getting things right, in other words. It is a matter of convention or unencumbered decision on our part, which could just as well have been otherwise. It is entirely up to us.

Even so, sometimes certain choices of representation are clearly better than others. A further question is why, or in what way, they are better. Philosophers of physics have generally thought that the quality of representation also invariably comes down to pragmatic or other sorts of extrinsic and subjective factors having to do with us. There is no more objective or intrinsic sense in which one representation in physics is better than any other.

We do of course often choose to use particular representational devices for pragmatic reasons, as when we choose to speak French rather than English for purposes of getting around Paris, or decide to use one coordinate system rather than another to make certain calculations easier to carry out. However, there are also instances in physics where one representation is better than another in a more objective, intrinsic, non-pragmatic sense—where one is what I will call, appropriating a recent buzzword, more *perspicuous* than another. That is what I aim to show here. One interesting consequence is that there is a physically significant, non-pragmatic sense in which representations that differ only in their level of perspicuity are not equivalent, where this includes different formulations of a physical theory.

My focus is on this aspect of representation in physics, especially mathematical representation in physics, without assuming any particular account of representation (either in general or in science in particular). My aim is to show that there is a sui generis notion of perspicuity of representation in physics, which is not just a matter of truth or accuracy, but is nonetheless an objective feature, and which is an important facet of our physical theorizing. This is independent of one's account of representation. (As Mauricio Suárez (2003) notes, an account of representation comes apart from an account of accurate or true representation, and, I would add, of perspicuous representation as well.[1]) I will not be offering a full-fledged account of perspicuity of representation, either—again: my aim is to show that there is such a thing that is significant for physics, contrary to suggestions in the philosophy of physics literature (although related notions have been bouncing around the metaphysics literature for some time, this has generally been spurned by philosophers of physics), primarily by way of prodding intuitions through examples. I do not have space to do more here, and more to the point, my aim is to advertise the core idea to philosophers of physics who otherwise hold disparate views on matters that will affect what such an account should look like. That said, there will be intimations as to the general contours required.

I will begin by discussing a view that is prevalent in philosophy of physics and philosophy of science, which sees our choices of representation as constrained by nothing more than pragmatic factors, and the quality of representation as an essentially subjective matter, arguing that such a view cannot be entirely correct (Sect. 2). I then use that discussion to motivate the thought that there is an objective and non-pragmatic sense in which one representation in physics can be better, or more perspicuous, than another, while identifying aspects of this quality of representation (Sect. 3). After that (Sect. 4), I turn to some intermediate views, which see the perspicuity of representation as not just a pragmatic matter, but neither quite an objective one either, arguing that these do not go far enough in accounting for the phenomenon, and outlining the general shape of the sort of approach that does. Finally (Sect. 5), I consider implications of this sense of perspicuity for questions of theoretical equivalence in physics. Note that in what follows I am going to simply assume some type of scientific realism. Aspects of the discussion can be construed in a non-realist spirit, but I will not address that here.

[1]To the extent that one denies this, the current discussion may have implications for an account of representation (n. 21). I do not explore this here.

2. The Permissive View of Representation

Let me begin by outlining a view that is reasonably common in philosophy of physics, where it is often implicitly assumed, at times explicitly defended, and which I will be arguing against to a certain extent.

Think of the various sorts of devices we use to represent things, among them the mathematical tools we use to represent things in physics. These devices in themselves do not have any particular representational content. If I hand you some mathematical formalism, say a matrix algebra, that in itself does not represent any particular thing or other; it certainly does not represent anything in particular in physics. I have to stipulate or tell you that it does. Representational devices, in order to represent something, have to be stipulated by someone into doing so.

There is furthermore a lot of leeway in these representational stipulations. We can use all sorts of devices to represent all sorts of things in all sorts of ways. We can if we like, over dinner one day, decide to use a salt shaker to represent Madagascar, or one's left hand to represent the Platonic form of beauty, in examples from Craig Callender and Jonathan Cohen (2006). I just have to stipulate that I am going to use the item in question to represent what I have in mind, and it is so, just as I can stipulate that I am going to use a matrix algebra to represent the physics of quantum systems, and it is so.

Indeed, it seems we can in principle use anything to represent anything at all, if we so choose: "Virtually anything can be stipulated to be a representational vehicle for the representation of virtually anything," in Callender and Cohen's words (2006, 74). In particular, any mathematical device can in principle be stipulated to represent anything at all in physics. After all, these devices are "our tools not our masters," as Shamik Dasgupta (2011, 134) puts it of mathematical models in physics—*we decide* which representational devices to use, and what to use them for. The underlying idea is something that Hilary Putnam (1983) calls "trivial semantic conventionality." It is the idea that, in Trevor Teitel's words, "any representational vehicle can in principle be used to represent the world as being just about any way whatsoever" (2021, 4125). All it takes is the appropriate stipulation on our part.

Relatedly, other people or communities are free to make very different representational stipulations from one's own. Other choices may strike us as odd, but there is nothing objectively or inherently wrong with them; no one is making a mistake. At most, they may have made things more difficult for themselves. Think of using polar versus Cartesian coordinates to describe the motion of a particle in a Euclidean plane. If the motion is along a circular path, it will be particularly convenient to use polar coordinates. If the motion is along a straight line, then Cartesian coordinates will be convenient. But some other community which, as a matter of their representational practice, decides they are only ever going to use Cartesian coordinates cannot be faulted for doing so, other than on pragmatic grounds. Consider an example from Teitel (2021) of a community which stipulates that negative numbers cannot be used to represent the norms of timelike vectors. Where we regard the choice of one Lorentzian signature versus the opposite in formulating a relativistic theory as a mere difference in notation that doesn't correspond to any physical difference, this community demurs. Odd, to us. But there is nothing inherently wrong with it, should this community wish to do things that way for whatever reason. It is entirely up to them.

What I am calling the permissive view holds that all our representational choices, including our choices of mathematical representation or formulation in physics, are like this. A representation is achieved simply by stipulative decree, and the only things constraining the choice of representation are factors having to do with its usefulness or convenience given our aims and interests in the context. There are in particular no constraints coming from inherent features of the tools we might use or the things we wish to represent. The quality of representation likewise depends on extrinsic factors having to do with us, no one representation being better than any other in any objective, intrinsic, non-pragmatic sense.

I am relying here on a rudimentary conception of notions like "pragmatic" as well as "subjective" as opposed to "objective," notoriously difficult to pin down precisely.[2] For our purposes, we can understand pragmatic factors as things that further our aims in a given context, and which are rendered immaterial given appropriately different aims or in rele-

[2] Reiss and Sprenger (2020); John (2021) contain overviews of objectivity in science.

vantly different contexts. Subjective features or factors are likewise things that have to do with us: they are "tied to *us* in some way—to human language, biology, history, or psychology" (Sider, 2011, 18). Something that is subjective depends on or holds relative to a subject or agent or perspective, and so is to some extent in or about us rather than the world. Both these notions are in contrast to the objective. Both concern things that depend upon us and are not fully about how things are in themselves apart from us (objectivity has to do with "representing reality apart from humans" (John, 2021, 5)). When it comes to representation particularly, both involve things that are extrinsic to the inherent natures of the representational device and target and the direct relationship between them. (The pragmatic need not always be in direct opposition to the objective—it can be an objective matter that if one has a certain goal, then such-and-such means is the best way of achieving it—but the initial tension remains. In particular, by virtue of having to do with us and our aims and interests, the specter of the subjective remains; and to the extent that it does not, this is where the current sense of perspicuity is going to enter in.) "Conventional" is another notion in the vicinity, and is similarly opposed to the objective. A conventional choice of representation is one that is up to us and involves a certain amount of arbitrariness. Not completely arbitrary, as there can be reasons for a particular choice, yet it will be "based on convenience and other predilections—reflecting human interests and volition" (Dürr and Read, 2024, 10); which is to say that no one choice is objectively better than any other, but better for reasons that ultimately concern us.[3] These intuitive, rough-and-ready ideas will suffice here. More particularly, when I talk about subjective or pragmatic or conventional aspects as opposed to objective ones, it suffices to call to mind the basic difference between aspects that are tied to us rather than things themselves.

[3]Thus, the conventional is "the artificial, the invented, the optional, as against the natural, the fundamental, the mandatory" (Goodman, 1989, 80); "'convention' generally signifies an arbitrary choice amongst equally good ways to achieve a certain goal by collective action" (Sider, 2011, 54); "conventions are 'up to us', undetermined by human nature or by intrinsic features of the non-human world. We *choose* our conventions, either explicitly or implicitly" (Rescorla, 2024); conventional decisions are a matter of "*free* decision," which "reflect human preferences—matters not of truth, but of convenience" (Dürr and Read, 2024, 2).

