PERSPECTIVES ON SCIENCE AND CHRISTIAN FAITH VOLUME 63, NUMBER 4 DECEMBER 2011

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Theme Issue: Information, Intelligence, and Origins

"The fear of the Lord is the beginning of Wisdom."
Psalm 111:10

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- **Patrick Franklin** (psfranklin@gmail.com): book review coordinator; subject areas: ethics, philosophy, and theology.
- **Arie Leegwater** (leeg@calvin.edu): cosmology, engineering, history of science, mathematics, non-biotechnologies, and physical sciences.
- **Don MacDonald** (eieio@spu.edu): anthropology, psychology, and sociology.
- **Robin Rylaarsdam** (rrylaarsdam@ben.edu): biology, environment, genetics, and origins.

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Editorial

Last Call: Reflections of an Editor

Arie Leegwater

No, this is not the last call at your local pub, much as I delighted in reading Daniel Okrent's recent book, *Last Call: The Rise and Fall of Prohibition* (New York: Scribner, 2011). Rather, as editor of *PSCF*, I need to compose a short opinion piece for each issue. Writing it has been one of the more challenging duties I assumed when becoming editor four years ago. This editorial will be my "last call." Beginning in 2012, James Peterson, Director of the Center for Religion and Society at Roanoke College in Salem, Virginia, presently one of our book review editors, will become the new editor of *PSCF*. Perhaps this period of transition is a good occasion to analyze and reflect on some of my experiences as editor of a journal dealing with "perspectives on science and Christian faith."

One thing I learned is that the avowed goal of "the integration of science and religion" has become a tired cliché or a seemingly impossible aspiration for many. Frequently in our analysis, we identify science with its findings, conclusions, and products, and religion with theology. As a consequence, we often negate or neglect the cultural imbeddedness of both science and theology. Connecting theology and science can then all too easily become an arid conceptual exercise which neglects or negates the social, philosophical, and historical contexts. By taking such an approach, we undercut the very idea of Christian scholarship as well as any sense of solidarity that we may have with others who do not share our take on the world. As I have argued before, we tend to settle too quickly for c-words: contrast, conflict, complementarity, convergence, etc., when the operative norm is integrality.

A second matter, which I often shared with inquiring authors, is, what criteria make for a good submission? Besides issues of style, length, fit, and grammar, the chief criteria in evaluating manuscripts were the following: Is the article well argued (does it flow so to speak) and well documented? Is it fair in its treatment of a particular theory and its advocates? Does the article provide some fresh new elements and perspectives of interpretation? Does it advance Christian reflection on the subject? More germane, do the authors adequately describe or assess the theological, philosophical, and cultural backgrounds? Does the article adequately reflect the extant literature or engage sources in a critical way? All too often the theological reflection presented was added to an article as an after- or forethought, but was not integral to, nor did it sustain, the argument in the paper.

One goal I advanced—perhaps unsuccessfully—was to generate a balanced discussion of controversial issues, a balance that reflected responsible scholarly work and advanced the cause of Christian scholarship. Editors are always keen to solicit mature articles that give evidence of solid Christian engagement with, and reflection on, current discussions occurring in the evangelical and secular communities. Articles that aim to challenge received positions, for example, the easy acceptance of complementary arguments and analogical arguments in faith/science discussions, or a facile realism (as if nothing can be gleaned from current discussions of postmodernism) were welcomed. The challenge of Christian scholarship has a dual nature: one side is more internal and radical, namely, to have a distinctive voice, while working out of a tradition, without becoming insular; the other side is more external and pluralistic, namely, not to accede to the idea that Christian scholarship is characterized as a value-added interpretation to a more or less commonly accepted set of facts or realities, or, at best, one of many interpretative slants on an issue. Christian scholarship has a "bite" to it. It rests on well-grounded and warranted beliefs, but it also requires engagement with others in interpreting, understanding and shaping the common world we live in.

Editorial

Last Call: Reflections of an Editor

Surveying the past four years of *PSCF*, many submitted articles were devoted to questions of origins, flood geology, or biblical "numerology," often promoting a concordistic reading of science and the scriptures. I continue to hold that if ASA wishes to speak to and attract newly minted Christian scientists and engineers, we need to continually tackle current issues dealing with the environment, climate change, gene therapy, agricultural practices, and biotechnology. Doing this will also make the journal more credible in the eyes of the "secular" community. Another factor, which the journal needs to continue to nurture, is historical memory—an important ingredient in the exercise of Christian scholarship. We need to realize that we are in this venture for the long haul, and the Christian community has done much reflection on these issues throughout history. And we can learn from history if we read it aright. The past is not dead, for God speaks through the "remembered past." The overriding challenge is to keep the Christian tradition alive and vibrant in its scholarly pursuits without turning on itself, constantly keeping its face open to the world. In short, I think that we have to become far less defensive and apologetic about our Christian stance and become far more positive, showing how we as Christians, in all our weakness, address problems which we share with others as God's fellow creatures.

As I turn over the task of being editor to Jim Peterson, I wish him every success with the sure confidence that with the good help of our new cohort of book review editors and professional referees, ASA members can look forward to being challenged and informed when reading upcoming issues of *PSCF*. Deep thanks and appreciation goes to Lyn Berg (managing editor) and Esther Martin (manuscript editor) who kept me on the straight and narrow, by catching and correcting my numerous editorial errors. Their work is of invaluable editorial service to *PSCF*. In addition, the strong support of ASA Executive Director Randy Isaac, as well as the editorial board of *PSCF,* has made my work as editor that much easier.

Allow me, in closing, to offer a final thought: recently, while listening to a reading of the book of Ecclesiastes in eight different voices [translated by Calvin Seerveld], I was reminded once again of the comfort that undergirds all our work. There may be a time to go and a time to stay. And casting your bread upon the waters may indeed mean that you will not experience an immediate tangible return, for what works or will work is not within one's grasp. But there is hope found in Eccles. 3:15, "Whatever is and will be has already been: God picks up the pieces." *Oant sjen!*

Arie Leegwater, *Editor*
leeg@calvin.edu

In This Issue

This special theme issue has a triptych arrangement. The first panel has three articles devoted to a thorny topic: information, intelligence and origins. I owe a debt of gratitude to Randy Isaac who spearheaded the effort of soliciting these articles, written by scientists representing three different disciplines: Randy Isaac (physicist, ASA), Jonathan Watts (biochemist, University of Texas, Southwestern Medical Center) and Stephen Freeland (astrobiologist, University of Hawaii). The nature of information, its generation, and biological consequences are central issues in the current debates about origins.

In the second panel, we have an article by Janet Warren (MD and doctoral candidate, University of Birmingham, UK) exploring how chaos and chaos-complexity theory may help us better understand demonology.

The third panel has an extensive book review section and two letters to the editor. All three of these panels, each in its own way, reflect a diversity of interests and concerns that continue to exercise ASA members.

A final word: My departure from *PSCF* will be somewhat gradual. I will continue to function as one of four book review editors for *PSCF*. In addition, Jack Swearengen and I will serve as co-editors of the articles in the special theme issue on "Responsible Technology and Issues of Faith" slated for March 2012.

Arie Leegwater, *Editor*
leeg@calvin.edu

Article

Information, Intelligence, and the Origins of Life

Randy Isaac

Randy Isaac

The term "information" has a connotation of knowledge in the midst of ignorance, an order that arises amid disorder. Information exists everywhere around us, and we spend our lives acquiring, storing, transmitting, and processing it. Yet it is hard for us to define or describe it, in part because the word can be used in so many different ways. In this article, four main categories of usage of the word "information" are explored, paying specific attention to its relationship to intelligence. Thermodynamics *includes information on all possible physical microstates;* capacity *of information refers to the maximum number of physical states possible in a system corresponding to pre-established conventions;* syntax *refers to the particular physical state of that system at a point in time;* semantics *are the meaning, function, or significance of that physical state. Living systems, in particular, are complex information systems. A look at how living cells process information provides some clues, but not yet a solution, to the mystery of the origins of life.*

The explosive growth of information technology in the last several decades impresses on us the potency of information transfer. Lest we think this phenomenon is unique to our generation, we must recall that the ability to exchange symbolic information among individuals for collective learning is one of the crucial enablers of the development of humankind. Though the pace of change may have been slower, the generation, storage, transfer, and reception of information among intelligent agents have been the enablers of human civilization, if not of the very existence of our species. It is no wonder that we tend to view information as inextricably linked to intelligence. Today we often refer to our era as the "information era" and marvel at the ease of global information exchange through the internet.

The study of the concept of "information," known as information theory, has moved into the arena of science and Christian faith largely because of its potential apologetic value. As biochemists unravel the secrets of information processing within living cells, the similarities of those processes to information processing in our communication and computing systems becomes ever more intriguing. If such information processing could be shown to be necessarily related to intelligent sources, then we might establish a scientific inference toward an intelligent agent as a causal factor in the origin of life. For some, it is a small but obvious leap of faith to connect such an indeterminate intelligent agent with the Creator God whom we as Christians worship. It is essential

Randy Isaac *was vice president of science and technology at the IBM Thomas J. Watson Research Center prior to retiring in 2005 and taking his current position as executive director of the ASA. He received his BS degree in physics from Wheaton College in Wheaton, Illinois, in 1972 and his MS and PhD degrees in physics from the University of Illinois at Urbana-Champaign in 1974 and 1977, respectively. In 1977 he joined the IBM Thomas J. Watson Research Center in Yorktown Heights, NY, as a research staff member in silicon technology. He was director of silicon technology before becoming project manager of the joint IBM/Siemens development program of the 64Mb DRAM product. In 1995 he was the founder and director of the IBM Austin Research Laboratory in Austin, Texas, which focuses on high-performance microprocessor design. As vice president of science and technology, he had worldwide responsibility for physical science research, including information theory, and for semiconductor, packaging, and communications technologies.*

to have a deep understanding of the nature of information to assess the value of such an apologetic.

Despite its prominence in our society, information continues to be a poorly understood concept. The term is used in so many different ways with so little precision, that confusion and misunderstanding abound. The intent of this article is to explore the various categories of meaning of the term "information," to discuss the relationship of information to intelligence, and to consider the implications for our understanding of the origins of life.

What Is Information?

Our most common understanding of "information" is an idea, a concept, or an observation which we hold in our minds. But "information" is a much broader and more general concept. In his sweeping history of information, James Gleick attributes one of the earliest articulations of "information" to John Wilkins. He was a vicar and mathematician who later became master of Trinity College in Cambridge, and he was a founder of the Royal Society. In 1641 Wilkins wrote, "For in the general we must note, That whatever is capable of a competent Difference, perceptible to any Sense, may be a sufficient Means whereby to express the Cogitations."[1] That is to say, information exists wherever something could be different; information does not exist where nothing could be different.

In the broadest possible sense, every elementary particle in the universe could be otherwise. Its properties, such as velocity or spin, could be different, or it could cease to exist or be transformed into energy. In this sense, there are estimates that all the particles in the universe comprise on the order of 10^{90} bits of information.[2] This type of usage of the term "information" is in a category that might be called *thermodynamics* since many of these properties are involved in thermodynamic considerations such as entropy.

To be useful in conveying conceptual information, it is necessary to restrict consideration to a subset of the vast thermodynamic category. Upon defining and selecting a specific convention for conveying information, a common usage of the term "information" is in the category of *capacity* or the number of bits available. This refers to the number of differences that are possible, such as the number of letters in the alphabet.

A third category of usage of the term "information" is the *syntax*, which is the specific selection made to convey the conceptual information. The term "information" can be used in various ways to explore the sequence in which the selected letters of the alphabet, for example, are arranged.

Finally, there is a category of *semantics* in which the usage of the term "information" refers to the meaning or function of the selected syntax.

When we wish to express or convey conceptual information, we embody it in a particular physical pattern, according to previously established conventions. These conventions could be, for example, the meaning of a sequence of sounds when we speak, or of the series of black shapes on a white background such as that you are now reading. This pattern is part of the category of information called the *syntax*, while the idea embodied by the pattern is in the category of *semantics*. To have meaning (semantics), the physical pattern that carries a specific piece of information must be drawn from a much larger number of possible physical patterns. If only one pattern were possible, it would not convey a distinguishing idea. The total set of all physical patterns that can be utilized for the embodiment of an idea is the *capacity* of information. The relationship among these categories is schematically illustrated in figure 1.

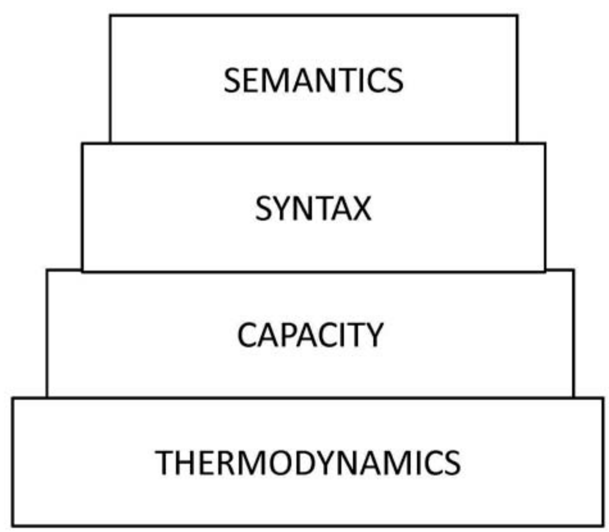

Figure 1. Categories of Information. Our most common concept of information involves semantics which attributes meaning to the syntax of a particular physical pattern, selected from a large capacity of possible patterns, which in turn are a subset of all thermodynamically possible physical states.

As an example, consider the information of the number of items in a group, say, 14. We can think of this number and retain it in our minds, which presumably are correlated in some way with our brain states. When we wish to convey this number to someone else, we express it in a physical pattern with any physical substance that can be shaped to resemble the form of the numerals 1 and 4 adjacent to each other. This conforms to established conventions for expressing numbers. There are alternatives, such as expressing the number in binary form so that the shape 1110 would be understood to signify the same number. This representation works if our convention has been adjusted to interpret the syntax in a binary format. The significance of a particular syntax depends on the set of possibilities that exist. The set of possible physical shapes can be thought of as the capacity of information. For two-digit Arabic numerals, the capacity would be 100, while for a 4-digit binary system, the capacity is 16.

In normal communication among humans, the primary message is conveyed using a common language, which is a convention of meaning assigned to specific physical patterns. Only a tiny fraction of the information available within our chosen medium (sounds, marks on a piece of paper, or electrical states on a silicon chip) is actually used. In the case of "marks made on a piece of paper," there is a much larger capacity (number of possible physical patterns) which is not useful in conveying a message simply because it is not part of our convention for expressing information. For example, variations between two styles of handwriting may not affect the primary message but might convey different information about the identity of the writer.

In our digital world, we find it convenient to express all information in terms of binary digits, or "bits" for short. To designate a bit of information, we need a physical feature that can have two possible states, 0 or 1, as in figure 2. In the terminology used above, the system in figure 2 has a capacity of one bit. In the case of a coin toss, the potential barrier is so high between "heads" and "tails" that no spontaneous transition can occur. In the case of an atom that could be in position 0 or 1, it is possible for thermal activation to occur between 0 and 1. The actual state of the system, whether 0 or 1, is the syntax.

The world around us is permeated with complex physical configurations which can, in principle, be expressed as a large collection of bits, as if figure 2 were replicated many times. Every particle or combination of particles can exist in more than one configuration with multiple variables that can have different values. The amount of information, I, is given by the logarithm of all possible states, N, that can exist: $I = log_2 N$. The selection of which states to include in this equation depends on the context being used. For thermodynamic discussions of energy, entropy, and conservation laws, all possible microscopic states must be included. For the more common intent of conveying a message from a sender to a receiver, there must first be an established convention known by both the sender and the receiver.

In the case of a coin toss, a thermodynamic discussion of information might entail consideration of the atomic composition of the coins. This is irrelevant when the message is simply "heads" or "tails," in which case the number of states depends only on how many coins are used. The use of different coin types, such as pennies in addition to quarters, would change the result only if the convention in use involved coin types as well as "heads" or "tails." The amount, or capacity, of information therefore depends both on the communication convention being used and on the number of elements, such as coins, that are used.

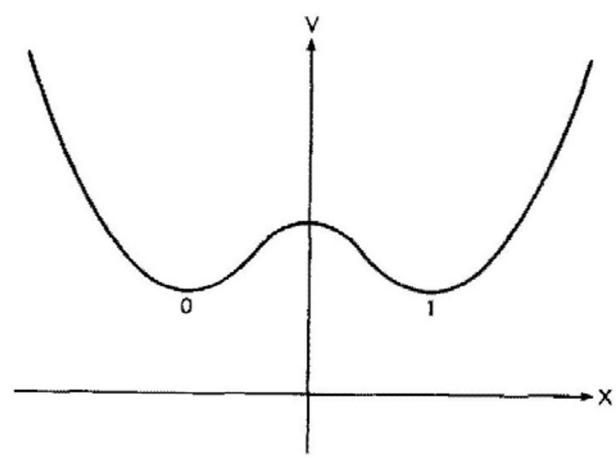

Figure 2. Bistable Potential Well. x is a generalized coordinate representing a quantity which is switched. (From Rolf Landauer, "Irreversibility and Heat Generation in the Computing Process," *IBM Journal of Research and Development* 5, no. 3 (1961): 184, used with permission.)

Another example may help elucidate the distinction among these categories. Consider the collection of ink molecules on paper comprising the words "red" and "blue." The thermodynamic category of information encompasses all possible atomic and molecular states. One might extract information on the source or age of the ink, chemical properties of adhesion, the style of font, etc. The capacity of information in these words depends on the language that is chosen. For English, as opposed to say Chinese, the capacity is limited to an alphabet of 26 characters plus special symbols, or an established vocabulary of more than 100,000 words. The syntax category includes several types of analysis such as word order or grammar, encryption, or abbreviation, but always deals with the actual letters and words selected. The category of semantics deals with the meaning of the words. In various contexts, the meaning, in this case of "red" and "blue,"could refer to a particular wavelength of light, to an emotional state of mind, or to a political party inclination.

From this discussion, we can see that for communication purposes, the capacity, syntax, and semantics are all defined according to the convention known and accepted by the sender and the receiver.

Living organisms contain an immense amount of information in each of the categories listed. The sequence (the syntax) of all (the capacity) the nucleotide base pairs in the DNA molecules comprises coded genetic information that is translated into sequences of amino acids assembled into proteins. These proteins have physical and chemical functions (the semantics). A cell will survive only if these functions carry out the steps for metabolism, reproduction, etc. The information content (sequence of base pairs and/or amino acids) of a cell can and does change through a persistent series of natural reproduction events with change. For this reason, researchers studying the origins of life seek to determine whether such processes might be able to explain not only the continual transformation and development of the building blocks of life, but also the transition from nonlife to life.

This introduction to information has made it clear that information permeates the entire universe. Virtually all physical elements can be expressed in some form similar to figure 2. The capacity, syntax, and semantics of information depend on the perspective of the sender and the receiver, be it an intelligent agent or a natural environment. We now turn to a more detailed discussion of each of these categories.

Information and Thermodynamics

In this section, we consider the usage of information in what we have called the thermodynamic category. Arguably, the most significant breakthrough in information theory was Rolf Landauer's observation fifty years ago that energy must be expended to erase information. He showed that the energy required to erase one bit of information is at least $kT \ln 2$.[3] Paul Gough points out that

> Landauer's principle applies to all systems in nature so that any system, temperature T, in which information is "erased" by some physical process will output $kT \ln 2$ of heat energy per bit "erased" with a corresponding increase in the information of the environment surrounding that system.[4]

To erase information, as opposed to changing the information, it is necessary to modify the potential wells in figure 2 so that only one state is possible. Paradoxically, there is no minimum energy requirement to generate information.

