# Workshop "Reduction and Emergence in Physics and Cosmology"

Abstracts:

## Reduction and Emergence in Physics and in Technological Applications

George Ellis

A key issue in discussing reduction and emergence is the difference between synchronic and diachronic effects. In the former case full knowledge of the lower-level state does indeed determine the higher-level state at that time. However in the latter case this is not true because all real physical and technological systems are open systems, therefore full knowledge of the initial state does not determine the final state. Astrophysical systems and digital computers are examples. The usual arguments about the differences between weak and strong emergence are in practice unimportant (although one can make a good case the latter is indeed what occurs in condensed matter physics). What matters is that effective laws at each emergent level are indeed effective. In Aristotelian terms they are cases of efficient causation, enabled by both formal and material causation - both instances of downward causation. Examples are existence of quasi-particles in crystals, and of Cooper pairs in superconducting media. Abstract causation occurs in the case of digital computers, because algorithms and data are abstract entities that determine outcomes. Final causation also occurs in this case because all technological devices have a purpose that determines their design, algorithms, and data.

## Levels of Description and Levels of Reality: A General Framework

Christian List

I will sketch a general framework for representing levels and inter-level relations. The framework is intended to capture both epistemic and ontological notions of levels and to clarify the sense in which levels of explanation might or might not be related to a levelled ontology. The framework also allows us to study and compare different kinds of inter-level relations, especially supervenience and reduction but also grounding and mereological constitution. This, in turn, enables us to explore questions such as whether supervenience implies explanatory reducibility and whether there can be irreducible higher-level explanations or even "emergent" higher-level properties. The paper on which the presentation is based is available at: https://philpapers.org/archive/LISLOD.pdf

**Analogies, Emergence, and the Structure of Effective Theories: Lessons from Quantum Field Theory**
Stephan Hartmann

This talk explores how analogies function not just as heuristic tools but as vehicles for understanding emergence in contemporary physics. Using the development and application of the Nambu–Jona-Lasinio model as a case study, I show how concepts from superconductivity were transferred to quantum field theory and ultimately to quantum chromodynamics. This transfer illustrates how analogical reasoning can help construct effective field theories that capture emergent phenomena—such as dynamical symmetry breaking—without being reducible to more fundamental microphysical accounts. I will discuss the epistemic status of such analogies, the extent to which they support or challenge reductionist strategies, and whether their success lends support to structural realist views of scientific knowledge. In doing so, I aim to clarify how analogical modeling contributes to the explanatory autonomy of emergent theories and what this means for understanding the layered architecture of physical reality.

**Emergent (Relational) Cosmology from Quantum Gravity**
Daniele Oriti

We outline key steps, assumptions and approximations taken to extract an emergent cosmological dynamics for both cosmological backgrounds and perturbations around them (thus effective quantum field theory) from quantum gravity models in the tensorial group field theory (thus spin foam and LQG) formalism. We also discuss in more detail recent results, showing an emergent cosmological acceleration at both late- and early-times produced by quantum gravity interactions.

**Laws without Spacetime: the Strategy from Global Constraints**
Laurie Letertre

Recent approaches in quantum gravity suggest that spacetime may not be a fundamental aspect of reality, but rather an emergent phenomenon arising from a non-spatiotemporal substratum. This raises a significant challenge for traditional accounts of laws of nature, which are typically grounded in spatiotemporal concepts. In this talk, I will explore a possible strategy for formulating laws of nature without spacetime, drawing on the framework of laws as global constraints. The aim is to defend this conception of laws against the objection that it is too thin to provide genuine understanding and explanatory power.

**Is the Universe Fundamentally a Density Matrix?**
Alyssa Ney

This paper examines the case for density matrix realism, as an approach to the fundamental ontology of our world. To date, there are two arguments that have been used to motivate density matrix realism. One is that we get a simpler metaphysics if we move from wave function realism to density matrix realism. The second is that density matrices are more general than wave functions, in allowing that the universe could be in a mixed state. To be convincing, these arguments can't rest on the logical possibility that our universe could be in a mixed state. After all, if we assume standard understandings of mixedness, it's a contradiction to say that the universe as a whole could (objectively) be in a mixed state. Thus, one would need to appeal to some scientifically-backed argument that the Quinean web of belief needs revision. Here, Hawking's model of black hole evaporation seems poised to come to the rescue, and so we develop an argument to this effect. Although we find the prospect of using black hole evaporation to argue for density matrix realism to be intriguing and worthy of investigation, we show that there is substantial reason to be cautious. Most physicists, including Hawking, believe that this model will be superseded by a more fundamental theory of quantum gravity. Despite the lack of consensus on the details of such a theory, the guiding principles that do enjoy some consensus point away from an interpretation of black hole evaporation in which the universe as a whole evolves into an (objectively) mixed state. We conclude that there do not seem to be compelling motivations coming from the most sophisticated candidates for fundamental physics to entertain situations in which the universe is characterized by a density matrix rather than by a wave function or state vector.

**How to Reduce the Quantum Formalism? The Quantum Reconstruction Program vs. The Ontological Model Framework**
Mario Hubert

I argue that the Quantum Reconstruction Program (QRP) and the Ontological Model Framework (OMF) represent analogous, yet competing approaches to reduce the operational formalism of quantum mechanics: QRP builds on information-theoretic principles (creating principle theories), while OMF requires an underlying ontic state (generating constructive theories). I show that their overlap is limited to ψ-credal interpretations, with most QRP-derived theories being incompatible with the OMF. This incompatibility reflects a deeper philosophical divide about whether physical theories should emerge from principles or from postulates about objective physical states.

**What is Effective Metaphysics?**
Sebastien Rivat

Kerry McKenzie recently challenged the possibility of effective metaphysics in the context of naturalized metaphysics, where by 'effective metaphysics' she means the study of non-fundamental items in their own terms and independently of fundamental metaphysics. The goal of this talk is to address her argument and propose a refined account of what effective metaphysics consists in. In particular, I will suggest that we ought to be more selective: the possibility of effective metaphysics hinges on focusing on non-fundamental items that depend only very little on fundamental ones from the perspective of the theories that describe them.