Now there is without question a lot of freedom in our choices of representation, as the permissive view emphasizes, and as commonplace examples—speaking different languages, using different coordinate systems, formulating a theory in different ways—attest to. Even so, the permissive view cannot be quite right as it stands when it comes to representation in physics. The reason is that some representational stipulations *can't* be made. No mere stipulative fiat will allow us to use the integers to represent the physics of Newtonian systems, for example. We cannot just stipulate our way into using this device, and not because of pragmatic considerations having to do with whether it will be especially useful for us. The integers simply do not have the right nature or structure for the representational task: there aren't enough integers available to represent all the different possible physical states these systems could be in. By their very nature, the integers fail to be capable of representing Newtonian physics and the kinds of systems it describes.[4]

This means that there *are some* constraints on representation in physics that are non-pragmatic and objective, flowing from the intrinsic natures of the candidate representational device and target and the direct relationship between them, rather than extrinsic factors having to do with us. Our representations in physics are not all a matter of mere stipulation governed solely by pragmatics; they are not entirely up to us.[5] (Perhaps this is what Callender and Cohen and Teitel have in mind when they say that "virtually" anything can be stipulated into being a representation of "virtually" or "just about" anything else. It is worth being explicit about this, as it begins to show how our representations in physics can be constrained in ways that are not just about us and our aims. If you are concerned that this nonetheless invokes an aim of doing physics, hold that thought until the end of Section 3.)

[4]This is assuming we require of a theoretical formulation that it be capable of representing distinct possible physical states by means of distinct aspects of the mathematics, a minimal requirement on any reasonable formulation (cf. de Haro and Butterfield (2025, 11.3.4); North (2025)). The above point applies to the set of integers with their usual structure, which is not to deny the integers can be used to define other sorts of structures. (Bear in mind that I refrain from taking a stance on the nature of representation, though the above may have certain implications for such an account.)

[5]See Boesch (2017); Jacobs (2023); Hall and Ramírez (2024) on other kinds of non-pragmatic constraints on representation in science.

It is of course true that for anything we wish to represent, there will be many different ways of doing so. So even if you agree with the discussion so far, you might think there can be no objective, non-pragmatic, intrinsic sense in which some representations in physics, from among all those that *can* be used, are better than others; that none is better than any other in this way beyond the fact that some are worse by virtue of being incapable of being used. In the following section, I argue against this too.

3. The Quality of Representation

In working up to the idea that there is a non-pragmatic, intrinsic, more objective sense in which one representation in physics can be better than another, consider first of all that we would not be satisfied with expanding our mathematical device for representing Newtonian physics beyond the integers to include all the real numbers, and then using some bizarre permutation of our usual numerical assignments, even though (with the appropriate representational conventions) we *can* use such a thing. We want more than this kind of crude or forced representation; for we want more than the mere ability or capacity, by brute stipulation, to represent things in physics. We also want to represent things *well*, in a sense that is not just pragmatic—to represent things naturally or perspicuously or directly. Defending this will be the focus of the rest of the paper.

Think of a physical space with the structure of the Euclidean plane, and think of the different sorts of mathematical devices we can use to represent it. One of these is the real numbers: we can represent the plane by assigning a distinct real number to each point. However, this is clearly a worse representation than one in terms of ordered pairs of real numbers. The mapping from points in the plane to single real numbers will be highly convoluted and contrived. Given the appropriate stipulations, real numbers can be used to represent this space; nonetheless, this is a bad choice of representation.

It is furthermore bad in an intuitively objective and non-pragmatic way. The representational stipulations required will be so unnatural and contrived that even a Laplacean demon with unlimited computational powers could reasonably be faulted for choosing to represent the plane this way. It is true that such a representation will result in massive computational complexity for (and will hardly be usable by) us, whereas the Laplacean demon by hypothesis could use it to grasp everything about the plane without struggle. This might make it seem like an equally good representational choice for a creature like that, so that it is only for us that it is worse. Yet although the representation does bring with it calculational complexity specific to creatures like us, there is also a sense in which it is worse that is independent of us and our aims and capabilities. After all, it is hard to imagine a context we could be in, or aims we could have, for which real numbers would yield a better representation of the plane than ordered pairs. This suggests it is a worse representation regardless of what we plan to do with it and how difficult it will be for us to achieve that aim by means of it.

Although the real-number representation is worse in a pragmatic way, it is also worse in a non-pragmatic, objective, intrinsic sense—a badness of representation that is not tied to us but flows directly from the intrinsic nature of the plane, on the one hand, the real numbers, on the other, and the relationship between them. The real numbers differ sufficiently in nature from the plane that the representational stipulations will have to be highly unnatural and indirect, effectively "undoing" or "overriding" their nature in order for them to be able to represent it. For instance, the set of real numbers (under its usual ordering) does not possess the topological structure of the plane, with the result that there will be points that form connected sets within the plane that cannot be represented by sets of points that are connected on the real line. The representational stipulations must in effect tell you to ignore the disconnectedness of those points, and interpret them as connected. The plane and the real line likewise differ in metric structure, with the result that points that are near each other according to the structure of the plane will have to be represented by numbers that are not near each other according to the (standard metric and topology on the) reals, and the representational conventions must effectively override the apparent non-nearness within the mathematical device.

The real numbers are inherently ill-suited to or misaligned with the nature of the plane, resulting in representational stipulations that are unnatural and convoluted and indirect. Ordered pairs, on the other hand, are better-suited to the nature of the plane—the set of ordered pairs possesses the same topological structure (e.g., the dimensionality) as the plane—with the result that the representational stipulations will be more natural and direct. The topological features of the representational vehicle can be taken at face value, as it were, with no need for contrived stipulations to undo them.

When it comes to different mathematical representations of the plane, the quality of representation doesn't have to do only with extrinsic, subjective, and/or pragmatic factors concerning us, our aims, the context, and so on. There is a sense in which some representations are better than others that is due to such factors. Yet there is also a sense that flows directly from the intrinsic nature of the space, and the fact that certain representational devices are inherently better-suited to it than others.

Now, I am assuming that a space like the plane *has* an intrinsic nature or structure. This is as opposed to philosophers such as Poincaré (1952) and Reichenbach (1958), who think there is no fact of the matter about a space's structure independent of conventional stipulations on our part. As long as you are not a conventionalist or anti-realist about this, you should agree that there are facts as to the match in structure between a given space and candidate representational device. I am simply going to set aside here the view that a space (or other mathematical or physical entity) has no intrinsic topology or other structure, and assume that there are facts about this.[6] I am going to assume a "structural realism" of the kind I defend in North (2021) (not to be confused with other philosophical views that go by the name).[7] (This is not to deny that a mathematical item can have different structures defined on it. The real numbers, for instance,

[6]See Sider (2011, 3.4); Wallace (2019); North (2021, ch. 2); Dewar (2023) for different accounts of the intrinsic structure of a space. See Dürr and Read (2024) for a recent defense of conventionalism about spacetime structure.

[7]This kind of view further holds that we should take the mathematical structure of our best physical theories seriously when it comes to figuring out what they say about the world, an aspect that brings it into affinity with the approach characterized by McKenzie (2024). The more familiar form of view with the name is a metaphysical thesis about the existence or relative priority of structure or relations as opposed to objects and their intrinsic natures (or in the view's epistemic guise, about our knowledge of these things), and concomitant scientific realism about a theory's structure rather than objects; see Ladyman (2023) and references therein. That type of view concerns matters orthogonal to those here.

can be equipped with various structures, including a non-standard metric or topology (such as the discrete topology, on which the dimensionality will be different from that assumed above). The mathematical entities discussed here are all assumed to have a certain definite structure, more particularly, their standard, or natural (in the mathematicians' sense), structure.)

Given the appropriate stipulations, we can likewise represent the physics of Newtonian systems by means of a random scrambling of our usual numerical representations. However, as in the case of real numbers versus ordered pairs for a plane, this is clearly a worse choice of representation, in an intuitively objective and non-pragmatic sense—a sense that is not merely a matter of its calculational complexity for us (although it is worse in that way) but flows directly from the intrinsic natures of the representational device and target physics. In particular, it will fail to characterize the relationships among different physical states or quantity values at all naturally or directly. It might label a 9 kg mass as "2 kg" and a 4 kg mass as "7 kg", say; so that the representational conventions must in essence tell you to ignore various features of the representation, and instead interpret things so that the second is less massive than the first—a contrived, unnatural, indirect representation.

Keep in mind that in the examples being discussed in this section, it is not the case that the mathematical device fails to represent the target. Unlike the case of the integers from the previous section, in these cases the device in question is capable of representing the target; more, the relevant stipulations are assumed to have been made so that the target is in fact being represented. By assumption, the representation is true, even accurate, under the conventions. Even so, there is an objective, non-pragmatic, sui generis sense in which it represents things less well, sui generis in not being merely a matter of the representation's truth or accuracy under the conventions.[8] (This is to understand accuracy as something like correctness, freedom from error, veracity, even precision: given the relevant stipulations, the representation possesses these qualities. One could instead construe accuracy as more akin to directness, in which case the notion will more closely align with the current sense of perspicuity.

[8]This may contravene certain accounts of representation, depending on the details: n. 21.

The important thing is that this is a quality of representation that is over and above its truth and is not merely a matter of its pragmatic benefits.)

