Foundations of Physics (2020) 50:515–521
https://doi.org/10.1007/s10701-020-00344-6

EDITORIAL

Modality in Physics

Gábor Hofer-Szabó[1] · Joanna Luc[2] · Tomasz Placek[2]

Received: 3 March 2020 / Accepted: 24 April 2020 / Published online: 30 April 2020

One of the grand metaphysical questions that David Hume left to us concerns the nature of modality, i.e., possibilities and necessities. Are modalities, or at least some varieties of modalities, an irreducible feature of the objective world? Or, on the contrary, perhaps all modalities reduce to some features of our language, or of our conceptual framework, so they are not really a part and parcel of our objective world?

In an attempt to elicit a response to this query, it seems natural to turn to the natural sciences, however partial or tentative that response might be. Moreover, the more fundamental a science, the better authority it has in this area, hence the turn to fundamental physics which is clearly discernible in the papers collected in this volume. *Prima facie* a theory of physics touches upon the modality question at three junctions, namely the concepts of the law of nature, of temporal evolution, and of symmetry. We discuss these three meeting points in turn.

Clearly, a theory of physics comes with some laws which are encapsulated in its mathematical formalism. Now, laws of nature are uncontroversially believed to be a source of natural necessity, as they impose some sort of necessity on the facts they cover or, more precisely, on the propositions expressing those facts. How strong that necessity is, and whether it is reducible to some non-modal factors, are large questions which have dominated the debate over the laws of nature for decades. On the one hand, neo-Humean positions, made popular by David Lewis's best system analysis, identify laws of nature with a rather complex feature of a linguistic description of our world. On one neo-Humean account, one is invited to think of alternative axiomatisations of this description; the theorems of the best axiomatic system with respect to the combination of the competing features of simplicity and informativeness are identified with the world's laws of nature. On this reductive analysis, laws of nature have some albeit negligent modal aspect, as they permit one to pick the set of possible worlds that are physically similar to a given world; this in turn allows one to define physical necessity as truth in physically similar worlds. That does not mean, of course, that there are necessary connections in our world. After all, which

✉ Tomasz Placek
uzplacek@cyf-kr.edu.pl

1 Research Centre for the Humanities, Budapest, Hungary

2 Institute of Philosophy, Jagiellonian University, Kraków, Poland

worlds are physically similar to our world is determined by our world's description, and ultimately by non-modal matters of facts obtaining in our world. (Whether all these facts are local, so they form a Humean mosaic, which is "the doctrine that all there is to the world is a vast mosaic of local matters of particular fact, just one little thing then another", is a separate issue that need not concern us here).

The opposite camp, that of friends of non-reducible modalities, is unlikely to come with a substantial explanation of modalities, as it typically takes the relevant modalities to be a primitive notion; it thus views reductive analysis as a mistaken enterprise, opting instead for an explicatory account that would show how possibilities and necessities are intertwined with a family of some other concepts, like space and time, probability, or agentive actions. To give an example of that approach, in Belnap's framework of branching space-times [1] (which descend from a simpler theory of branching time of Prior [10], one begins with an intuitive notion of real possibilities. To elucidate this notion, it is really possible for a given electron to go up as well as, alternatively, to go down in a Stern-Gerlach device, given the setting of this experiment. In contrast, given the setting of a particular coin tossing experiment, it is *not* really possible for that coin to land heads up as well as, alternatively, to land tails up (see Diaconis et al. [4]). Building on the intuition of real possibilities, the branching project develops a formal theory of spatio-temporal possible histories that have probabilistic aspects as well. The project's aim is elucidatory: at the end of the day, the resulting formal theory casts more light on the primitive notion of real possibilities it started with.

Friends of non-reductive modalities face a further question about the relation between laws of nature and modalities anchored in some this-wordly objects, like potencies or dispositions. The way modern physics has developed, and the way philosophical reflection on physics has followed, accords a predominance to the laws of nature: if there are dispositions and potencies, they derive their modal character from the modally-loaded laws of nature. Turning against the Humean tradition may, however, reverse this relation, as it then looks attractive (which does not necessarily mean "tenable") to derive the laws, in particular their modal aspects, from the modal profiles of individual objects present in our world (for the notion of modal profiles, see e.g., Rumberg [12]). To what extent this vision is compatible with the mathematical form of laws of current physics still constitutes uncharted territory.

