INTRODUCTION

The present collection assembles new work in the flourishing field of the metaphysics of physics, running the full gamut from the philosophical consideration of the foundations of contemporary physics to a scientifically informed analysis of traditional metaphysical concerns. Our desire to understand the innermost foldings of the world we inhabit has naturally brought physics and philosophy in close contact over the millennia; in fact, both disciplines have emerged out of the same systematic attempts to satiate this human zeal. Despite occasional dissonance and miscommunication, the nexus between the two fields was mutually beneficial for the most part, and forged the foundation of modern science in the first scientific revolution of the 16th and 17th centuries and was instrumental in initiating the second scientific revolution during the late 19th and early 20th centuries. The resulting unprecedented success of physics in predictive accuracy, explanatory abundance, and range of technological applications has led to a more asymmetric relation between physics and philosophy: as the former shines in its well-deserved acclaim as the kingpin of science, the latter struggles to remain relevant as foundational and philosophical questions are increasingly seen as arcane, inscrutable, and unnecessary. Lest the reader mistakes us to condone philosophy's supposed plight, we affirm that instead of waning in significance, foundational and philosophical work has acquired new urgency in the light of fundamental physics' continued struggle to even just formulate a complete quantum theory of gravity, let alone a comprehensive and unified foundation for all of contemporary physics.

This volume is concerned with specifically metaphysical issues that connect to physics. But even if the state of philosophy is altogether not that precarious, the prospects of metaphysics are routinely considered downright daunting and its standing has only very recently started to recover from the logical empiricists' onslaught almost a century ago. Its status and even its possibility have been the subject of protracted debates for long – in fact, long before the heyday of logical empiricism. Although we

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share the staunchly scientific spirit of the logical empiricists, we believe that the rehabilitation of metaphysics is long overdue and offer the following collection as evidence that naturalism and metaphysics can productively interact with one another.

1. Metaphysics and its Subject Matter

So what, precisely, is metaphysics, and what possible intimate relations with cutting-edge scientific theories can it have? In a nutshell, metaphysics is the study of the fundamental structure of reality.

Let us try to be more specific. A discipline can be identified by its unique subject matter and by its specific methodology. Regarding the former, the subject matter of any field of inquiry is usually assumed to consist of a set of objects – the domain – and a set of distinguished properties and relations among these objects. Using Kit Fine's terminology (Fine 2013) we may say that elements of the subject matter for a given discipline can occur in it either objectually, or predicatively. One characteristic trait of metaphysics is that every object can in principle be an element of its domain of inquiry; another that it is customary to differentiate metaphysics from other branches of philosophy by excluding from its subject matter only the epistemic relation between the object of knowledge and the perceiving subject. This general trait is characteristic of physics too, with the additional restriction that the domain of physical inquiry is limited to material, spatiotemporal objects. Generally, metaphysics does not obey this restriction, as metaphysical considerations can, and often do, reach out into the realm of non-physical entities (abstracta, possibilia, values, etc.). However, it has to be admitted that there is a substantial overlap between the objectual parts of the subject matters for both physics and metaphysics.

The difference in the subject matter between the two disciplines becomes more conspicuous when we turn to the predicative part. While physics deals with fairly broad concepts, such as the notion of material objects, elementary particles, fields and interactions, metaphysics centers its analyses around even broader categories of objects, properties, identity and the like. However, it would not be correct to explicate the generality of metaphysical concepts simply in terms of the breadth of their scope. For instance, the concept of identity seems to be more universal than the concept of a (mereological) part, and yet the scope of the latter clearly includes the entire former category (as the numerical identity of objects x and y obviously implies that x is an (improper) part of y). In light of this observation Kit Fine (ibid.) proposes to spell out the requisite notion of generality in terms of invariance. Since the relation of identity is invariant under all permutations, while in the case of parthood a much narrower set of rearrangements of objects leave this relation unchanged, identity is less sensitive to the difference in descriptive character of objects than parthood, and therefore is considered more universal. With respect to its generality, metaphysics can be located between even more general – and topic-neutral – logic and decidedly less general science, including physics. It goes without saying that there are no clear cut-offs on the scale of diminishing generality that could precisely separate these fields of inquiry, and therefore some logical and scientific questions can, on this criterion, be plausibly categorized as borderline metaphysical.