All of this is to say that some representations in physics are intrinsically better—what I will call *more perspicuous*—than others. This notion of a perspicuous representation is similar to what Thomas Møller-Nielsen calls a "metaphysically perspicuous characterization," which is one that "corresponds to, or 'limns,' reality's structure in some suitably faithful way" (2017, 1257).[9] However, Møller-Nielsen goes on to say that a more perspicuous characterization is one that more faithfully represents the fundamental physical ontology, in the way that a formulation of classical electromagnetism in terms of the Faraday tensor rather than the potentials more directly represents a physical ontology of fields. I agree; but I wish to add that one representation can be more perspicuous than another in this sense even without a difference in ontology, as in the case of the different mathematical representations of the Euclidean plane. The different representations of the plane agree on a fundamental ontology of points, as it were—they equally faithfully or directly represent a space made up of points—but they differ in how faithfully or directly they represent the organization of those points; in how naturally they represent the space's structure.

Different representations in physics, then, can be more or less perspicuous than others; and what makes a representation better or worse in this way flows directly from the intrinsic natures of the representational vehicle and target. Some representational vehicles, by their very nature, will be better-suited than others to the nature of what's being represented, with the result that some representations will be more natural, more direct, less contrived than others. This is the case even granting that there will always be different representations one *can* use, and that in certain contexts some of these can be more useful than others (including

[9]Compare Jacobs' notion of a perspicuous formalism for a physical theory, which "match[es] the metaphysical picture provided" by the theory, or "directly correspond[s] to its metaphysical posits" (2022). Also compare Maudlin's notion of a "canonical presentation" of a physical theory, for which "the mathematical expression of the Nomology should be couched in [*sic*] only in terms of the Physical Ontology and the Spatiotemporal Structure" (2018, 13) rather than what he calls mathematical fictions or derivative ontology.

the less perspicuous ones).

Relatedly, a choice of representation can reasonably be criticized for more than either incoherence or pragmatic drawbacks. Someone who only ever employs a single-real-number representation of a plane, or a scrambled numerical version of Newtonian physics, or a formulation of classical electromagnetism in terms of the potentials—who may not even realize there is a more perspicuous representation to be had—can reasonably be faulted for missing something about the nature of the target. Recall Teitel's imagined community which stipulates that negative numbers do not represent the norms of timelike vectors. This community is not being incoherent, nor is there a pragmatic reason for rejecting their representational choice. Even so, they can reasonably be faulted for making a worse stipulation, one which suggests they are missing something about the nature of what's being represented (they are missing in particular something about the symmetries; below). There can be a physics that treats metrics of opposite signatures differently. General relativity is not such a physics,[10] yet this community does not seem to realize this. Compare a community which stipulates that a metric with opposite signature of what they ordinarily use to represent a Euclidean geometry does not also represent such a geometry. They, too, appear to be missing something about the nature of the target and the devices we can use to represent it, even if their choice is neither incoherent nor worse on pragmatic grounds.[11]

To be clear: a representation that is relatively imperspicuous is one that is true, it is correct, even accurate, under the representational conventions; it nonetheless lacks a further, sui generis good-making feature. A representation that is relatively perspicuous is one that not only is true, but also possesses a distinctive quality concerning the correspondence or match with what's being represented. (We might say there are two senses

[10] But see Gibbons (1994, 2012); de Haro and Butterfield (2025, ch. 11) for subtleties surrounding this standard idea.

[11] One might insist that a metric must be positive-definite in order to count as Euclidean. Such a stipulation is not as well-suited to the nature of the geometry. (Thus: "If the metric is positive-definite, then its canonical form must have all $+1$s, and the space is Euclidean. If the metric is negative-definite it is also said to be Euclidean, since what is important for the space is whether the signs are all the same or not" (Schutz, 1980, 66).)

of "getting it right" when it comes to representation, as Peter Finocchario (2023) puts it of belief: truth, and the relevant match.[12]) Representations that differ in perspicuity differ not in *what* is represented, but in *how* it is represented, the way in which it is represented. (Recall the two representations of the plane.)[13] A related notion has been a point of discussion in metaphysics for some time.[14] The aim of this paper is to advertise the idea as significant for physics.[15] And whereas discussions in metaphysics tend to construe the notion as tied to certain views of fundamentality and cognate ideas that many philosophers of physics recoil from, I wish to emphasize that even philosophers of physics who are chary of metaphysics should be open to the idea of there being such a quality of representation that is over and above its truth, which is moreover non-pragmatic and objective insofar as it concerns the intrinsic natures of a device and target and the relationship between them. It is a "worldly matter," as the metaphysicians say. It has to do with reality, with the nature of what is represented (notwithstanding the fact that it involves representation); it is objective in the sense of concerning "faithfulness to facts" about the world (Reiss and Sprenger, 2020, sec. 2), rather than being merely in or about or tied to us.

I won't be discussing the metaphysics literature in any detail here, but

---

[12]The two senses are that of a belief's being true, and its being "fidelic," which "is not merely a matter of truth" (Finocchario, 2023, 394). Sider (2024, 333) similarly mentions the idea of a belief's possessing more than just truth but also "something truth-like" that involves a "match with reality."

[13]Compare Russell: "Perspicuity is a feature of language, rather than of what that language says. The very same thing can be said either perspicuously or imperspicuously" (2018, 567). Eklund: "If it is possible for there to be two true sentences both of which correspond to or are made true by the same fact, or by the same aspect of the world, while one represents the world more perspicuously than the other, there must be some difference in *the way* in which these sentences represent the world" (2024, 16). Lee: "we value true representations above false representations. Nevertheless, …the *manner* of representation matters as well" (2024).

[14]Hawthorne and Cortens (1995); Fine (2001); Turner (2010); Sider (2011, 2024); Russell (2018); Finocchario (2023); Eklund (2024); Rubenstein (2024).

[15]Compare Møller-Nielsen (2017, 1257): "such a notion is frequently alluded to, and made use of, in contemporary analytic metaphysics…. But metaphysical perspicuity is also…a notion that is reasonably serviceable in physical (rather than 'merely metaphysical') contexts."

let me mention one reason I think the basic idea should appeal even to philosophers of physics of an anti-metaphysical bent. It is sometimes suggested in the metaphysics literature that a representation is imperspicuous to the extent that it distorts or approximates the fundamental or real or true facts.[16] I see the phenomenon evinced by the examples here a bit differently. The imperspicuous representations do not distort the true nature of the target, exactly, nor do they merely approximate it: they are by stipulation accurate, true, precise. (They may initially appear to distort things, until we pay proper attention to the representational stipulations that have been laid down, which correct for those distortions.) They are nonetheless worse, by virtue of being unnatural or contrived or indirect in a distinctive way, as a result of the inherent mismatch between representational device and target. This doesn't require committing to claims such as that one representation is given in more fundamental terms than another, or that sort of thing; not obviously or immediately so, anyway.[17] (This is to presuppose a distinction between the intrinsic nature or structure of a representational device or target, on the one hand, and the representational conventions we lay down, on the other. This flows from my (broadly structural realist) assumption that any given mathematical or physical entity has a particular structure, that there is a fact about its structure, which can effectively be undone by means of our representational stipulations laid down on top, as it were.)

You might think the very word "perspicuous," colloquially understood as meaning transparent or lucid *to us*, essentially concerns our own cognitive features and perspective and abilities, and so cannot signify a truly objective notion, in the sense of something that isn't tied to us. The current idea goes against that particular conception of the word: a

[16]Fine notes that certain propositions can fail to "*perspicuously* represent the facts—there will be some divergence between how the facts are 'in themselves' and how they are represented as being" (2001, 3). Russell says an imperspicuous way of saying something "distorts the way the world really is" (2018, 566). Rubenstein discusses the idea of a conception of reality that is "perspicuous, or less metaphysically distorted," where a fact is "better approximated as various layers of distortion are removed" (2024, 1108; 1114).

[17]But see Sider (2011) for sustained counterargument. Hunt (2021, 2022, 2023, forthcoming), discussed in Sect. 4, is an account that explicitly aims to avoid such metaphysical commitments. Lee (2024) disentangles perspicuity from fundamentality in a different way.

candidate representation can be perspicuous in this way even if there had been no human beings around to implement it.[18] I use the word because it nonetheless encapsulates the gist of what I have in mind, and to link things up to related uses in recent literature, in metaphysics as well as philosophy of physics.[19] But another term could be substituted instead, such as that of a representational device's being inherently "harmonious with" (Hawthorne and Cortens, 1995, 148), or well-suited or "well-tuned" to (Earman, 1989, 59), or which "matches" (North, 2021), the nature or structure of a target. As mentioned, I won't enter here into discussion of exactly what it takes for there to be the requisite well-suitedness or match, the "suitably faithful" correspondence, in Møller-Nielsen's phrase. That will depend on one's conception of the relevant notion of structure,[20] and may involve one's views on scientific representation[21] and theoretical

[18]This is not to say that scientific representation is "radically naturalized" in the sense of Suárez (2003): that the holding of a representation in no way depends upon a user's aims and intentions or other extrinsic factors. A candidate representation can be perspicuous even if an agent is required to stipulate it into being a representation (compare Bartels (2006) on actual versus potential representation).

[19]Instances in philosophy of physics include Wallace and Timpson (2010); Møller-Nielsen (2017); Martens and Read (2021); North (2021); Jacobs (2022); Albert (2023, 123); Chen (2024a,b); Coffey (2024); Lee (2024); March (2025); Weatherall and Meskhidze (2025).

