controversy over the nature of sight (*intromissive* vs. *extramissive*, etc.), the recent evidence of a star being destroyed by a black hole, Boyle's contributions to the founding of modern experimental science, Alexander von Humboldt's important contributions to the value of a wholistic, multilevel vision of nature and science, Emmy Noether's astonishing discovery of the theoretical origin of conservation laws in physics, the discovery of the all-important fluctuation-dissipation theorem over 30 years (inaugurated by Einstein in 1905, applied to electrical noise by Nyquist in 1928, and fully generalized by Callen and Welton in 1951), the recent development at Caltech of a jet fuel polymer additive that greatly inhibits explosions of jet fuel (motivated in part by the horror of the fuel explosions on 9/11), and finally the full discovery of what causes rainbows by Theodoric in ca. 1310. The descriptions of these historic achievements are each fascinating in their own right and very readable—they alone, for me, would justify an investment in this book. When they are paired with a similar creative work from art, poetry, or fiction, the juxtaposition is extremely fruitful, though the philosophical/psychological analyses get much denser.

Many other discoveries are given much shorter treatment (less than one page), including Andrew Wile's solution to Fermat's Last Theorem, Dirac's mathematical discovery of spin and anti-matter, Poincaré's discovery of a new class of Fuchsian functions, Royer's recent proof of the Gaussian Correlation Inequality in statistics, and Heisenberg on discovering quantum matrix mechanics. The explorations into artistic and literary creativity are typically much shorter, but are nearly as numerous; they include a painting conceptually representing a string-quartet performance by English artist Graeme Willson, Virginia Woolf's *To the Lighthouse*, Robert Schumann's orchestral work *Konzertstück*, and Picasso's masterpiece *Guernica*.

At nearly four hundred pages, this is not light reading and takes some patience and time to get through. It is written at a very high level of sophistication, and therefore one is often "bogged down" trying to make complete sense of what one is reading. (However, if one is not writing a review of the book, one need not spend quite so much time disentangling every dense sentence to get the main gist of the passages.) Also difficult are the many references to previous parts of the book. While these references are entirely appropriate, they are quite demanding of the reader given the sheer number of names and amount of material covered. I had to do quite a bit of flipping back and forth, checking the index to remember exactly what so-and-so said that is now being referenced 100 pages later. In other words, this is a thoroughly academic text.

This is a revised edition of the book, which was first published in 2019. The overwhelming positive response, according to the new preface, prompted the author to immediately answer some of the initial reviews and friendly critiques, which I believe made the book quite a bit better (initially there was not nearly as much about poetry; the comparison of poetry with theoretical science now became a separate chapter, enabling McLeish to more logically and thoroughly cover the territory he had staked out). McLeish sadly died very recently (February 2023) at age 60, while holding the newly created chair in Natural Philosophy at University of York. He was a lay preacher in the Anglican Church and a Fellow of the Royal Society.

Reviewed by Peter Walhout, Chemistry Department, Wheaton College, Wheaton, IL. 60187.

DOI: https://doi.org/10.56315/PSCF9-23Bishop2

EMERGENCE IN CONTEXT: A Treatise in Twenty-First Century Natural Philosophy by Robert C. Bishop, Michael Silberstein, and Mark Pexton. Oxford, UK: Oxford University Press, 2022. 363 pages. Hardcover; $103.65. ISBN: 9780192849786.

Reductionists dream of a day when all scientific truths can be derived from fundamental physics. Bishop, Silberstein, and Paxton show that dream is now dead, or at least it's quite ill. But what will replace it? One answer is "emergence," although that term is ambiguous. In its weak sense, it merely expresses pessimism about our ability to fully understand how microphysics produces all other phenomena. In its strong sense, it means that some entities have a kind of autonomy from physics, with their own "causal powers," including downward causation. Bishop et al. seek to replace strong and weak emergence with "contextual emergence."

Let's start with an example (sec 2.4). Rayleigh-Bénard convection occurs when a fluid is trapped between a heating plate below and a cooler one above. Convection cells emerge as warmer fluid rises toward the top and cooled fluid sinks. While molecular interactions play a part in this, sustained convection is impossible without the macroscopic plates. This behavior is not wholly determined by the fluid's constituent parts but rather by the context in which the fluid exists.

