PHYSICS, STRUCTURE, AND REALITY

Jill North

Reviewed by Caspar Jacobs

Physics, Structure, and Reality
Jill North
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Of the three words that make up the title of Jill North's book—physics, structure, and reality—the middle one is the most important. North believes that the relevant kind of structure is both real and physical, but her emphasis is on the ways one can apply the concept of structure to various debates in philosophy of physics: substantivalism versus relationism, the interpretation of (gauge) symmetries, and theoretical equivalence. For each of these, North shows that paying attention to structure allows us to move beyond stalemates in current debates. *Physics, Structure, and Reality* is therefore relevant to anyone interested in these discussions.

In addition to the focus on structure, North's book presents a stylistic intervention. In response to what she perceives as a 'formal turn' in philosophy of physics, North aims to avoid mathematical formalism and instead foregrounds metaphysics. Rather than endless technicalities, the book contains a series of case studies. Other than the claim that structure matters, it does not present a unified thesis. The introductory chapter surveys various strands that are intertwined throughout the book: that structure is physically real, that cases of theoretical equivalence are hard to come by, that theories must represent the world 'directly', that this doesn't mean that all reference to coordinates is suspicious, and that the interpretation of physical theories cannot proceed without paying attention to our prior metaphysical assumptions.

In Chapter 2, North explains what she means by 'structure'. The approach here is similar to the 'Kleinian' approach discussed by Wallace ([2019]). In order to get at the structure of, say, Euclidean space, we look at all of the different, equally legitimate ways of coordinatizing this space—that is, the class of Cartesian coordinate systems—and consider what is common to them. In this case, that common structure will include a Euclidean metric. North emphasizes that structure, to her, is not the same as a class of symmetry transformations, nor simply identical to that which remains invariant under them. But neither does structure just consist of certain special properties and relations. Rather, one can define certain special properties and relations (such as the metric) from the relevant structure.

The analysis of structure in terms of coordinates leads to a problem. It is usually thought most 'natural' to use Cartesian coordinates for Euclidean space, but, as North recognizes, one could equally well use polar coordinates, or indeed any arbitrary coordinate system. This trivializes the idea of structure as that which is common across different coordinatizations. Although North expresses this conundrum more clearly than anyone before her, she does not quite escape it herself, as she continues to talk of structure as the reality underlying equivalent coordinate representations.

I wonder whether there is an alternative approach ready to hand here: define 'structure' in terms of the automorphisms of a particular domain. If we stipulate translations, rotations, and reflections as the automorphisms of a domain of points, for instance, then the Euclidean metric is an invariant quantity. North wishes to avoid definitions in terms of invariance because properties such as 'has velocity *v* in reference frame *F*' are also invariant, despite not seeming to reflect physical structure. However, any structure will have certain trivial features. For example, any point in space has the property of being the origin in some frame of reference. Could it not simply be said that although each structure has many such trivial features, the non-trivial features are the ones of interest?

North develops an alternative answer to this puzzle in Chapter 3, based on the form of the laws. The idea is that although one could use any arbitrary coordinate system, the laws of classical mechanics are simplest in Cartesian coordinates. This allows us to select a privileged class of reference frames from which one can glean the structure of classical space. Moreover, the fact that the laws of classical mechanics are invariant under translations, rotations, and reflections provides us with evidence that space is Euclidean. It does so via the 'matching principle' introduced by North, which says that we ought to posit enough structure to sustain the laws—but no more than that. This principle is related to Earman's ([1989]) famous 'SP1' and 'SP2', and plays an important role in chapters to come.

I am not sure that the laws can help in specifying a privileged class of 'natural' coordinates. There are cases where the coordinates in which the laws are simplest are not the ones that most naturally represent the structure of space. Consider a modification of Newtonian mechanics that introduces a time-dependent rotation, $R(T)$ The laws of this theory are identical to those of ordinary Newtonian mechanics as expressed in a rotating frame. On the one hand, it seems that despite this modification to the laws, the inertial frames continue to most naturally express trajectories. In particular, when using inertial coordinates it is clear that in this theory matter rotates. On the other hand, the laws are not simplest in inertial coordinates. If we perform coordinate transformation $x \to R^{-1}(t)x$, then the laws reduce to those of Newtonian mechanics. But in the latter coordinates, the trajectories of particles are misrepresented: the rotation vanishes. Hence the 'natural' coordinates can come apart from those that simplify the laws.