[20]See Dewar (2023) on how different conceptions of structure will result in different conceptions of a match in structure.

[21]According to so-called structural accounts, a certain kind of mapping or morphism between the structure of a vehicle and target is required for representation, with debate as to what kind of mapping is needed (discussion and references in Suárez (2010); Boesch (2015); Frigg and Nguyen (2021); Nguyen and Frigg (2022); Frigg and Hartmann (2025)). The current discussion aims to be neutral on an account of representation. That said, to the extent that such an account denies there can be anything to the perspicuity of a representation over and above its truth—if one denies the real-number representation of the plane is a representation (or even just an accurate one), say—I am effectively arguing against it. (The cognoscenti will notice that there are therefore ways in which the current discussion agrees with a broadly structural account of representation, and ways in which it departs from it. Although one might think that a structural account is unable to allow for the above sense of perspicuity since a certain match in structure is required for representation (or accurate representation) to begin with, my own view is that such an account can (and should) allow for differences in the quality of the relevant match as we see in the examples here.)

equivalence,[22] among other things, whereas the basic idea should appeal to philosophers of physics holding disparate views on such matters. For current purposes, we may rely on an intuitive if imprecise idea of there being an appropriate match or correspondence, as exemplified by the topological structure of ordered pairs of real numbers vis-à-vis the Euclidean plane, while leaving it open exactly what the appropriate sort of match or correspondence amounts to.

It is worth briefly noting the relevance of symmetries. One way for a representation to be more perspicuous than another is for the representational device to more directly reflect the symmetries of the target. (Recall Teitel's example earlier: the representation chosen by that community is less perspicuous since it fails to reflect the symmetries of the physics.) This is because one way of characterizing something's structure is in terms of its symmetries (on a so-called Kleinian conception, this is how to define a given mathematical structure).[23] The representation of the plane in terms of single real numbers is less perspicuous than the one in terms of ordered pairs since the set of real numbers is not topologically equivalent to the plane, and this is something that can be spelled out in terms of symmetries: the real numbers do not possess the topological symmetries of the plane, and so can only represent the plane in a convoluted way. A random permutation of our usual numerical representations of Newtonian states is less perspicuous since it will fail to possess the symmetries of a physical quantity like mass, and so can only represent those symmetries very indirectly. In general, a mismatch in symmetries will mean the device can only represent the target in an indirect and unnatural fashion.[24]

[22]According to so-called formal accounts, a certain type of mapping between theoretical structures is required (or perhaps even suffices) for physical theories to be equivalent, with debate as to what sort of mapping is required; discussion and references in Weatherall (2019a,b).

[23]This is not to say that all mathematical structures can be defined this way, which is an active point of debate (Barrett, 2018, 2022; Wallace, 2019; Barrett and Manchak, 2024, 2025; Gomes et al., 2024).

[24]This is not to take a stand on whether a "sophisticated" attitude toward symmetries (Dewar, 2019) makes for a more or less perspicuous representation. The "intrinsic" or "reduced" representation would generally seem more perspicuous, because more direct. But this turns on further questions concerning intrinsic formulations and explanations,

You might still regard this quality of representation as essentially dependent upon us and our own parochial situation. Ordered pairs of real numbers better enable us to discover features of the plane. Our usual mathematical representations of Newtonian systems better serve our purposes of making predictions and calculations straightforwardly. For that matter, a mathematical apparatus with cardinality greater than the integers allows us to do Newtonian physics. If we didn't care about discovering the nature of things or doing physics in any way, then any other representation would be just as good. Relatedly, even granting that some representational devices can be so unmatched to the nature of the target that it is only by means of highly unnatural stipulations that the representation can be implemented, you may still question whether this makes for an *objectively* worse *representation*. The requisite stipulations may be utterly bizarre and unnatural, even unusable—but they are bizarre and unnatural and unusable for us. God should be able to use such a thing just fine.

I suppose one can for these reasons consider this a subjective and pragmatic phenomenon, centrally tied to us; but only to the extent that physics, and representation more generally, is a subjective and pragmatic affair by virtue of being something that creatures like us are interested in and have a use for. God may not care about such a difference in representation, but God has no need for representation, let alone physics, at all. It doesn't follow that this aspect of representation must be dependent upon us in any deep way. Compare: it doesn't follow from the fact that physics is the kind of thing that creatures like us have a use for and interest in, and God does not, that the claims of physics must all be either subjective or only of practical value.[25] In the cases here, even if creatures like us had never existed, there would still be a fact as to the match in structure between device and target, hence the perspicuity of the resulting representation (should there have been agents around to implement it (n. 18)), which even God can allow.

It may be that at the end of the day, the opposition between objective, on the one hand, and subjective, pragmatic, and/or conventional, on the other, is not the most useful. I take it there is enough to these

in the sense of Field (1980): see Jacobs (2022); March (2025) for discussion.

[25]See Robertson and Prunkl (2023) for a related point in the case of thermodynamics.

distinctions, encapsulated by whether a phenomenon is tied to us or to things themselves, to be elucidating in the present context. But this is not the place to bear down fully on these notions. So suppose we set this aside and allow that objectivity, and hence perspicuity in the current sense, is a matter of degree.[26] Then we should all be able to agree that, say, the ordered-pair representation of the plane is objectively good or perspicuous to a greater degree than the single-real-number one. At the end, I am going to suggest that this difference in degree matters to physics in a distinctive way that other sorts of differences between representations do not.

4. Intermediate Notions

You might agree that there is a sense of perspicuous representation in physics that is not just a pragmatic matter, but think that it occupies a middle ground between that kind of thing and the more objective and intrinsic notion I have in mind. In this section I turn to recent views in philosophy of physics taking such an intermediate stance. The considerations against them will be related to the above, but additional examples will drive things home differently, and will also point toward one way an account of perspicuity might go.

Josh Hunt (2021, 2022, 2023, forthcoming) argues that some representations can be better than others by virtue of imparting greater intellectual understanding to us. They do this by making certain features manifest to us in certain contexts, with the result of ruling out epistemically possible solutions to a given problem of interest. (Hunt's focus in on reformulations of scientific theories. In his terms, what I call a perspicuous representation is a "significant reformulation.") A representation that is good in this way possesses a kind of non-practical epistemic value he calls "intellectual value." David Wallace and Christopher Timpson likewise suggest that one representation can be what they call "more perspicuous" than another, by virtue of "mak[ing] manifest the structure that the theory ascribes to the world" (2010, 702), thereby helping us achieve

[26]See Nagel (1986, 5); Reiss and Sprenger (2020) on objectivity's coming in degrees.

true understanding.[27] (They too are concerned with different theoretical formulations.) On this kind of view, the perspicuity of a representation concerns things tied to us and our intellectual aims in a context rather than the direct relationship between the intrinsic natures of a device and target. A representation that is good in this way is merely epistemically perspicuous, rather than also metaphysically perspicuous: an intuitively more subjective sense of perspicuity. (It can be an objective matter that a certain way of representing things yields a difference in understanding for us. The epistemic notion is nonetheless intuitively less objective by virtue of being tied to us.)

I am in agreement that a perspicuous representation is good in a distinctive way that concerns more than its pragmatic benefits and brings with it a certain intellectual value. But I think this does not go far enough in accounting for what makes it good in this way; why it possesses this value. The two-dimensional representation makes features of the plane manifest to us in a way that the one-dimensional representation does not. Yet (assuming there are facts as to the intrinsic structure of the plane) there is an underlying reason for this that is not tied to us: these features are more directly aligned with it. This mathematical tool is inherently better-suited to the nature of the plane; that is why it makes these features manifest. It is not merely that such a representation is good for us, that is, helping us understand things better in the context (though it is good in that way). It is also good in a sense that is independent of us and the context. It more faithfully corresponds to the structure of the plane, which is why it yields better understanding. It "enable[s] us…to get a clearer view" of things (Hawthorne and Cortens, 1995, 156) because it more directly aligns with them.

Or consider using a polar versus Cartesian coordinate system to describe the Euclidean plane. On the current view, neither type of coordinate system gives rise to an intrinsically better representation than the other. Each simply makes manifest to us different features of the plane, which can be epistemically significant to us in different contexts.

It is of course true that we can represent the plane either way. Yet as with ordered pairs versus single real numbers, so too are Cartesian

[27] See also Wallace (2012, Ch. 8.8). Neil Dewar, in a 2023 talk titled "Against 'Perspicuity'," has defended a similar idea.

coordinates better-suited to the space. Consider the plane's affine structure. Straight lines in the plane will be represented by linear functions of Cartesian coordinates, and linear functions correspond to straight lines. In polar coordinates, straight lines will generally be given by non-linear functions, and circular arcs can "appear" straight according to the coordinate function describing them. Similarly for the metric structure. Distances in the plane are given by a straightforward function of Cartesian coordinate differences ("Cartesian coordinates [are] such that coordinate differences equal Euclidean distances" (Glymour, 1977, 247)), unlike in polar coordinates.[28] The conventions will be such that the polar coordinate representation ultimately agrees as to the straight lines and distances in the plane; and polar coordinates will be better-suited to other kinds of spaces and to certain shapes and curves on the plane. Nonetheless, the Euclidean plane itself, its intrinsic nature, is more directly aligned with Cartesian coordinates, in the same way that cylindrical coordinates, in another example, are directly aligned with the nature of a cylinder. (Hunt says these simply make manifest to us features like the cylinder's length.)

