welcome. The anatomical overviews get complicated pretty quickly, but this may be unavoidable in most cases. Here, and throughout the text, the authors seek to mitigate these challenges by highlighting, in bold, key terms that may be unfamiliar to the reader, although occasionally some jargon slips into the text without being highlighted or defined. Throughout this chapter, photos and illustrations are used to demonstrate the structures being described. The labeled photos are of the highest quality, and although the line drawings of various skulls and skeletons are more simplified than I would like, they are sufficient for illustrating what they are intended to show.

The longest chapter of the book is chapter 4, which covers cetacean phylogeny and taxonomy. The authors systematically work through the various groups of extinct and modern cetaceans, beginning with the oldest forms (archaeocetes) and continuing through different groups of baleen and toothed whales up to the present. The summaries for some groups are brief, but most of them are fairly extensive. Throughout the chapter, the skulls of representatives from the different groups are illustrated with accompanying phylogenies to help keep track of the proposed relationships among the different groups. (Life constructions of many of these fossils are also included among the 16 full-color plates at the center of the book.) This chapter concludes with a short discussion of the current consensus and conflicts in cetacean phylogenetics. After completing this chapter, it is difficult not to come away with a sense of awe for the immense amount of biological and ecological diversity in the history of cetaceans.

The next several chapters discuss particular topics related to various aspects of cetacean ecology and evolution. Chapter 5 includes a more detailed discussion of several key cetacean fossils along with some nice photographs, but it focuses mostly on certain key innovations and developments in cetacean history. These discussions include the various lines of evidence for changes in locomotion, terrestrial competency, habitat preference, and sensory systems. This chapter also details the development of baleen for feeding in mysticetes, the evolution of echolocation in odontocetes, and the radiations of freshwater cetaceans. Chapter 6 focuses primarily on the evolution of different feeding strategies, but also includes briefer discussions of reproduction, migration, sexual dimorphism, and diving. The authors take a step back in chapter 7 to look more broadly at larger-scale patterns of biodiversity between the Eocene and the present. Hypotheses for the drivers of these radiations and extinctions are discussed, and the stratigraphic ranges of all known cetacean families are documented. Trends in the evolution of body size and brain size are covered, as are biogeographic patterns and instances of convergent evolution. In chapter 8, the authors explore some of the insights that the fossil record can give into the evolution of development in cetaceans. This chapter includes discussion of limb development, vertebral column regionalization, tooth morphology, and changes in the relative timing of developmental events.

The book ends with a very brief summary and synthesis in chapter 9. The key breakthroughs and discoveries "that finally cracked the cetacean conundrum" (p. 302) are highlighted, and the authors compiled the many cases discussed in prior chapters in order to describe the overall arc of cetacean evolution from their first forays into the water until now. This conclusion discusses the connection between humans and cetaceans, including the role that studying cetacean history can have in guiding future decisions about cetacean conservation.

In sum, this book is impressive in both its scope and depth. Given its well-written summaries and its copious citations and references, it will quickly become a go-to resource for researchers, graduate students, and undergraduate students interested in the evolution of these marvelous marine mammals. Professors and teachers who are not specialists will find much here that they could discuss with their students when looking at the evidence for evolution. However, this may be a difficult book to work through for individuals who do not have much background in the biological or physical sciences. Given its steep price tag, this book is unlikely to find a home on the shelf of a nonspecialist, but it is still well worth a read. It takes just a quick perusal of this book to make sufficiently clear why the evolution of cetaceans has become one of the most compelling examples of large-scale evolutionary change.

*Reviewed by Ryan M. Bebej, Calvin College, Grand Rapids, MI 49546.*

## Philosophy & Theology

**HOW CAN PHYSICS UNDERLIE THE MIND? Top-Down Causation in the Human Context** by George Ellis. Heidelberg, Germany: Springer-Verlag, 2016. 501 pages. Hardcover; $79.99. ISBN: 9783662498071.