It is often said, as we did above, that metaphysics is not merely a general study of objective reality, but a study of its most fundamental aspects. In other words, metaphysics is concerned with how things are by their very nature. Fine calls this feature of metaphysics *eidictic*, and he goes on to characterize eidictic theories as those whose propositions are true in virtue of their subject matter, where again the subject matter of a theory is assumed to consist of elements that occur objectually in its propositions, and elements that occur predicatively.[1] For instance, the logical proposition $\forall xy\ (x = y \rightarrow y = x)$ is true in virtue of the purely logical elements $\forall$ and $=$, and thus reflects the nature of these elements. However, the proposition $\exists x\ (x = x)$ is not true in virtue of the nature of the logical elements $\exists$ and $=$ only; we need the extralogical assumption (taken, for instance, from mathematics) that there is at least one object in the universe. According to Fine, metaphysics is not the only field of inquiry of an eidictic character – other eidictic theories include logic, mathematics and physics (for instance the statement 'Electrons are fermions' is arguably true by virtue of the nature of electrons and the property of being a fermion, i.e. the property of having a half-integer spin). However, the unique character of metaphysics is shown in that the concept of eidicity itself belongs to the (distinctive) metaphysical subject matter. Thus, only metaphysics contains propositions which explicitly use the expression 'by nature,' as in the following example: 'If a substance is composed of *X*, then it is composed of *X* by its nature.'

In Fine's approach, the necessity of metaphysical truths is a direct consequence of their eidictic character. As there are eidictic fields of inquiry other than metaphysics, they too define their own categories of necessity.

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[1] We are slightly simplifying Fine's proposal here. His original characterization of eidictic theories involves the subtler notion of distinctive subject matters which reflects the fact that some elements of the subject matter of a given theory may be borrowed from another field of inquiry (viz. logical concepts used in metaphysics).

Thus there is for instance the concept of logical necessity, which applies to all propositions that are true in virtue of the logical subject matter. Metaphysical necessity characterizes all eidictic propositions involving its subject matter that are not logically necessary. Analogously, physically necessary propositions include those propositions true in virtue of the nature of the physical subject matter that are not metaphysically necessary. Metaphysical possibility is assumed to be narrower than logical possibility but broader than physical possibility. For instance, the existence of electrons that are bosons (i.e., have an integer spin) is metaphysically (and logically), but not physically, possible. On the other hand, it is logically, but presumably not metaphysically, possible for an object to possess two determinate properties of one determinable (e.g., two distinct colors).[2]

2. The Epistemic Status and Methods of Metaphysics

We have so far portrayed metaphysics as a field of inquiry which does not place any restrictions on the objects of its investigations other than their subject-independent existence, which deals with significantly broad concepts, and whose statements are true in virtue of the nature of participating elements. But what possible method can help us attain reliable knowledge in the area of study characterized in such a way? A typical response to the question of the epistemic status of metaphysics is that it is an a priori discipline, strictly separated from experience. However, it seems unclear what the source of the metaphysical aprioricity might be. Is metaphysics, as some suggest, based on intuitions, or intuitive insight into the nature of things? Such an account of the rationalist, non-empirical character of metaphysical truths looks implausible, since the intuitions seemingly underlying these truths are most likely acquired through learning and experience. As Don Ross, James Ladyman and David Spurrett (2007, pp. 10–15) correctly observe, our common sense and intuitions result from interacting with medium-size objects occupying a very restricted, small region within the spatiotemporal vastness of the universe. It is unreasonable to expect that intuitions developed in such a parochial way could underlie a metaphysical theory that would be impervious to the verdicts of refined scientific studies of the empirical world.

[2] However, we should note that some scientifically oriented philosophers are skeptical as to the existence of a viable concept of metaphysical necessity/possibility distinct from physical necessity/possibility (see Callender 2011, p. 44).

A different, if somewhat related answer to the question of the epistemic source of metaphysics is that metaphysical truths are products of reflecting on our fundamental concepts by doing what is called conceptual analysis. In this approach metaphysics serves as a tool for systematizing and categorizing the conceptual framework in which we would like to describe the most fundamental aspects of reality. Consequently, metaphysical theses become something akin to the logical consequences of meaning postulates (terminological conventions) governing the use of the primitive concepts within a selected metaphysical framework. To those who are worried that this approach reduces metaphysical truths to trivial linguistic stipulations two responses may be offered. First, an analogous interpretation of mathematical theories and statements (as logical consequences of axioms which in turn serve the role of contextual definitions for the primitive terms of a given theory) does not seem to imply that mathematical facts are in any significant sense 'trivial' or 'merely linguistic.' Second, the choice of appropriate postulates characterizing the meaning of the terms of interest is by no means a trivial task. In selecting a particular conceptual framework we may be guided by several principles. One such principle may be the postulate to preserve some pretheoretical intuitions and snap judgments regarding a particular area of interest. However, the sway this principle holds on our philosophical analyses may be offset by a substantial increase in theoretical virtues, such as simplicity and parsimony. While theoretical virtues can offset pretheoretical intuition, the naturalism predicated of much of the work found in this volume demands this to be even more so for considerations arising from and connected to experience. For our current purposes it is of crucial importance to recognize that another important stimulus to develop a particular metaphysical framework can thus come from scientific theories. Due to its foundational character, physics seems to be best suited to offering guidance as to what such a metaphysical framework should look like.