Hunt rejects the alternative view for its commitment to substantial metaphysical notions such as natural kinds or fundamentality or the like, and he is especially concerned about our epistemic access to such things. As mentioned above, the basic idea may not require such commitments. Regardless, the scientific realist, at least, needn't be too bothered about these concerns of epistemic access, which are not so different in kind from those that arise for scientific realism itself. Even if we can never get outside our own perspective in order to ascertain that one representation is better than another by virtue of directly aligning with the nature of things and not merely because of the better understanding it affords us,

[28]Thus Gomes et al. (2024): "A *Cartesian coordinate system* on $\mathbb{E}^2$ is defined in terms of, and thus adapted to, the geometric structure of $\mathbb{E}^2$. The coordinate axes are chosen to be *straight*, *orthogonal* lines, and the coordinate values of a point are given by the (signed) *distances* from the corresponding axis. The terms emphasized in the previous sentence all advert to the geometric structure of $\mathbb{E}^2$. The definition secures that the distance $d(p,q)$ between two points p and q with coordinates (x_p, y_p) and (x_q, y_q) is encoded by the simple coordinate function $d(p,q) = \sqrt{(x_p - x_q)^2 + (y_p - y_q)^2}$." See Barrett (2022); Barrett and Manchak (2024, 2025); Jacobs (2025) for disagreement with aspects of this idea.

we can have good reason to infer this (more immediately below and in Sect. 5)—just as we may never be able to conclusively determine that a given scientific theory is (approximately) true, but we can have good reason to infer this. (You do not have to be a scientific realist to think there is a sui generis sense of perspicuity of representation, yet the idea goes naturally with realism: it is natural to think a perspicuous representation directly matches the true nature of things. That said, there are scientific realists who demur, such as Wallace and Timpson.)

Although the intermediate view might seem to be on firmer epistemic footing by virtue of committing to less (as Hunt, for one, suggests)—maintaining that some representations are better merely by virtue of making certain features manifest to us, without also committing to claims as to the underlying nature of things (claims that may furthermore bring in some heavy-duty metaphysics)—I think it is the alternative that is ultimately on the better epistemic footing. Compare something the scientific realist might say to the constructive empiricist who withholds belief in a theory's claims about the unobservable, while believing its claims about the observable. The realist has a better explanation as to *why* we should believe the theory's claims about observable phenomena—namely, its claims about the unobservable are true—which ultimately puts the realist in the better epistemic position. (Why believe in the atomic theory's claims about the observable if not for the truth of its claims about atomic behavior?) Analogously here. There is an underlying reason the perspicuous representation makes various features manifest to us, something that accounts for its superior intellectual value for us: which is that it more directly mirrors those features, thereby giving us a clearer view of them. In each case, "going deeper" results in explanatory power.

Another idea is to regard a representation's perspicuity as a matter of convention as much as the choice of representation itself is. Caspar Jacobs (2025) argues that no representation is intrinsically better than any other, because the quality of a representation depends on the chosen conventions, and different representations will be equally good under some representational convention or other. (His discussion is aimed at the question of how to define inertial frames, but in the course of criticizing one particular view on this, he addresses aspects of representation more generally.) Whereas a flat two-dimensional map may at first appear to misrepresent the earth, for example, given the appropriate conventions, it will represent the earth perfectly accurately. The adaptedness or suitedness of a representation, even the well-adaptedness or well-suitedness, is simply a matter of the representational conventions we lay down, any device being perfectly well-suited with the appropriate conventions. (Note that Jacobs does not take the quality of representation to invariably be wholly a matter of pragmatic or other intuitively subjective factors either: his is an intermediate idea.[29])

I agree that the map represents the earth accurately—with the appropriate conventions, the map is adapted to the earth—but I disagree that it is therefore just as *well*-suited or well-adapted to it as any other device. Just as there is no representational convention under which single real numbers represent the plane as well as ordered pairs, so too there is no convention under which the map is as well-adapted to the earth as a globe, the reason in each case being the mismatch in topology. Take a one-dimensional space in which point q is between points p and r, according to the space's topological structure, and consider a representation that assigns the number 8 to q, 4 to p, and 3 to r. The appropriate conventions will ensure that this represents the space accurately, that it is adapted to the space: just stipulate that q is between p and r, despite what the numerical representation seems to suggest. But it is not particularly well-adapted to it: this is an indirect, unnatural, contrived representation. (A more perspicuous representation would assign a number to q that is itself (on the standard topology) between the numbers assigned to p and r.[30]) On the assumption that there is a convention-independent fact as

[29]He argues in particular that a representation of spacetime structure can be privileged by the dynamical laws and their symmetries.

[30]Jacobs (2025, 12) writes of the mismatch in topology in the case of the map: "On the convention that a discontinuity in coordinates represents a discontinuity in spacetime, the map's coordinates are mal-adapted to spacetime's topological structure. But on the alternative convention that the −180° and 180° coordinates represent adjacent locations, the map does represent the Earth as round. (Compare this to a clock face: the fact that the number 1 does not come after the number 12 does not mean that one o'clock does not follow noon!)" I agree, the conventions ensure the device accurately represents the target. But I disagree that it is thereby perfectly well-suited to it. There is a failure in well-suitedness precisely because the topological structure of the target (time; the earth)

to the intrinsic structure of a space and a mathematical device we might use to represent it, there will be a convention-independent fact as to the match in structure between them, hence the perspicuity of the resulting representation.

In claiming that all representations are equally good under some convention, Jacobs is discounting the nature of the representational conventions themselves. Even without offering a full-fledged account of the perspicuity of representation, I take the examples here to show that a device can be inherently well-suited to a target, by virtue of a match in nature or structure between them, which ensures that the representational mapping will be relatively natural, direct, uncontrived; so that the representational conventions needn't override or undo the structure of the device. (As a side note, the opposing view would seem to eviscerate the notion of admissible coordinates familiar from physics. An admissible coordinate system is one that in some sense adequately or sufficiently respects a given structure. But if any coordinate representation is just as good or well-adapted as any other under some representational convention, then it is hard to see how to distinguish between the admissible and inadmissible coordinatizations.)

As a final thing to press the above thought and point toward one way an account of perspicuity might go, consider an idea from Maya Eddon (2014).[31] Consider the following from Brian Ellis (1960). Take two rods of equal length. What is the length of the two rods together? Lay them end to end, and we get a result that is twice as long as either one on its own. But what is to say that this is the way to measure their lengths taken together? Imagine laying down the second rod so that it is orthogonal to the first, and then taking the length along the hypothenuse formed by the resulting right triangle. Why not consider this to be twice the length of either rod? We could even choose a unit—Ellis gives us "dinches" (for "diagonal inches"), where n dinches equals n^2 inches—so that the putting together of lengths using the "right-angle rule" is additive as much as

does not match that of the representational device (the clock face; the map), so that a discontinuity in the device will have to be used to represent (indirectly, unnaturally, imperspicuously) a continuity in the target. The representation fails to be continuous in the same way or sense as the target.

[31] I am indebted to Caspar Jacobs for suggesting the connection to Eddon's discussion.

the usual way of putting together lengths is. What justifies our feeling that the usual measuring procedure and units are natural, the right-angle procedure and diagonal units not? In other words: in what sense is the usual way of representing lengths better than the intuitively wonky way? If there is no answer beyond its being a matter of convention, then the choice starts to "look very arbitrary" (Ellis, 1960, 46).

Focusing on the choice of scale, Eddon gestures at an answer: our usual way of representing lengths employs "perspicuous scales," for which "the numbers representing the scalar magnitudes stand in the *very same* relations as the scalar magnitudes themselves" (2014, 289).[32] Without taking a stand on whether numerical identity is the right thing to say (which would divert discussion to identity conditions on relations), we can see in this a like-minded idea. Focus on the measuring procedure, and assume for sake of discussion that the rods have negligible width and are in a background space, so that the length corresponds to the distance between the spatial points at which a rod's endpoints are located. On the assumption that there are facts about the space's (affine and metric) structure, there will be facts as to the distances between pairs of points given by the length of a geodesic between them (adding up infinitesimal distances between nearby points via local geodesics). Laying the rods at a right angle to find the length of the two together does not follow a geodesic—the second rod by hypothesis changes direction—and thus does not directly reflect the distance, in the sense of the length of a geodesic, between the outer endpoints. Laying the rods together in the usual way follows a geodesic, so that this measuring procedure directly aligns with distances.[33] Perspicuity on this idea involves a certain similarity between the notions characterizing the intrinsic structure of a target (such as distances in a space) and a representational device (a procedure for measuring distances; cf. n. 30)—on Eddon's suggestion, it is an identity of the relations between respective constituents—which results in a representation that is direct, natural, uncontrived. (Imagine

[32]This brings to mind the structural account of representation, though there are differences. The notion of perspicuity per se comes apart from such an account (n. 21).