In this *magnum opus*, as Philip Clayton described it in his endorsement, George Ellis lays out the case for top-down causation from an emergentist perspective. For decades he has been one of the leading proponents of emergence, a philosophical perspective that lies between strong reductionism on the one hand and vitalism on the other. Reductionist critics of emergence had claimed that the properties and substances that emerged from more fundamental

elements had no causal power of their own but were solely determined. Ellis powerfully argues that these emerging entities do indeed have top-down causal powers to constrain or structure more fundamental components and that any understanding of the mind, consciousness, and free will must take that into account. He credits many colleagues for work over several decades in compiling the evidence, including Nancey Murphy, Warren Brown, Tim O'Connor, Robert Russell, and others.

George F. R. Ellis was born in Johannesburg, South Africa, in 1939. He earned a BS degree in physics from the University of Cape Town and a PhD in applied math and theoretical physics at Cambridge University. He collaborated with Stephen Hawking to co-author the book *The Large Scale Structure of Space-Time*. He returned to the University of Cape Town in 1973 where he taught until retirement in 2005, becoming one of the world's leading theorists in cosmology. He is a Quaker, and a Platonist, and has served as president of the International Society for Science and Religion. He was awarded the Templeton Prize in 2004. He is a co-author with Nancey Murphy of the book *On the Moral Nature of the Universe: Theology, Cosmology, and Ethics*. Ellis has long worked on the emergence of complexity and top-down causality, the focus of this book.

Emergence is as much about the existence of entities, and their characteristics, that arise from the interaction of their components as it is about the process by which these components came together. Ellis suggests that there are three primary ways in which components come to interact.

First of all, in the inanimate, or abiotic, world, the primary way in which elements come together is self-assembly. That is, the basic forces of nature bring them together. For example, a very large number of hydrogen atoms in space are drawn together by gravitational force. Eventually, they self-assemble into a massive ball of fire when the hydrogen atoms come close enough to each other to ignite fusion. A star emerges from this interaction. The entire collection of atoms carries out top-down causation to force hydrogen atoms to come close enough to fuse, and the bottom-up causation ignites the star. Many similar examples are familiar to us, for instance, gems emerging from mineralization and compression, and sand dunes emerging from particles of sand. These tend to be very simple but are the easiest to understand.

A second type, dominant in the biological world, is the process of adaptation through, for example, natural selection. Biological cells and organisms emerge from a vast complex of interacting biochemicals and have the ability to reproduce. During development from embryo to organism, the cells reproduce and interact so that limbs, organs, and specialized tissue emerge from the interaction of those biochemicals. The top-down causation of reproduction modifies the collection of component biomolecules which, through bottom-up causation, form the organism. Since each reproduction involves a small amount of variation, new organic systems emerge from these reproductions.

A third type is design and construction by external agents. This occurs when birds build nests, bees construct hives, spiders weave webs, ants create hills, and humans make houses or tools such as computers. The agents use top-down causation to shape and constrain the atoms and molecules in solids, gases, and liquids which, in turn, use bottom-up causation so that the function desired by the agent emerges from the components. Emergence deals with the hierarchy of entities in the products that emerge at each level. The possibility space far exceeds that of the simple capacity of self-assembly and even the impressive power of natural selection.

Ellis also suggests that there are three main timeframes in which emergence occurs. The longest time frames involve the evolution of species or of objects such as stars and galaxies. Medium time frames are required for the development processes in which an individual object or being grows from conception to maturity. The shortest time frames relate to the development of the function of an object or being.

At the publisher's request, Ellis structured the book in such a way that each chapter could be sold as a separate stand-alone booklet, in addition to the entire set of eight chapters as a single book. This style led to a significant amount of repetition, especially of references, but in a sense, that repetition helped provide one with an illusion of actually understanding the material. A brief description of each chapter will help readers decide which option is best for them.

*Chapter 1:* "Complexity and Emergence"
Ellis introduces all the key terms and ideas in the first chapter, though with few examples and a minimum of detail. He sets forth the basic ideas of the hierarchical structure of the universe and of emergence of causal entities at the higher levels. He ends the chapter with some practical implications for health care, mental health, and education. The chapter therefore serves as an effectively complete summary of the book but will leave the reader seeking a more detailed exposition.