What this and scores of other examples show is that phenomena at a given scale often depend on a host of "stability conditions" at other scales—sometimes higher, sometimes lower. *Contra* the reductionist, the authors argue that the behavior of entities, properties, and processes at a given level is never wholly determined by events at a lower level. Macroscopic conditions (among other things) play an essential and ineliminable role. If we knew all the truths of nature, we would see that not all dependence is bottom-up.

"But the plates in your example are made of matter," says the critic, "We can reduce those to the behavior of atoms as well." A complete mathematical description without idealizations? "Well, it can be done in principle." Let's consider another example while we wait. Physicists in the Newtonian era devoted much time to the study of planetary orbits. One surprising stability condition is three-dimensional space. In four dimensions, regular orbits that resist small perturbations would be impossible (p. 29). Note that spatial dimensions are not part of the system. They are the context in which the system exists. Three dimensions are a necessary condition for stable orbits but cannot be reduced to the system's constituents even in principle. The properties of the parts do not determine the properties of the whole. This example illustrates why emergent properties are often inexplicable or unpredictable given complete knowledge of lower-level constituents: stability conditions are typically not at some lower level. While some stability conditions are causal and mechanical, like the plates in the convection examples, others are acausal, like conservation laws and least action principles. Still more are abstract properties of dimension and the geometry of mathematical spaces. Whichever the case, the authors consider those conditions to be as real or "fundamental" as anything at the level of elementary physics—something that sets this book apart from both reductionism and many other versions of emergentism.

Emergence is often associated with novelty, such as when a new and unexpected higher-level property emerges from its base. The authors believe this attention is misplaced. They focus instead on how stability conditions either open or close off areas of "possibility space." A possibility space is an abstraction in which each point represents a possible state or behavior of the system. For example, one point in the possibility space of a baseball represents its being in orbit—a possibility that will likely never be actualized. In Newtonian mechanics, the ball might also travel at the speed of light. Under special relativity, on the other hand, that part of possibility space is closed to the ball. As a result, no material object can reach that speed. The more interesting and neglected case occurs when stability conditions *create* access to parts of possibility space. For example, lasers do not exist in nature. Their stability conditions include the existence of a resonance cavity in which atoms can be electrically stimulated and isolated from their environment and putting those atoms in the proper state to begin the process (sec 4.9.1). When these conditions are in place, the area of possibility space representing coherent light becomes accessible. Such light has always been physically possible, but without the requisite context, it cannot become actual.

The authors make several applications to perennial questions in the philosophy of science that I do not have space to elaborate on. These include modality, dispositions/causal powers, properties, the laws of nature, causation, and determinism. Each of these has a relation to stability conditions that is often overlooked. The authors show how progress can be made on each question with less metaphysical baggage than many analytic metaphysicians assume.

Chapter 7 includes several possible objections, but one stands out. While we might need to use multiscale modeling in order to make predictions, that's because of our own epistemic limitations. Stability conditions are important, a critic might grant, but they are ultimately grounded in fundamental physics just like everything else. If we only knew enough about the system and its contexts, we would see how it's all due to the behavior of fields, particles, or whatever resides at the lowest level.

Bishop et al. reply that emergence has the evidence on its side, including an entire book with dozens of examples that cannot be reduced in the manner the critic envisions (p. 313). Nonetheless, the ontological reductionist continues to claim that while these examples have not yet been reduced to lower-level phenomena, it's just a matter of time. One wonders how long such promissory notes will be accepted.

My only concern is that contextual emergence might be *too* commonplace. Emergentists, especially of the strong variety, sometimes have difficulty providing convincing examples. Consciousness and quantum entanglement always make the list, but neither is fully understood. Contextual emergence, in contrast, is ubiquitous. Many examples are from biology and neuroscience, as one might expect, but most come from physics itself. Consider one more. Whether a dying star forms a white dwarf, neutron star, or black hole depends on its context, specifically how much mass the star had prior to collapse (sec 4.4). All three are therefore contextually emergent. But our hypothetical critic will surely complain that there's nothing *emergent* about this. The context is just mass, and mass is fundamental. Even some fellow emergentists might wonder whether calling every example that relies on necessary conditions "emergence" diminishes the significance of the term. Whatever the terminology, the book highlights a neglected aspect of what science tells us about the world. The objects and properties science studies depend on stability conditions, and those conditions are not typically found at smaller scales. Contextual emergence, therefore, stands in stark contrast to what reductionists had led us to expect.