[33]This is on the usual conception of distance in differential geometry and physics, which is not to say this is the only possible conception (Bricker, 1993). It is to say that, given this conception, one mathematical representation more perspicuously reflects it.

representing the length of a single rod by means of a circuitous path between its endpoints, while adopting units that counter the distortion—a contrived, unnatural, indirect representation.)

Once again, I am not here offering an account of perspicuity, which will turn on issues I wish to remain neutral on for present purposes. Eddon's discussion shows there are ways for such a thing to go. In any case, the basic idea should be clear. It concerns a match or alignment in nature or structure between a representational device and target in physics. Recall related ideas in metaphysics. A perspicuous representation "is not only true but reflects reality's structure," it "reflects reality itself" (Rubenstein, 2024, 1112, 1118); it "gets it right" in two senses (Finocchario, 2023)—a matter not of factors tied to us but of things themselves.

5. Perspicuity and Theoretical Equivalence

The above examples foster the intuition that there is a distinctive sense of perspicuity of representation. Yet the notion can seem fairly puzzling when pressed in a slightly different direction. The different representations in question are all representations of the same thing; by assumption, they have the same content, they just present it differently. This makes it hard to see how there really can be any objective or non-pragmatic differences as I have been suggesting. After all, that would seem to render the choice of representation a substantive choice, and yet a disagreement over how to represent something is the paradigm of a mere notational or verbal disagreement—a dispute over how to describe or talk about things, not about things themselves. That isn't a real disagreement: nothing of significance is at stake.[34]

Relatedly, if there is an objective and non-pragmatic sense in which some representations are more perspicuous than others, then there would seem to be an objective and non-pragmatic sense in which representations differing only in how perspicuous they are, are not equivalent. That too

[34]Thus Chalmers: "Intuitively, a dispute between two parties is verbal when the two parties agree on the relevant facts about a domain of concern, and just disagree about the language used to describe that domain. In such a case, one has the sense that the two parties are 'not really disagreeing': that is, they are not really disagreeing about the domain of concern, and are only disagreeing over linguistic matters" (2011, 515).

sounds wrong. Consider different formulations of a physical theory. Pick your favorite example—matrix and wave quantum mechanics, fields and potentials versions of classical electromagnetism, Lagrangian and Hamiltonian classical mechanics, etc. The two formulations are said to be theoretically equivalent, mere notational variants—they say all the same things, just in different ways—with no substantial, non-conventional, non-pragmatic differences between them.[35]

This is right to an extent, but it elides something important. Examples from the history of physics show that how we represent things matters to physics in a distinctive way. Just as the earlier examples suggested that there is more to the quality of a representation beyond truth or pragmatic factors and which underlies any intellectual value, so too when it comes to different formulations of a physical theory. There can be good theoretical reason for choosing one formulation over another, even from among different ones that are all true. In such a case, there is a kind of substantive choice to be made (even if it may not be evident at the time which one we should make). Something of significance beyond mere notational matters is at stake.

Take the theory of classical electromagnetism, which Maxwell initially formulated in terms of the vector and scalar potentials, in twenty or so equations. It was Oliver Heaviside who jettisoned the potentials, and in so doing came up with the improved and streamlined version we are familiar with today.[36] As Heaviside explains in his writings, he was motivated by thinking clearly about the nature of the physical reality characterized by the theory—classical electromagnetism governs a world of physical electric and magnetic fields, not potentials (which are mere mathematical devices that do not directly correspond to anything physical)—and aiming at a formulation that directly represents this reality: he was aiming at a perspicuous formulation.[37] (This is not to deny there are alterna-

[35]An overview of accounts of theoretical equivalence is in Weatherall (2019a,b).

[36]Equations involving field quantities appear in Maxwell (1890), but Heaviside gathered and streamlined them, furthermore eliminating the potentials (and making use of a mathematical innovation of vector calculus). Maxwell "made the electromagnetic potential the centerpiece of his theory," whereas "Heaviside replaced the electromagnetic potential field by force fields as the centerpiece of electromagnetic theory" (Barrett and Grimes, 1995, vii).

[37]See Heaviside (1892, 173, 481–5, 511) and (1893a, Preface). He wrote that he

tive ontologies one could posit for a classical theory of electromagnetic phenomena. For current purposes, assume the theory governs a physical reality of fields, as Maxwell and Heaviside both thought, and as we nowadays familiarly conceive of it.[38])

By assumption, Heaviside's is a reformulation of Maxwell's theory. It says all the same things, just in different ways; it characterizes the same kind of physical reality; it agrees on the way the world is (the potentials in particular are stipulated to be alternative mathematical tools for characterizing the fields). However (by above assumption), it is more perspicuous, and this resulted in theoretical progress. For one example, it made evident an asymmetry in the equations applied to moving bodies that is not present in the phenomena (the theory gives a different account of electromagnetic induction depending on whether the conductor or the magnet is in motion, although the observed phenomenon depends solely on their relative motion), which prompted Einstein to his special theory of relativity.[39] For another, it made clear a mathematical symmetry between gravitational and electromagnetic phenomena, which led Heaviside (1893b) to note early on the possibility of gravitational waves.

Particular scientific discoveries were enabled by the perspicuous formulation, the one that more directly reflects the nature of the physical reality being characterized, thereby yielding a clearer view of it. Imperspicuous formulations can mislead us about this—as a potentials formulation of classical electromagnetism can mislead us into thinking there are things that travel faster than the speed of light, when we shouldn't

formulated the theory in terms of fields "instead of the potential functions which are such powerful aids to obscuring and complicating the subject, and hiding from view useful and sometimes important relations" (1893a, Preface).

[38]That is, electric and magnetic fields, in the case of Maxwell and Heaviside's theory; in the relativistic regime, electromagnetic fields. See Maudlin (2018) on different ontologies one might posit, each of which results in a distinct theory, albeit they bear commonalities leading each to be regarded as a theory of classical electromagnetism. (Strictly speaking, "the theory of classical electromagnetism," as I call it at the beginning of the paragraph, needs to be disambiguated; for our purposes, assume this is done in part by way of the above assumption about fields versus potentials.) Cf. North (2021, ch. 7) on differences and similarities between distinct theoretical formulations.

[39]In his original paper, Einstein does not mention the potentials, and references what he calls the Maxwell-Hertz equations, which are Heaviside's version of the equations.

take this physically seriously: it is just an artifact of an imperspicuous formulation. This kind of misleadingness can hinder discovery. Einstein once said the reason it took him so long to develop the general theory of relativity, once he had discovered special relativity, is that "it is not so easy to free oneself from the idea that co-ordinates must have an immediate metrical meaning" (Schilpp, 1970, 67). Theoretical progress was in this case hampered by a relatively imperspicuous formulation in terms of coordinates.

The intermediate views from Sect. 4 can of course agree somewhat. Hunt and others can allow that a perspicuous representation, which imparts greater understanding to us, will for that reason yield theoretical progress. Yet on that kind of view, remember, this is simply because it makes various features manifest to us, with no underlying reason as to why it does. Thus, the potentials formulation of classical electromagnetism simply obscures from us aspects of the physical reality that is being characterized.

One hankers after an explanation for the alternative formulation's success in this regard, and the natural thought is that it more directly aligns with the nature of things. The fields formulation better reflects the nature of the physical reality depicted; that is why it offers a less obscured view that yields theoretical progress. (A theoretical formulation that randomly assigns numbers to systems so as to enable us to use a huge lookup table in order to infer true things about them would be too misaligned with reality to do that.) The perspicuity doesn't bottom out at its perspicuity for us (its epistemic perspicuity), but at the direct match with reality that underlies and accounts for its perspicuity for us (its metaphysical perspicuity).

This isn't to say that an imperspicuous formulation can never result in, or has never resulted in, theoretical progress, or that we could not have stumbled upon the relevant scientific discovery by means of such a formulation; of course not.[40] It is to say that, just as the scientific realist

[40]Maxwell made theoretical progress by means of his formulation, which he combined with a fictional molecular vortex model of fields (Siegel, 1991; Bokulich, 2015). It remains a large and interesting question why fictions and idealizations can yield scientific understanding and progress, which I do not address here. Note the potentials formulation may be more perspicuous when it comes to the extension to quantum

regards a certain level of empirical success as evidence of a theory's truth (even though we might be wrong about this, and even though there have been empirically successful theories which turned out to be false), so too a certain level of theoretical progress is evidence that a formulation is not only true but also perspicuous (even though we might be wrong about this, and even though imperspicuous formulations can result in theoretical advances). It is not my aim here to argue for the standard realist position that various theoretical virtues (predictive success, explanatory power, and so on) are markers of (approximate) truth; but to the extent they are, so too are they (theoretical discovery in particular) evidence of perspicuity—evidence that a theoretical formulation is getting it right in both senses (as per Finocchario (2023)).[41]

This goes hand in hand with thinking that the goal of science is not simply to get at the truth about the world, as the scientific realist in any case believes, but to characterize the world well. David Baker (2023) calls this attitude "robust realism," where "an important goal of theorizing is to put forward a theory that is not merely true in its propositional content, but also matches the structure of reality."[42] The success of a theory is in turn evidence not only that it is true, but that it matches that structure. This also goes hand in hand with thinking that the goal of science is more than successful prediction, but also explanation. The more perspicuous representation—think of classical electromagnetism in terms of fields—generally yields the better explanation of the phenomena, for it invokes what is really going on physically rather than couching things in terms of indirect mathematical contrivances.[43]

Other cases reveal more generally that features specific to a particular formulation can guide us toward discovering things about physical reality we didn't previously know—as Bell noticed that, as a mathematical

theory; the claim is that Heaviside's is more perspicuous with respect to its own domain. For an opposing viewpoint, see de Haro and Butterfield (2025, 13.2.1).