Complexity lies in the hierarchical structure, in which the bottom layers are the fundamental forces and particles of physics and chemistry. The higher levels

are composed of combinations and interactions of the entities in the lower levels. Ensembles of large numbers of interacting entities at one level enable new entities at the next higher level. Those higher-level entities can, in turn, have a causal effect on the lower-level entities by controlling the scope and bounds of their interaction. These higher-level entities are said to emerge from that interaction. Bottom-up causation refers to the lower levels of physical particles and their interactions generating higher level, more complex entities. Top-down causation refers to the higher levels imposing constraints or boundary conditions on the lower-level entities.

Reductionists claim that top-down causation is an illusion and everything is determined in a bottom-up fashion. Vitalists, and, in a sense, spiritualists, posit a vital or spiritual force that provides the top-down causation to the lower-level entities. Emergentists claim that the top-down causation of higher-level entities is real, necessary, and sufficient for the joint top-down/bottom-up causal effects to explain the structure of the universe. Ellis ignores the vitalists and addresses this book as a response to reductionists.

Ellis is careful to caution that there is no way of knowing with certainty what is the lowest or the highest level in the hierarchy. Though we now think we know what are the fundamental particles and basic forces of nature, we may in the future learn of additional underlying levels. Likewise, higher levels of interaction may also exist or come into existence in the future.

*Chapter 2:* "Digital Computer Systems"
Anyone who, like me, has participated in the design of a computer hardware system or who has written any software program will greatly enjoy this chapter. Ellis describes the hardware and software as hierarchical systems that display all the key features of emergence. A reader unfamiliar with or uninterested in computing systems can safely skip this chapter, but it does provide an illuminating description of the major features of emergence.

Most, though not necessarily all, higher-level entities in computing systems are created by intelligent designers and do not emerge through self-organization of the lower levels or through natural selection. In other words, the higher levels of the hierarchy that impose constraints on the lower levels are constructed by intelligent agents external to the computing system itself. A circuit designer, for example, can direct a computer processor chip manufacturer to constrain the size and shape of a transistor. The atoms and molecules in that transistor then interact within the confines of that top-down constraint and effect the behavior desired by the designer. Emergence refers to the properties and entities that arise when the designer has implemented the desired constraints and context, and not to the way in which those interactions and higher-level entities came into being. Emergence deals primarily with the consequence of an interacting ensemble of components rather than with the method by which that interaction arose.

Ellis closes this chapter with this gem: "At a higher level, the existence of computers is an outcome of the human drive for meaning and purpose: it is an expression of the possibility space of meanings, the higher levels whereby we guide what actions take place" (p. 80).

*Chapter 3:* "The Basis of Complexity"
Chapters 3 and 4 lay out the technical details of emergence. In chapter 3, the focus is on the hierarchical structure that forms the basis for complexity. Moving from a lower level to a higher level in the hierarchy, the components of one level are composed of ensembles of interacting elements of the next lower level. For example, solid materials are composed of a very large number of atoms which occupy a lower level in the hierarchy. These atoms, in turn, are composed of protons, neutrons, and electrons which comprise an even lower level. Looking upwards, the solid material forms the basis, when shaped or combined with other solids, of an object that can be used as a tool. The tool may result from an even higher level of intent or purpose to carry out a particular function. The shape of that tool forms a basis for the range of motion of the component atoms. In this way, both top-down and bottom-up causation can be seen.

*Chapter 4:* "Kinds of Top-Down Causation"
The second part of the technical explanation of emergence emphasizes the many different ways in which top-down causation can occur. The simplest types are deterministic as in the lower levels where, say, quarks interact to form protons and neutrons with little variation. More complex types occur in higher-level systems in which feedback can occur. Feedback systems in mechanical systems are common to all of us, such as in thermostats and audio amplifiers. In biological systems, we observe homeostasis, in which our bodies maintain a nearly constant temperature, blood pressure, and oxygen levels in blood. Ellis does not focus on how such biological feedback systems might have evolved but delineates all the ways in which emergent feedback systems operate.

At even higher levels there are many more interesting types involving adaptive systems. When a higher-level entity can change in such a way that the lowest levels are channeled into enabling a modified higher-level system, then adaptation has occurred. It is here that the tremendous power of emergence can be seen.