Information is, therefore, a fundamental physical parameter in the universe, related to energy and entropy. Entropy is a measure of uncertainty which increases as the number of possible states increases. Information is the reduction of uncertainty by the designation of one of those possible states. An increase in the number of possible states increases the uncertainty and consequently increases the amount of information when one of those states is selected. Information and entropy are therefore related and both tend to increase in a closed system. Information changes in a similar way as entropy, and can be transformed from one form to another, like energy, as the universe expands. This information includes all possible variables of all constituents in a closed thermodynamic system. Many, if not most, of these variables are not accessible to us for use in computing or communication or other information processing. For example, there are variables connected with the spin states of each individual electron, proton, or other elementary particles. Other variables are connected with the location of atoms relative to their lattice sites in solid crystals, such as vacancies and interstitials. These are difficult, if not impossible, for us to detect and modify and store at a pace that is useful. Our discussion of information can be reasonably restricted to those variables that are information bearing, that is, those that are associated with distinguishable physical states that can be readily used to convey a message.

Restricted to these information-bearing variables, information is not inherently conserved. The erasure of a bit involves the transfer of information to a non-information-bearing degree of freedom, usually as energy dissipation to the surrounding environment.

Since information is a universal characteristic of all physical systems, there is no necessary relationship between information and intelligence. One could argue that intelligence is a particular method, but not the only one, of processing information. Natural processes continually transform information in our universe. However, the restriction of consideration to "useful" information-bearing variables is itself an action by intelligent agents and not by nature. That restriction is technology dependent. If, in the future, we were to invent a method of rapidly detecting and modifying the spin state and location of every atom in a solid, the information-processing potential would be extraordinary. Similar observations led Richard Feynman to exclaim more than fifty years ago, "There's plenty of room at the bottom,"[5] and there still is.

Our focus in this article is to understand information in order to determine its relationship to intelligence and to obtain clues to the origin of life. In the cosmological scheme of the universe, both life and what we consider to be intelligence seem to have appeared at least once, approximately 10 billion years after the big bang. Transformation of information appears to be a continuing universal process since the beginning of time.

Capacity of Information

At the heart of all information is its physical embodiment. Distinguishable physical states are necessary for information to be generated, stored, transmitted, and received. The capacity of information addresses the question, "How many bits are there?" and is simply the logarithm of the number of possible states. Though we still deal with the legacy of information being expressed in base 10 or base 12, 24, 60, etc., it is the binary system, base 2, that dominates today's information processing world. The unit of information is the "bit," which is a contraction of "binary digit." As noted above, the amount of information that can be expressed in any physical system is given by $I = log_2 N$ where N is the number of distinguishable physical states.

Coin tosses are an easy example to illustrate this concept. Tossing four identical coins can result in sixteen distinguishable outcomes, leading to a bit capacity of 4, which we already knew since we had four coins, each of which can have two outcomes. A pair of dice is somewhat more complex since each die can have six outcomes. If the sequence of the dice is distinguished, then there are 36 possible outcomes or 5.17 bits.

Coins can also illustrate the importance of distinguishability. If the four coins mentioned above are all identical, say all quarters, then the order in which the coins are tossed is indistinguishable. If the coins are all different, say a quarter, a nickel, a dime, and a penny, then there are additional distinguishable outcomes. If the sequence is important, then there are 384 possible outcomes, or 8.6 bits of information. On the other hand, if all of the coins are identical and are perfectly smooth so that the two sides of the coins are indistinguishable, then only one outcome is possible and the bit capacity is zero.

Combinatoric information is a key subtype of capacity information that grows exponentially by the number of bits. For example, if each coin in a series of coin tosses is different and if the sequence is important, then the number of possible combinations is vast. Each possibility counts in the magnitude of capacity.

In computer logic and memory applications, physical states are designed for density, speed, and power efficiency in storing and processing bits of information. Typically, a node of a circuit can be held at either a voltage of 0 or of the supply voltage V. Either one can be arbitrarily assigned the symbol "0" and the other is assigned a "1." With specified constraints on the physical states and their interaction, computers can be designed to generate, process, store, retrieve, and transmit vast amounts of information. Capacity of information is familiar to us as the capacity of a hard drive (e.g., 250GB) or of computer memory (e.g., 4GB). These values are independent of what, if any, messages are actually stored on those devices.

Communication technology has also grown exponentially, allowing bits to be transmitted at rates that were scarcely dreamed of only a few decades ago. Photons guided through optical fibers are the dominant physical mode of information transfer in our internet world. These photons are constrained according to specifications established by the communication designers. Claude Shannon of Bell Labs wrote the seminal paper on information communication in 1948,[6] showing how to determine the capacity of information that could be transmitted in a noisy channel.

Distinguishable physical states can be established either through natural causes or by intelligent agents. It is not sufficient to observe distinguishable states to determine evidence of an intelligent source. However, the constraint that these physically distinguishable states must be easily detected, modified, and transmitted puts a significant limitation on what constitutes useful information. It is almost always the case that information useful for intelligent agents involves physical states established by those agents. The clearest way to ascertain an intelligent source is whether the physical states in question conform to the constraints imposed by an intelligent source. In other words, if the physical states meet criteria established by intelligent agents, then the source of those physical states is most likely, though not necessarily, an intelligent agent. The linkage between information and intelligence is derived not from the fact that the physical states represent information, but that they conform to the constraints imposed by the intelligent agent. The connection between information and intelligence is derived from the intelligent source and not from the information per se.

Applying these considerations to a living cell, we can detect a number of information-bearing variables. The best-known one is the DNA molecule, called the genome, containing a sequence of nucleotide base-pairs. There are other information-bearing components in the epigenetic system, and it is possible, even likely, that more such variables will be discovered in the future. For convenience we will focus on the DNA sequence, while recognizing that many other aspects of information may be present.

The genome has a vast capacity for information because of the nature of the physically distinguishable states. Each site along the nuclear DNA can have one of four distinguishable nucleotides. With approximately 3.5 billion sites in the human genome inherited from each parent, the bit capacity is an incredible 7 billion bits while the number of possible combinatoric outcomes is an inconceivable $10^{2,100,000,000}$. In combination with a second copy inherited from the other parent and a large variety of epigenetic factors that influence which genes are expressed to what degree, the information capacity is beyond comprehension.

Genome sequencing in the past decade indicates that only a small fraction of the genome actually codes for genes, and a very large portion of the genome has no apparent function. The capacity for useful combinations of the nucleotide base-pairs that do serve as codons is still so vast that the number of possibilities is countless. This capacity can be modified, either increased or decreased, by numerous mechanisms, ranging from single nucleotide insertion or deletion to relocation or duplication of a large segment of DNA.

Syntax of Information

Another category of usage of the term "information" relates to the actual state, out of all the possible states, in which the system exists. This usage addresses some variation of the question, "What are the bits?" The previous category of capacity was independent of the actual value of any bit, whereas this category deals with the values and relationship of values among the various bits. It basically considers whether any particular bit is a "0" or a "1" and the relative relationship among all of the bits.

Consider again the tossing of four identical coins. The capacity of information is always 4 bits, no matter what the outcome. Syntax is concerned with whether those coin tosses are heads or tails and the relationship between the results of the various coins.

If the outcome of four coin tosses results in all heads, the relationship of the values of the various bits attracts attention. The probability of that outcome is 1 in 16, no different than that of any other particular outcome such as 3 heads and 1 tail. But the outcome is noteworthy because we recognize a specific relationship among those values. If the number of coins were very large, we would be justified in suspecting a process other than pure random coin tosses. Our clue would be more than the low probability of occurrence of that pattern. It also notes that the pattern of results matches an a priori relationship established by intelligent agents.

In the case of coins, we understand the process of tossing coins, and we can therefore assess probabilities of particular outcomes with reasonably high accuracy. In each toss, the history of previous tosses is effectively erased and has no bearing on the outcome. However, in many cases, the particular physical state is a function of a series of past events, essentially a contingent-history syntax. For example, a sample of rock studied by a geologist would have an atomic concentration, or syntax, that depends on its history. A well-known example is the ratio of radioactive elements in that sample. Understanding the probabilities of any particular concentration depends on a clear knowledge of the process steps that can modify such information over time. In general, when the particular state of information can change over time, an attempt to calculate the probability of occurrence of that state requires detailed understanding of all the various ways in which it could arise. Coupled with the knowledge of possible changes, an information state can lead to a deeper level of information about its history and origin.

We can also note that if all coins are heads, the information content, from the syntactical perspective, is smaller than if there is a mixture of heads and tails. It is of considerable interest to mathematicians and engineers to find algorithms that can express the values of a large number of bits with a much smaller number of bits. The mathematical elegance that can result has been explored by Kolmogorov and Chaitin and the result is known as Kolmogorov-Chaitin information, sometimes referred to as algorithmic entropy or descriptive complexity. This addresses the question of "What is the minimum number of bits required to express a given sequence of bits?" An information system can be called complex if a pattern of bits cannot be expressed algorithmically in a much smaller number of bits. Paradoxically, in this sense, a purely random sequence would be considered to have the maximum information, while a highly ordered sequence would have less information.

Engineers are interested in this category of information to achieve efficient compression techniques. Reducing the number of bits required to describe the actual sequence of bits is a valuable tool to reduce information capacity requirements as well as data transmission times. Video transmission in particular relies on compression where the action is slow or portions of the image are identical.

In a living cell, the syntax is primarily about the sequence of base pairs in the nuclear DNA. That sequence can be seen to have a small probability of changing during a reproduction event or during external stimulation such as radiation. These changes can occur as point mutations or as larger-scale shifting of DNA segments, such as gene duplication or transposons which are rearranged in the genome.

Semantics of Information

The category of meaning of the term "information" that we use the most often is semantics. This category addresses the question "What do the bits mean?" Our primary concept of information is the message that the bits are intended to convey. Paul Revere famously used two lanterns to indicate a powerful message, reducing the British means of transportation to a signal conveyed by one or two lanterns. The bit capacity was small but the semantic meaning was profound.

Information theory does not address semantics. Shannon explicitly excluded meaning from his consideration. James Gleick quotes Shannon as writing,

> Frequently the messages have meaning; that is they refer to or are correlated according to some system with certain physical or conceptual entities. These semantic aspects of communication are irrelevant to the engineering problem.[7]

Semantic information is not quantifiable in the sense that capacity or syntax can be defined. Mathematical formulations may indicate what physical configurations are useful and might have a meaning in certain circumstances, but do not express the meaning itself.

The semantic meaning may nevertheless be important in determining the capacity, for example, of the information channel. Shannon showed how information is inversely proportional to the probability of occurrence. Accordingly, knowledge of the frequency of occurrence of a letter of the alphabet or of a combination of letters, or of a word, can be used to determine the probability and thereby optimize the capacity of a communication channel. The semantics of the English language influences the usage, which can be measured and used to optimize capacity. But the meaning itself is not part of the information-engineering calculation.

For some, the term "semantics" assumes the presence of an intelligent agent as a sender and as a receiver of the message.[8] In this article, the term is used more broadly to indicate the significance of a message, whether or not an intelligent agent is involved. It includes the possibility that the message is a physical effect, a causal factor for a physical or chemical action.

Symbols, commonly in the syntax category of information, are physical representations of meaning. In physical symbolism, the symbol has a physical property which serves as the message. For example, a shiny, smooth metal surface can serve as a symbol of high reflectivity. Or a north pole of a magnet serves as a physical symbol of attraction to a south pole magnet. The meaning or significance of a physical symbol is derived from the physical properties of the symbol itself.

In abstract symbolism, the symbol has a meaning assigned to it which does not necessarily derive from its physical properties. For example, the meaning of the shape of the letter "A" in the English language is assigned to that shape and does not derive from the shape itself. Paul Revere's message was not derived from the number of lanterns but was assigned to it. Anyone intercepting the message had no way of decoding the message from the physical characteristics of the lanterns without acquiring the knowledge of the abstract relationship assigned by the sender.

Abstract symbolism is a hallmark of intelligence, especially as manifest in language and communication techniques. The ability to associate abstract symbolic significance with a distinguishable physical pattern is a key indicator of intelligence, though not the only factor. Primatologists look for signs of such ability in order to assess the degree of intelligence in primates, for example. Abstract relationships are so important in our daily lives that we often take them for granted. All of our communication technology, computing technology, mathematics, and virtually any activity involve some degree of abstract thinking. This is a key feature that links intelligence with information.

When abstract relationships are a necessary part of information systems, then an intelligent agent must be involved to generate or interpret or design that system. In computer technology, for example, the criterion for verifying proper design involves testing the output for the right answer. If 2 plus 2 produces an answer of 5, then the physical connections from the input to the output produce an answer that correctly reflects the actual design of the logic components. But an agent with knowledge of arithmetic must be involved to determine whether such connections meet the desired design. It may not be possible to determine if the answer is correct solely from the physical connections themselves. If 2 plus 2 is 4, then the computer meets the test of our abstract concept of arithmetic and the design is pronounced to be correct.

A communication system is tested by comparing the message received with the message intended to be transmitted by the sender. That abstract relationship means that an intelligent agent must be involved in setting up the communication system. A physical test could determine whether the same syntax exists in the received message as the sent message, but an agent would need to decipher any abstract meaning.

For living cells, significance seems to be all physical and chemical. There appears to be no abstract meaning assigned in the operation of the cell. Even the coding of a base pair sequence that translates into a sequence of amino acids to produce a protein is a chemical process and not an abstract one. We can generate an abstract coding table (a "look-up table," relating any given codon to a corresponding amino acid sequence) to describe what is happening, but the actual translation event occurs physically, independent of the influence of any intelligent agent. A more detailed discussion of the nature of the biochemical information processing in living cells is provided by Jonathan Watts and by Stephen Freeland in other articles in this issue.[9]

We now turn to a closer examination of the information contained in living cells to see what other clues there may be that pertain to the origin of life.

Clues to Life's Origins

Where there is no change, there is no history. Seeking the origins of life involves sifting through the patterns of change in living systems that might provide evidence of the kinds of changes that may have given rise to life. The detailed answer of how life began may never be fully known, but a study of the information in living cells provides tantalizing leads to plausible scenarios.

William Dembski has claimed that information is conserved and can only be generated by intelligent beings.[10] Recognizing that this is not true of all information, he considers what subset of information obeys this type of conservation law and whether DNA information is of that type. Dembski focuses on complex specified information (CSI), a term attributed first to Leslie Orgel,[11] as being that subset. The term "complex" refers not only to a large capacity but also to a syntax that is not reducible to a much simpler equivalent formulation. Specificity is essentially the functionality or meaning of the syntax of that information. Specificity does not lend itself to mathematical formulation and is part of the semantic category that is not addressed in the field of information theory as noted above.

Stephen Meyer expands on the concept of CSI and shows how DNA information is part of that subset.[12] He shows that specificity can include functionality as well as meaning and that DNA information is specified information because of its functionality. He then asserts that CSI is habitually generated by intelligent sources and, therefore, the genetic code must have been as well.[13]

The primary objection to this assertion is empirical. Observation of biochemical systems shows that while DNA information meets the definition of complex specificity, new CSI is also generated without involvement of intelligent agents. One example is provided by Craig Story in his discussion of the immune system and the generation of cells that produce antibodies in response to antigens.[14] An original population of cells with identical nuclear DNA produces a population of lymphocytes that have a novel sequence of base pairs in a particular subset of their DNA and which produce antibodies that have high affinity to the antigens. This constitutes specificity through the functioning of the antibody. New CSI information is generated, without involvement of an intelligent agent, in the production of useful antibodies. Other examples are given by Watts in this issue.[15]

In a much broader sense, we observe that the offspring of virtually all sexually reproducing species have a DNA sequence that is similar but new compared to their ancestors. The functionality that meets the criterion for specificity is clear in the survival of the offspring and is subtly different from that in the parents. We can therefore see that the conservation law of CSI does not hold for biological systems and is not universally applicable.

Meyer's argument also falls short theoretically of being compelling. Meyer uses only inductive reasoning, claiming that all known abiotic examples of CSI require an intelligent source, and extrapolates that, therefore, nonliving systems cannot generate life. He points to similarities in examples such as computer programming, language texts, and phone numbers which inherently require an intelligent source. These analogies, while intriguing, are hardly conclusive. Meyer does not present a characteristic of CSI that is necessarily related to intelligent agents.

One possibility that could relate intelligent agents to a subset of CSI is abstract symbolism. With the ability to carry out abstract reasoning as a trait uniquely attributed to intelligent agents, it would follow that abstract specificity would therefore require intelligent agents. Unfortunately, Meyer does not pursue the distinction between physical and abstract specificity. Since the functionality of DNA information resides in its physical-chemical action, no abstract specificity is evident in a living cell.

This discussion still leaves open the possibility that even if biological evolution involves an increase of CSI without intelligent agents, perhaps chemical evolution is restricted. Nonliving information systems are vastly simpler than living systems, and information, even useful information, can be generated without intelligent agents. But could chemical evolution occur? Is it possible for a nonbiological system to increase CSI to the point of becoming a living biosystem? No one has offered a compelling answer to this question. It is the heart of research in the origin of life and is discussed further by Freeland elsewhere in this issue.[16]

Information theory does not seem to provide any basis for claiming that such chemical evolution could not happen. A physical information system can be generated from a prior system with less (or more or different) information, corresponding to the thermodynamic, capacity, or syntax categories. Whether such systems can have meaningful semantics is not within the purview of information theory. If there is clear evidence of new abstract specificity, it is reasonable to infer that an intelligent agent was involved. If there is no such clear evidence and only physical symbolism is evident, then such involvement cannot be inferred.

Does a living cell exhibit any form of abstract symbolism? Considering the details of any living cell, the criterion for significance is functionality and contribution toward survival of the cell, usually shown by the cell's ability to reproduce itself. This is a physical criterion that includes no connection to an abstract relationship. Though the existence of information and its structure are fascinating and interesting, particularly in the similarities to information-handling techniques humans have devised in recent decades, no feature of the information content inherently requires an intelligent source. We must take a closer look at the information in order to determine how to invest research activity into the origins of life.

We first note that, from a thermodynamics perspective, living cells are dynamic, open systems that continually exchange energy, entropy, and information with their surrounding environment. For multicellular organisms, that environment is, first of all, a vast collection of cells with nearly identical nuclear DNA, while single-celled organisms interact directly with their ecological system. For example, mitochondria (organelles within most eukaryotic cells) act as power sources that convert a variety of fuels from the environment into usable energy. Thus there is plenty of opportunity for information to be transformed from one variable to another, from various physical states to useful information-bearing variables. Information in a cell is not conserved, just as entropy is not conserved in an open system.

The capacity for information in living cells, as noted earlier, is immense. The sequence of nucleotide bases along the nuclear DNA is the best known, but other variables, such as receptors for various biochemical molecules, can also bear key elements of information. The number of distinguishable physical states possible is not only inconceivably large but it can change as, for example, the length of the DNA increases or decreases. For complex eukaryotic organisms, the capacity for information can change considerably during reproduction through a variety of processes such as gene duplication. In humans, for example, genomic studies indicate that there are approximately 10 to 50 major changes, increases or decreases, in the number of genetic sites between parent and child, with some as large as a million base pairs.[17] Many of these are copy number variants of genes or transposons that have been moved to another region of the DNA. Even larger changes can be seen in terms of chromosomal rearrangements or extra copies of entire chromosomes. This is still miniscule compared to the total number of base pairs in the human genome, but the principle is clear. The DNA information capacity of a cell or organism can and does change through the natural process of reproduction.