[41] Compare Sider: "A good theory isn't merely likely to be *true*.... For the conceptual decisions made in adopting that theory... were vindicated; those conceptual decisions also took part in a theoretical success, and also inherit a borrowed luster" (2011, 12).

[42] Again compare Sider: "The goal of inquiry is not merely to believe truly (or to know). Achieving the goal of inquiry requires that one's belief state reflect the world" (2011, 61).

[43] See North (2021, ch. 7).

consequence of the usual formalism for quantum mechanics, no local theory can reproduce all the standard predictions (as experiment later confirmed); or as Aharanov and Bohm derived their eponymous effect from the formalism of quantum mechanics applied to electromagnetic phenomena (also later experimentally confirmed; and which further suggested to many the physical reality of the potentials in the quantum realm).[44] Mathematical aspects of a particular theoretical formulation were shown to have profound physical implications.

When developing a physical theory, we don't start out knowing everything about physical reality and formulating a theory that directly mirrors it. We start out knowing some things, and formulating a theory that reflects what we know reasonably well; at which point we might revise the formulation in light of the theory's picture of reality (as Heaviside did with classical electromagnetism), or discover new things about physical reality on the basis of a particular formulation (as Heaviside and Einstein did with classical electromagnetism, Bell with quantum mechanics, Aharanov and Bohm with quantum electromagnetism). Theoretical progress involves a back and forth between a theory's formulation and its conception of physical reality, adjusting one in light of the other, and different formulations can affect this process differently. The choice of formulation can in this way be more than a choice of the shallow sort that is a hallmark of mere notational or conventional matters. Something of significance is at stake.

So although in one sense the different theoretical formulations that are said to be notational variants are equivalent—by stipulation, they say all the same things, just in different ways—in another, physically significant sense, they are not fully equivalent or *mere* notational variants. Particular scientific discoveries were enabled by the perspicuous representation, the one that is better in this sui generis sense that is not just a matter of truth or pragmatic or intellectual value, but of the alignment with the nature of physical reality.

[44]These are reasonably standard, if not uncontroversial, takes on the two cases (Aharonov and Bohm, 1959; Belot, 1998; Maudlin, 2014). Note that I am taking classical electromagnetism (with an ontology of electric and magnetic fields) and quantum electromagnetism (with a potentially different ontology) to be distinct theories; cf. n. 38.

6. Conclusion

A merely pragmatic, epistemic, or conventional take on the various sorts of differences in quality between different representations—an extrinsic and intuitively subjective take that chalks up any such difference to things tied to us—cannot account for all facets of mathematical representation in physics. There is a sui generis sense in which one representation in physics can be better than another, a sense that is not just a matter of truth or accuracy, but concerns the extent of the alignment between the nature of the mathematical apparatus and what is being represented—in the way that ordered pairs better align with the nature of the plane than single real numbers do, even though with the appropriate stipulations each will yield a true, even accurate, representation of the plane.

Even those who disagree with me can allow for various epistemic and psychological differences between otherwise-equivalent theoretical formulations or representations, including differences in their capacity to guide us in cases for which we do not yet know the full nature of things. And yet, this may still seem entirely specific to our own situation. Maxwell's formulation of classical electromagnetism should be just as good as Heaviside's as far as God is concerned—God has no need to be guided toward the nature of things. Perhaps the different representations cannot differ in any way that isn't tied to us, after all.

I take the examples here to show that a difference in perspicuity is not just about us, notwithstanding the fact that we are the ones who devise and make use of these representations. Even God, with no need for representation, can allow that certain representational vehicles more directly match the nature of things. That one representation is for this reason better than another is intuitively tied to it, not to us.

However, at this point we can fall back on the idea that objectivity, and with it perspicuity, comes in degrees. Then we do not have to settle whether Heaviside's formulation is objectively better, full stop, given that Maxwell's will be just as good as far as God is concerned. We can say that it is objectively better or perspicuous to a greater degree. The important thing is that this difference in degree *matters* to physics, which aims at more than just truly characterizing the world, but at characterizing it well. The choice of formulation or representation may be up to us in that we could always decide to use another one without loss of content; not always without losing something else of significance to physics.

Not every difference between representations will be significant in this way. Describing a system's center of mass as being at one versus another coordinate location, or stating a theory in French as opposed to English, or formulating quantum mechanics in terms of matrix versus wave mechanics, is not.[45] But to take *all* representational choices in physics to be on a par with the choice between different coordinates or natural languages or a matrix algebra versus differential wave equations—to say that all representations are equally good, differing at most in pragmatic or other sorts of subjective respects that are tied to us—is to lump too much together. The difference may be a matter of degree, but the degree matters. Some representations are objectively better for physics.

Acknowledgements

I am grateful to David Builes, Valeriya Chasova, Sebastian de Haro, Josh Hunt, Caspar Jacobs, Ted Sider, two anonymous reviewers for this journal, and audiences at an online workshop on symmetries in physics hosted by Valeriya Chasova; the European Conference on Foundations of Physics; the Annual Conference of the British Society for the Philosophy of Science; the physics and philosophy departments at Reed College; and the LanCog Summer Metaphysics Workshop in Lisbon. This research was funded in part by the National Science Foundation (grant no. 2419293).

References

Aharonov, Y. and D. Bohm (1959). "Significance of Electromagnetic Potentials in the Quantum Theory." *Physical Review* 115, 485–491.

Albert, David Z (2023). *A Guess at the Riddle: Essays on the Physical Underpinnings of Quantum Mechanics*. Cambridge, Mass.: Harvard University Press.

[45]The last case can be debated on perspicuity grounds (North, 2021, ch. 7).

Baker, David John (2023). *Symmetry in Physics and Metaphysics*. Unpublished mansucript.

Barrett, Terence William and Dale Mills Grimes, eds. (1995). *Advanced Electromagnetism: Foundations, Theory and Applications*. Singapore: World Scientific.

Barrett, Thomas William (2018). "What Do Symmetries Tell Us About Structure?" *Philosophy of Science* 85(4), 617–639.

—— (2022). "Coordinates, Structure, and Classical Mechanics: A Review of Jill North's *Physics, Structure, and Reality*." *Philosophy of Science* 89, 644–53.

Barrett, Thomas William and J. B. Manchak (2024). "On Coordinates and Spacetime Structure." *Philosophy of Physics* 2, 1–24.

—— (2025). "What Do Privileged Coordinates Tell Us About Structure?" *Philosophy of Science* 92, 528–547.

Bartels, Andreas (2006). "Defending the Structural Conception of Representation." *Theoria* 21(1), 7–19.

Belot, Gordon (1998). "Understanding Electromagnetism." *British Journal for the Philosophy of Science* 49, 531–555.

Boesch, Brandon (2015). "Scientific Representation." *Internet Encyclopedia of Philosophy* URL `http://www.iep.utm.edu/sci-repr/`.

—— (2017). "There *Is* A Special Problem of Scientific Representation." *Philosophy of Science* 84(5), 970–981.

Bokulich, Alisa (2015). "Maxwell, Helmholtz, and the Unreasonable Effectiveness of the Method of Physical Analogy." *Studies in History and Philosophy of Science Part A* 50, 28–37.

Bricker, Phillip (1993). "The Fabric of Space: Intrinsic vs. Extrinsic Distance Relations." In P. A. French, T. E. Uehling, and H. K. Wettstein, eds., *Midwest Studies in Philosophy*, vol. 18, pp. 271–294. Notre Dame: Notre Dame University Press.

Callender, Craig and Jonathan Cohen (2006). "There Is No Special Problem About Scientific Representation." *Theoria* 21(1), 67–85.

Chalmers, David J. (2011). "Verbal Disputes." *Philosophical Review* 120, 515–566.

Chen, Lu (2024a). "Algebraicism Is Not Substantivalism." *Philosophy of Physics* 2, 14(1), 1–26.

—— (2024b). "Symmetries as Isomorphisms." *British Journal for the Philosophy of Science* doi:10.1086/733266.

Coffey, Kevin (2024). "(Competing?) Formulations of Newtonian Gravitation: Reflections at the Intersection of Interpretation, Methodology, and Equivalence." *Journal of Philosophy* 121(11), 628–656.

Dasgupta, Shamik (2011). "The Bare Necessities." *Philosophical Perspectives* 25(1), 115–160.

de Haro, Sebastian and Jeremy Butterfield (2025). *The Philosophy and Physics of Duality*. Oxford: Oxford University Press.

Dewar, Neil (2019). "Sophistication about Symmetries." *British Journal for the Philosophy of Science* 70(2), 485–521.