The purported detachment from experience of metaphysics as traditionally conceived has been the source of well-known severe criticism by numerous philosophers, from the British empiricists through Immanuel Kant to the logical positivists. One possible reaction to this challenge is to embark on a research program that can be called naturalistic metaphysics. Alyssa Ney in her recent response to the neo-positivist critique of metaphysics (Ney 2012) points out that a naturalistic metaphysician can focus her attention on identifying entities, structures and principles that are present in every fundamental physical theory, and seem to be indispensable to our best scientific theories. Ney believes that in naturalistic ("neo-positivist") metaphysics there is still room for armchair methods. These rationalist methods can be used to elucidate the consequences of the metaphysical commitments indispensable for science, and to fill in the details of an incomplete metaphysics arrived at during the first, scientifically informed stage of inquiry. Similar ideas regarding scientifically oriented metaphysics are expressed by Craig Callender (2011). Callender remarks that a naturalistic metaphysics, while informed by our best science, does not have to be a 'handmaiden' to science. Scientific theories often leave serious gaps in the interpretation of their fundamental concepts, and this is where a serious and autonomous metaphysical analysis can prove its worth.

3. Between Metaphysics and Physics

How can we understand the expression 'metaphysics in physics'? In what sense can metaphysics be 'present' in physics? There are two broad options available here: either metaphysics can be somehow discovered as 'preexisting' in physics, or it can be put in there 'by hand.' Let's call the first option 'intrinsic' ('from within') and the second 'extrinsic' ('from without'). The 'from within' option attempts to extract the metaphysical implications of a physical theory, e.g. by developing a broad conceptual framework representing the fundamental features of a world in which the theory is stipulated to be true. To put it more succinctly, we are asking the question of what the world should look like in its most fundamental aspects for a particular physical theory to be true.

The main problem that this approach must face is the notorious phenomenon of the underdetermination of metaphysics by physics (see e.g. French 2011). A classic example of this phenomenon is provided by the quantum theory of many particles of the same type. Due to the symmetrization postulate imposed on the joint states of identical bosons and identical fermions, particles of the same type cannot be distinguished by appropriate reduced states. This arguably leads to the conclusion that particles of the same type violate the *Principle of the Identity of Indiscernibles*, and therefore their individualities cannot be grounded in differences in their properties. The original underdetermination thesis concludes that there are two metaphysical views compatible with this fact: one claiming that quantum particles possess so-called transcendent individualities (individualities grounded in non-qualitative features, such as *haecceities*), and the other denying that quantum particles are individuals in any metaphysically significant sense. It turns out that the situation may be even worse than that, as more metaphysical options have been recently added to the debate on the identity and individuality of quantum particles. These options include the widely debated proposal of grounding the numerical distinctness of particles in weakly discerning relations,[3] as well as an unorthodox approach to the problem of individuation and symmetrization which implies that fermions and bosons can be discerned by their properties after all (for more on this most recent suggestion see the contributions by Adam Caulton and Tomasz Bigaj in this volume).

Similar arguments in favor of the underdetermination of metaphysics by physics can be found in virtually all cases where attempts are made to draw metaphysical lessons from physical theories. To mention one more famous example: the initial hope that general relativity will break the impasse between the rival metaphysical positions of substantivalism and relationism in favor of the latter has been shattered by well-known arguments based on the existence of the vacuum solutions of Einstein's field equations (cf. the contribution by Matteo Morganti). Thus it seems that a physical theory can at best restrict the vast array of possible metaphysical frameworks by imposing on them the demand of the compatibility with its physical contents, without actually being able to select one that uniquely meets the requirements of the theory. In order to make such a selection, additional assumptions need to be accepted, and these assumptions will most likely come from outside the physical theory in question. For instance, philosophical arguments against haecceities (purported non-qualitative properties unique to all individual objects) can be brought into consideration when discussing the metaphysical consequences of the symmetrization postulate in quantum mechanics. But these arguments are not, strictly speaking, part of the considered physical theory – they have to be introduced *from without*.

This brings us to the second, extrinsic role that metaphysics can play in relation to physics. Two ways of introducing metaphysical theses into physics can be distinguished. One is related to the process of constructing a new fundamental theory. Sometimes certain metaphysical assumptions are explicitly built into a newly developed physical theory as part of its foundation. This method of incorporating metaphysical presuppositions into physical science is best illustrated by how Einstein approached the task of constructing his general theory of relativity. As is well known, Einstein's intention was to design a new theory which would satisfy certain general principles of a broadly metaphysical character, such as the principle of relativity, stating the fundamental physical equivalence of all coordinate systems. Similar foundational aspects are being taken into account by some physicists in their latest attempts to combine general relativity and quantum mechanics into a consistent theory of quantum gravity.

