Effective Theories, Mixed Scale Modeling, and Emergence

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Center for Philosophy of Science, University of Pittsburgh

BRIEF ABSTRACTS

Speaker: **Mark A. Bedau, Philosophy, Reed College**

Title: A Defense of Pluralism About Emergence

Clarity about the relations between computational models and theories at different scales in nature and in multiscale models depends in part on distinguishing different kinds of emergence. Pluralism about emergence helps focus attention on important productive questions and deflects attention away from irrelevant and unproductive questions. This pluralism has been implicit throughout my earlier work on emergence (e.g., Bedau 1997, 2003, 2008, 2011). My talk defends a form of pluralism about kinds of emergence and applies it to multiscale phenomena and models.

Speaker: **Karen Crowther, Philosophy, University of Pittsburgh**

Title: Decoupling Reduction and Emergence in Physics

An effective theory in physics is one that is supposed to apply only at a given length (or energy) scale; the framework of effective field theory (EFT) describes a `tower' of theories each applying at different length scales, where each `level' up is a shorter-scale theory. Owing to subtlety regarding the use and necessity of EFTs, a conception of emergence defined in terms of reduction is irrelevant. I present a case for decoupling emergence and reduction in the philosophy of physics. This paper develops a positive conception of emergence, based on the novelty and autonomy of the `levels', by considering physical examples, involving critical phenomena, the renormalisation group, and symmetry breaking. This positive conception of emergence is related to underdetermination and universality, but, I argue, is preferable to other accounts of emergence in physics that rely on universality.

Speaker: **Sebastian de Haro, Philosophy, University of Cambridge and University of Amsterdam**

Title: Emergence and RG in Gauge/Gravity Dualities

Recent developments in gauge/gravity dualities suggest that RG flows and the dynamics of spacetime are intimately related. The direction along which the theory's couplings 'flow', typically an energy scale, is reinterpreted as a dimension (spatial or temporal) in which fields can evolve. It is often claimed that space, time, and-or gravity 'emerge' from a lower-dimensional theory in this way.
In this talk I will: (i) present a framework for discussing emergence in cases of duality; (ii) assess the claims of emergence in the best studied case of gauge/gravity duality: the AdS/CFT correspondence; (iii) comment on the possibility of carrying these ideas over to a cosmological context, viz. of de Sitter space-time.
Regarding (i): after introducing general notions of duality and emergence, I will argue that these two notions preclude one another. Coarse-graining will come to the rescue, suggesting two possible ways in which emergence can take place in the case of dualities (and I will argue that this exhausts the possibilities). Then I will: (ii) introduce holographic RG techniques as used in AdS/CFT. I will then employ the general framework of dualities and emergence to assess in what sense these are cases of emergence. In the last part of the talk, I will: (iii) discuss the conjectured dS/CFT correspondence for cosmological scenarios. After (a) discussing some of the difficulties for holographic theories of de Sitter spacetime, I will (b) review current progress on two proposals for dS/CFT, and (c) discuss in what sense time can be said to emerge in such scenarios.

Speaker: **Nicolas Fillion, Philosophy and Center for Scientific Computing, Simon Fraser University**

Title: The Scale-Dependence of Model Adequacy and Tractability

The concept of explanatory relevance plays a fundamental role in many philosophical accounts of scientific explanation. It is especially prominent in the so-called 'difference-making' approaches to explanation. At the same time, this concept is also central to modeling strategies employed by applied mathematicians in practice. Indeed, the key challenge they face is to find a balance between the exactness and the tractability of mathematical models built for the purpose of capturing at the very least the explanatorily relevant factors. A crucial task involved in the justification of models consists in characterizing the scales at which various causal factors contributing to the behavior of the system are operative. This fact has been recognized in the philosophical literature, but the methodology deployed to efficiently diagnose scale-dependent aspects of explanatory relevance remains underappreciated, despite the fact that it points to a much richer account of the context of justification of scientific practices. From this point of view, I will describe a perspective on approximation methods (specifically, numerical and perturbation *analysis) that is philosophically and mathematically beneficial, especially in singular problems that contain essential scale-dependent elements. As a result, a relatively general picture of the implicit methodology employed by applied mathematicians to diagnose explanatory relevance will emerge from the discussion.*

Speaker: Samuel Fletcher, Philosophy, Munich Center for Mathematical Philosophy

Title: Emergence from Scale's Labyrinth

I give a precise formal definition of a type of emergence that can be found in the context of limiting relationships between scientific theories, showing that it can apply fruitfully to a variety of physical examples. An advantage of this definition is that, tied as it is to limiting relationships, it does not in general track autonomy along a single simple dimensional scale such as energy, length, or time, but can instead involve labyrinthine balancing relationships between these scales. This complicated the usual view of emergence as occurring at linearly (or even partially) ordered levels.