*Chapter 5:* "Room at the Bottom?"

Ellis asks whether the notion of bottom-up and top-down working simultaneously would overdetermine the system. If the physics of the lowest levels is causally closed, can top-down causation really occur? Here Ellis provides several ways in which top-down causation can work. There can be contextual constraints or constraining structures or a change in the nature of the lower-level elements. An example of the latter is that a free neutron has a lifetime of less than 15 minutes, but when the neutron forms a higher-level nucleus by interacting with one or more protons or other neutrons, it is stable. The interaction of the neutron with other particles changes the nature of the neutron. Causality from above influences the outcomes of the lower-level causal forces.

Quantum dynamics comes into the picture at the lowest levels. Inherent uncertainty and probabilistic descriptions are important when quantum effects dominate. This is one reason why determinism fails. No explanation at the lowest levels can deterministically predict the effects at higher levels. Randomness and uncertainty prevail.

Another more pervasive reason for indeterminacy is the ubiquitous nature of what Ellis calls "equivalence classes." These classes refer to, on the one hand, a set of differing states at one level that can all arise from the same lower-level state, and, on the other hand, a set of differing states at a lower level that lead to the same higher-level state. For example, there can be many different combinations of kinetic energy of molecules in a gas that lead to the same pressure and volume of the whole.

*Chapter 6:* "The Foundations: Physics and Top-Down Causation"

Physicists and chemists as well as astronomers and cosmologists will revel in reading this chapter. Ellis dives into the details of the lower levels of the hierarchies in this universe to examine the fundamental forces. He explores quantum dynamics, the arrow of time, and numerous other examples from condensed-matter physics and chemistry. The principles of emergence as laid out in the previous chapters are beautifully illustrated by many examples. Those who are not enamored with physics or chemistry can safely skip or skim the chapter.

*Chapter 7:* "The Mind and the Brain"

At last Ellis arrives at the issue everyone is waiting for. How can the brain give rise to the mind? No one should miss this chapter. Not only are biologists and neuroscientists in prominence but also those broadly involved in the social context of our world.

A typical complex organism includes the capability of sensory perception, such as sight or smell. The organism responds to its environment by reacting to these perceptions. The network of neurons integrates these perceptions with the cells, such as muscle cells, that initiate responsive action. The interaction of these complex networks leads to the emergence of ever more sophisticated capabilities. Ultimately, the ability to sense one's self as distinct from the environment underlies self-awareness and consciousness in a way that is still far from understood.

In the hierarchical perspective, a brain is enabled from the bottom by a series of levels from the fundamental particles up through the biochemistry of life and the neurons and neural networks. In turn, these networks in the brain enable a higher level of individual consciousness which, in turn, enables a society of interacting individuals forming a culture. All of this occurs in the context of an environment and leads to a fine-tuned system.

The high-level social interactions of individuals, together with the environment, affect personal perceptions, ideas, and purpose, leading to decisions and actions that causally work downward to direct biochemical activity. Such activity then enables the desired actions. In this way, bottom-up and top-down causality work together to implement what we perceive as our intention. Free will exists because of the equivalence classes, in which a variety of high-level states can be equally realized from the bottom-up effects which are constrained and selected by purposeful top-down action from the brain. There is no single deterministic solution from the bottom up.

Ellis is careful to clarify that he has not solved the mystery of free will and consciousness. Rather, he claims that the emergent properties of top-down/bottom-up causation are vital parts of what will someday be the story of consciousness.

The importance of adaptive systems is emphasized in this chapter. Biological systems are far more adaptive than nonbiological systems. When higher-level entities are able to modify selection criteria and adapt to the environment by influencing the outcomes of the lower-level processes, then a vast spectrum of possibilities opens up. This is another description of the process of evolution.

*Chapter 8:* "The Broader View"

Ellis refers to this portion of the book as a polemic that sets emergence apart from reductionism. He reprises the full concept of emergence and then looks at the broad implications.