[3] Cf. Saunders (2006), Muller and Saunders (2008), and the recent critical overview by Bigaj (2015).

Some go as far as to claim that no successful theory of that kind can be built without a serious reconsideration of the fundamental metaphysical questions regarding the ultimate nature of reality.[4]

However, metaphysics can still influence physical theories even after they have been developed and empirically confirmed. The second way of introducing metaphysics from without has to do with the general task of providing an interpretation of the established mathematical formalism of a given theory, especially in the light of outstanding conceptual difficulties. Nowhere is this approach more perspicuous than in the case of quantum mechanics and its numerous interpretations. In spite of its tremendous empirical successes, since its inception quantum mechanics has been afflicted with fundamental conceptual problems, of which the measurement problem is the most prominent. In order to cope with these difficulties, several new additions to the standard formalism have been considered, each with its own metaphysical assumptions and implications. Thus the famous many-worlds interpretation comes with the bold metaphysical conjecture of the possibility of the existence of an infinite number of parallel universes which are created when the world splits into an array of copies of itself each with its own unique measurement outcome. The competing GRW theory includes an assumption of fundamental and irreducible randomness in the world, while Bohmian mechanics presupposes a world which at its most basic level is perfectly deterministic and dynamically complete. Some of the latest foundational works in quantum mechanics focus on the problem of how to interpret the concept of the wave function,[5] and this issue opens the door to even more metaphysics inside physics, including the widely discussed dispositional account of laws and properties (cf. the contribution by Mauro Dorato and Michael Esfeld).

4. The Contents of This Volume

The current volume offers but a sample of the extensive work that has recently been done at the border of metaphysics and the physical sciences. The reader can find here a rich variety of approaches and perspectives on the relations connecting metaphysical considerations with questions coming from our best physical theories. Some contributions put stronger

[4] See the recent special issue on principles in quantum gravity of Studies in the History and Philosophy of Modern Physics edited by Karen Crowther and Dean Rickles.

[5] For an excellent, up-to-date overview of this topic see Ney and Albert 2013. Cf. also Vincent Lam's contribution.

emphasis on the metaphysical side, while others pay more attention to the technical aspects of selected theories in contemporary physics. Together, they span the full spectrum from metaphysics to physics.

The opening chapter by Kerry McKenzie and Steven French sets the stage for all the subsequent contributions by tackling head-on the controversial question of the relation between metaphysics and science. As has been already noted, many contemporary philosophers of science denigrate mainstream analytic metaphysics for being woefully detached from scientific endeavors. While sympathetic to the scientifically-oriented motivations behind this general charge, McKenzie and French nevertheless attempt to rehabilitate at least some parts of contemporary metaphysical inquiries. Their main claim is that metaphysics can play a useful heuristic role by providing scientists and philosophers of science with a set of conceptual tools with which they can analyze and interpret their own theories. In their earlier analysis of this problem McKenzie and French expressed the hope that their heuristic approach to metaphysics can supply a criterion distinguishing between metaphysical projects that have the potential of being scientifically interesting from the projects that don't. Such a criterion can be given in the form of the compatibility principle, which states roughly that the constraints placed by a metaphysical theory on some entities should be compatible with at least some scientific theories that invoke these entities. McKenzie and French carefully discuss and repel a popular argument against the compatibility principle based on the premise that metaphysics deals with possible objects while science concerns itself with actual objects only.

However, the main challenge to the heuristic approach analyzed in the current contribution is that, as it appears, there is some tension between the compatibility principle and the fact that it is difficult, if not outright impossible, to predict the future development of scientific disciplines. If metaphysical theories are to be legitimized by their potential applications to the interpretative problems created in the wake of scientific progress, then it seems unreasonable to criticize even the most ill-conceived metaphysical speculations for fear that they might just happen to be useful in the context of some future scientific developments. McKenzie and French respond to this challenge by observing that the heuristic justification of metaphysics is highly conditionalized on the specific goings-on in science and natural metaphysics, and therefore it cannot offer a blanket recognition for any metaphysical speculation whatsoever. The fact that a given metaphysical project can fortuitously become a useful tool for future scientists and philosophers of science does not relieve the metaphysicians from their duty to engage with current science.

The ambitious goal of Douglas Kutach's contribution is to "demonstrate how a general metaphysical framework can be fruitfully integrated with contemporary fundamental physics to help advance our understanding of quantum ontology" (p. 55). The proposed framework of 'empirical fundamentalism' distinguishes between a fundamental reality – the actual world – and a 'derivative' one. Whether something is fundamental or not is a primitive fact about that thing that resists further analysis. The fundamental and the derivative realities are related to one another by a process of 'abstreduction,' "an ontological reduction where the derivative quantity is identified as an abstraction from fundamental quantities." (p. 58) Once this framework is in place, an 'empirical surrogate,' i.e. a formal representation of the phenomena, is introduced to bridge the gap between the fundamental and the derivative. Kutach then applies his 'empirical fundamentalism' to classical spacetime theories and to non-relativistic quantum mechanics. In both cases, a Machian spacetime containing point-particles carving out inextendible worldlines serves as empirical surrogate. An identification of what is fundamental then requires delicately balanced trade-off between parsimony and the avoidance of "conspiratorial arrangements of attributes" (p. 65). This balance, Kutach maintains, leads the empirical fundamentalist to side with the space(-time) substantivalist and against the main interpretations of quantum mechanics as they are standardly understood.