Speaker: Nigel Goldenfeld, University of Illinois at Urbana-Champaign

TITLE: Patterns, universality and computational algorithms

Can we use computational algorithms to make accurate predictions of physical phenomena? In this talk, I will give examples where complicated space-time phenomena can be exquisitely captured with simple computational algorithms, that not only produce patterns resembling those seen in experiment, but also make accurate predictions about probes of dynamics and spatial organisation, such as correlation functions. I use examples from condensed matter physics, as well as from geophysics. Because many patterns involve structure on multiple length and time scales, I also discuss how one can develop multiscale methods for real materials processing from the nanoscale on up. I show how computationally-efficient multiscale approaches can be developed to solve a minimal model of crystalline materials. The approach is to systematically use renormalization group or equivalent techniques to derive appropriate coupled phase and amplitude equations, which can then be solved by adaptive mesh refinement algorithms.

Speaker: **Ken Jordan, Chemistry, University of Pittsburgh**

Title: Coarse Graining of Dynamical Correlation Effects in Electronic Structure by Use of Quantum Drude Oscillators
(credit to Kenneth D. Jordan, Tuguldur Odbadrakh, and Mary Sherman)

Dispersion interactions involve the correlated motion between the electrons of well separated entities (atoms, molecules or surfaces). Such interactions are necessarily attractive and play a major role in the cohesion of liquids and molecular crystals as well as in determining the structure of biomolecules. A major weakness of common density functional methods is that are unable to describe long-range dispersion interactions. Two-body dispersion effects are recovered by second-order many-body perturbation theory, but this approach has a computational cost O(N5) where N is the number of electrons in the system, and also does not recover many-body dispersion effects that can be very important in condensed phase systems. In this talk, I will focus on coarse-grained approaches to treating dispersion, with particular emphasis on modeling collections of electrons as three-dimensional Drude oscillators. A Drude oscillator consists of two fictitious charges, a fixed +Q charge and a displaceable –Q charge, that are coupled harmonically. (For a water molecule, this reduces the 10 electron problem with a three-dimensional harmonic oscillator.) If one allows only dipole-dipole coupling between the Drude oscillators, one can analytically solve for the interaction energy by a change of variables, and this nicely illustrates that the dispersion energy is associated with the change of zero-point energy resulting from the coupling of the oscillators. I then show how we can use quantum Drude oscillators to recover many-body dispersion effects, and also discuss how the Drude oscillator can be extended for describing the interactions of excess electrons with molecules and clusters. Finally, I show how Drude oscillators are useful for understanding Feynman's conjecture that long-range dispersion interactions lead to permanent dipoles on each atom (molecule) and that the dispersion energy can be calculated classically based on the altered charge distributions, which suggests new approaches for correcting density functional theory for dispersion.

Speaker: **Patrick McGivern, Philosophy, School of Humanities and Social Inquiry University of Wollongong**

Title: Realism and Multiscale Modeling

When should multiscale models be considered realistic? The appeal to multiple scales and the construction of effective theories has many of the hallmarks usually associated with pragmatic, instrumentalist, or even fictionalist views of scientific modeling: multiscale techniques often seem to be matters of mathematical convenience, justified by the fact that our interests ultimately lie in results within a certain degree of adequacy. However, from another perspective, *multiscale modeling and effective theory construction have features that are closely connected with much more realistic views of modeling. The construction of such models is typically highly non-arbitrary, relying on a variety of specific 'characteristic' scales from the micro to the macro. In this paper I examine the prospects for realism about multiscale modeling, and consider what criteria would be appropriate for distinguishing between the realistic and the purely pragmatic components of multiscale models.*