While discussing the laws of nature above, we focused on necessity, in line with a large tradition. But then how can the laws of nature relate to possibilities, if there are such? The dominant compatibilist school explains possibilities as anything that is not in conflict with (does not contradict) laws of nature. The move has, however, an undesirable consequence of relegating possibilities to the domain of unruly and capricious stuff, not governed by any laws (for a discussion, see Prior [9]). Here current physics can help conceptually to construct a more subtle and more adequate notion of possibilities. To illustrate, the fact that a particular electron in a Stern-Gerlach apparatus has no unique possible trajectory does not mean that it can go anywhere in the apparatus. On the contrary, quantum mechanics provides two eigenvalues of the spin projection operator for an electron, so given the electron's speed and the values of the magnetic field, it has precisely two possible trajectories in this experiment.[1] That there are exactly these two possibilities for an electron's motion, follows immediately from the quantum mechanical spectral theorem applied to the spin projections of electrons. Compatibilists need to argue, however, that these two alternative results are exactly what is *compatible* with the laws of nature. Perhaps there is a way to read the spectral theorem as saying which results are prohibited by Nature (namely all results but the two, in the case considered). This interpretation nevertheless strikes us as a roundabout and futile manoeuvre. One might instead take from quantum physics an inspiration to develop laws of possibility, as opposed to necessarian laws of nature that philosophy is used to dealing with.

The topic of possibilities makes us turn to the second meeting point of physics and modality: temporal evolution. Most theories of physics come with a law describing how systems falling under the scope of this theory evolve in time. Newton's second law, Schrödinger's equation, or Einstein's field equations are canonical examples of such laws of evolution for classical mechanics, quantum mechanics, and general relativity, respectively. Finding solutions to laws of evolution for given boundary conditions (initial values) is an important task for theoretical physicists. But do these solutions always exist? Since the equations of evolution are typically stated as differential equations, in part the question is mathematical. Depending on the kind of differential equations, mathematics provides subtle and diverging answers as to under what conditions there exist solutions to a given differential equation, and (more importantly for the possibility questions), under what conditions there exists a unique solution to that equation. To stress again, these are subtle and hard issues, and in some cases the answers are unknown (see e.g., Fattorini [6]). Without going into details, we can make two observations. First, there is a customary distinction drawn in the context of the existence and uniqueness questions (as the two questions above are usually called), which contraposes the local existence (uniqueness) and global existence (uniqueness) of solutions to differential equations. It is one thing to guarantee the existence (uniqueness) of a solution in a vicinity of considered initial conditions, and another thing to ensure the existence (uniqueness) of a solution for the whole range of a given parameter (typically the parameter in question is time). To put it somewhat differently, combining a large number of local solutions (which are only good in the vicinity of selected initial values) does not necessarily result in a global solution (i.e., a solution good for the whole time). The distinction between local and global solutions is supported by many results in the theory of differential equations. Obviously, the distinction is well-known to philosophers of physics, yet, it seems, it has not been taken to heart in modal metaphysics. The dominant approaches to modality, be it the neo-Humean possible-world theory of Lewis, or Kripke's analysis, or Stalnaker's theory, or the avowedly anti-Humean branching space-times theory of Belnap, invariably employ global objects, like possible worlds, histories, scenarios, or chronicles. A few extant analyses of modality that are based on local notions, like the Müller–Rumberg theory of transitions [7, 11], or Placek's [8] theory of alternative possible continuations, form a negligible

[1] Our talk of trajectories in a quantum experiment should be replaced by that of alternative possible results, i.e., traces on a photo-sensitive screen left by the electron.

minority. Still, judging by the situation in mathematics, a local concept of modality deserves more attention.

The second remark concerns typicality, however fuzzy that notion is. It is rather typical that a differential equation has no unique global solution, not the other way round. This observation prompted one mathematician (a friend of ours) to exclaim: "Of course, physics is indeterministic! It is physicists who are determinists". Contrary to the simplicity of this exclamation, the implications of the failure of the uniqueness of solutions to differential equations capturing laws of evolution for the modality issue are far from straightforward.

This brings us to the third juncture where physics and modal metaphysics meet: the concept of symmetry. Symmetries seem to play at least two roles in modal considerations in the context of physics. On the one hand, they can be used to draw a distinction between physically meaningful and purely mathematical differences between solutions to the laws of evolution. The thought is that some seemingly different solutions may turn out to differ only in physically-irrelevant aspects, so that they represent one and the same physical situation. Therefore, symmetries may influence our verdict concerning the following question: how many physically different possible scenarios does a given theory predict? Typical examples of that sort concern so-called gauge symmetries, for example, in classical electrodynamics. The issue is more subtle for classical space-time symmetries.