The syntax of the DNA information in living systems provides the most intriguing insight into life's origins. Whole organism genomic sequencing has become not only possible but also affordable in the last three decades, opening a treasure trove of insight into the information contained in living cells. Since any particular sequence of DNA is derived from a very similar yet different DNA sequence, the syntax is strongly historical-contingent. A given sequence occurs as a result of a long history of changes. Without a clear understanding of all possible historical paths, no credible probability of occurrence can be determined. Irreducibility, the term used to describe a sequence that could not be derived from any other smaller sequence, cannot be compellingly demonstrated simply due to the vastness of the possible historical pathways. Walter Bradley provides a fairly rigorous treatment of information and entropy but fails to recognize that probabilities and improbabilities cannot be reliably assessed unless all historical pathways and processes are well understood.[18]

The semantics of DNA information is the subject of many courses in biochemistry. The significance of the information is the biochemical function that is carried out. The genetic coding is translated in ribosomes into chains of amino acids that form proteins which fold in unique ways to carry out elaborate functions that contribute to the survival of the organism. The term "genotype" is used to refer to the syntactical information in the portion of the genome that codes for genes. The term "phenotype" is used to refer to the semantic information, or function, of those genes. What concerns us here is that all of these functions are physical or chemical processes without evidence of an abstract symbolic value. Coding in and of itself does not necessitate intelligence unless the coding represents abstract symbolic meaning.

Two primary conclusions can be drawn from detailed studies of genomic sequences. The first conclusion of note is common ancestry of all organisms. Charles Darwin and Alfred Russel Wallace drew on their detailed observation of many species to conclude that all organisms may have descended from a common living form. Using techniques these naturalists could never have imagined, geneticists can now examine the sequences of base pairs in DNA to determine inheritance. Going far beyond paternity suits, the patterns of similarity and differences of DNA sequences reveal information about family ties that go back billions of years. The evidence continually grows stronger: all species seem to have derived from a common source rather than have independent origins.[19] This is a major clue which sharpens our research into life's origins to the genesis of a simple life form in a primordial environment. It confirms the historical path of incremental changes of DNA information.

The second conclusion is derived from observations about the location where DNA information changes. Comparing the genomes of various individuals within a species as well as with those in other species, it is clear that DNA regions that code for some critical genes change at a far slower rate compared to regions whose function is less critical. This is a consequence of natural selection. If a change occurs in a function necessary for life, the organism will not survive. Those changes will not be seen. Changes in less critical regions of the genome will have no or negligible impact on survival, and these changes may persist. Some of the changes might be beneficial for survival and be adopted rapidly in the population.

While neither chance alone nor deterministic necessity can lead to the diversity of information required for life, the combination of chance and necessity is a powerful method of designing the proper building blocks of life. The signature we find in the syntax of information in living cells is a process of natural selection which is powerful in enabling efficient derivation of functional configurations. We do not yet know what kind of system could have preceded and generated an initial RNA complex that might have initiated biological evolution. It is fair to extrapolate that processes analogous to reproduction with variation and natural selection, which explain the development of species, may account for such an origin of life from nonbiological sources. No principle from information theory precludes such a scenario. Discoveries in the past few decades of autocatalytic processes, self-assembly, and other analogous processes, give an indication that this research is moving in the right direction.

Though the mysteries of life's origins have not yet been solved, it seems reasonable to conclude that the inference to the best explanation is not an indeterminate intelligent agent but processes akin to reproduction with variation and natural selection. As Christians, we have faith in the existence of an Intelligent Designer who utilizes the design tools of these natural processes to carry out his creative intent.

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Notes

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Article

Biological Information, Molecular Structure, and the Origins Debate

Jonathan K. Watts

Jonathan K. Watts

Biomolecules contain tremendous amounts of information; this information is "written" and "read" through their chemical structures and functions. A change in the information of a biomolecule is a change in the physical properties of that molecule—a change in the molecule itself. It is impossible to separate the information contained in biomolecules from their structure and function. For molecules such as DNA and RNA, new information can be incorporated into the sequence of the molecules when that new sequence has favorable structural and functional properties. New biological information can arise by natural processes, mediated by the interactions between biomolecules and their environment, using the inherent relationship between structure and information. This fact has important implications for the generation of new biological information and thus the question of origins.

A traveler is checking in for a flight and her bags are slightly over the weight limit. Without hesitating, she pulls out her iPod. It is very heavy, she explains to the check-in agent, since it contains thousands of songs. She deletes most of the music, repacks the iPod, and reweighs the bags—which are now well within the weight limits.

Or consider a kindergarten student, learning to write letters. He writes a whole page of A's with no trouble. Next he wants to practice writing the letter G. But after a few G's are written, they seem to want to fold onto each other, as though he were writing on the sticky side of a piece of tape. Each new G he manages to add contributes a new wrinkle or fold, until eventually he gives up and decides to practice writing a less troublesome letter.

When we laugh at these two impossible stories, it reveals how deeply, almost reflexively, we tend to feel that information should be distinct from physical properties. At least in terms of computer code or printed text, we expect that similar devices containing different information will have similar physical properties. By contrast, different devices may contain the same information in spite of their dramatically different physical properties (for example, the printed and online versions of this article).

But biological information is quite different. This article will show that there is a fundamental difference between biological information and abstract information such as computer code or text: the biological information cannot be separated from its structure. The structure and reactivity of biomolecules can give rise to new informa-

Jonathan Watts *is a postdoctoral fellow in the Departments of Pharmacology and Biochemistry at the University of Texas Southwestern Medical Center at Dallas. He received his BSc in chemistry from Dalhousie University (Halifax, Canada) and then spent a year on mission in Côte d'Ivoire before returning to science and obtaining his PhD in nucleic acid chemistry at McGill University (Montreal, Canada) in 2008. His research interests center on the chemistry, chemical biology, and therapeutic applications of oligonucleotides. He has published eighteen papers. Jon and his wife Katie have two preschool children, Liam and Lydia. He enjoys music and often leads worship at his church. Correspondence can be sent to jonathan.watts@ymail.com.*

tion without the direct input of an intelligent agent. Thus we need to be careful when analogies from the world of computers or literature are applied to biological information. This is important in terms of the debate on the origin of life.

The Information-Structure Duality of Biomolecules

Discussion of biological information is often limited to the DNA (or RNA/protein) sequence, which superficially looks much like the kinds of abstract information we are familiar with. When the human genome sequence was published, biology was said to have entered an information age. Stephen Meyer begins his book *Signature in the Cell* by quoting from sources as diverse as Bill Gates and Richard Dawkins who find that "the machine code of the genes is uncannily computer-like." Meyer's next question is highly pertinent: "If this is true, how did the information in DNA arise?"[1]

While I enjoyed reading much of *Signature in the Cell,* I felt that the analogy between DNA and abstract information was taken too far. The issue is that biological information is not abstract: it is always mediated and interpreted by physical interactions. While studying the chemistry and biochemistry of oligonucleotides (short sequences of DNA, RNA, and their chemically synthesized analogues), I have often come face-to-face with the frustration that can be caused by forgetting how tightly information and structure are intertwined.

Some oligonucleotide sequences can be manipulated easily enough, such as the letters within an abstract line of text. But other sequences have repeatedly reminded me that a DNA sequence is not just an abstract line of text. For example, a famous sequence called the Dickerson-Drew dodecamer (5'-CGCGAATTCGCG)[2] can bind another copy of itself by classic Watson-Crick base pairing (A-T and G-C pairs, figure 1a). But under different conditions, it will instead fold back on itself, forming into a "hairpin" structure while still making use of Watson-Crick base pairs (figure 1b). Various factors, including chemical modifications, can favor one structure over the other.[3] While the sequence information is the same, the two structures respond very differently in experiments (i.e., they exert different functions).

Some of my colleagues have made various chemically modified analogues of the sequence GGTTGGTGTGGTTGG.[4] Since this sequence contains only one half of each possible Watson-Crick base pair, one might expect that it would behave "properly" and exist as a nice unstructured line of chemical "letters." On the contrary, it folds into a very complex structure having nothing to do with Watson-Crick base pairing (figure 1c).[5]

The two stories we began with were not chosen at random. Separating and characterizing biomolecules by their mass, for example, is one of the simplest ways to analyze their information content. After synthesizing an oligonucleotide, I first analyze it by gel electrophoresis (here, my desired sequence and any impurities that may be present are separated according to their mass as they are pulled through a gel by an electric field). Then, before carrying out experiments with the oligonucleotide, I inject a small part of each sample into a mass spectrometer to determine its mass more precisely. If the mass of a synthetic oligonucleotide is correct, we can generally assume that the sequence is what we were trying to produce (i.e., the oligonucleotide contains the expected information).[6]

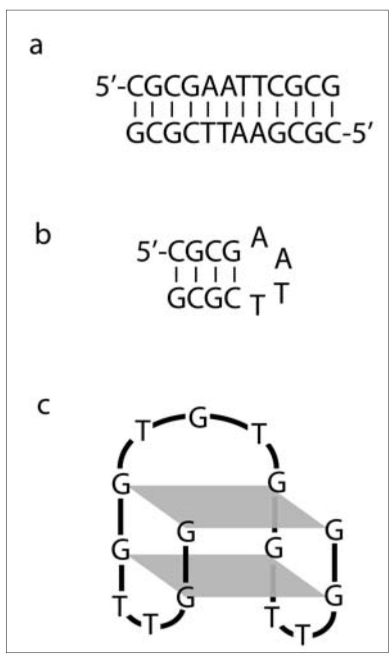

Figure 1.
Some Structures of Oligonucleotides.
(a) The duplex form of the Dickerson-Drew dodecamer, which is in equilibrium with (b) the hairpin form. One form may predominate, depending on the experimental conditions and the chemistry of the sequence. Both are based on Watson-Crick base pairing: G with C and T with A.
(c) An example of a highly stable structure having nothing to do with Watson-Crick base pairing. The G residues arrange themselves in "quartets" in a stacked planar arrangement.

The second story, as you may already have guessed, relates to the DNA bases A and G, adenine and guanine. While both are purine bases and are closely related, guanine folds into a much greater variety of structures and binds to itself with high affinity (as in the sequence from figure 1c). It is nearly impossible, using standard biochemical techniques, to copy a DNA sequence containing dozens of adjacent G's. On the other hand, sequences containing dozens of A's are easy to copy and are used each day in laboratories around the world ("polyA" sequences similar to these are also added to the ends of all of the messenger RNA in our cells).

In a companion article in this issue, Randy Isaac explores the nature of biological information.[7] He points out that when there is an abstract linkage between a given type of information and its meaning, we can readily identify that the information was directly written by an intelligent agent. In contrast, when the linkage between information and its meaning is entirely physical (for example, molecular structure, or function mediated through thermodynamic interactions), we may not be able to attribute intelligent agency as quickly.

So, in thinking about biological information as it relates to the origin of life, we must be careful with analogies from the familiar world of computers or books. The information in a book can be stored in multiple physical forms: a large-print hardcover edition, an electronic PDF version, or even Braille. When we read it with the appropriate media or tools, we obtain the same information. In contrast, biological information cannot be separated from its structure. Three different representations of the nucleobase adenine are shown in figure 2. The first representation, A, is a common abbreviation used in sequence analysis. It is a letter, a symbol, of the biological information carried by adenine. This simple representation facilitates communication and information transfer among researchers. In the second representation, the various atoms are specified. Much more information is included here—the types of atoms contained in adenine and the arrangement of bonds that hold it all together. Chemists would be very comfortable with the second representation. But the readers and writers of biological information (enzymes or other nucleic acids, for example) have to work with something even more complex, something much more similar to the third structure: a three-dimensional electron surface with a defined shape and regions of positive and negative charge.

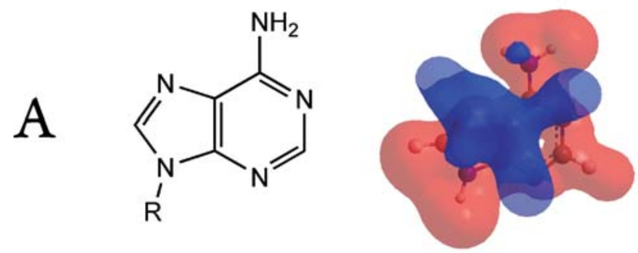

Figure 2. Three Ways of Representing the Nucleobase Adenine. Left, the letter "A," as commonly used when discussing the DNA sequence. Center, the chemical structure of adenine, showing the atoms that make up adenine, their spatial arrangement, and the types of bonds that connect them. "R" represents the sugar-phosphate backbone. In keeping with organic chemistry convention, carbon is assumed to be at any corner not labeled with a different letter, and carbon-bound hydrogens are left out. Right, a computed model of adenine, showing electron surfaces of net positive or negative charge (light gray or dark gray, respectively, in the print version of this article; red or blue, respectively, in the PDF version of this article). The model was generated using Gaussian03W and Chem3D.

Figure 2 gives three levels of understanding of the information conveyed by a single "A" in the DNA sequence. The one on the left looks something like computer code or text, but, in fact, the complex electronic structure on the right is what enzymes and other "information readers" have to interpret. There is much more information in this full structure, but it is much harder to quantify and looks nothing like text or code. Perhaps surprisingly, taking this more complex view of biological information and its connection to structure will make it easier to see and to understand how new functional information can be generated without being directly written by an intelligent agent.

The Generation of New Sequence Information from Structural or Functional Components of Biomolecules

William Dembski[8] and others in the intelligent design (ID) community[9] claim that natural causes are insufficient to produce complex specified information. Their "law of conservation of information" can, like any law, be disproved if examples are found that violate the law. Yet I find that the law as formulated by Dembski does not work in the laboratory;

information can and does arise without direct intelligent input.

Much of the response to the idea of such a law[10] has discussed the information that arises through processes of mutation and natural selection.[11] Others have written about the new information generated by the immune system when it is presented with an antigen.[12] In these cases, information (and associated function) is not directly written by an intelligent agent, but arises from the interplay of an organism with its environment.

In *Signature in the Cell,* Meyer restricts his version of the law of conservation of information to a nonbiological starting point.[13] In keeping with this context, I will also discuss a nonbiological example that is commonly encountered in both academic and corporate research labs. New information can arise from the structure of a molecule such as DNA and the molecules it interacts with.

To begin this experiment, a random oligonucleotide is made on an automated gene synthesizer. These instruments are usually used to make specific (nonrandom) sequences, which can be programmed into the instrument according to what the scientist specifies. The instrument goes through a "synthetic cycle" for each successive nucleotide in the chain—adding one nucleotide at a time, drawing from the appropriate choice of four vials: one for each of A, T, G, and C. For our experiment, we will adapt the instrument to make a random oligonucleotide sequence by simply combining the four building blocks in a single vial so that all are equally likely to be incorporated at each coupling step. Repeating the synthetic cycle, say fifteen times, would yield an oligonucleotide 15 nucleotides long. There are 4^{15} (or just over a billion) different 15-nucleotide sequences. At a typical synthesis scale (25 nanomoles), about 10 million copies of each different option would be present. So far we have lots of complexity but no specificity. In other words, there are a lot of sequences carrying a lot of information,[14] but no useful, *functional* information is present because we have not chosen between any of the options.

However, we can provide specificity by selecting sequences according to their structure or function. For example, our pool of random 15-nucleotide sequences will likely contain GGTTGGTGTGGTTGG, the oligonucleotide from figure 1c. This complex structure binds tightly to the protein blood-clotting factor thrombin. If we wash our entire pool of random oligonucleotides across a sample of thrombin, this sequence will stick more tightly than others (figure 3). This is based on a real example: the sequence GGTTGGTGTGGTTGG was not rationally designed to bind thrombin, it was discovered by a similar

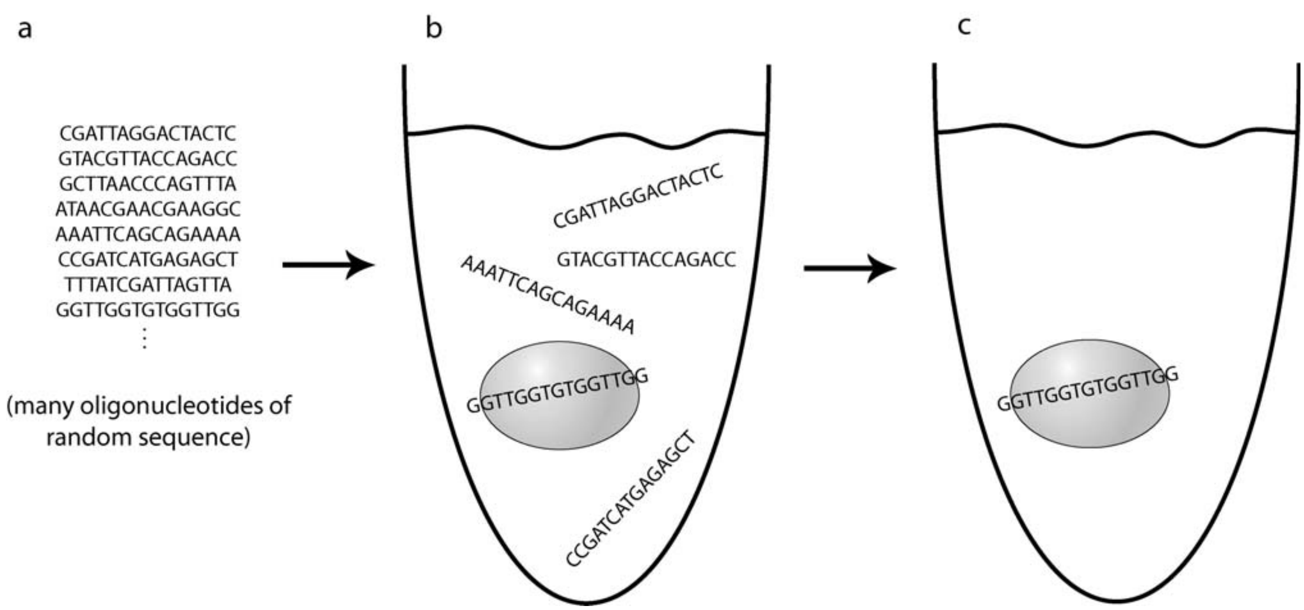

Figure 3. *In vitro* selection of an oligonucleotide consists, at its simplest, of (a) generating random sequences, then (b) selecting and identifying sequences with the desired properties from the pool. Here we show protein binding as a selection step; the sequences that do not bind are removed as shown in part (c). Those sequences that bind their target may be amplified (copied) and then undergo the selection cycle several more times. In this way, the best candidates can be identified.

experiment to the one I have just described.[15] Yet it clearly has generated or uncovered a DNA sequence with specified information.

Variations of this technique are commonly used to develop DNA, RNA, or even proteins with desired properties.[16] Beyond a simple function such as binding to a given target, it can produce more complex functions such as catalysis of a chemical reaction.[17] The general process is called *in vitro selection*, or sometimes *in vitro evolution* or *SELEX* (Systematic Evolution of Ligands by EXponential enrichment).[18] Generally, the selection cycle is repeated several times to improve the signal-to-noise ratio and to identify oligonucleotides with the very best properties. In between each repetition of the selection step, the surviving oligonucleotides are copied ("amplified"). SELEX-derived sequences have proven their usefulness as probes to bind target proteins and small molecules alike,[19] and have even led to an FDA-approved therapeutic.[20]

Objections Addressed

Meyer claims that substantial amounts of information are put in by scientists during an *in vitro* selection process, to the extent that negligible net information is really produced.[21] For example, random oligonucleotides are often synthesized with "wings" attached at either end, consisting of a known sequence. This helps the experimenter to amplify the selected sequences (copy them in sufficient quantity for further use). This amplification is typically done using information-rich enzymes. And the selection step itself is designed by the experimenter.