Quantum physics offers very rich grounds for metaphysics and its frequent appearance in this volume should surprise no one. One of the recurring themes in this context is the question of just what ontology quantum physics recommends, requires, or rules out in the light of such challenges as the measurement problem and quantum non-locality. Vincent Lam argues that an ontic structural realist framework is what solves the main interpretative conundrum for an advocate of Bohmian mechanics trying to fit wave functions into her primitive ontology of elementary particles. The original challenge for the Bohmian camp insisting on a 'primitive ontology' of some fundamental material stuff floating around in three-dimensional space is to accommodate the all-important wave function, which is a denizen not of 3-space, but instead of a generally very high-dimensional configuration space. Lam discusses three Bohmian proposals of addressing this challenge, and settles for the third, which takes the wave function to be nothing but a codification of relations obtaining among the local beables, the Bohmian particles. On this understanding, the wave function encodes a holistic property of the entire configuration of these particles, a highly non-local relational complex.[6] This offers a natural entrée for ontic

[6] Cf. the contribution by Dorato and Esfeld for a similar claim.

structural realism, which suggests that we thus interpret the wave function as a physical structure in 3-space (or 4-spacetime).

Lam continues that although ontic structural realism salvages the Bohmian insistence on a primitive ontology in the case of non-relativistic quantum mechanics (and perhaps in quantum field theory), matters get complicated in the more speculative realm of quantum gravity. On many approaches to quantum gravity, spacetime turns out to be emergent rather than fundamental.[7] If spacetime vanishes from the fundamental ontology in quantum gravity, then the structuralist salvation of the primitive ontologist's troubles with the wave function and its attendant manifest explanatory stratagem will no longer succeed, even though a purely structuralist framework remains a live ontological option, Lam argues.

In a similarly structuralist vein, Dean Rickles and Jessica Bloom defend the ontological view according to which on the fundamental level there are no things but irreducible relations only. Thus things ought to be reconceptualized in terms of primitive relations. In a clear exemplification of the approach described in the previous section as 'intrinsic,' the authors argue that the overwhelming support for this claim is provided by modern physical theories, especially ones that Einstein referred to as "principle theories." Rickles and Bloom insist that their variant of ontic structural realism (which falls between the moderate structuralism of Michael Esfeld and Vincent Lam and the radical eliminativist structuralism of James Ladyman and Don Ross) has the potential to lead to new kinds of advancements in physics. If true, this contention would strengthen the claim of the 'from without' relationship between metaphysics and physical theories. However, most of the chapter is devoted to the discussion of four examples from contemporary physics that can either provide an object-free framework or receive a better explanation within such a framework. Among these examples are the application of category theory to the formalization of physical theories, the notorious case of quantum entanglement, and the phenomenon of duality present in many contemporary physical theories.[8]

The abandonment of the ontology of individual objects in the context of the quantum theory is similarly urged by Olimpia Lombardi and Dennis Dieks. Their proposal is to reinterpret quantum particles as bundles of properties, without positing any kind of substratum or haecceity. In their approach, different from the traditional bundle theory, bundles associated

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[7] Cf. Huggett and Wüthrich 2013 and the contribution by Vassallo.

[8] It should be noted, however, that the question of which structuralist position is supported by the reformulation of physical theories in terms of category theory remains a controversial and debated issue (see Lam and Wüthrich, forthcoming).

with individual quantum systems consist of type-properties (represented by self-adjoint operators) and case-properties (represented by eigenvalues). However, due to the quantum-mechanical limitations, such as the one imposed by the Kochen-Specker theorem, fully determinate bundles of actual case-properties are impossible. Lombardi and Dieks note that their version of the bundle theory can throw new light on the notorious problem of the indistinguishability of quantum particles. Two bundles of identical type-properties and case-properties are considered one whole with no individual components (this is best described as one bundle which is doubly instantiated). But in some cases a twice instantiated type-property may receive two different case-properties (for instance two different locations of a wave packet). Consequently, individuality turns out to be an emergent property, since its applicability appears to depend on contingent physical facts.