However, sometimes symmetry considerations are used for the opposite purpose: to generate new, unknown solutions from known ones rather than identifying some of the already known solutions. For an example, if a theory is Lorentz-symmetric, it is enough to find a solution corresponding to a system at rest, and then obtain all other solutions by applying Lorentz transformation to that one. Because new solutions are symmetry-related to the original solution, we are guaranteed that they will be solutions of the same equation. We thus see a subtle role of symmetries in modal arguments.

In the paragraphs above, we wrote as if indeterminism were a modal notion, that is, as if by finding an indeterministic evolution one automatically had a case for the existence of alternative possibilities in Nature. Arguably, this modal aspect is a root idea in an intuitive notion of indeterminism, if there is such a thing. The modal idea of alternative future possibilities is a core of Aristotle's depiction of indeterminism in his famous cloak story (*De Interpretatione* 19a): a given cloak might wear out, but it could be cut up first, that is, before wearing out. The modal aspect of indeterminism has also been assumed in the writings of other champions of indeterminism, like Prior or Łukasiewicz. It is present in a large part of the literature on agency and the logic of actions. Notably, however, modal overtones are absent in an influential epistemic formulation of Laplace's, who uses the metaphor of a super-intelligence capable of "seeing" the entire past and future of the universe, thanks to its grasp of an instantaneous state and knowledge of all the forces acting in the Universe. Now, a considerable achievement of the neo-Humean camp was to provide a non-modal explication of indeterminism by precisifying Laplace's formulation and cleaning it completely of its epistemic overtones. The resulting analysis characterises indeterminism in terms of the models of a theory (or Lewisian possible worlds) and the similarity of the initial segments of such models. The underlying intuition is the following: a theory is indeterministic iff it admits two dissimilar models with similar initial segments. The analysis forms what is now a received view in the philosophy of science, and is championed by Earman [5] and Butterfield [3]. Thus, the punch-line of this discussion is that there is a substantial conceptual work for friends of modality to persuade philosophers that finding an indeterministic system of the currently accepted theory of physics argues in favor of the existence of alternative possibilities in Nature.

With the mention of conceptual work, we come to the final reflection of this editorial. What kind of question is "Is there some kind of possibility and necessity in Nature itself?" We have seen that to address it one needs to tackle deep conceptual issues. Still, this problem does not appear to be purely conceptual, like for instance the task of finding a good concept of numerosity, i.e., of assigning numbers to sets of objects. If that is so, purely philosophical reflection is not enough to resolve the question. It thus seems to us that the modality in Nature question has both a conceptual component as well as a factual one. It is then similar to physico-philosophical problems that once appeared insoluble and philosophical, but were later resolved, as the learned public was persuaded to accept one solution. Although it might sound controversial, our question then appears to be similar to the problem of whether matter is corpuscular or continuous, an issue that was a battle-ground of speculative philosophy for centuries. However, ingenious experimentation, supported by theoretical considerations and arguments, persuaded the learned public to adopt the corpuscular view around 1900 (for how it happened exactly, see e.g., Bigg [2]). Needless to say, the current atomism is much subtler than the atomism of earlier philosophers, as it addresses various conceptual and mathematical problems that were not even on the radar in the past. Still, it is atomism, broadly speaking, and in physics it is not a contentious doctrine anymore.

We hope that one day the issue of modality in Nature will also be resolved by the same means: experiments, theoretical considerations, and argumentation. With the hope that the present volume might make some (however slight) contribution to this grand aim, we offer here eight papers on this subject. The above overview of topics falling under the title heading "modality of physics" intimates the multifarious and multifaceted landscape of philosophical issues. The papers collected in this volume testify to this multifariousness.