In Chapter 4, North turns to the issue of theoretical equivalence. This is the most stimulating chapter of the book. North argues, contrary to received wisdom, that the Newtonian and Lagrangian formulations of classical mechanics are inequivalent. What is more, they are not just inequivalent in that the former but not the latter posits entities such as forces; they are structurally inequivalent. Here, North relies on the notion of structure she has developed over the previous chapters. Roughly, the idea is that whereas Newton's laws are only form-invariant under Galilean transformations, the Euler–Lagrange equation is invariant under almost any coordinate transformation. Newton's laws become rather ugly when expressed in polar coordinates, for example, whereas the Euler–Lagrange equation retains the same form. Therefore, Lagrangian mechanics posits less spacetime structure than Newtonian mechanics. This is a radical conclusion: it means that relations such as the Euclidean metric are not part of the basic structure of Lagrangian mechanics, despite the fact that on a formal level Newtonian and Lagrangian mechanics are inter-translatable.

Of course, it is precisely because this conclusion is radical that one can cast some doubt upon it. For example, North formulates these theories in terms of state-spaces, but the leap from state-space structure to spacetime structure leaves some wiggle room. One might also worry that while the Euler–Lagrange equations remain form-invariant, the Lagrangian itself does not. I want to suggest a different lesson. Perhaps the conclusion we ought to draw is not so much that Lagrangian mechanics does not posit a Euclidean metric, but rather that it doesn't care about the representation of that metric, contrary to Newtonian mechanics. To elaborate: In Cartesian coordinates, distances in two-dimensional space are expressed as $\sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2}$. This expression is invariant under translations, rotations, and reflections, but not under more complicated transformations. The fact that Newtonian mechanics is only invariant under the former class of reflections means that it relies on the expression of the metric in this particular form. But it is possible to express the metric differently. In polar coordinates, for example, it has the form $\sqrt{r_1^2 + r_2 - 2r_1r_2cos(\theta_1 - \theta_2)}$.

This is still the same metric—the same piece of spacetime structure—just differently represented. I suspect that the form-invariance of the Euler–Lagrange equation does not signal that space has no Euclidean metric, but rather that it is more flexible in how one represents that metric. This is merely a suggestion; North presents a convincing case and a full response requires further research.

Chapter 5 is based on an earlier paper on the substantivalism-versus-relationism debate (North [2018]). Here I would have expected North to continue the themes from the previous chapters, and argue that only one out of substantivalism or relationism posits the 'correct' structure for classical mechanics. Yet North claims that both sides of the debate can posit the same amount of spacetime structure, although in the case of relationism this requires 'going modal'. The difference between these views lies in what grounds this spacetime structure: for the substantivalist, spacetime structure is part of the fundamental (that is, ungrounded) structure of the world, whereas to the relationist it is grounded in matter. Given the structural equivalence, it would seem that the 'matching principle' from Chapter 3 has no grip here. But North modifies the matching principle to say that not only should a theory posit enough structure to sustain the laws, but that this structure should also be fundamental. This stipulation tips the balance in favour of substantivalism. The chapter thereby nicely illustrates how attention to structure can revive even the stalest of debates in philosophy of physics.

The brief Chapter 6 discusses the representation of structure. North believes that theories have to represent structure 'directly'. In particular, North argues against 'quotienting': the idea that one can simply declare theories or models of theories equivalent without an account of the structure in virtue of which they are equivalent. I am sympathetic to this point, which is in the same spirit as Møller-Nielsen's ([2017]) 'motivationalism'. But North also claims that in some cases it is legitimate to quotient, for instance, when the models of a theory are isomorphic. The question then is when to quotient: when an equivalence relation on models 'quotients nature at the joints', a phrase she borrows from Laura Ruetsche. I wish North would have said more on this point, although I suspect it would take another book to provide a satisfactory answer.

Finally, Chapter 7 returns to the issue of theoretical equivalence. In particular, North argues that cases of theoretical equivalence are hard to come by. This chapter runs the whole gamut from Newtonian gravitation and electrodynamics to quantum mechanics. This is another place where I would have expected North to appeal to the matching principle and claim that seemingly equivalent versions of the same theory—say, Newtonian gravitation versus Newton–Cartan theory—in fact posit different structures. North opts instead for a more metaphysical approach, arguing that even if those theories have the same structure, they offer different 'pictures' of the world. For example, Newtonian gravitation offers a picture of the world in which particles in flat spacetime act on each other at a distance, whereas Newton–Cartan theory offers a picture in which particles follow the geodesics of a curved spacetime. One might respond that Newtonian gravitation describes the same world as Newton–Cartan theory, but in a more roundabout way. In response, North reverts to the fall-back position that even in that case, only one of these theories represents the structure of the world more perspicuously. I am not sure whether this still counts as a case of theoretical inequivalence, but the point is well taken otherwise.

North makes a convincing case that structure really is one of the most important concepts in physics, while clearly demonstrating that the subject is far from exhausted. The writing is lucid and the lack of unnecessary formalism is refreshing, while the abundance of examples further enhances the book's clarity. *Physics, Structure, and Reality* opens up many further avenues for research and thus is a must-read for anyone interested in the physical structure of the world.

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