Tomasz Bigaj in his contribution focuses on the extrinsic aspect of metaphysical analyses in the interpretation of physical theories. The starting point of his discussion is the general question of how to identify fundamental physical objects in counterfactual situations. In response to this question Bigaj advances a metaphysical doctrine he calls "serious essentialism." In a nutshell, this position asserts that the only acceptable way of determining which possible objects can represent *de re* a given actual object is with the help of purely qualitative properties, typically referred to as 'essential.' The doctrine of serious essentialism can be used to evaluate some debates in the foundations of physical theories, such as the controversy over the status of spacetime in the light of the infamous hole argument, and the problem of the indiscernibility of quantum particles which results from the permutation invariance. Serious essentialism appears to give support to a moderate version of spacetime substantivalism, as well as to the claim that the absolute discernment of particles of the same type is possible, despite the symmetrization postulate.

The connection between the concepts of qualitativity and symmetry is scrutinized by Thomas Møller-Nielsen. The main goal of his article is to criticize the commonly accepted doctrine ("Received View") that physical symmetries indicate the superfluousness of certain non-qualitative structures. Møller-Nielsen argues that there are symmetries, such as the Galilean boost symmetry in Newtonian gravity (relating solutions that differ with respect to the absolute velocity of all matter) and the gauge symmetry of electromagnetism, which connect qualitatively discernible solutions. Moreover, the author points out that the view that symmetries should act as guides to redundant nonqualitative structures runs into two serious problems. One problem is that, by analogy with the famous Leibniz shift argument aimed at showing the non-existence of absolute space, the fact that permutations of intrinsically indiscernible particles are symmetries leads to the unpalatable conclusion that individual objects (particles) should be eliminated as well. The second problem arises in connection with Tim Maudlin's distinction between kinematic and static shifts in Newtonian gravitation theory. Plausibly, the argument leading from the existence of a symmetry connecting two qualitatively indistinguishable scenarios before and after a kinematic shift to the excision of the superfluous nonqualitative structure can be resisted, as we can use indexicals to distinguish the current location from the shifted one.

Matteo Morganti urges the reconsideration of a relational, as opposed to a substantivalist or an eliminativist, metaphysics of time. Arguing in a naturalistic mode, he bases his stance on Julian Barbour's 'Machian' program of formulating non-relativistic physics and outline of a quantum theory of gravity. He contends that Barbour's insights would better serve a relational interpretation of time, rather than the radically eliminativist gloss that Barbour himself offers. On this suggestion, Barbour's 'best matching' relations would constitute the temporal relations connecting the states of a system at different 'times.' Morganti proposes to mix this temporal relationalism with substantivalism about space as at least a serious interpretive option. This preservation of a Machian perspective on time without Barbour's attendant eliminativism, Morganti argues, promises a more direct recovery of time and consequently avoids the shortcomings of Barbour's 'error theory' to account for our phenomenology of temporality. Time, on Morganti's proposal, would thus rather straightforwardly emerge from the ordering of the fundamental ontology of spatial states. To explicate the emergence of time (and possibly space) from an ontology devoid of substantial time (and space) remains one of the most urgent tasks of research programs in quantum gravity.[9]

One paper to address the emergence of spacetime in quantum gravity is Antonio Vassallo's. Vassallo considers what it might mean to incorporate the lessons of general relativity into extensions of the theory. He amalgamates these lessons into what he dubs "GR-desideratum" – essentially the demand that the classical limit of a successor theory be a theory formulated on a d-dimensional pseudo-Riemannian spacetime with the d-dimensional diffeomorphisms as its gauge group. The main part of the paper is dedicated to an investigation of two 5-dimensional generalizations of general relativity, Kaluza-Klein theory and Paul Wesson's 'space-time-matter' approach it inspired. In the latter, the complete physics of our apparently 4-dimensional world, including, importantly, its matter and

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[9] Cf. Huggett and Wüthrich (forthcoming).

energy content, is induced by the fundamental 5-dimensional metric tensor. Vassallo finds that these extensions of general relativity only satisfy a relaxed version of the GR-desideratum and expresses his hope that such a relaxation might benefit other troubled issues such as the problem of time in canonical quantum gravity.

Ioan Muntean also considers the metaphysics of physics beyond the currently accepted theories – in his case string theory. String theory is an attempt at unifying the physics of the standard model of particle physics with general relativity, our best theory of the fourth force, gravity. In line with the outlook of this entire collection, he assumes that contemporary physics is a legitimate and important resource for building a metaphysical program. He contends, however, that this does not only apply to securely confirmed theories such as quantum mechanics and general relativity, but also to more speculative, 'good enough' theories such as string theory. Muntean argues that the resulting insights from 'string ontology' and 'string ideology' suggest a model-based and pluralistic metaphysics rather different from what one might expect from quantum field theory. In particular, though some weaker form of fundamentalism can be maintained, the 'duality-pairing' relation among models of string theory suggests a non-reductive, non-hierarchical ontology. Muntean concludes to a pluralism about fundamentality, grounding, parthood, and modality. We agree with Muntean that the novel conceptions of standard metaphysical notions in string theory, and in other programs of quantum gravity, should motivate any philosopher to take a closer look.