Speaker: Patricia Palacios, Philosophy, Munich Center for Mathematical Philosophy

Title: The Role of Approximation in a Reductive Model for Phase Transitions

Phase transitions, roughly understood as sudden changes in the phenomenological properties of a system, have recently motivated a debate about reduction and emergence in the physical sciences. In this debate there are two main positions: i) Phase transitions are paradigmatic cases of emergent or irreducible behavior (Lebowitz 1999, Batterman 2000, 2002, Bangu 2011); ii) phase transitions represent a successful case of Nagelian reduction (Butterfield 2011, Menon and Callender 2011, Norton 2012). This leads one to conceive of the discussion in the following terms: Phase transitions are either non-reductive phenomena or reductive phenomena satisfying the Nagelian model of reduction. In this paper I will suggest that this dichotomy is misleading. In fact, there are good reasons for considering phase transitions as a case of reduction that does not satisfy the Nagelian model of reduction, either in its strict or more liberal versions.

Speaker: Joshua Rosaler, Philosophy, University of Minnesota

Title: Reduction in Physics: A Local, Model-Based, Empirical Approach

A conventional wisdom about the progress of physics dictates that theories in physics grow progressively more universal in scope and precise in their depictions of physical reality, so that each successive theory in a given realm wholly encompasses the domain of applicability of its predecessor. Numerous efforts have been made to give a general account of the relation between successive theories that underwrites this subsumption, which is often known as "reduction." Here, I propose a novel account of this relation that incorporates crucial insights underscored by previous accounts of reduction in physics while correcting some of their shortcomings. This account differs from earlier accounts both in the particular combination of features that it possesses and in the fact that it is grounded in a more fundamental notion of *reduction between models of a single physical system. Like variations of Nagelian reduction formulated in response to concerns about multiple realization, this account of reduction is local in that it allows for many context-specific derivations rather than requiring a single global derivation of one theory's laws from those of another. Like Kemeny-Oppenheim reduction, it regards reduction as an empirical, a posteriori relation rather than as a purely logical or mathematical relation between theories. Like the "physicist's" limit-based concept of reduction, it is strongly attentive to the specifically mathematical character of reductive relations in physics. I argue that this concept of reduction is strong enough to support the kind of subsumption of domains required by the conventional wisdom about the progress of physics but not so strong that it fails to apply to the particular theory pairs for which the conventional wisdom requires subsumption of one theory's domain by another. Anti-reductionist arguments based in multiple realization and singular limiting relations are considered, and it is argued that neither of these issues poses a serious obstacle to reduction in the particular sense described here. Open questions and further avenues for elaboration of this approach are then discussed.*

Speaker: Porter Williams, Philosophy, Columbia University

Title: Naturalness, Effective Field Theory, and the Autonomy of Scales

For approximately 40 years, the majority of theorizing about physics beyond the Standard Model has been guided by the principle of `naturalness'. Originally formulated by Ken Wilson in 1971 and first explicitly used as a guide to BSM model building by Leonard Susskind in 1979, naturalness quickly became a centrally important principle guiding model building in the high-energy physics community, a status it continues to enjoy today. During this time is has received a number of dissonant characterizations, alternatively described as (i) a problem of fine-tuning, (ii) a symmetry principle, (iii) an `aesthetic preference' of theorists, or (iv) an issue with `quadratic divergences'. This talk aims to clarify the conceptual and physical significance of the naturalness principle in the effective field theory framework, arguing that it is best understood as a principle concerning the autonomy of scales. I also argue that recent LHC data suggesting that the Standard Model is unnatural has consequences for philosophical proposals according to which effective field theories support an ontology of layered, quasi-autonomous domains.

Speaker: Mark Wilson, Philosophy, University of Pittsburgh

Language Design: Lessons from Multi-scalar Modeling

Grasp of linguistic meaning is frequently described in a fashion that would place impossible demands upon our brain capacity if we actually approached language employment in that manner. Modern breakthroughs in multi-scalar modeling have suggested clever architectures of "divide and conquer" data allocation that can significantly reduce the computational demands of naive expectation. In this talk I will outline a typical multi-scalar architecture and discuss its potential ramifications with respect to everyday thinking about the world around us.