Let us take these objections one at a time, and I will try to explain why either they are not strictly necessary to a SELEX experiment, or they do not count as an inappropriate introduction of information. First of all, the wings of a known sequence are used for making copies of our selected sequences and for measuring the sequence information.[22] This is an analytical problem: the sequences with higher affinity have *already* been selected by their binding to the protein, and thus we already have a certain degree of new, functional, specified information, even before we amplify or read the sequences. And, of course, whether or not wings of a known sequence are present during a selection, a *region of genuinely random sequence* is being selected and yields new specified information. The constant wings are present both before and after and so do not count against the new information generated.

What about a polymerase enzyme used to make new copies of the selected sequences at each amplification step? First of all, progress is being made toward enzyme-free amplification of nucleic acids, so an enzyme may someday not be required to amplify our sequence of interest.[23] Otherwise, all of the same responses can be given at this point. *The selection of information has already taken place when one sequence binds its target with higher affinity than others;* thus the amplification and sequencing are again simply analytical tools. And finally, the information contained within the enzyme is unchanged and remains constant throughout the selection; thus its presence does not detract from the fact that new information is being obtained.

Finally, what about the information put in by designing and executing a series of selection steps? Scientists carefully design SELEX experiments, it is true. However, I think there are at least three reasons why this objection does not stand.

First, the key selection step actually occurs when one oligonucleotide binds its target to a greater extent than others. This is a purely physical process and does not depend on investigator input.

Secondly, while amounts of information can be hard to quantify when comparing different types, it is hard to argue that a short series of manipulations, moving liquid from one tube to another, contributes anything similar to the amount of information contained in, for example, a 15- to 60-nucleotide chunk of DNA of a specific and functional sequence.

Thirdly, it is not always necessary for researchers to intervene at each step, showing the parallel between SELEX and putative natural examples of molecular evolution. For example, two groups have demonstrated systems for the continuous *in vitro* evolution of biomolecules.[24] In these two different examples, in place of a series of selection steps, a system is designed so that biomolecules (RNA and proteins) are continually optimized through mutation and replication, and the best sequences are preserved. Continuous *in vitro* evolution is very closely related to natural selection. Thus we have come full circle: *in vitro* selection steps mimic natural selection, something that clearly does not require direct human input. In the simplest SELEX experiment, oligonucleotides that confer a needed function (say, binding to a target) survive (by being copied and identified). In nature, the functions may be different, but survival and reproduction are still just as relevant. Thus the selection carried out by a researcher to obtain oligonucleotides with desired properties is parallel to the selection pressures of the environment on any adapting molecule or organism when a new generation survives and multiplies.

In summary, the interventions and manipulations by researchers have parallels in natural selection and biomolecular evolution—diversification by mutation, selection by survival, repetition. The key selection step—that is, the step that specifies information from the complex-but-random starting pool—occurs by the interaction of a biomolecule with its environment, not by intervention by the researchers. Even if researchers set up certain conditions, the desired sequence is unknown by any intelligent agent involved in the experiment. Useful, functional, specified information is generated from a random starting point.

Is the amount of information generated in a SELEX experiment so small as to be negligible? A specific 20-nucleotide sequence corresponds to 40 bits of information.[25] There are hundreds of examples of functional oligonucleotides generated by *in vitro* selection.[26] Thus *in vitro* selection experiments have generated thousands of bits of information over the past two decades.

Where Does the Information Come From?

At the end of a SELEX experiment, a biomolecule contains more information than the researchers put in. Is there another source for this information? Yes. During a SELEX experiment, *information from the environment is captured in the form of a particular DNA or RNA sequence*.[27] This information transfer works because of the relationship between structure and information.

The surface of the target contains information about the positions and charges of a huge array of electron orbitals (something similar to figure 2c, but much larger and more complex). This information is mirrored in the structure of a particular oligonucleotide that folds in a unique way, and the match allows the two molecules—DNA and target—to bind. We use the relationship between the DNA and the target protein to transfer the information into a form we can easily amplify, read, and reproduce—a DNA sequence. The same principles apply when we select an oligonucleotide that catalyzes a chemical reaction or binds to a small molecule rather than to a protein.

Molecules are constantly interacting with each other. Most of the time they "bounce off" one another, but occasionally they bind together, or even undergo a chemical reaction with each other. The interactions between molecules are information-rich (for example, as any chemist will tell you, sometimes the reactivity of a molecule can be used to identify its structure). So why have I focused this article on the transfer of information into a sequence of DNA or RNA? Nucleic acids such as these are a wonderful medium for molecular evolution because they are so easy to copy and analyze. No other type of complex molecule that we know of can be synthesized chemically, copied enzymatically, and sequenced so readily.

However, various creative researchers have nonetheless found ways to evolve other types of molecules and reactions in the laboratory. For example, one strategy is to tether reactive molecules to short pieces of DNA: when two particular groups are joined under a particular set of reaction conditions, they leave a trace in the DNA sequence that can be amplified and measured.[28] This has led to the discovery of new types of chemical reactions.[29]

SELEX, Serendipity and Complexity

SELEX experiments are so useful precisely because of their ability to capture so much information. In fact, one reason scientists incorporate randomness and evolution into our discovery efforts is that reality is often too complex for our attempts at the alternative: rational design.[30] We allow chance and selection room to work (in this case, by beginning with a random oligonucleotide). While SELEX is only twenty years old as a technique, the idea of the importance of serendipity in science is much older.

In the same way, researchers on *both sides* of the origins debate must recognize that the science of origins is too complex for our attempts to understand. Indeed, origin-of-life researchers themselves are often the first to admit that they do not understand how life originated. Just because we can generate biomolecules containing new information in a SELEX experiment does not mean we are anywhere near understanding or recapitulating the origin of life.

The ID community should also recognize the limits of our knowledge. Biological information is too dynamic to support a law of conservation of information. Hard lines cannot easily be drawn between the information in biomolecules and the information in the rest of the environment. Substantial empirical evidence shows that biological information increases through natural causes; SELEX provides one example of such an increase. When information is properly understood in its connection to biomolecular structure, it is not surprising that new biological information can arise from natural processes. Thus the structural component of biological information adds another level of complexity to the origins debate. Biological information is too complex and too dynamic for us to be able to make probabilistic claims of a "designed" origin based on the amount of information contained in biological systems today.

Meyer and Dembski claim that the probabilistic resources of the universe are simply not sufficient to allow the generation of information-rich self-replicating biomolecules.[31] However, an evaluation of the probability of a sequence arising depends almost entirely on our knowledge of the mechanisms whereby such an event may occur.[32] For example, Wilf and Ewens have shown that the probability of generating a given sequence depends strongly on whether the sequence is independent of history (as in a coin toss) or can preserve advantageous elements from "ancestor" sequences (as in many types of both SELEX and natural selection).[33]

Meyer claims that the argument for direct intelligent design of DNA is not based on an absence of knowledge, but a knowledge of absence.[34] Yet, if the ID community responds to the points I have made here, they will likely do so using gaps: "No one knows how random oligonucleotides could self-assemble to provide a starting pool on which prebiotic selection could act." "No one knows how early RNAs could replicate in the absence of polymerase enzymes." These statements are currently correct—but rapid progress is being made in both areas.[35] It would simply not be true to say, "We *know* that random-sequence oligonucleotides cannot self-assemble" or "We *know* that enzyme-free RNA replication is impossible." Thus, in spite of his objections to the contrary, Meyer's arguments about generation of biomolecular information at the origin of life are substantially based on absence of knowledge.[36]

Conclusions

We must be careful when comparing biological information to familiar forms of information such as text or computer code. Biological information is not abstract; it is intimately tied to the structure and function of biomolecules. As such, the biological information in cells can increase through natural processes. Perhaps the first cell was created out of nothing—but the high information content of modern cells does not prove this "special creation" of the first life. Another option is that processes closely or distantly analogous to SELEX could have been used to increase the amount of information in a primitive replicating system, although science has not yet identified such a system. A sense of wonder and worship of the Creator is appropriate in either case.

As a Christian I believe deeply and thoroughly in design. But that design does not oppose the fact that both organisms and molecules can accumulate information through natural processes. When I read about experiments in molecular evolution, I am often inspired by the complexity and beauty of the biomolecules that can generate new information by interacting with their environment. I am also inspired by the creativity of the researchers who did not *directly* design new sequences, but set up a system in which they could measurably evolve. I see unmistakable parallels in God's activity in the world—the beauty and complexity around us speaks of God's subtlety and majesty, even as there is abundant evidence that molecules and organisms can generate new information through physical interactions with their environment.

It is essential that we avoid the false dichotomy of "things God did" versus "things science can understand." In all of our research, including questions of origins, we should worship God in both the places of our ignorance and of our knowledge. The gaps in our knowledge should lead us to greater humility and thus worship. Likewise, each new discovery opens our eyes to new depths of beauty in creation, and these should also lead us to worship.

Notes

[1] S. Meyer, *Signature in the Cell* (New York: HarperOne, 2009), chapter 1.

[2] R. E. Dickerson, H. R. Drew, B. N. Conner, R. M. Wing, A. V. Fratini, and M. L. Kopka, "The Anatomy of A-DNA, B-DNA, and Z-DNA," *Science* 216, no. 4545 (1982): 475–85.

[3] J. K. Watts, B. D. Johnston, K. Jayakanthan, A. S. Wahba, B. M. Pinto, and M. J. Damha, "Synthesis and Biophysical Characterization of Oligonucleotides Containing a 4'-Selenonucleotide," *Journal of the American Chemical Society* 130 (2008): 8578–9.

[4] L. C. Bock, L. C. Griffin, J. A. Latham, E. H. Vermaas, and J. J. Toole, "Selection of Single-Stranded DNA Molecules That Bind and Inhibit Human Thrombin," *Nature* 355, no. 6360 (1992): 564–6; C. G. Peng and M. J. Damha, "G-Quadruplex Induced Stabilization by 2'-deoxy-2'-fluoro-D-arabinonucleic Acids (2'F-ANA)," *Nucleic Acids Research* 35, no. 15 (2007): 4977–88.

[5] R. F. Macaya, P. Schultze, F. W. Smith, J. A. Roe, and J. Feigon, "Thrombin-Binding DNA Aptamer Forms a Unimolecular Quadruplex Structure in Solution," *Proceedings of the National Academy of Sciences of the USA* 90, no. 8 (1993): 3745–9.

[6] Because the four bases have different masses, we can calculate the predicted mass of our desired oligonucleotide. If the mass is correct, it does not confirm the sequence of the bases, but because of the nature of the chemical synthesis cycle, nucleotides are not usually delivered in the incorrect order. If our synthesis fails, it is much more likely to produce a truncated sequence (i.e., the oligonucleotide missing one or more nucleotides) and will thus be of incorrect mass.

[7] R. Isaac, "Information, Intelligence, and the Origins of Life," *Perspectives on Science and Christian Faith* 63, no. 4 (2011): 219–30.

[8] W. A. Dembski, *The Design Inference: Eliminating Chance through Small Probabilities* (New York: Cambridge University Press, 1998).

[9] For example, see Meyer, *Signature in the Cell,* chapter 13.

[10] D. R. Venema, "Seeking a Signature," *Perspectives on Science and Christian Faith* 62, no. 4 (2010): 276–83; several responses are available online, including Darrel Falk's review of the book at http://biologos.org/blog/signature-in-the-cell and a multipart series by Dennis Venema beginning at http://biologos.org/blog/evolution-and-origin-of-biological-information-part-1-intelligent-design.

[11] For evidence that natural selection can generate new *genes*, see C. Chandrasekaran and E. Betrán, "Origins of New Genes and Pseudogenes," *Nature Education* 1, no 1 (2008), available online at http://www.nature.com/scitable/topicpage/origins-of-new-genes-and-pseudogenes-835.

Novel *functions* can arise through natural selection, as shown in Lenski's long-term evolution experiment; see N. Philippe, L. Pelosi, R. E. Lenski, and D. Schneider, "Evolution of Penicillin-Binding Protein 2 Concentration and Cell Shape during a Long-Term Experiment with *Escherichia coli*," *Journal of Bacteriology* 191, no. 3 (2008): 909–21; Z. D. Blount, C. Z. Borland, and R. E. Lenski, "Historical Contingency and the Evolution of a Key Innovation in an Experimental Population of *Escherichia coli*," *Proceedings of the National Academy of Sciences of the USA* 105, no. 23 (2008): 7899–906.

For evidence that complex *molecular machines* can evolve, see K. Miller, "The Flagellum Unspun," http://www.millerandlevine.com/km/evol/design2/article.html.

New information arises through *whole-genome duplication* events and subsequent independent evolution of the two copies. See, for example, P. Dehal and J. L. Boore, "Two Rounds of Whole Genome Duplication in the Ancestral Vertebrate," *PLoS Biology* 3, no. 10 (2005): 1700–8.

For a perspective on the evolution of information associated with *developmental programs and body plans*, see Sean Carroll's book *Endless Forms Most Beautiful* (New York: Norton, 2005).

[12] C. Story, "The God of Christianity and the G.O.D. of Immunology," *Perspectives on Science and Christian Faith* 61, no. 4 (2009): 221–32.

[13] While Meyer does discuss biological evolution to some extent in *Signature in the Cell,* he restricts his version of the law of conservation of information as follows: "In a nonbiological context, the amount of specified information initially present in a system, S_i, will generally equal or exceed the specified information content of the final system, S_f." See Meyer, *Signature in the Cell,* chapter 13.

[14] This is sometimes called "information capacity" or Shannon information.

[15] Bock, Griffin, Latham, Vermaas, and Toole, "Selection of Single-Stranded DNA Molecules That Bind and Inhibit Human Thrombin." The oligonucleotide sequences in the actual experiment were much longer—60 nucleotides of randomized sequence surrounded by 18 nt of known sequence on each end (so 96 nt total). The known-sequence ends are required for PCR (polymerase chain reaction) amplification (the implications of this for information input are discussed later in my article). After five rounds of SELEX, the surviving 96-nt oligonucleotides were sequenced, and the researchers observed that a 15-nt motif was responsible for the high binding affinity.

[16] As a lighter example of SELEX in practice, I could mention that Maureen McKeague won *Science* magazine's 2010 "Dance Your PhD" contest by choreographing the *in vitro* selection of a DNA sequence that binds homocysteine. See http://news.sciencemag.org/sciencenow/2010/10/and-the-dance-your-phd-winner-is.html

[17] Gerald F. Joyce, "Forty Years of *in Vitro* Evolution," *Angewandte Chemie International Edition* 46, no. 34 (2007): 6420–36.

[18] A. D. Ellington and J. W. Szostak, "*In Vitro* Selection of RNA Molecules That Bind Specific Ligands," *Nature* 346, no. 6287 (1990): 818–22; G. F. Joyce, "Amplification, Mutation and Selection of Catalytic RNA," *Gene* 82, no. 1 (1989): 83–7; C. Tuerk and L. Gold, "Systematic Evolution of Ligands by

Exponential Enrichment: RNA Ligands to Bacteriophage T4 DNA Polymerase," *Science* 249, no. 4968 (1990): 505–10.

[19]N. K. Navani and Y. F. Li, "Nucleic Acid Aptamers and Enzymes as Sensors," *Current Opinion in Chemical Biology* 10, no. 3 (2006): 272–81.

[20]E. W. M. Ng, D. T. Shima, P. Calias, E. T. Cunningham, D. R. Guyer, and A. P. Adamis, "Pegaptanib, a Targeted Anti-VEGF Aptamer for Ocular Vascular Disease," *Nature Reviews Drug Discovery* 5, no. 2 (2006): 123–32.

[21]See Meyer, *Signature in the Cell,* chapters 13–14 and Appendix A. These references focus specifically on ribozyme engineering, a sub-type of SELEX.

[22]The oligonucleotides are amplified after each step by the polymerase chain reaction (PCR). This famous technique makes use of a polymerase enzyme that requires a primer to start the synthesis of each copy it makes. So the wings of known sequence surrounding our random oligonucleotide are primer binding sites (each one is complementary to a short primer, and primers must be added during the amplification step). In a similar way, DNA sequencing makes use of a polymerase enzyme and thus requires a primer binding site of known sequence.

[23]C. Deck, M. Jauker, and C. Richert, "Efficient Enzyme-Free Copying of All Four Nucleobases Templated by Immobilized RNA," *Nature Chemistry* 3, no. 8 (2011): 603–8; T. A. Lincoln and G. F. Joyce, "Self-Sustained Replication of an RNA Enzyme," *Science* 323, no. 5918 (2009): 1229–32.

[24]K. M. Esvelt, J. C. Carlson, and D. R. Liu, "A System for the Continuous Directed Evolution of Biomolecules," *Nature* 472 (2011): 499–503; M. C. Wright and Gerald F. Joyce, "Continuous *in Vitro* Evolution of Catalytic Function," *Science* 276 (1997): 614–7.

[25]Calculated as the base 2 logarithm of the number of possible states, 4^{20} or 1.1×10^{12}.

[26]The interested reader can explore work from researchers such as Larry Gold (U. Colorado at Boulder), David Liu (Harvard), Gerald Joyce (Scripps), Andy Ellington (U. Texas at Austin), Yingfu Li (McMaster), Frances Arnold (Caltech), and many others, along with various companies whose focus is generating useful nucleic acid structures by *in vitro* evolution and applying them as diagnostic tools, therapeutics, molecular biology reagents and so on: SomaLogic, Aptagen, Archemix, and others. Hundreds of evolved functional sequences are indexed and catalogued by the Ellington lab at http://aptamer.icmb.utexas.edu/.

[27]The concepts in this section are discussed more fully and in their application to biological evolution in the companion article by Stephen Freeland, "The Evolutionary Origins of Genetic Information," *Perspectives on Science and Christian Faith* 63, no. 4 (2011): 240–54.

[28]M. W. Kanan, M. M. Rozenman, K. Sakurai, T. M. Snyder, and D. R. Liu, "Reaction Discovery Enabled by DNA-Templated Synthesis and *in Vitro* Selection," *Nature* 431, no. 7008 (2004): 545–9; M. M. Rozenman, M. W. Kanan, and D. R. Liu, "Development and Initial Application of a Hybridization-Independent, DNA-Encoded Reaction Discovery System Compatible with Organic Solvents," *Journal of the American Chemical Society* 129 (2007): 14933–8.

[29]Ibid.

[30]F. H. Arnold, "Design by Directed Evolution," *Accounts of Chemical Research* 31 (1998): 125–31.

[31]For example, see Meyer, *Signature in the Cell,* chapter 14.

[32]J. S. Wilkins and W. R. Elsberry, "The Advantages of Theft over Toil: The Design Inference and Arguing from Ignorance," *Biology and Philosophy* 16, no. 5 (2001): 709–22.

[33]H. S. Wilf and W. J. Ewens, "There's Plenty of Time for Evolution," *Proceedings of the National Academy of Sciences of the USA* 107, no. 52 (2010): 22454–6.

[34]Meyer, *Signature in the Cell,* chapter 17.

[35]C. Deck, M. Jauker, and C. Richert, "Efficient Enzyme-Free Copying of All Four Nucleobases Templated by Immobilized RNA," *Nature Chemistry* 3, no. 8 (2011): 603–8; T. A. Lincoln and G. F. Joyce, "Self-Sustained Replication of an RNA Enzyme," *Science* 323, no. 5918 (2009): 1229–32; T. R. Cech, "The RNA Worlds in Context," *Cold Spring Harbor Perspectives in Biology* (2011); P. C. Joshi, M. F. Aldersley, J. W. Delano, and J. P. Ferris, "Mechanism of Montmorillonite Catalysis in the Formation of RNA Oligomers," *Journal of the American Chemical Society* 131, no. 37 (2009): 13369–74; M. W. Powner, B. Gerland, and J. D. Sutherland, "Synthesis of Activated Pyrimidine Ribonucleotides in Prebiotically Plausible Conditions," *Nature* 459, no. 7244 (2009): 239–42.