Mereology (the formal theory of parthood) is often considered a prime example of a bona fide metaphysical theory. Adam Caulton argues that the principles of mereology are not entirely immune to empirical falsification. To prove his case he uses fermionic composite systems as an example. The standard quantum theory imposes an important restriction, known as permutation invariance, on the joint states of identical fermions. Caulton insists that permutation invariance be interpreted as reflecting a representational redundancy of the standard formalism of quantum mechanics. This heterodox interpretation of permutation invariance prompts a revision of some quantum concepts, such as the notion of an entangled state. Focusing his attention on the assemblies of fermions which are non-entangled in this sense, Caulton shows that their states can be represented by subspaces of the single-system Hilbert space, while the relation of being a part of is best interpreted as the relation of subspacehood. Given the appropriate translation rules from the quantum-mechanical formalism to the language of mereology it can be proven that the principle of mereological fusion is violated, i.e. there are subsystems of the entire assembly that do not jointly constitute a whole satisfying the conditions of a mereological fusion (even though subsystems create *fermionic* fusions, which however lack the required Boolean structure). At the end of his paper Caulton suggests that mereology can be saved by admitting arbitrary mereological fusions which are not fermionic systems.

Mereological considerations intersecting with classical and quantum physics also take center stage in Andreas Hüttemann's contribution. He argues that a particular brand of physicalism – what he dubs "part-whole physicalism" – is not supported by considerations of classical physics and quantum mechanics. Part-whole physicalism asserts that the "properties of compound systems are the way they are in virtue of the properties of their parts," plus some relational facts including concerning how they interact. Crucially, part-whole physicalism includes a reference to the 'in virtue of' relation, a grounding relation of asymmetric determination. In other words, part-whole physicalism demands that for all wholes, there exist parts which, together with relational facts about these parts, asymmetrically determine the whole. On this conception, part-whole physicalism can only be true if the determination is asymmetric, i.e., if facts about a whole are partially grounded in facts about any of its specific part, but not vice versa.

Hüttemann then goes on to argue that in systems described by classical physics as well as in dynamics of multipartite quantum systems, while the properties of the whole are indeed determined by its parts, asymmetry of determination does not obtain: just as the whole is determined by its parts and relations among them such as laws of composition and interaction, a part is equally determined by the whole, the other parts, and relations among them. In other words, the partial determination between the whole and any of its parts is mutual and thus symmetrical. So unless the part-whole physicalist comes up with some way to break the symmetry of determination she cannot hope to succeed. Hüttemann does not see how such an asymmetry could be introduced, at least not as long as there is no additional case for insisting that all determinates of a determinable need to be at the same level (either all micro or all macro) and as long as the macrostate contains sufficiently 'fine grained' information.

Jessica Wilson's paper contains a comprehensive metaphysical analysis of the notion of emergence. All accounts of emergence should reflect its two aspects: synchronic dependence of higher-level entities on lower-level entities, and ontological and causal autonomy of higher-level entities. In spite of the enormous diversity of existing explications of emergent dependence and emergent autonomy, Wilson claims that there are actually only two schematic conceptions of higher-level metaphysical emergence, which she calls "Strong emergence" and "Weak emergence." They can be viewed as two possible responses to the problem of higher-level causation, articulated by Jaegwon Kim, which arise from the fact that certain plausible requirements regarding how special science entities cause effects cannot be jointly satisfied. Strong emergence solves the difficulty by denying physical causal closure, that is, by admitting that higher-level entities have novel powers which are not identical with lower-level powers. Weak emergence (or non-reductive physicalism), on the other hand, accepts overdetermination and assumes that the set of higher-level powers is a proper subset of the set of lower-level powers. The article shows how various and seemingly diverse accounts of emergent dependence and autonomy can be subsumed under the two broad schemas mentioned above.

One of the central questions of naturalistic metaphysics concerns the ontological status of the laws of nature. Primitivism and dispositionalism are two dominating non-Humean solutions to this problem. Mauro Dorato and Michael Esfeld compare these two metaphysical options available to anti-Humeans using two case studies: one from classical physics and one from quantum physics. Classical physics is founded on the Newtonian laws of motion, of which the first law is uninstantiated due to the impossibility of screening off gravitational interactions. Dorato and Esfeld argue that primitivism, in contrast to dispositionalism, has difficulties with accommodating uninstantiated laws of nature. Dispositionalism, in turn, implies that there is no possible world in which actual physical properties (such as mass) would be instantiated and yet the laws would be different. The second case study discussed by the authors is the 'primitive ontology' approach to quantum mechanics, as exemplified by Bohmian mechanics and two versions of the GRW theory. The main difference between the dispositionalist interpretations of the quantum and the classical cases is that in the quantum scenario laws encoded in the wave-function are grounded in global and holistic properties of matter, rather than local or intrinsic properties of individual particles. In spite of this setback, the authors maintain that dispositionalism is to be preferred over primitivism, since it can better accommodate the fact that the (nomological) wave-function develops according to the Schrödinger equation, and that there are many wave-functions that are compatible with the same dynamical laws.