—— (2023). "On Internal Structure, Categorical Structure, and Representation." *Philosophy of Science* 90(1), 188–95.

Dürr, Patrick and James Read (2024). "An Invitation to Conventionalism: A Philosophy for Modern (Space-)Times." *Synthese* 204: 1(1), 1–55.

Earman, John (1989). *World Enough and Space-Time*. Cambridge, Mass.: MIT Press.

Eddon, M. (2014). "Intrinsic Explanations and Numerical Representations." In Robert M. Francescotti, ed., *Companion to Intrinsic Properties*, pp. 271–290. Berlin: De Gruyter.

Eklund, Matti (2024). *Alien Structure*. Oxford: Oxford University Press.

Ellis, Brian (1960). "Some Fundamental Problems of Direct Measurement." *Australasian Journal of Philosophy* 38, 37–47.

Field, Hartry (1980). *Science Without Numbers*. Oxford: Blackwell.

Fine, Kit (2001). "The Question of Realism." *Philosopher's Imprint* 1(2), 1–30.

Finocchario, Peter (2023). "Seek the Joints! Avoid the Gruesome! Fidelity as an Epistemic Value." *Episteme* 20(2), 393–409.

Frigg, Roman and Stephan Hartmann (2025). "Models In Science." *Stanford Encyclopedia of Philosophy (Summer 2025 edition)* .

Frigg, Roman and James Nguyen (2021). "Scientific Representation." *Stanford Encyclopedia of Philosophy (Winter 2021 edition)* .

Gibbons, G. W. (1994). "Changes of Topology and Changes of Signature." *International Journal of Modern Physics D* 3, 61–70.

Gibbons, Gary W. (2012). "The Emergent Nature of Time and the Complex Numbers in Quantum Cosmology." In Laura Mersini-Houghton and Rudy Vaas, eds., *The Arrows of TIme: A Debate in Cosmology*, pp. 109–148. Berlin: Springer.

Glymour, Clark N. (1977). "The Epistemology of Geometry." *Noûs* 11(3), 227–251.

Gomes, Henrique, Tushar Menon, Oliver Pooley, and James Read (2024). "How to Recover Spacetime Structure from Privileged Coordinates." Unpublished manuscript. Available at `https://philsci-archive.pitt.edu/23811/1/ReKlein2.pdf`.

Goodman, Nelson (1989). "Just the Facts, Ma'am!" In Michael Krausz, ed., *Relativism: Interpretation and Confrontation*, pp. 80–85. Notre Dame: Notre Dame University Press.

Hall, Geoffrey and Sebastián Murgueitio Ramírez (2024). "Symmetries and Representation." *Philosophy Compass* 19(3).

Hawthorne, John (O'Leary-) and Andrew Cortens (1995). "Towards Ontological Nihilism." *Philosophical Studies* 79, 143–165.

Heaviside, Oliver (1892). *Electrical Papers*, vol. 2. London and New York: Macmillan and Co.

—— (1893a). *Electromagnetic Theory*, vol. 1. London: *The Electrician* Printing and Publishing Company.

—— (1893b). "A Gravitational and Electromagnetic Analogy." In *Electromagnetic Theory*, vol. 1, pp. 455–66. London: *The Electrician* Printing and Publishing Company.

Hunt, Josh (2021). "Understanding and Equivalent Reformulations." *Philosophy of Science* 88, 810–23.

—— (2022). *Symmetry and Reformulation: On Intellectual Progress in Science and Mathematics*. Ph.D. thesis, University of Michigan.

—— (2023). "Epistemic Dependence and Understanding: Reformulating through Symmetry." *The British Journal for the Philosophy of Science* 74(4), 941–974.

—— (forthcoming). "On the Value of Reformulating." *Journal of Philosophy* .

Jacobs, Caspar (2022). "Invariance, Intrinsicality, and Perspicuity." *Synthese* 200, 135.

—— (2023). "Are Models Our Tools Not Our Masters?" *Synthese* 202: 121(4).

—— (2025). "How (Not) to Define Inertial Frames." *Australasian Journal of Philosophy* doi:10.1080/00048402.2025.2481921.

John, Stephen (2021). *Objectivity in Science*. Cambridge University Press.

Ladyman, James (2023). "Structural Realism." *Stanford Encyclopedia of Philosophy (Summer 2023 Edition)* .

Lee, Chanwoo (2024). "Metaphysical Perspicuity." Unpublished manuscript. Available at https://philsci-archive.pitt.edu/24193/.

March, Eleanor (2025). "What is the Value in an Intrinsic Formalism?" *Erkenntnis* doi:10.1007/s10670-025-01008-5.

Martens, Niels C. M. and James Read (2021). "Sophistry about Symmetries?" *Synthese* 199, 315–44.

Maudlin, Tim (2014). "What Bell Did." *Journal of Physics A: Mathematical and Theoretical* 47, 1–24.

—— (2018). "Ontological Clarity via Canonical Presentation: Electromagnetism and the Aharonov–Bohm Effect." *Entropy* 20(6), 465.

Maxwell, James Clerk (1890). "On Physical Lines of Force." In W. D. Niven, ed., *The Scientific Papers of James Clerk Maxwell*, vol. 1, pp. 451–513. New York: Dover. Originally in the *Philosophical Magazine*, Vol. 21.

McKenzie, Kerry (2024). "Structuralism as a Stance." *Philosophy of Physics* 2.

Møller-Nielsen, Thomas (2017). "Invariance, Interpretation, and Motivation." *Philosophy of Science* 84, 1253–1264.

Nagel, Thomas (1986). *The View from Nowhere*. Oxford: Oxford University Press.

Nguyen, James and Roman Frigg (2022). *Scientific Representation (Cambridge Elements in the Philosophy of Science)*. Cambridge: Cambridge University Press.

North, Jill (2021). *Physics, Structure, and Reality*. Oxford: Oxford University Press.

—— (2025). "Paving the Way for A Middle Way on Theoretical Equivalence." Unpublished manuscript.

Poincaré, Henri (1952). *Science and Hypothesis*. New York: Dover. Republication of the first English translation, published by Walter Scott Publishing, London, 1905.

Putnam, Hilary (1983). "Equivalence." In *Realism and Reason: Philosophical Papers, volume 3*, pp. 26–45. Cambridge: Cambridge University Press.

Reichenbach, Hans (1958). *The Philosophy of Space and Time*. New York: Dover.

Reiss, Julian and Jan Sprenger (2020). "Scientific Objectivity." *Stanford Encyclopedia of Philosophy (Winter 2020 Edition)* .

Rescorla, Michael (2024). "Convention." *The Stanford Encyclopedia of Philosophy (Spring 2024 Edition)* .

Robertson, Katie and Carina Prunkl (2023). "Is Thermodynamics Subjective?" *Philosophy of Science* 90, 1320–30.

Rubenstein, Ezra (2024). "Two Approaches to Metaphysical Explanation." *Noûs* 58, 1107–36.

Russell, Jeffrey Sanford (2018). "Quality and Quantifiers." *Australasian Journal of Philosophy* 96(3), 562–577.

Schilpp, Paul Arthur, ed. (1970). *Albert Einstein: Philosopher-Scientist*. La Salle, IL: Open Court, 3rd edn. First edition published 1947.

Schutz, Bernard F. (1980). *Geometrical Methods of Mathematical Physics*. Cambridge: Cambridge University Press.

Sider, Theodore (2011). *Writing the Book of the World*. Oxford: Oxford University Press.

—— (2024). "3D in High-D." *Journal of Philosophy* 121(6), 305–334.

Siegel, Daniel M. (1991). *Innovation in Maxwell's Electromagnetic Theory: Molecular Vortices, Displacement Current, and Light*. Cambridge: Cambridge.

Suárez, Mauricio (2003). "Scientific Representation: Against Similarity and Isomorphism." *International Studies in the Philosophy of Science* 17(3), 225–244.

—— (2010). "Scientific Representation." *Philosophy Compass* 5(1), 91–101.

Teitel, Trevor (2021). "What Theoretical Equivalence Could Not Be." *Philosophical Studies* 178(4), 4119–4149.

Turner, Jason (2010). "Ontological Pluralism." *The Journal of Philosophy* 107, 5–34.

Wallace, David (2012). *The Emergent Multiverse: Quantum Theory According to the Everett Interpretation*. Oxford: Oxford University Press.

—— (2019). "Who's Afraid of Coordinate Systems? An Essay on Representation of Spacetime Structure." *Studies in History and Philosophy of Modern Physics Part B* 67, 125–136.

Wallace, David and Christopher G. Timpson (2010). "Quantum Mechanics on Spacetime I: Spacetime State Realism." *British Journal for the Philosophy of Science* 61, 697–727.

Weatherall, James Owen (2019a). "Part 1: Theoretical Equivalence in Physics." *Philosophy Compass* 14: e12592(5).

—— (2019b). "Part 2: Theoretical Equivalence in Physics." *Philosophy Compass* 14: e12591(5).

Weatherall, James Owen and Helen Meskhidze (2025). "Are General Relativity and Teleparallel Gravity Theoretically Equivalent?" *Philosophy of Physics* 3: 6(1), 1–16.