[36]Venema has drawn attention to the particular danger of gap-based arguments in a rapidly evolving field of research: see "Intelligent Design, Abiogenesis, and Learning from History: A Reply to Meyer," *Perspectives on Science and Christian Faith* 63, no. 3 (2011): 183–92.

Stephen Freeland

Article

The Evolutionary Origins of Genetic Information

Stephen Freeland

Any living branch of science achieves progress by testing new ideas. The results of these tests determine whether each new idea is accepted as a change to what we thought we knew, is dismissed as incorrect, or simply stagnates, owing to a lack of clear evidence. For evolutionary theory, one such proposition is that some features of genetic information cannot evolve through natural processes unless we allow a role for an intelligent designer. This proposition claims testability by defining information in a way that is usually reserved for human creations, such as computer programming code. The argument is that since we know that intelligent beings create computer code, then perhaps similar features found within genetic information indicate a similar origin. However, many biologists perceive that they are able to understand exactly where life's genetic information comes from (the local environment) by thinking in terms of more fundamental and well-established definitions of information that do not involve intelligent design.

Current science does not have a detailed, widely accepted description for how a genetic information system evolved in the first place. Intelligent design (ID) proponents suggest that this is a key weakness of existing evolutionary theory, consistent with the need for an intelligent designer. I describe the progress that mainstream science has made toward understanding the origin of genetic information ever since the molecular basis of genetic information was first understood, encouraging readers to reach their own conclusions.

Biological evolution describes the natural process that transfers information from a local environment into the chemical known as DNA. Something similar happens when gravity causes raindrops to form a puddle, and the shape of the ground beneath becomes reflected in the underside of the water.

ASA member **Stephen Freeland** *is currently project manager for the NASA Astrobiology Institute research team based at the University of Hawaii. Steve's academic background (a bachelor's degree in zoology from Oxford, a master's in biological computation from York University, and a doctorate in genetics from Cambridge) has led him to spend the past twelve years researching the evolution of genetic coding. Steve's current research explores the evolution of the amino acid "alphabet"—the set of twenty building blocks with which life has been making the proteins of metabolism for more than three billion years.*

Underlying this research is a growing interest in the cosmological question, "To what degree is life on Earth (or elsewhere) a result of chance?" As the son of a biology teacher who retrained as a Methodist minister, Steve has been blessed with an encouraging environment with which to explore the interface of science and faith since childhood.

This unusual definition of evolution seeks to clarify an ambiguity in traditional alternatives, such as "biological evolution is a natural process of change in genetic material over time."[1] The phrase "change in genetic material" describes and limits exactly what scientists measure and test to develop their evolutionary theory; however, any description of this sort omits two aspects of a living science. One is the group of all propositions that have been revealed as incorrect through tests (such as *recapitulation*—the claim that the embryos reenact their evolutionary history as they develop from a single fertilized egg cell).[2] Let us call these incorrect propositions "Category 1" omissions. Knowing about them can help scientists avoid wasted time spent repeating previous errors.

The second element missing from a classic definition comprises all propositions for which science has yet to find clear evidence, for or against. We may refer to these as "Category 2" omissions. Propositions in this second category are especially important to science because all suggestions to change existing scientific understanding start here. In other words, Category 2 propositions can gather supporting evidence until they become accepted as scientific truth, altering what we previously thought we understood, perhaps even requiring a change in definition of that science. (It is both humbling and inspiring to remember that scientific knowledge is presently incomplete in ways that are actively misleading us.) However, many Category 2 propositions follow a different trajectory as careful application of the scientific method reveals them as incorrect, and therefore reclassifies them as Category 1 propositions. A third fate is possible for Category 2 propositions. If they do not generate sufficient evidence to make a clear case, whether it be for or against, then they will stagnate. A proposition often ends in stagnation if it fails to generate clear, testable hypotheses that have the power to transform established theory.

Intelligent design theory (ID) has already started its life in Category 2 by suggesting that current evolutionary theory cannot adequately explain the origin of new genetic information. The unusual definition of evolution written above hints why many scientists, including Christians such as myself, think this is an incorrect (Category 1) proposition. What follows seeks to explain why in greater detail—and to equip you to judge for yourself.

Evaluating Suggestions for Changes to Evolutionary Theory

Start by imagining a line that describes every conceivable degree of genetic difference that could separate any two living organisms (figure 1). In fact, we do not have to rely on imagination—such differences can be measured precisely, due to life's shared biochemistry of DNA and proteins (see box 1). Most criticisms of evolution are, upon careful inspection, claims that evolutionary theory is incomplete. They suggest that evolutionary theory can explain differences only up to a specific point on this line. For example, older versions of creationism claim natural processes cannot change anything more than the frequency (number of copies) of genetic material already present within a species. In effect, this defines a point ***X*** on the line shown in figure 1. To the right of ***X*** lie larger differences in genetic material, such as those that separate different species. Under creationism, these differences are considered too large for natural processes to explain, and are therefore explained by divine intervention.

A growing weight of detailed evidence shows that new species form by the accumulation of changing gene frequencies within a population.[3] This evidence has led many contemporary versions of creationism to increase the acceptable limit for evolution, moving point X on the line in figure 1 to point ***Y***. An explanation is that God created fundamental *kinds* of animals and plants so that the formation of new species *within these kinds* are legitimate outcomes of natural processes.[4] Accepting this interpretation, it is now the larger degrees of genetic difference lying to the right of ***Y*** that require supernatural explanation.

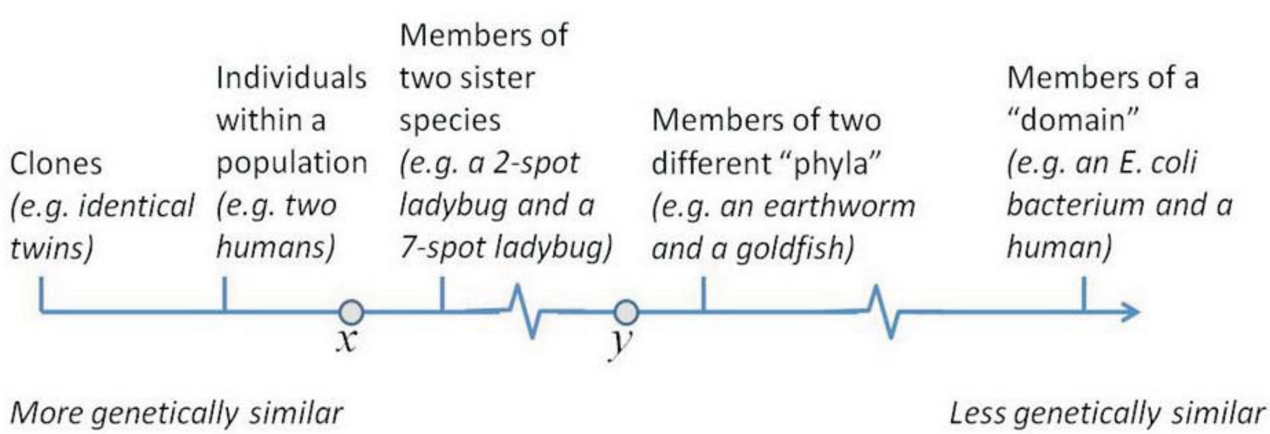

Figure 1. Any two or more organisms can be compared for genetic similarity (e.g., in terms of differences in DNA sequence), and thus plotted as a point on a line that runs from "complete genetic similarity" (clones or identical twins) to "very little genetic similarity," such as a human and an *E. coli* bacterium.

For our purposes, what matters is that different versions of creationism all accept some degree of evolution but place a cutoff on the extent of change that evolution can produce, explaining anything above that point by divine intervention. Wherever the cutoff is perceived, the same terminology is used: *microevolution* (anything to the left of the acceptable limit) is attributable to natural processes, but *macroevolution* (anything to the right of this point) requires a new explanation—direct creation by God.

The terms "*microevolution*" and "*macroevolution*" come originally from similar suggestions made within secular science during the early development of evolutionary theory.[5] Biologists working early in the twentieth century were learning how to cause genetic mutations in a laboratory setting. These mutations could, in a single generation, produce large changes in an organism's appearance. Some pioneers of this new science (*genetics*) thought that their discoveries changed evolutionary theory. Darwin had previously described a process of evolution

Box 1. An Introduction to Biological Coding and the Central Dogma of Molecular Biology

A *code* is a system of rules for converting information of one representation into another. For example, Morse Code describes the conversion of information represented by a simple alphabet of dots and dashes to another, more complex alphabet of letters, numbers, and punctuation. The code itself is the system of rules that connects these two representations. Genetic coding involves much the same principles, and it is remarkably uniform throughout life (figure 2): genetic information is stored in the form of *nucleic acid* (DNA and RNA), but organisms are built by (and to a large extent from) interacting networks of *proteins*. Proteins and nucleic acids are utterly different types of molecule; thus it is only by decoding genes into proteins that self-replicating organisms come into being, exposing genetic material to evolution. The decoding process occurs in two distinct stages: during *transcription* local portions of the DNA double-helix are unwound to expose individual genes as templates from which temporary copies are made (*transcribed*) in the chemical sister language RNA. These *messenger RNA* molecules (mRNA's) are then *translated* into protein.

The language-based terminology reflects the fact that both genes and proteins are essentially 1-dimensional arrays of chemical letters. However, the nucleic acid alphabet comprises just four chemical letters (the 4 nucleotides are often abbreviated to A, C, G, and T—but see endnote 28), whereas proteins are built from twenty different amino acids. Clearly, no 1:1 mapping can connect nucleotides to amino acids. Instead nucleotides are translated as nonoverlapping triplets known as *codons*. With four chemical letters grouped into codons of length 3, there are 4x4x4 = 64 possible codons. Each of these 64 codons is assigned to exactly one of 21 meanings (20 amino acids and one "stop translation" signal found at the end of every gene). The genetic code is quite simply the mapping of codons to amino acid meanings (figure 2a). One consequence of this mapping is that most of the amino acids are specified by more than one codon: this is commonly referred to as the *redundancy* of the code.

Although the molecular machinery that produces genetic coding is complex (and indeed, less than perfectly understood), the most essential elements for this discussion are the *tRNA*'s and *ribosome*. Each organism uses a set of slightly different tRNA's that each bind a specific amino acid at one end, and recognize a specific codon or subset of codons at the other. As translation of a gene proceeds, appropriate tRNA's bind to successive codons, bringing the desired sequence of amino acids into close, linear proximity where they are chemically linked to form a protein *translation product*. In this sense, tRNA's are adaptors and translators—between them, they represent the molecular basis of genetic coding. The ribosome is a much larger molecule, comprising both RNA and various proteins, which supervises the whole process of translation. It contains a tunnel through which the ribbon of messenger RNA feeds; somewhere near the center of the ribosome, a window exposes just enough genetic material for tRNA's to compete with each other to bind the exposed codons.

by natural selection, and this process could be observed changing the frequencies of genes within populations over one or more generations. However, subtle differences in the genetic makeup of a population seemed too small to connect with the large jumps being witnessed in laboratories, and the latter seemed more relevant to the formation of new species. A typical evolutionary debate from this time also defined a point somewhere near ***X*** on the line shown in figure 1. Everyone agreed that Darwin's process could explain changes to the left of this point (microevolution), but some now argued that a fundamentally new phenomenon called *genetic mutation* or *macromutation* was responsible for the larger-scale differences to the right (macroevolution).

At first sight, *macromutationism* and *creationism* seem similar. Both propose a cutoff point for the degree of genetic change that evolutionary theory can explain, and both propose that a new cause must be

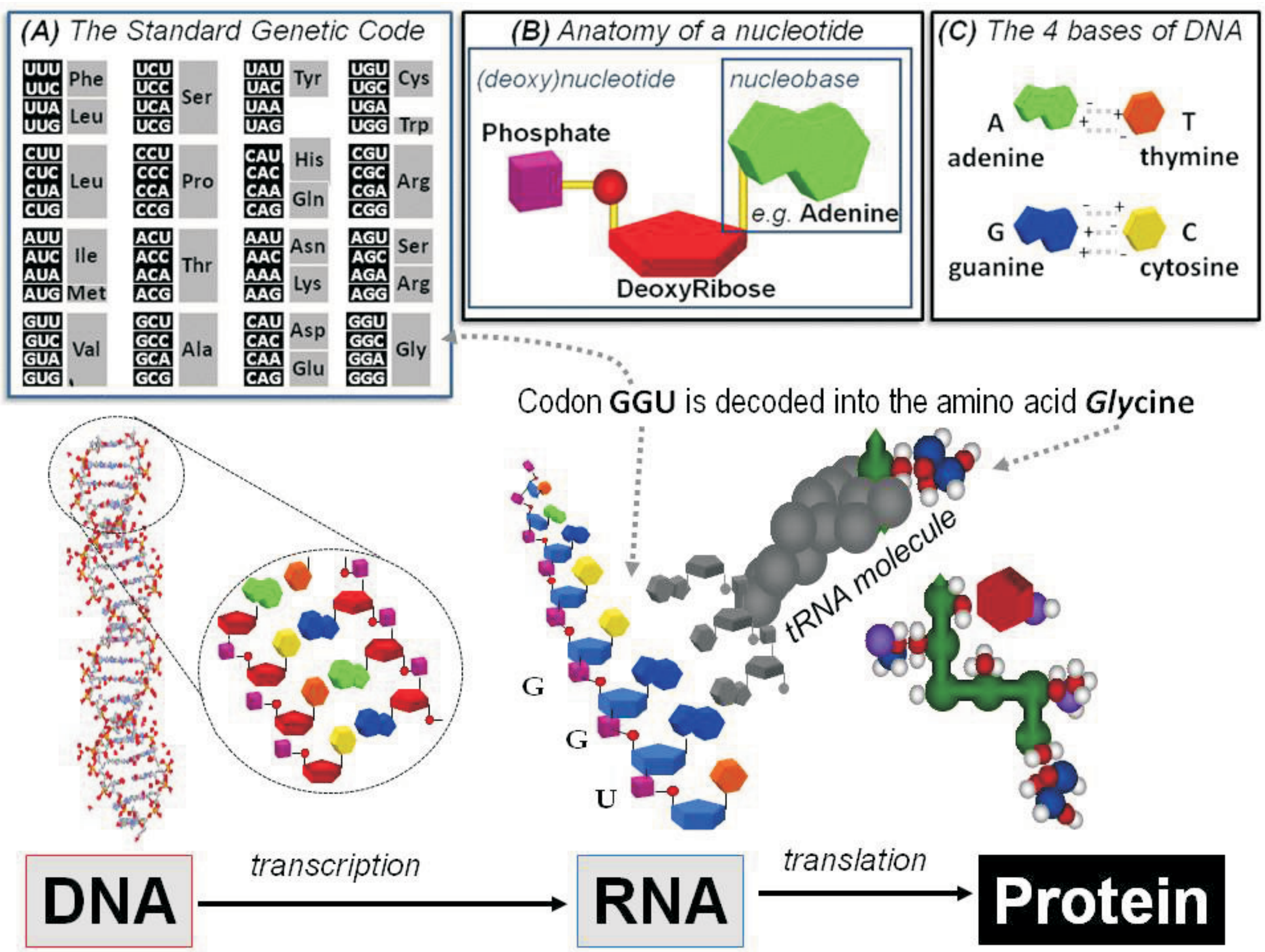

Figure 2. The Central Dogma of Molecular Biology. Short stretches of DNA *nucleotides* are copied into the chemical sister language RNA, and these are then decoded into *amino acids*. A triplet of RNA nucleotides (*codon*) corresponds to a single amino acid. Many amino acids linked together form a protein—the basic unit of metabolism. The decoding molecules are *transfer RNA's* (tRNA's), which operate within the context of the ribosome (not shown here). **(A)** The *Standard Genetic Code* is the set of rules defining which codon each amino acid is decoded into. This used to be known as the Universal Genetic Code, but since the 1970s many slight variants have been discovered, all of which diverged from the standard genetic code. **(B)** The building block of DNA is a *nucleotide*. This is not to be confused with a *nucleobase*—nucleobases must be joined to a ribose molecule and a phosphate to become a nucleotide. This distinction is important to the origin of genetic information because although amino acids, bases, and even ribose are widely thought to be produced by non-biological processes throughout the universe, nucleotides are not so (see endnote 48). **(C)** The four bases of DNA are adenine, thymine, guanine, and cytosine. When placed edge to edge, each base finds a matching counterpart in one of the others. This explains why DNA is so stable as a double helix: two strands of nucleotides run in opposite directions, allowing hundreds of bases to match in pairs, like the teeth on a zipper. RNA uses the same four nucleobases, except for Thymine: here RNA uses a chemical variation known as Uracil. Thymine is more chemically stable than Uracil, fitting with a general picture that DNA evolved to carry information with greater stability than RNA once the latter had "subcontracted" the work of chemical catalysis to proteins.

added to explain genetic differences beyond this cutoff. Where the two propositions differ for science is in their potential for tests. Supernatural causes (literally, those that come from beyond nature) cannot be tested directly from within the natural universe. Science can get no nearer than searching for indirect evidence, such as natural phenomena that cannot be explained by any known, natural cause. Evidence of this kind is unlikely to carry creationist propositions from Category 2 suggestions into accepted science. In part, the problem is that specific data used to justify unnatural causes tend to find an equal or better explanation in terms of the natural causes measured by science as new data become available.[6] Mostly, however, the problem is that unnatural phenomena can never be more than *consistent with* a supernatural cause. Even where specific claims for unnatural phenomena have not been refuted, it remains equally possible that science has yet to understand natural causation, and science keeps growing its understanding in ways that support evolution.[7]

In contrast to creationism, the work of the early geneticists referred to strictly natural phenomena (i.e., those occurring within the observable, natural universe). This focus allowed for direct evaluation by science. Through a series of hypotheses and tests, geneticists revealed that early examples of laboratory-induced macromutation were, in fact, large-scale genetic damage caused by powerful doses of radiation and chemicals. Meanwhile, other tests clarified that within nature, genetic mutations of far greater subtlety do indeed account for the minor differences between members of a species (microevolution). Further evidence indicated that microevolution accumulates over time to account for all larger degrees of evolutionary diversification (macroevolution). In other words, science not only failed to find supporting evidence for the idea that macromutations are responsible for the emergence of new species, but it also undermined the observation that had led to this hypothesis in the first place. Science refuted the claim that macromutations filled a gap within evolutionary theory by discovering that there was no gap to fill. Macromutationist ideas for the origin of new species have therefore moved from Category 2 (ideas for which the evidence is unclear) to Category 1 (ideas that are incorrect), and they are no longer actively researched by evolutionary biologists.[8] The most noticeable place where remnants of macromutationist ideas are to be found today is within popular culture, in which characters ranging from Spiderman to X-men are stubbornly explained in terms of these outdated views of evolution.

Over the years, secular science has proposed many other novel factors that evolutionary theory should absorb to better explain biological diversity. So far, all have gone the way of macromutationism.[9] However, cutting-edge research is, by definition, constantly probing for evidence to support new insights. For example, one recent claim is that without adding any new causal factors, enough biological evolution will ultimately produce something similar to our own sentient species.[10] Contrary to popular belief, this outcome is not predicted by current evolutionary science.[11] The new claim of *inevitable outcomes* has not been refuted by science, nor has the supporting evidence become overwhelming. In fact, scientists still do not know quite how to weigh the evidence—how to measure inevitability when it comes to evolution. As a result, *inevitable outcomes* remains a Category 2 idea, a topic of active debate and research until scientists gather a clear majority of evidence either to reject it or to accept it into science.[12] If such evidence is not forthcoming, the idea will likely atrophy.