Inserted into this chapter is a section on "Learning to Read and Write," which Ellis co-authored with his wife, Carole Bloch. They argue that modern methods of teaching people to read overemphasize a bottom-up approach. This means that there is a focus on the elemental phonemes before putting it all together into a meaningful sentence. Rather, they recommend a greater emphasis on top-down learning in which the meaning is emphasized first. Then the combination of top-down and bottom-up learning leads to a more efficient process. This exemplifies Ellis's view that everything in our universe can be treated as an integrated bottom-up/top-down system.

Ellis does not allude to the implications for science and faith. He is a man of faith and has written elsewhere of his disagreement with atheism and with those who advocate a scientific religion. His views seem to be essentially that of Non-Interventionist Objective Divine Action (NIODA) as advocated by Robert Russell, Nancey Murphy, and others. The emergence that he describes in this book is easily compatible with such a view. Multilevel explanations lend themselves well to including the spiritual domain, as Donald MacKay, for example, explained in the middle of the twentieth century. However, materialists can also find support for their own presupposition in this book. The higher levels of explanation, including those leading to meaning and purpose, are fully enabled by the underlying physics and need no external source. If spiritual levels are not required, though not negated, by a complete hierarchical explanation of a system, then on what basis do we believe they exist?

Most of all, this book strikes at the heart of dualism, at least in the sense of the body and mind. The mind is described as enabled by the brain through the emergence of entities capable of supporting consciousness and rational thought through the interaction of a vast number of complex neurological components. It cannot exist independently from the brain and needs no external vitality other than the environmental interaction for food and energy. The implications of top-down causation for neuroscience are significant and were ably discussed by William Newsome in his plenary lecture at the 2016 ASA annual meeting.[1] The concepts in this book will fuel discussions on faith and science for a long time to come.

Is there more to biology than physics and chemistry? Is there telos, meaning, and purpose in our universe? Walter Thorson posed these questions in the 2012 Robert Herrmann Lecture Series.[2] Ellis addresses the same questions and answers with a resounding yes. But that affirmative is not in the sense of an external deity imposing its intentions or vitalism to the material world. Rather, for Ellis, the telos emerges from the physical system. It is more than physics or chemistry because it cannot be explained by the laws of physics at the fundamental level, not because something external must be added to the causal mix. Purpose arises from the ability to causally adapt the lower-level elements to achieve higher-level functions.

Ellis closes the book with this final paragraph:

> The daily world in which we live came about by imaginative investigation of possibilities, discarding those that don't work: the adaptive process that is a central theme of this book, enabled by a modicum of randomness at the macro- and micro-levels, interacting with necessary physical processes. And it is these processes that also allow the emergence of the ordinariness of everyday life …: which actually is quite extraordinary. Bottom-up effects are crucial to emergence. Physics underlies all. Nevertheless, the vitality of life, which arises from physics, transcends it. (p. 454)

Many parts of the book, and particularly parts of this chapter, have the character of a dictionary or encyclopedia that lists and describes all the possibilities of top-down causation. As a result, the book is more like a reference book than a persuasive, flowing prose that presents an elegant defense of a philosophical view.

The book suffers from the weight of making each chapter a stand-alone booklet. The flow is uneven and repetitive. The benefit is that each chapter can indeed be read by itself and a reader interested in only one aspect of emergence can profitably select the relevant chapter. The reader will then be left hungry for more and will want to return for the remaining chapters. I found the book to be persuasive but, admittedly, I was inclined toward an emergentist perspective before I started reading the book. Nevertheless, I sense it would be difficult for a strong reductionist to counter what appears to me to be an overwhelming collection of evidence for emergence.

The casual reader seeking a relaxing fireside read is advised to look elsewhere. This book is an indispensable resource for anyone who seriously ponders the structure of the universe, the miracle of life, and the mystery of consciousness.

Notes

[1]William Newsome, "Of Two Minds: A Neuroscientist Balances Science and Faith," plenary address, ASA Annual Meeting, Azusa Pacific University, Azusa, CA, July 22, 2016, http://www2.asa3.org/movies/ASA2016Newsome.mp4.

[2]Walter R. Thorson, *The Woodpecker's Purpose*, ed. Emily Ruppel (Wenham, MA: Center for Faith and Inquiry at Gordon College, 2014).

*Reviewed by Randy Isaac, ASA Executive Director Emeritus, Topsfield, MA 01983.*