The problem of determinism also belongs to the canons of scientifically motivated metaphysics. Marek Kuś considers the question of whether classical and quantum physics admit genuine randomness which is not a mere result of the limitation of our knowledge. Classical mechanics leaves some room for indeterminism, as the existence of systems with non-unique solutions for some initial conditions attests. However, quantum mechanics stands a much better chance of proving the existence of inherent randomness in the world. Experimental confirmations of the violation of Bell's inequalities are usually taken as indicative of the non-deterministic character of quantum processes, but this conclusion can be questioned on the basis of the fact that we have to assume first that the selection of measurement settings is genuinely random.[10] However, as Kuś argues, a better argument is provided by the phenomenon of the amplification of randomness. Such a process starts with a sequence of bits of a given randomness (or even a perfectly deterministic one) and produces new sequences of an increasing degree of randomness. It has been proven that the amplification of randomness is impossible in the classical regime. However, recent investigations have revealed that by using a string of Bell-type experiments it is possible to achieve a genuine amplification of randomness, thus confirming that quantum mechanics outperforms classical physics in this respect.

There are some technical aspects of contemporary physical theories that arouse a particularly keen interest of philosophers of science. The notion of renormalization, used in the context of quantum field theory, belongs to that category. As Jeremy Butterfield and Nazim Bouatta explain in their extensive article, there are two main approaches to the problem of renormalization. According to the old school, renormalizability acts as a selection rule for theories. An acceptable quantum field theory has to be renormalizable, that is, it has to be possible to eliminate infinities occurring in this theory. The new approach, on the other hand, places emphasis on the general question why certain theories are renormalizable while others are not. This approach makes precise mathematical sense of the notion of a space of theories and a flow on this space, and using these concepts it offers an explanation of the renormalizability of some theories. Butterfield and Bouatta clarify in details the concept of a renormalization group flow central to this approach. At the end of the chapter they compare the concept of universality present in renormalization theories with the Nagelian conception of inter-theoretical reduction, and they argue that universality is a particular instantiation of the general philosophical idea of multiple realizability.

Tomasz Bigaj and Christian Wüthrich

[10] Cf. also Wüthrich 2011.

REFERENCES

Bigaj, T. (2015). Dissecting weak discernibility of quanta. *Studies in History and Philosophy of Modern Physics* **50**, 43–53.

Callender, C. (2011). Philosophy of Science and Metaphysics. In: S. French and J. Saatsi (eds.), *The Continuum Companion to the Philosophy of Science*, pp. 33–54. London – New York: Continuum.

Crowther, K., Rickles, D. (2014). Principles of Quantum Gravity. *Studies in the History and Philosophy of Modern Physics* **46**, 135–326.

Fine, K. (2013). What is Metaphysics? In: T. Tahko (ed.), *Contemporary Aristotelian Metaphysics*, pp. 8–25. Cambridge: Cambridge University Press.

French, S. (2011). Metaphysical underdetermination: why worry? *Synthese* **180**, 205–221.

Huggett, N., Wüthrich, C. (2013). The emergence of spacetime in quantum theories of gravity. *Studies in the History and Philosophy of Modern Physics* **44**, 273–364.

Huggett, N., Wüthrich, C. (forthcoming). *Out of Nowhere: The Emergence of Spacetime in Quantum Theories of Gravity*. Oxford: Oxford University Press.

Lam, V., Wüthrich, C. (forthcoming). No categorial support for radical ontic structural realism. *British Journal for the Philosophy of Science*.

Muller, F.A., Saunders, S. (2008). Discerning fermions. *British Journal for the Philosophy of Science* **59**, 499–548.

Ney, A. (2012). Neo-positivist metaphysics. *Philosophical Studies* **160**, 53–78.

Ney, A., Albert, D. (2013). *The Wave Function: Essays in the Metaphysics of Quantum Mechanics.* Oxford: Oxford University Press.

Ross, D., Ladyman, J., Spurrett, D. (2007). In defence of scientism. In: J. Ladyman and D. Ross (eds.), *Every Thing Must Go*, pp. 1–65. Oxford: Oxford University Press.

Saunders, S. (2006). Are quantum particles objects?. *Analysis* **66**, 52–63.

Wüthrich, C. (2011). Can the world be shown to be indeterministic after all? In: C. Beisbart and S. Hartmann (eds.), *Probabilities in Physics*, pp. 365–389. Oxford: Oxford University Press.