These three propositions, *creationism, macromutationism,* and *inevitable outcomes,* provide context for discussing another idea that has arisen in Category 2: the idea that evolutionary theory would be improved by allowing a role for a guiding intelligence. Nothing is inherently unscientific about this suggestion so long as it can find appropriate evidence (through tests) to help scientists decide, one way or the other. One idea for a test is to ask whether we can identify properties of genetic information that resemble human-created information. The idea is that we are intelligent, so if genetic material looks like the sort of thing we would make, then it might be better explained as the product of intelligent design, especially if science can identify features of genetic information inexplicable by known evolutionary processes.[13] ID names one of these features *specified complexity.* Specified complexity is a measurement that tries to capture the semantic content of information (the amount of *meaning* within a piece of information). The assertion is that natural processes, lacking a guiding intelligence, can neither produce new genetic information nor can they explain the origin of genetic information because this implies an increase in specified complexity. Each of these claims warrants careful consideration.

Can Natural Processes Generate New Genetic Information?

Unless life began in greater quantity than now exists, evolution requires that natural processes have, over time, increased the total quantity of genetic material (DNA) present on our planet. One way in which science currently believes that genetic information has increased over time is that a natural process has increased the number of copies of DNA molecules without any need for guidance by an intelligent agent. This kind of increase in genetic information is exactly what we see whenever a natural population grows (e.g., bacteria during an infection). Clearly, this type of information increase is not at issue. Indeed, ID refers to this as a *flow of information*, rather than as the *creation of new information*.[14]

Along similar lines, unless life originated containing more DNA than the most genetically complex organism alive today, then some lineages must have increased the quantity of DNA they contain through evolution.[15] Established science knows ways to observe and measure this kind of increase in genetic information. For example, genome-sequencing technology has revealed small variations in the length of genetic material carried by different individuals within every natural population, including our own species.[16] *Indels* (short for "insertion/deletion mutations") form one of the fundamental types of mutation recognized by geneticists. Indels represent microevolution, but why could insertions not accumulate faster than deletions over time, causing genetic material to grow in size? This is exactly what we would expect if microevolution adds up to produce macroevolution. Again, ID agrees with mainstream science that this is entirely within the realm of causation by existing theory and that a focus on *quantities* of DNA is misleading. Genetic differences between a human and an amoeba are only partly attributable to the different quantity of genetic material present in each. For example, the *Amoeba proteus* genome contains 100-fold more DNA than a human genome; other species of Amoebae contain both much larger and much smaller quantities of genetic information.[17]

More important than the quantity of DNA present in each species is the different order in which nucleotides are linked together to spell out genetic messages. DNA has the unusual property of being aperiodic. This means that the sequence of nucleotides within a DNA molecule is not constrained to any kind of repeating pattern (see Box 1). It is precisely this property that allows DNA or anything with similar properties to carry a large amount of information. For example, written English is an aperiodic sequence built from relatively few symbols. Everything ever written in English can be copied using one simple keyboard. The trick is to arrange these building-block symbols into particular aperiodic sequences. The major difference between this article and *Harry Potter* lies not in the quantity of letters and punctuation used but in the sequence in which these symbols have been assembled. Where current evolutionary science disagrees with ID is in the suggestion that some sequences of genetic information can only be generated by a guiding intelligence.[18] ID asserts that natural processes cannot produce changes in genetic information if these changes correspond to an increase in specified complexity. Specified complexity is measured in a way that tries to capture the difference that separates this article from *Harry Potter*. More accurately, specified complexity is the information that distinguishes any random sequence of symbols from orderings that have meaning.[19]

The idea that some sequences of DNA cannot be produced by natural processes, owing to the information they contain, has no empirical support from modern genetics. In fact, quite the reverse is true. Genetic information is stored in sequences of nucleotides that have been chemically linked together to form a molecule of DNA. Genetics, bioinformatics, biochemistry, and molecular biology all agree that natural processes can cause any nucleotide to become the neighbor of any other within a DNA sequence. Mutations that interconvert each of the four nucleotides have been observed within natural populations and within the laboratory, as have insertions, deletions, and translocations of minisequences from one region of the DNA sequence to another. These elementary components of modern genetics are, in principle, more than sufficient to produce any

DNA sequence from any other. Try this for yourself by listing a series of mutations that convert the word "*evolution*" into "*creation*" with the restriction that each mutation must either change a single letter, insert or delete one or more letters, or move the position of any subgroup of letters. There are many ways to reach the outcome, and this remains true for any two words that you can choose.[20]

The biochemistry that describes how genetic information is stored, replicated, corrected, and translated into proteins is fascinating but requires no novel concepts regarding semantic information. The question is whether the addition of this latter concept can reveal insights, such as limitations too subtle to observe with empirical science. As the companion article by Randy Isaac explains, science recognizes several types of information.[21] One of the most fundamental types is thermodynamic information, a fundamental parameter of physics that reflects all that could be different about the universe. If evolutionary theory implies an increase or loss in thermodynamic information, then it would be in conflict with established ideas belonging to another branch of science. This is not the case. Nothing about biological evolution ever involves an increase (or decrease) in the thermodynamic information present within the universe. Indeed, evolution can be described precisely in terms of thermodynamic processes by which sources of energy bring into being particular states of information within a DNA molecule. The opening definition of this article tries to emphasize this point: "*Biological evolution describes a natural process that transfers information from a local environment into the chemical known as DNA*." To understand why this causes many biologists to doubt whether additional concepts regarding information are necessary or helpful, one must return to Darwin's original insight.

Within a population of individuals that vary from one another, those that best match their environment will, on average, leave behind the most offspring. Wherever the match is genetically programmed, the version of the genetic program associated with the best match will tend to increase in frequency over time by leaving behind more copies of itself. As these advantageous versions are copied from one generation to the next, they will mix with new variations that either increase or decrease the match. All the while, the environment keeps changing and mutations keep occurring, and thus the matching process continues. Repeating this process over and over will create a pool of genetic programs that have accumulated variations, maximizing the overall match between organism and environment (quite simply because those that did not match as well left behind fewer copies of themselves).[22]

Through this process, genetic material will evolve to mirror some of the information presented by the environment in which it is copying itself. This information might include patterns in time and space by which ambient temperatures vary, or patterns of chemical resources found in the environment. Things get especially interesting when we realize that some of the most significant information about an organism's environment is specified by other organisms. The color of leaf on which an organism feeds may become reflected in its genetic material, if this type of genetic programming helps the herbivore to hide from predators; conversely, genetic material may evolve to program colorations that contrast with the background of other organisms in an environment where finding and attracting mates is the strategy that leaves behind the most copies. Each reflection originates in physical parameters, but these collide, transfer information, and start new emanations as they become reflected in the genetic material of the organisms. No matter how complex these rebounding reflections of the environment become, they will never create new information (any more than your image in a reflection of a reflection of a reflection contains more information than you do).[23] Viewed in this light, biological evolution is a natural process that distills thermodynamic information from a highly complex environment into molecules of DNA.[24]

Evolution is to DNA what gravity is to a puddle of water. In both cases, it is possible to isolate elements of the whole that carry impressively complex information (species really do contain lots of complex genetic programs written out in DNA, as does the shape produced when a body of H_2O perfectly matches some of the information inherent to the collection of rocks and debris beneath). If we considered only the water, we might be tempted to think that some sort of intelligence had sculpted such a complex and accurate reflection of the environment. We might even measure this information content to demonstrate its improbability of arising by chance. But step back far enough to see the whole picture, and we realize that evidence consistent with design can be better understood as a result of natural processes (gravity and a preexisting, information-rich environment). In the case of biological evolution, evolution and DNA take the place of gravity and water. Gravity and evolution not only permit the transfer of environmental information into a chemical medium, but inevitably and inexorably lead to this information transfer. Given this understanding, it is hard to see what evolutionary science would gain by accepting other concepts of semantic information that create a problem to be solved by invoking an indeterminate intelligent designer.

Can Natural Processes Account for the Origin of Genetic Information?

The description of evolution given above applies once the world contains a genetic material that can influence its own rate of copying by reflecting the environment. In living systems, these remarkable properties are produced by the *central dogma of molecular biology* (DNA, proteins, and the genetic code that allows the former to specify the latter; see box 1 and figure 2). Perhaps a stronger argument for ID is that no natural process could create such a versatile system in the first place.

It is true that, at present, evolutionary science does not have a clear, detailed, and well-accepted explanation for how the central dogma of molecular biology emerged. But does that mean it is time to embrace ID as a better approach? By analogy, current medical science has not found the cure for cancer. Taken in isolation, this sound bite could lead to the misleading view that existing research directions, developed for decades, are best written off as a failure. This would miss an important context. Many aspects of cancer are now being treated with far greater effectiveness than ever before as a result of ongoing research. However, these cures are not robust (all-encompassing) enough to be summarized in the statement, "we have found the cure for cancer." This status is typical of big questions within science: failure to reach the sound-bite goal should not be mistaken for evidence that the research program has failed. Scientific progress is measured by the insights that research produces, and their implications for where we might usefully look next. These insights may even open up new awareness of just how much we do not understand, but characterizing the past few decades of cancer research as an exhaustive search that has ended in failure would be more than premature: it would be actively misleading. This final section of the article offers context to help the reader judge whether a similar situation holds for current research into natural processes that explain the origin of genetic information.

Let us start by making entirely clear what scientists are looking for. As the previous section explains, the challenge is not to find a natural process that can create enough information for a simple genetic system. The universe is replete with information capacity and syntax—from the positions of stars within our galaxy (and billions of others) to the arrangement of atoms in a single grain of sand. Within living systems, most of this information is ignored—so the question is not, "where did the information come from?" (unless we wish to talk cosmology—a very different subject) but rather, "how does nature create systems that focus on some of this natural information?" Put another way, the challenge for understanding the origin of genetic systems is to find how natural processes can simplify a large amount of thermodynamic information into a syntax that displays only the disciplined chemical semantics of a self-replicator.

The exact details of life's genetic information system came into focus during the middle of the twentieth century.[25] In 1953, Watson and Crick published the structure of DNA,[26] revealing the innate capacity of this molecule to replicate and evolve indefinitely. Thirteen years later, a consortium of scientists published the details of the genetic code by which the information carried by DNA is translated into specific protein sequences.[27] The system was so fundamental to understanding life, yet so simple and easy to explain that it has become known as the *central dogma of molecular biology* (box 1 and figure 2). However, it was puzzling from an evolutionary perspective. Protein catalysts supervise the construction of individual nucleotides (the building blocks for making DNA and RNA). Other proteins link these nucleotides into DNA or RNA sequences, depending on their type (deoxyribonucleotides into DNA, and ribonucleotides into RNA). Proteins can perform these roles because each one has just the right chemical properties to catalyze a specific chemical reaction (such as linking a molecule of the nucleotide "A" to T, G, or C to start building a genetic message).[28] Each protein is a long chain of amino acids (typically several hundred) that have been chemically linked together. The function and shape of a protein emerge spontaneously according to the sequence of these amino acids—just as the meaning of a word is carried (for us) by a sequence of letters drawn from the English alphabet.[29] The only way to reliably build the right sequence(s) of amino acids to make the proteins of metabolism is to follow genetic instructions, one code-word (*codon*) at a time. In other words, for more than 3 billion years, everything living has needed proteins to make genetic information—and needed genetic information to specify how these proteins are to be made.

At the time of discovery, this system looked like something that ID proponents might call *irreducibly complex*: an irreducibly complex system is one that cannot evolve from simpler precursors, because any simplification would lose the entire functional value of the system. This perception of an unevolvable code was further enhanced by the discovery that the same exact genetic code is at work in organisms as different as human beings and *E. coli* bacteria. (Refer back to figure 1. This is about as genetically different as living organisms can be!) Scientists at the time came to think that one genetic code was universal for all living systems on our planet. This led Francis Crick to propose that the genetic code is a "*frozen accident*" of evolution,[30] universal across life precisely because once it had formed (by some unknown event), it was so fundamental to all biochemistry that it could never change again. Specifically, he pointed out that any change to the rules of genetic coding would be equivalent to a simultaneous mutation in every single gene in the organism (box 1).[31] While evolutionary theory requires that occasional small mutations produce a better fit to the environment, the simultaneous mutation of thousands of genes seems extreme even by the standards of macromutationism. However, subsequent science has developed at least three major lines of research that undermine the concept of a frozen accident (and irreducible complexity) for genetic coding.[32]

First, it has been discovered that the genetic code is not universal. Around a dozen or so minor variations exist.[33] These variations are mostly codes in which one or more genetic codons have altered their amino acid "meanings." Some involve a more significant change—the addition of a twenty-first or twenty-second amino acid.[34] Everything indicates that these genetic codes evolved from the standard genetic code during the past few hundred million years, and continue to evolve today.[35] Arguments for the evolvability of the code are strengthened by the finding that amino acids are assigned to genetic code-words nonrandomly. In particular, codons are assigned to amino acids in such a pattern that common mutations produce minor variations as proteins are decoded. A growing body of evidence connects this feature of the code to the idea that considerable evolution by natural selection had gone into shaping this system.[36] Everything suggests that the genetic code is evolved and evolvable after all.[37]

The second major insight into the origins of genetic coding is that multiple, independent lines of evidence suggest that the standard amino acid *alphabet* of twenty building blocks grew from a smaller earlier alphabet corresponding to an earlier stage in genetic code evolution. Many variations have been proposed.[38] Most derive their views by considering only one or two types of evidence: sophisticated calculations of the amino acid sequences of truly ancient proteins, the repertoire of amino acids found in meteorites; simulations of an early, prebiological planet Earth; and so on. What is interesting is an unlooked for match between the broad findings of these different approaches. In particular, different approaches end up dividing the twenty amino acids of modern organisms into ten that were around in the earliest systems, and ten that arrived later, as by-products of early biological evolution. The members of each group are remarkably consistent,[39] hinting directly at the process by which the genetic code evolved, growing more complex over time from simpler beginnings. Recent findings are also starting to make sense of why natural selection created this particular alphabet of building blocks.[40]

The third line of insight takes us backwards to the possible origins of genetic coding. Some scientists have used the SELEX approach that is described in a companion article by Jonathan Watts to define mini-sequences of RNA that specifically bind to a particular amino acid.[41] Although results have been patchy, some amino acids seem to associate with surprising choosiness to the code-words assigned to them in the standard genetic code. This association

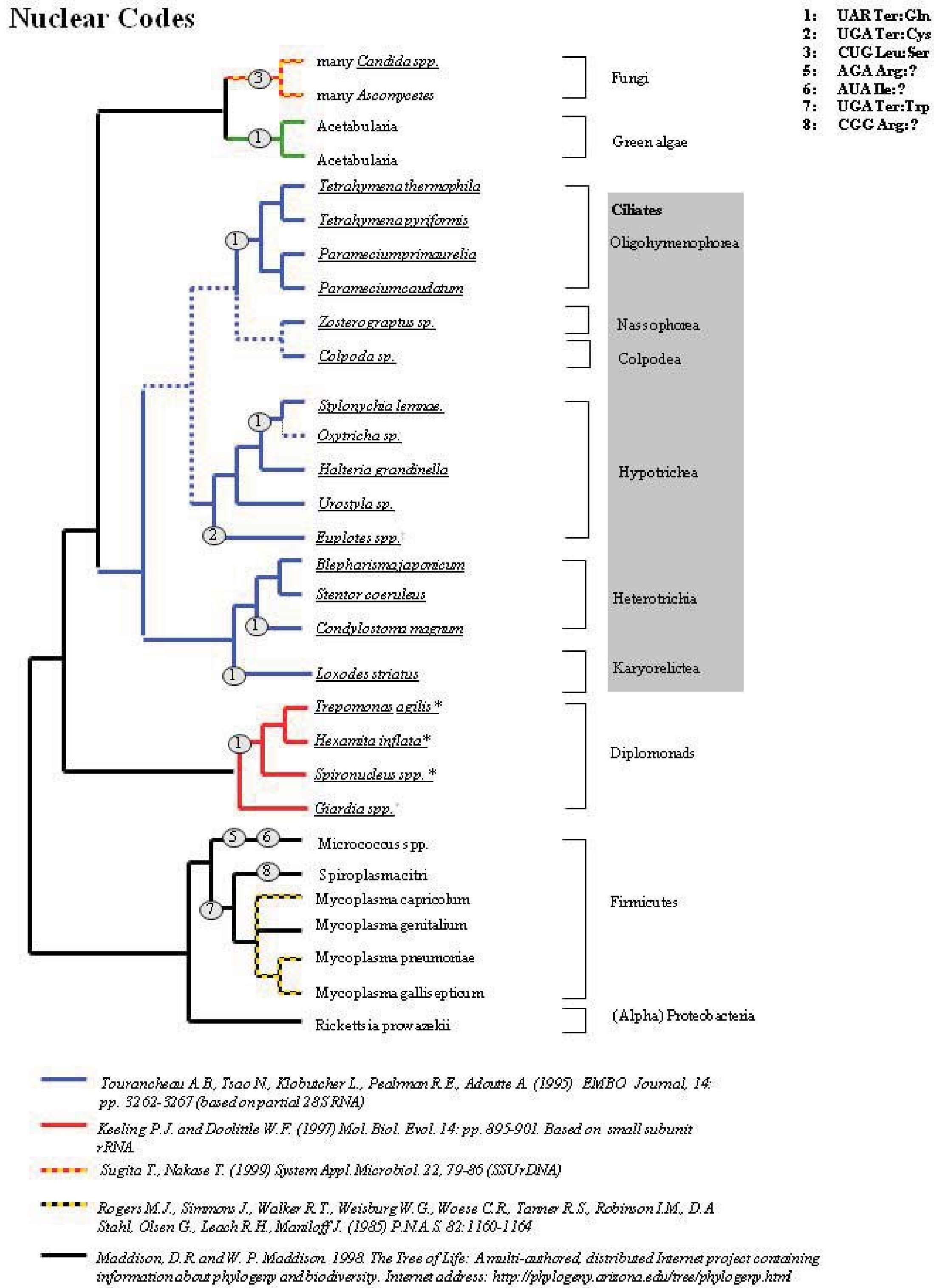

Figure 3. Some of the nonstandard genetic codes that have been discovered since the time of the frozen accident hypothesis, together with their evolutionary relationships (adapted from R. D. Knight, S. J. Freeland, and L. F. Landweber, “Rewiring the Keyboard: Evolvability of the Genetic Code,” *Nature Reviews Genetics* 2 [2001]: 49–58). Recent work that has examined the process by which genetic coding evolves is reviewed by G. R. Moura, J. A. Paredes, and M. A. Santos, “Development of the Genetic Code: Insights from a Fungal Codon Reassignment,” *FEBS Letters* 584 (2010): 334–41.

suggests that the earliest steps in genetic coding may have been nothing more than simple physical affinities between two types of chemical.

Between them, these insights represent significant progress from the impossibly self-referential system viewed by Crick and those around him just fifty years ago. This half-century of research indicates that the standard genetic code at work in modern cells may be a product of substantial evolution that had taken place by around 3 billion years ago. But perhaps the most interesting progress is that few scientists still regard the emergence of life's central dogma as the origin for genetic information.

The Deepest Origins of Genetic Information

The observation that RNA sequences can bind amino acids hints at something very important: proteins are not the only type of molecule that can spontaneously fold into shapes with interesting properties. As described in the companion article by Watts, sequences of RNA can exhibit protein-like behavior.[42] Technologies first developed in the 1980s and 1990s have been used to lab-evolve a wide variety of molecules, dubbed *ribozymes* in deference to the previously known class of protein catalysts known as enzymes. These ribozymes now cover most steps of fundamental biochemistry (such as linking together carbon atoms to make important biological molecules).