Some of the collected papers challenge the mentioned Humean picture of the world, either by arguing that to account for the development of science it needs to be supplemented by some modal components, or, on the contrary, by trying to show that this picture assumes even more than can be justified by available resources. To the first camp belongs Tim Maudlin, who claims that Hume's proposal to abandon modalities was motivated by his empiricist semantics. Since the project to develop such a semantics in detail (by the neopositivists) failed, we no longer have good reasons to endorse this proposal. According to Maudlin, modal locutions (concerning possibility, necessity, causation and subjunctive conditionals) can be valid and their semantics can be read off from mathematical structures expressing the laws of nature and the notion of the direction of time (both of which are treated by him as primitive). To the second camp belong Márton Gömöri and László E. Szabó. Gömöri argues that one of the crucial Humean notions, that of regular connection (which is intended to be a Humean replacement for the more modally-loaded notion of a law), is conventional rather than objective. To tell whether there is a correlation between two types of events, one needs to discriminate between the cases in which their instances occurred together and this *together*, according to Gömöri, seems to be a matter of convention. Szabó challenges another concept crucial for Humeans, namely the notion of an intrinsic property, that is, a property whose possession is independent of the existence of other objects in the world (although he does not relate his considerations explicitly to the Humean picture). Physical concepts, including those referring to physical properties, are defined by semantic conventions (which ultimately cannot be disentangled from the whole physical theory); and assuming a physicalist ontology, a physical theory should be identified with a physical object (e.g., a string on a piece of paper), so for the properties to be defined there must always exist some other physical objects, excluding their intrinsicality. Another paper related to the Humean project is that of Balázs Gyenis's, who investigates the sensitive interdependence between the concepts of determinism, physical possibility and the laws of nature. He argues that a particular formulation of the received view of physical possibility ("a world is physically possible if and only if it has *the same physical laws* as does the actual world") and a weakened form of Lewis's Best System Account of the laws of nature ("Laws are propositions of the deductive systems which best balance simplicity, *approximation to truth*, and informativeness") can together provide a strategy to regain determinism in a physical theory.

Another approach adopted by some papers in our collection is, instead of attacking the issue of modality in its full generality, to present case studies of particular theories of physics and ask whether particular objects in particular theories can be interpreted modally. This question is asked by Samuel Fletcher with reference to events and (piecewise smooth) timelike curves in general relativity. By considering non-typical cases of curves with loops, he concludes that the standard interpretation of such curves as possible worldlines of massive pointlike particles leads to conceptual problems, but perhaps can be saved with some modification. Tomasz Placek poses this question with reference to causets in the theory of causal sets and argues that such objects should be interpreted as possible states of a theory rather than alternative possible events. He consequently claims that there is no sound concept of alternative possible developments in this theory. Joanna Luc considers the question of whether non-Hausdorff manifolds in general relativity are legitimate objects of this theory and argues that their modal interpretation helps to solve some interpretative problems concerning them.

Yet another stance towards modalities is represented in the paper by Thomas Müller, who harnesses real possibilities to do some useful work for a physics-informed world view. He uses the concept as a resource to solve an interpretative problem of relativity theory, namely the lack of relativistically-invariant and non-trivial notion of co-presentness. To this aim, he employs branching space-times theory, which attempts to reconcile relativity with modally understood indeterminism, and constructs the notion of co-presentness, which relies on the intuition that time only really passes if there is a real (i.e., indeterministic) change in the world.

The early drafts of the papers in this issue were given at the workshop *Modality in Physics*, hosted by the Philosophy Department of the Jagiellonian University in

Kraków between the 11th and the 13th of June, 2018. JL and TP gratefully acknowledge the support of the National Science Centre (Research Grant Opus 2016/23/B/HS1/00464).

References

1. Belnap, N.: Branching space-time. Synthese **92**, 385–434 (1992). http://philsci-archive.pitt.edu/archive/00001003
2. Bigg, C.: Evident atoms: visuality in Jean Perrin's Brownian motion research. Stud. Hist. Philos. Sci. A **39**(3), 312–322 (2008)
3. Butterfield, J.: Determinism and indeterminism. Routledge Encyclopedia of Philosophy. Routledge, London (2005)
4. Diaconis, P., Holmes, S., Montgomery, R.: Dynamical bias in the coin toss. SIAM Rev. **49**(2), 211–235 (2007). https://doi.org/10.1137/S0036144504446436
5. Earman, J.: Aspects of determinism in modern physics. In: Butterfield, J., Earman, J. (eds.) Handbook of the Philosophy of Physics, pp. 1369–1434. Elsevier, Amsterdam (2006)
6. Fattorini, H.O.: The Cauchy Problem. Cambridge University Press, Cambridge (1983)
7. Müller, T.: Alternatives to histories? Employing a local notion of modal consistency in branching theories. Erkenntnis **79**, 343–364 (2014). https://doi.org/10.1007/s10670-013-9453-4
8. Placek, T.: Possibilities without possible worlds/histories. J. Philos. Log. **40**, 737–765 (2011)
9. Prior, A.N.: Limited indeterminism. Rev. Metaphys. **16**(1), 55–61 (1962)
10. Prior, A.N.: Past, Present and Future. Oxford University Press, Oxford (1967)
11. Rumberg, A.: Transition semantics for branching time. J. Log. Lang. Inform. **25**, 77–108 (2016a)
12. Rumberg, A.: Transitions: toward a Semantics for Real Possibility. PhD thesis, University of Utrecht (2016b)