Insofar as reductionism is incompatible with theism, this is the main takeaway for Christian academics. Science still tends to operate under a reductionist narrative that can deal with religious belief only in terms of psychological predispositions and sociological pressures. But if this narrative is false even in the physical sciences, then religious beliefs need not be restricted to such cramped corners. One might even wonder whether some of those beliefs are true.

Reviewed by Jeffrey Koperski, Professor of Philosophy, Saginaw Valley State University, University Center, MI 48710.

PHYSICS

DOI: https://doi.org/10.56315/PSCF9-23Palmer

THE PRIMACY OF DOUBT: From Quantum Physics to Climate Change, How the Science of Uncertainty Can Help Us Understand Our Chaotic World by Tim Palmer. New York: Basic Books, 2022. 297 pages. Hardcover; $30.00. ISBN: 9781541619715.

Tim Palmer, a distinguished physics professor at the University of Oxford, has authored a captivating popular science book exploring chaos in complex systems. Early in his career, he switched fields from mathematical physics to weather forecasting and made significant developments in ensemble weather prediction, revolutionizing our understanding of weather patterns. The author discusses how delving into this realm reveals a chaos geometry, describing difficult-to-understand real-world phenomena. He takes the reader through various complex systems that exhibit a marked sensitivity to initial conditions, like the renowned "butterfly effect." Chaos geometry describes a system that is predictable and stable for a long time, but occasionally veers into new directions. The study of chaotic complex systems challenges traditional notions of predictability.

The book is divided into three parts. Part 1: The Science of Uncertainty explores the concept of chaos geometry. Palmer captivates readers from the start by sharing a true story about a renowned BBC weather forecaster. In 1987 this forecaster infamously failed to predict the most severe storm in 300 years, striking England. This incident highlighted the unsettling truth that complex systems can deviate significantly from historically stable patterns. As a polymath, Palmer generously shares captivating examples and illustrations from fields such as history, philosophy, and art. Part I is solid science and mathematics, but without equations.

Part II: Predicting Our Chaotic World explores Palmer's influential technique to forecast inherently uncertain systems, running models multiple times with slightly different initial conditions. Chaos geometry offers a powerful description of the behavior of these systems. The author focuses on Lorenz's idea that even with infinitesimally small uncertainty, we cannot predict beyond a finite horizon in time. The author extends the concepts from Part I from well-established domains such as climate, to emerging areas such as disease, economics, and conflict.

Part III: Exploring the Chaotic Universe and Our Place in It delves into speculative realms and may appeal to readers of *PSCF* as it engages with metaphysical inquiries regarding Christian theism. Palmer grapples with perplexing intellectual dilemmas, including free will, consciousness, and the nature of God. In his pursuit to unravel nature's workings, he confronts philosophical and theological quandaries. At its essence, he posits that the universe operates under determinism and challenges the notion that uncertainty in nature is primarily ontological as Bohr espoused, rather than epistemic as advocated by Einstein. Raising a thought-provoking query, the author asks, "Could there be something fundamentally flawed with quantum mechanics itself?" He asserts we must face the fact that the violation of Bell's inequality can be explained only by either abandoning the concept of definite reality or considering the equally dreadful notion of quantum action-at-a-distance. Subsequently, Palmer presents a naturalistic explanation involving counterfactual worlds and puts forth two conjectures.

Conjecture A suggests that the universe operates as a nonlinear dynamical system, unfolding within a cosmological state space defined by a fractal attractor. In simpler terms, a fractal invariant set is a mathematical idea in which a set demonstrates self-resemblance at various magnitudes, containing miniature replicas of itself through a repetitive pattern. Meanwhile, Conjecture B suggests that the deepest laws of physics describe the geometric properties of a fractal invariant set within the cosmological state space.

Palmer's abstract and subtle perspective challenges the prevailing view in physics, which embraces Bohr's interpretation of inherent uncertainty in quantum mechanics. Instead, Palmer aligns himself with Einstein and Schrödinger, rejecting the idea of God playing dice and the concept of a cat being both alive and dead. According to Palmer, the laws of physics are deterministic, devoid of randomness. He suggests conceptualizing our world as a specific solution set within a space of permissible solutions, influenced by a