Proteins are much less necessary for life than they seemed a couple of decades ago. This observation finds unlooked-for synergy with another line of scientific discoveries. In modern living systems, not all RNA performs the simple role of carrying genetic information from DNA to be decoded into proteins. A handful of the genes that are faithfully copied from DNA into RNA fold up into complex three-dimensional shapes that act as if they were proteins. Interestingly, these natural ribozymes tend to occur in the most ancient metabolic pathways—those shared by bacteria, humans, and everything else alive today. Aspects of biology that have not changed much in billions of years of evolution are likely still with us because they have been doing their job very well throughout this period. In other words, this type of RNA behaving like a protein is exactly what one might expect to see if the ribozymes produced by SELEX resemble a stage of our truly ancient evolutionary past when genetic coding of proteins was far less important (if it was present at all).

Oddly enough, Crick (of the frozen accident) had suggested something similar to this concept of *molecular fossils* when he looked at how genetic decoding works. He noticed that the *adaptor molecules* responsible for decoding individual genetic code-words into specific amino acids are nothing more than folded-up RNA. He also noticed that the biggest and most complex molecular machine involved with genetic decoding (the *ribosome*) seemed to be made of RNA with a few proteins thrown in for good measure. Three decades later, new technology allowed researchers enough precision in their study of the ribosome's structure to confirm that this is correct: although proteins are embedded within the tangled, folded RNA, they appear to offer little more than structural enhancements.[43] At its core, the *ribosome* is a *ribozyme*. It seems likely that a primitive ribosome could function without any encoded proteins, exactly what we would expect if genetically encoded proteins emerged from a simpler, earlier world in which only RNA existed.

Of equal interest, everything points toward DNA being the last arrival out of the three fundamental biomolecules: DNA, RNA, and protein.[44] DNA is made by complex, genetically encoded protein enzymes without a ribozyme in sight. The individual building blocks of DNA (*deoxynucleotides*) are made by taking and modifying a nucleotide of RNA. Again, all this is exactly what we would expect if DNA evolved from RNA, after genetically encoded proteins had already entered the picture. Indeed, DNA is a more chemically inert version of RNA—better for safe storage of genetic information, worse for folding up into a catalyst. This is what you might expect if it emerged after RNA had already handed off the job of catalysis to genetically encoded protein enzymes. The RNA would end up sandwiched in the middle of DNA and proteins, just where we find it today.

Observations that expand on all of these themes continue to accumulate and are beginning to sketch a framework that was completely unknown in the mid-1960s. At its best, this "RNA-world" hypothesis solves much of the puzzle for the origin of living systems. One molecule, RNA, is its own catalyst and information carrier. However, many puzzles remain. For instance, the universe seems quite good at making amino acids without life. They have been found in meteorites, formed in simulations of the conditions of interstellar space, and turn up reliably in just about every possible simulation of our planet's early conditions. For nucleotides, the building blocks of RNA, the exact reverse is true. It seems relatively simple to make the nucleobases (such as adenine and guanine)—but these must be chemically linked to a ribose sugar and a phosphate in order to make a single nucleotide in processes that are antagonistic to those in which the bases form: there are real chemical difficulties in forming the individual nucleotide building blocks, and even bigger difficulties for linking them together into sequences that do not also contain all sorts of unwanted molecular garbage.[45] If RNA came first, then why is it so much easier to make amino acids than RNA from nonbiological scratch?

Scientists are relatively confident that our world, in which DNA genes are copied into mRNA transcripts *en route* to protein translation, was preceded by a simpler biology that comprised only RNA and (genetically encoded) proteins. Every clue that we can find supports this conclusion. A more mysterious question is how this earlier RNA-protein world emerged. One broad class of ideas asserts that we have simply failed to discover some set of conditions that encourages sequences of RNA to form spontaneously. Mineral surfaces are often mentioned here, as they can catalyze many chemical reactions. For example, in 2004, the mineral borate was shown to catalyze the notoriously difficult synthesis of ribose—an essential component of the chemical structure of every single nucleotide.[46] Perhaps other minerals will be found to help other steps in nucleotide synthesis, and for linking nucleotides into sequences. Certainly chemists, geologists, and biologists are talking more than ever before as they seek to add up their knowledge of the ways in which life, chemistry, and the planet interact. Among them, increasing attention is coming to focus on hydrothermal vents as a good place to look next in the search for the origin of life.[47] Here, hot water full of interesting chemicals is forced to flow over richly diverse minerals. This can produce a slew of chemical reactions, most of which are still poorly understood.

Another view is that scientists searching for nonbiological origins for RNA are looking in the wrong place. Instead, genetic information, at least in the form that we think of (polymerized nucleotide sequences), was itself an evolutionary invention of an earlier metabolism, a pre-RNA world. Perhaps significantly, proponents here are also drawn to minerals and to hydrothermal vents because the same conditions that might aid nucleotide synthesis produce a wide diversity of interesting and newly discovered chemical reactions.[48]

It might even be that these two views will meet up one day. Since the mid-1960s, a scientist by the name of Graham Cairns-Smith has been proposing that minerals *were* the original genetic information.[49] Crystalline minerals show the interesting property of harnessing energy from the environment to grow by making copies of themselves. As they do this, they are creating chemical order from chaos. That is exactly what a salt crystal is doing as you watch saltwater evaporate in a glass or a rock-pool. Crystalline minerals also show the potential to catalyze specific chemical reactions on their surface according to their exact atomic composition.[50] In effect, they might carry simple genetic information that starts to trap the energy flowing through the system into a chemical reflection of the environment. But by now we are talking about one of the swarm of competing ideas at the edge of Category 2. Here they will compete and rise or fall according to the evidence that can be gathered through careful and ingenious tests.

Summary

Evolutionary theory, like any other branch of science, achieves progress by testing new ideas. Some of these ideas will go on to change what we thought we knew, others will be found incorrect, and some will stagnate as they fail to gather clear evidence, for or against. For evolutionary theory, many suggestions have been made for new causal factors that are required to explain how genetic diversity has arisen. ID, for example, proposes that some types of genetic information cannot evolve through natural processes unless we admit a role for an intelligent designer. This proposition claims testability by using a definition of information that usually refers to creation by an intelligent agent. Meanwhile, many biologists perceive that they are able to understand exactly where life's genetic information comes from (the local environment) by thinking in terms of more fundamental and well-established definitions of information that do not involve intelligent design. A related suggestion is that current evolutionary theory cannot explain how natural processes could produce a genetic information system in the first place. I agree that we are far from a full understanding, but I choose to outline some major themes in the scientific progress made since the discovery of life's central dogma in 1966 to provide a context for readers to judge for themselves.

It would be remiss to finish an article in this journal without some comment on the theology of all this. If we accept the evolutionary explanations sketched above, then science is taking major steps toward understanding the mechanism by which life came into the universe. Some famous advocates of this science claim it presents a logical connection to an atheistic worldview.[51] Many others (myself included) perceive that any connection between evolution and spirituality is an act of faith—and faith in atheism is only one of many options.[52] For my part, I find excitement and challenge in the search to unravel this marvelous mystery. I choose to associate that inspiration with a loving creator God whose universe I am exploring. I agree with Dawkins (and Darwin) that from a human standpoint, the suffering and death implicit to natural selection form questions for my faith—and I am grateful that scientists and theologians are able to discuss such issues in forums such as this,[53] where I can read, learn, and grow my relationship with God through an exploration of science.

Notes

1 This definition appears, for example, within the classic textbook for undergraduates, D. J. Futuyma, *Evolution* (Sunderland, MA: Sinauer Associates, 2005).

2 For an accessible discussion of this topic, see Neil Shubin, *Your Inner Fish: A Journey into the 3.5-Billion-Year History of the Human Body* (New York: Vintage, 2009).

3 For example, see the review by K. Omland and D. Funk, "Species Level Paraphyly and Polyphyly," *Annual Reviews in Ecology, Evolution and Systematics* 34 (2003): 397–423; Christopher E. Bird, Brenden S. Holland, Brian W. Bowen, Robert J. Toonen, "Diversification of Sympatric Broadcast-Spawning Limpets (*Cellana spp.*) within the Hawaiian Archipelago," *Molecular Ecology* 20 (2011): 2128.

4 For example, see Gary Parker, *Creation: Facts of Life* (Green Forest, AR: New Leaf Press, 2006), 75–148. This text is freely available online at: http://www.answersingenesis.org/articles/cfl/.

5 For an excellent review of the history by which evolutionary thought absorbed and dismantled these ideas to reach the "(neo-)Darwinian synthesis," see P. J. Bowler, *Evolution: The History of an Idea* (Berkeley, CA: University of California Press, 1983), chapter 9, "The Eclipse of Darwinism."

6 P. Senter, "Using Creation Science to Demonstrate Evolution: Application of a Creationist Method for Visualizing Gaps in the Fossil Record to a Phylogenetic Study of Coelurosaurian Dinosaurs," *Journal of Evolutionary Biology* 23 (2010): 1732–43. For a more accessible overview of this article, see http://www.bbc.co.uk/blogs/wondermonkey/2011/07/faith-versus-science-does-crea.shtml.

7 A good, recent summary is presented by Jerry Coyne, *Why Evolution Is True* (New York: Viking Penguin, 2009).

8 Natural mutations can sometimes have large effects, particularly in genetic regions that influence deep developmental pathways of multicellular organisms (i.e., the genes that control how other genes are switched on and off to build an adult organism from a single fertilized egg cell). However, these changes are generally deleterious to the organism, and are therefore unusual components of an evolutionary lineage. A deeper discussion of this type of mutation can be found in S. B. Carroll, "Homeotic Genes and the Evolution of Arthropods and Chordates," *Nature* 376 (2005): 479–85. I would draw the reader's attention to the broader context: these sorts of mutations are limited to relatively few events on one small branch of the tree of life. In terms of general macroevolution for life on our planet, biologists do not view these events as typical in the formation of new species.

9 Some of these suggestions for "skyhooks" and "cranes" that would like to lift the natural processes of evolution to produce higher levels of genetic change are discussed in chapter 3 of Daniel Dennett, *Darwin's Dangerous Idea: Evolution and the Meaning of Life* (New York: Simon and Schuster, 1995), 61–84.

10 See, for example, Simon Conway Morris, *Life's Solution: Inevitable Humans in a Lonely Universe* (Cambridge: Cambridge University Press, 2003).

11 See, for example, Stephen Jay Gould, *Wonderful Life* (New York: W.W. Norton, 1989). Gould is extreme in his view, but is closer to the position of mainstream evolutionary science, as can be seen from reviews of the books in which Morris (*Life's Solution*) argues for inevitable humans (e.g., the review by the National Center for Science Education, http://ncse.com/rncse/30/review-deep-structure-biology).

12 For example, see Simon Conway Morris, ed., *The Deep Structure of Biology: Is Convergence Sufficiently Ubiquitous to Give a Directional Signal?* (West Conshohocken, PA: Templeton Foundation Press, 2008).

13 For example, see William Dembski, *Intelligent Design: The Bridge between Science and Theology* (Downers Grove, IL: InterVarsity Press, 1999), chapter 6.

14 William Dembski, "Intelligent Design as a Theory of Information" (1998). Web material copyrighted to William Dembski, http://www.arn.org/docs/dembski/wd_idtheory.htm.

15 Nothing in evolutionary theory suggests that there *must* be an increase in the length or complexity of a DNA molecule over time: for example, many bacteria and viruses appear to

have undergone extensive natural selection to reduce the size of their genetic material as a specific adaptation to make copies of themselves faster than their competitors. For a recent example, see: N. Nikoh, T. Hosokawa, K. Oshima, M. Hattori, T. Fukatsu, "Reductive Evolution of Bacterial Genome in Insect Gut Environment," *Genome Biology and Evolution* 3 (2011): 702–14, doi:10.1093 /gbe/evr064.

[16]R. Redon, S. Ishikawa, K. R. Fitch, L. Feuk, G. H. Perry, T. D. Andrews, H. Fiegler, M. H. Shapero, A. R. Carson, W. Chen, E. K. Cho, S. Dallaire, J. L. Freeman, J. R. González, M. Gratacòs, J. Huang, D. Kalaitzopoulos, D. Komura, J. R. MacDonald, C. R. Marshall, R. Mei, L. Montgomery, K. Nishimura, K. Okamura, F. Shen, M. J. Somerville, J. Tchinda, A. Valsesia, C. Woodwark, F. Yang, J. Zhang, T. Zerjal, J. Zhang, L. Armengol, D. F. Conrad, X. Estivill, C. Tyler-Smith, N. P. Carter, H. Aburatani, C. Lee, K. W. Jones, S. W. Scherer, and M. E. Hurles, "Global Variation in Copy Number in the Human Genome," *Nature* 444 (2006): 444–54.

[17]For an excellent, evolving review of the interesting topic of genome sizes, see T. R. Gregory, *Animal Genome Size Database* (2005), http://www.genomesize.com/statistics.php.

[18]Dembski, "Intelligent Design as a Theory of Information."

[19]If you would like to consider the implications of combinatorial language in greater detail without any formal mathematics, try reading Jorge Luis Borges's famous short story entitled "*The Library of Babel*." Available in English, *Labyrinths: Selected Stories and Other Writings,* ed. D. A. Yates and J. E. Irby (New York: New Directions Publishing, 1964), 51–9.

[20]In fact, what is harder is to deduce which of the many routes is most likely, if you assign slightly different probabilities to each different type of step. This explains why the past couple of decades have seen considerable research effort go into developing computer algorithms that estimate the most likely series of mutation steps that separate two versions of genetic material. To understand the level of complexity here, consider some different routes by which a series of letter-mutations could transform the word "evolution" into "creation," and then scale that challenge upwards to do something similar for two sentences, two paragraphs, two novels. A good, recent overview is given in K. Tamura, D. Peterson, N. Peterson, G. Stecher, M. Nei, and S. Kumar, "MEGA5: Molecular Evolutionary Genetics Analysis Using Maximum Likelihood, Evolutionary Distance, and Maximum Parsimony Methods," *Molecular Biology and Evolution* 28 (2011): 2731–9.

[21]Randy Isaac, "Information, Intelligence, and the Origins of Life," *Perspectives on Science and Christian Faith* 63, no. 4 (2011): 219–30.

[22]For an accessible, eloquent discussion of where this can lead, see Richard Dawkins, *The Blind Watchmaker* (New York: W. W. Norton & Company, 1986), 43–77.

[23]On a different note, it is interesting to see how this same line of thought parallels theological examination of the famous biblical text that humanity was created in the image of God (Gen. 1:27). If each of us is built in the image of God, and each of us is different, then it follows that each of us is capable of developing a different relationship with God based on the unique perspective granted us. This observation provides a logical check to any theologies that assert necessary submission to a single, all-embracing interpretation of God's revealed truth. Within the Gospels, Jesus's personal encounters show a consistent emphasis on the unique point of connection between an individual's perspective and God's greater truth (e.g., compare John 3:1–7; John 4:1–29; Mark 17:10–22; Matt. 8:5–13; Luke 23:33–43), together with a consistent wariness toward group ideologies (e.g., Mark 12:18–27; Matt. 12:1–9; Matt. 15:1–11).

[24]This reductionist description of evolution contains little that is new (scientifically) precisely because the aim of this article is to explain how classic neo-Darwinian orthodoxy addresses the issue of the origin of (new) genetic information. This view of evolution is probably best known through the popular works of writers such as Dawkins, and everything written here is in true alignment with insights expressed in his books such as *The Selfish Gene, The Blind Watchmaker,* and (most relevant to criticisms of reductionism) *The Extended Phenotype*. Behind these works lies an extensive primary research literature that has developed these ideas, before and after, with respect to genomics, genetics, biological development ("embryology"), animal behavior, morphology, life history strategies, and so on. This reductionist view does not overlook the existence of phenotype as the filter through which the environment passes its information into DNA—thereby explaining why *The Extended Phenotype* is the most relevant popular work to discuss in this context—but as Dawkins explains so clearly in *The Selfish Gene*, environmental pressures that do not create a corresponding "match" within DNA are irrelevant to evolution precisely because heritability is one of the three tenets (variation, heritability, and competition to reproduce) that lead to Darwin's inescapable conclusion: heritable variations which increase the reproductive success of a lineage will, over time, accumulate.

[25]For a fascinating and accessible discussion of the incorrect ideas that paved the way for these discoveries, see B. Hayes, "The Invention of the Genetic Code," *American Scientist* 86 (1998): 8–14.

[26]J. D. Watson and F. H. C. Crick, "A Structure for Deoxyribose Nucleic Acid," *Nature* 171 (1953): 737–8.

[27]L. Frisch, ed., "The Genetic Code," *Cold Spring Harbor Symposia on Quantitative Biology* (1966): 1–747.

[28]More accurately, "A", "T", "G," and "C" refer to the four bases used in genetic coding. Bases are part of a whole nucleotide—the base must be added to a molecule of ribose and a phosphate to form a nucleotide. The ribose-phosphate construction is used as a universal scaffolding for joining together sequences of bases. This technical differentiation becomes important to the origin of genetic information because bases are relatively easy to produce under prebiotic conditions, full nucleotides much less so. This and other subtleties are described further in a later section, explained well in Robert Shapiro, "A Simpler Origin for Life," *Scientific American* (June 2007): 47–53.

[29]This key insight brought Christian Anfinsen a Nobel prize in 1972, and a brief overview is found in his classic paper, C. B. Anfinsen, "Principles That Govern the Folding of Protein Chains," *Science* 181 (1973): 223–30.

[30]F. H. C. Crick, "The Origin of the Genetic Code," *Journal of Molecular Biology* 38 (1968): 367–79.

[31]Given that there are really only 64 different rules for converting genetic information into proteins, and an individual protein can be several hundred amino acids in length, most genes use each of these rules many times over.

[32]For a much more thorough and technical version of this section, including several hundred references to the primary scientific literature, see S. J. Freeland, "'Terrestrial' Amino Acids and Their Evolution" in *Amino Acids, Peptides and Proteins within Organic Chemistry* 1, ed. A. B. Hughes (Weinheim, Germany: Wiley-VCH, 2009).

[33]R. D. Knight, S. J. Freeland, and L. F. Landweber, "Rewiring the Keyboard: Evolvability of the Genetic Code," *Nature Reviews Genetics* 2 (2001): 49–58.

[34]For a brief overview, see J. F. Atkins and R. Gesteland, "The 22nd Amino Acid," *Science* 296 (2002): 1409–10.

[35]Knight, Freeland, and Landweber, "Rewiring the Keyboard: Evolvability of the Genetic Code."

[36]For an accessible overview of this topic, see S. J. Freeland and L. D. Hurst, "Evolution Encoded," *Scientific American* 290 (2004): 84–91. A more technical and more recent treatment of this topic can be found in A. S. Novozhilov and E. V. Koonin, "Exceptional Error Minimization in Putative Primordial Genetic Codes," *Biology Direct* 4 (2009): 44.

[37]For a detailed review, see E. V. Koonin and A. S. Novozhilov, "Origin and Evolution of the Genetic Code: The Universal Enigma," *IUBMB Life* 61 (2009): 99–111.

[38]More than fifty models are considered in E. N. Trifonov, "Consensus Temporal Order of Amino Acids and Evolution of the Triplet Code," *Gene* 261 (2000): 139–51.

[39]Compare the similarities in two recent reviews: P. G. Higgs and R. E. Pudritz, "A Thermodynamic Basis for Prebiotic Amino Acid Synthesis and the Nature of the First Genetic Code," *Astrobiology* 9 (2009): 483–90; and H. J. Cleaves, "The Origin of the Biologically Coded Amino Acids," *Journal of Theoretical Biology* 263 (2010): 490–8.

[40]G. K. Philip and S. J. Freeland, "Did Evolution Select a Nonrandom 'Alphabet' of Amino Acids?" *Astrobiology* 11 (2011): 235–40.

[41]Jonathan K. Watts, "Biological Information, Molecular Structure, and the Origins Debate," *Perspectives on Science and Christian Faith* 63, no. 4 (2011): 231–9. The current status of data here is reviewed in M. Yarus, J. J. Widmann, and R. Knight, "RNA-Amino Acid Binding: A Stereochemical Era for the Genetic Code," *Journal of Molecular Evolution* 69 (2009): 406–29.

[42]Watts, "Biological Information, Molecular Structure, and the Origins Debate," 235.

[43]For an introduction and references to more detailed material, see T. R. Cech, "The Ribosome Is a Ribozyme," *Science* 289 (2000): 878–9.

[44]A brief review of data here is found in S. J. Freeland, R. D. Knight, and L. F. Landweber, "Do Proteins Predate DNA?" *Science* 286 (1999): 690–2.

[45]Readers who are interested in this particular subtopic are encouraged to read Shapiro, "A Simpler Origin for Life." Shapiro's passionate emphasis represents the best traditions of scientific skepticism, ruthlessly pointing out some very real problems with all current attempts to explain how a nonliving universe could have produced RNA. In particular, widespread enthusiasm for the RNA-world has become so fashionable that even high-profile scientific publications which explicitly seek to demonstrate prebiotic origins for the RNA-world continue to ignore well-understood and long-standing criticism of the problems. For example, one recent high-profile paper claims to demonstrate prebiotic plausibility for synthesis of nucleotides: M. W. Powner, B. Gerland, and J. D. Sutherland, "Synthesis of Activated Pyrimidine Ribonucleotides in Prebiotically Plausible Conditions," *Nature* 459 (2009): 239–42. This interesting work shows that exactly the right purified solution of linear organic molecules can cyclize under the right conditions to present activated nucleotides. However, it entirely misses Shapiro's "garbage bag" point—that one of the biggest challenges for understanding the evolution of an RNA-world is to understand how building blocks form into oligonucleotides when they are coming from any sort of messy molecular organic broth (rather than from a purified solution of exactly the right reactants under exactly the right conditions). There is no chemical reason why nucleotides should form and stick to one another rather than to other chemicals produced in the same broth—such as amino acids, alcohols, esters, etc. Of further note, the chemistry reported in this *Nature* paper bears no resemblance to the reactions by which living organisms have been making nucleotides for more than 3 billion years. Maybe early life changed its metabolic pathways beyond recognition—but as yet we have absolutely no evidence for this whatsoever: prebiotically *possible* and prebiotically *plausible* are subtly different concepts.

[46]For example, see the comment by Steve Benner on page 52 of Knight, Freeland, and Landweber, "Rewiring the Keyboard: Evolvability of the Genetic Code." For a more detailed treatment, see H. J. Kim, A. Ricardo, H. I. Illangkoon, M. J. Kim, M. A. Carrigan, F. Frye, and S. A. Benner, "Synthesis of Carbohydrates in Mineral-Guided Prebiotic Cycles," *Journal of the American Chemical Society* 133 (2011): 9457–68.

[47]A very readable overview of this topic can be found in Nick Lane, *Life Ascending: The Ten Great Inventions of Evolution* (New York: W.W. Norton & Company, 2009), chapter 1.

[48]One recent example is given by R. E. Mielke, M. J. Russell, P. R. Wilson, S. E. McGlynn, M. Coleman, R. Kidd, I. Kanik, "Design, Fabrication, and Test of a Hydrothermal Reactor for Origin-of-Life Experiments," *Astrobiology* 10 (2010): 799–810.

[49]Although Cairns-Smith's ideas date back to the mid-1960s, they are most accessibly presented in his later book, *Seven Clues to the Origin of Life* (New York: Cambridge University Press, 1985).

[50]For a broad introduction to this progress, as of 2001, see Robert M. Hazen, "Life's Rocky Start," *Scientific American* 284 (2001): 77–85.

[51]For example, see Richard Dawkins, *River Out of Eden* (New York: Basic Books, 1995), 95–135.

[52]For example, see the letter(s) and signatories of the Clergy Letter Project, http://www.theclergyletterproject.org/.

[53]For example, the excellent pair of articles, Junghyung Kim, "Naturalistic versus Eschatological Theologies of Evolution," *Perspectives on Science and Christian Faith* 63, no. 2 (2011): 95–107; and Keith Miller, "'And God Saw That It Was Good': Death and Pain in the Created Order," *Perspectives on Science and Christian Faith* 63, no. 2 (2011): 85–94.

E. Janet Warren

Chaos and Chaos-Complexity Theory: Understanding Evil Forces with Insights from Contemporary Science and Linguistics

E. Janet Warren

Since the Bible lacks a cohesive demonology, scholars tend to either maximize or minimize the ontology of evil. I suggest two solutions to reconcile these views: metaphor theory can elucidate the diverse biblical descriptors, and chaos-complexity theory can provide a model for demonology. Metaphors/models can depict reality, are frequently used in science, and are especially relevant to supersensible realities. Chaos-complexity theory describes systems that are nonlinear, sensitive to feedback, and self-organizing. Using it as a model for demonology can help reconcile biblical ambiguities and ontological perspectives. Demons can be compared with insect swarms, having minimal individual ontology, but capable of self-organizing into powerful forces.

Demonology is particularly relevant today because of the growth of Christianity in the Global South. It is a difficult area of study for three reasons: this reality is inaccessible to the usual senses, biblical references to Satan and evil spirits are scattered and often obscure, and there are large cultural differences. Although not usually explicit and intentional, scholarly and popular writers on the subject can be classified into two groups: ontological maximizers and ontological minimizers.[1] The first group comprises most popular writers, as well as some academic authors. Perhaps, in an attempt to fill the biblical "gaps," they view the demonic "kingdom" as highly organized, with Satan as the commander in chief; there is a hierarchy of evil spirits, many with specific names and functions, which seek to attack Christians. The second group, largely academicians, believes demonology is not relevant in contemporary Christianity, or that evil spirits are symbolic of psychological projections.

I suggest many of the above inconsistencies can be addressed and perhaps clarified by considering, first, metaphor theory and, second, chaos-complexity theory as a model for demonology. The aim of this article is to apply insights from contemporary linguistics and scientific chaos-complexity theory to further our understanding of evil spirits. Using different models with which to understand a topic can provide a fresh perspective and perhaps further insight. First, I briefly review some biblical ambiguities, and then discuss those who maximize and those who minimize the

Janet Warren *is a family physician in Guelph, Ontario, Canada, with a special interest in counseling and deliverance. She received her BSc in psychology from McMaster University, her MD from the University of Toronto, her MTS from Tyndale Seminary, and is currently completing her PhD in charismatic theology at the University of Birmingham, UK. Her thesis, "Cleansing the Cosmos," develops a biblical model for conceptualizing and counteracting evil using nonwarfare metaphors. Janet is a member of the Christian Medical Dental Society, the Society for Pentecostal Studies, and the American Scientific Affiliation. When her PhD is complete, she hopes to continue working in both medicine and theology, incorporating sessional teaching as well as writing.*

ontology of evil. Possible solutions to the confusion are then investigated. The contributions of metaphor theory are discussed, in addition to its use by science with regard to evil. Next, chaos-complexity theory is described along with its application to theology. Finally, the application of chaos-complexity to demonology is discussed.

Chaos can have three meanings, which are related. In common usage, it means complete disorder; in ancient literature, including the Old Testament, it is juxtaposed to cosmos and is a metaphor for evil; and in science, it is used to describe phenomena that appear disordered but are actually governed by simple rules. The hypothesis of this article is that evil forces are, in fact, complex systems not amenable to classification or confident descriptions. Biblical chaos and scientific chaos are thus related. This relationship may shed light on the apparent ambiguity of biblical references as well as perhaps reconcile the ontological perspectives on evil spirits.

Biblical and Experiential Ambiguities

The Bible does not present a cohesive, consistent, and clear demonology; references are scattered, and there is ambiguity. The following examples illustrate this (without consideration of hermeneutical complexities). Numerous terms are used to describe spiritual forces of evil; some are fairly clear (demons), others more obtuse (powers); some are clearly metaphorical (darkness), others more personal (Satan). Evil spirits are often depicted as animals, including dragon (Isa. 27:1; Rev. 12:9), serpent (Rev. 12:9), locust (Rev. 9:3, 7), and scorpion (Luke 10:19; Rev. 9:3). They are described as inhabiting humans (Luke 22:3), animals (Mark 5:1–13), the air (Eph. 2:2), the earth (Rev. 12:4), the heavens (Eph. 6:12), and prison (1 Pet. 3:19). Some verses suggest that Satan is merely a servant of God (e.g., Judg. 9:23; 1 Cor. 5:5); other verses claim that he is an enemy of God who actively opposes Christians (e.g., Zech. 3:2; Matt. 13:39; 1 Pet. 5:8).

In the Old Testament, evil is primarily symbolized by darkness, the deep, and chaos. In the Gospel of John, evil is depicted as darkness, whereas in the synoptic Gospels, demons and unclean spirits are the favored terms. Within the Synoptics, there is ambiguity in the descriptions of demons with regard to *number* and *name*. For example, with respect to *number*, the unclean spirits in the stories of the synagogue and of the Gerasene demoniacs, are described by both singular and plural pronouns (Mark 1:21–27; Luke 4:31–37; Matt. 8:28–34; Mark 5:1–20; Luke 8:26–39). With respect to *name*, the woman healed on the Sabbath is crippled by a "spirit" and bound by "Satan" (Luke 13:11, 16); also, in Luke's summary in Acts, Jesus is described as healing those afflicted by the "devil" (10:38), whereas the gospel accounts describe people as afflicted by "demons."

Many statements about demons appear only once: request for a demon's name (Mark 5:9; Luke 8:30), reference to a "kind" of demon (Mark 9:29), and reference to "more evil" demons (Matt. 12:45). There is also a vague relationship between sin and the demonic (e.g., Eph. 4:26, 27). These apparent inconsistencies are perhaps a result of difficulties inherent to all biblical interpretation (cultural gap, etc.) or perhaps because the nature of evil spirits is intrinsically ambiguous.[2]

Furthermore, there is much confusion surrounding experiences of demonization in missiology and contemporary deliverance ministries. Within a worldview that is accepting of evil spirits, beliefs are very different from those accustomed to a rationalistic worldview. In traditional African religion, for example, evil spirits are believed to be highly involved in everyday life.[3] In Western cultures, at least until the recent New Age Movement, spiritual beings have been disregarded. In contemporary charismatic Christianity, some believe demonization is rare;[4] others claim that everyone is demonized to a degree.[5] Ideally, beliefs regarding evil spirits should concur with both biblical evidence and experience, but this has not proved an easy task.

Ontological Maximizers

Given the apparent ambiguities discussed above, it is perhaps understandable that many writing on demonology attempt to "fill the gaps." They often come to confident conclusions, and it is not always clear whether these are biblically or anecdotally based. Merrill Unger, in his classic work on biblical demonology, refers to Satan's "highly organized empire of roving spirits."[6] He further divides this into a Satanic order of the earth (ruling over humankind) and of air (ruling over fallen spirits).[7] He claims that demons can adopt human form, "possess personality, are everywhere presented as intelligent and voluntary agents," and possess superhuman knowledge and strength.[8] Missiologist Charles Kraft believes that Satan is a high-ranking angel, akin to an archangel, and that demons are "ground level" troops which take their order from those further up in the hierarchy.[9] He also interprets the Pauline powers as cosmic-level principalities, which have authority over places, social organizations, and sinful behaviors. Roman Catholics Michael Scanlan and Randall Cirner describe different types of spirits such as anger, fear, insecurity, depression, and bitterness. They note that spirits can cluster, for example, "a spirit of guilt may involve self-condemnation, shame and unworthiness," and they believe that sin provides an entry point for demons.[10]

Even some conservative scholars are confident in their conclusions. Bruce Waltke, for example, asserts that it is "clear this anti-kingdom host is organized, not disorganized."[11] Theologian Gregory A. Boyd claims that the biblical belief is that the world is "virtually infested with demons" and "the number of these demons was indefinitely large."[12] These beings, described as an "army of demons," possess free will and are morally responsible.[13] Boyd asserts that demons and the powers exist in a hierarchy, although he admits that we do not know the details. These authors make some valuable contributions to demonology; however, I believe that many authors are overly confident in their conclusions and do not consider the ambiguity of the biblical evidence. In addition, many scholars conflate exegesis and experience. There have been many critiques, especially of the popular literature, but seldom are constructive alternatives suggested.[14] Perhaps in an attempt to bring balance, some scholars go to the opposite extreme in denying the reality of evil spirits.

Ontological Minimizers

The idea of evil having little or no ontological status has been discussed from biblical and theological perspectives. With respect to the Bible, many of the claims about the unreality of evil spirits are based on interpretations of the Pauline powers, Walter Wink being perhaps representative of this position. In his well-known trilogy, he advocates a demythologizing approach to the powers.[15] He thinks that the ancients only personified evil forces because they had no other way of describing them and that it is "impossible" for moderns to "believe in the real existence of demonic or angelic powers."[16] Wink believes that the powers are a "generic category referring to the determining forces of physical, psychic, and social existence"; they consist of an outer, visible manifestation (e.g., political institutions) and an inner spirituality or interiority; and they "must become incarnate, institutionalized or systemic in order to be effective."[17]

In theology, there is a long tradition of viewing evil as nonbeing. A well-known variation of this is Karl Barth's confusing idea of "nothingness," which refers to the chaos and evil in the world that is antithetical to God.[18] Barth describes it as a malignant, perverse being that is equated with darkness, evil, chaos, demons, and Hades.[19] Although nothingness lacks ontological status, he claims that nothingness, sin, evil, death, the devil, and hell are very real. Nothingness attains reality, or a concrete form, through death, sin, and the devil. Demons are "null and void," but not nothing, although they arise from nothingness.[20] Barth has been criticized mostly because of the confusion surrounding the difficult language and ontology of nothingness.[21]

It is appealing to many to minimize the ontology of evil, but this approach does not reconcile well with the gospel portrayal of demons and is also not helpful to those in missions and counseling who deal with people to whom evil spirits are a daily reality. Since neither extreme of maximizing or minimizing the ontology of evil spirits is satisfactory, it is prudent to investigate alternative approaches.

Solution 1: Metaphor Theory

To my knowledge, there has been no systematic application of metaphor theory to demonology. This is surprising because unseen realities are best, if not only, described using metaphors. Biblical metaphors for evil are common in the Bible, and authors often layer multiple metaphors. Isaiah associates chaos, the wilderness, the desert, demons, Lilith, and wild animals (Isa. 34:9–15). The story of the Gerasene demoniac contains an overabundance of metaphors: demons, death, unclean/wild animals, wilderness, the sea, and the abyss (Matt. 8:28–9:1; Mark 5:1–20;

Luke 8:26–39). Paul mentions Beliar, darkness, lawlessness, and idolatry in binary opposition to Christ, light, righteousness, and the temple (2 Cor. 6:14–16). John uses multiple metaphors—devil, Satan, dragon, serpent—to describe the ultimate evil being (Rev. 12:9; 20:2). Recognizing the metaphorical function of these terms can perhaps elucidate some of the interpretive difficulties as well as further our understanding of demonic ontology.

Contemporary metaphor theory claims that metaphors go beyond ornamentation or simple substitution and have semantic power.[22] They are cognitive and conceptual; they can afford new meaning and assist with organization of concepts.[23] Metaphors are universal and frequently unconscious, guiding thoughts as well as language. They have the power to depict reality and are frequently multivalent and multilayered. Models are larger variants of metaphors, being described as sustained and systematic metaphors,[24] or imaginative tools for ordering experience.[25] More than one model is usually needed to describe a difficult concept; multiple metaphors provide multiple snapshots of reality.

Metaphor theory is particularly applicable to supersensible reality which can only be described using figurative language. Typically, metaphor works because we know one realm better than the other. Thus the spiritual realm can be described using images from the physical realm. Biblical scholar G. B. Caird believes almost all language about God is metaphorical and emphasizes the cognitive function of language, "illumination of the unknown by the known."[26] Although metaphors have been discussed in reference to the divine, they are equally applicable to the demonic. The scattered and multiple biblical metaphors for evil spirits can be viewed as each providing one snapshot of this unseen reality. Taking them together and recognizing that they depict reality can enrich our understanding of demonology, as well as bridge the gap between maximizers and minimizers.

Some scholars appear to apply linguistic insights without elaboration on metaphor theory. Old Testament scholar Walter Brueggemann claims that the different terms for chaos can be summarized as death or nihil.[27] New Testament scholar Clinton Arnold does not explicitly refer to linguistics, but in a table listing "the powers of darkness in Paul's letters," he includes Satan, devil, evil one, prince, spirit, Belial, the enemy, the serpent, the tempter, the god of this world, angel, principalities, powers, dominion, thrones, world rulers, spiritual hosts, elemental spirits, and demons.[28] He suggests that Paul drew from a reservoir of terms and "lumped all manner of spirits together."[29] Historian J. B. Russell thinks that the relationship between the devil and demons is blurred; reality and perceptions of it are complex and "multiplicity produces a view of the world that is rich and broad."[30]

These scholars recognize that no one term is adequate to describe the complex biblical reality of evil. Instead, multiple metaphors are needed to give insight into the unseen realm of evil. It makes sense to consider the metaphors as a group rather than isolating individual metaphors and then making generalizations (as some ontological maximizers have done). Attempts to determine precise causal and other relationships between the various terms are likely to be fruitless and lead to confusion. Recognizing that demonology is best described using figurative language and that metaphors have the power to depict reality may help reconcile ontological maximizers and minimizers.

Metaphor theory allows us to affirm the reality of evil spirits, while recognizing that the language used to describe them is not precise. This helps reconcile the differing depictions of evil in the Bible. In addition, Barth's confusing term "nothingness" can be clarified by labeling it as a metaphor. An emphasis on metaphors for evil may also improve comprehension of the nature of evil spirits and how to deal with them. Metaphor theory provides valuable insight into biblical and experiential evil, but there is still potential confusion regarding which metaphor to privilege or how to hold all metaphors together conceptually. Given the multiplicity of metaphors for evil forces, it might be helpful to determine what type of framework is most helpful for organizing the various terms. Scientific models prove helpful in this regard.

Science and Metaphors

Using science to enlighten us regarding demonology may appear strange; demons are hardly amenable to scientific analysis. Scientific inquiry does not usually examine evil, but, like the Bible, includes the polarities of chaos/cosmos and light/dark. Science also deals with unseen realities and derives conclusions based on observations of known realities. Partly for this reason, the science-religion dialogue has progressed in the last four decades. Science has long recognized the value of metaphors and models to gain understanding of both small- and large-scale phenomena. Max Black describes various types of models, the theoretical (which attempts to describe unseen reality, or to offer an explanation for observed phenomena, such as Bohr's model of the atom) being the most relevant.[31] The model is taken from a familiar realm and applied to an unfamiliar one; one is used as a lens through which to see the other. Scientist-theologian Ian Barbour notes the similarities between scientific and religious models. Both are analogical, help order and explain observations, offer partial views of reality, and recognize that all experience is interpreted. Theoretical models are "postulated by analogy with familiar mechanisms or processes and used to construct a theory to correlate a set of observations."[32] They function to understand reality and although not a literal picture, often make some ontological claims. Barbour points out that in contemporary science many phenomena require more than one model, often complementary.[33] It is increasingly recognized that contemporary science talks more of models than of laws.[34]

With respect to historical context, Newtonian physics dominated science for two centuries. Newton's laws describe simple, linear systems and claim that with the correct information, anything can be predicted; the universe operates with stability and reliability. Newtonian physics is reductionistic in that complexities of nature are assumed to have underlying, yet undiscovered, simple laws. Philosophically, this led to a mechanistic and deterministic worldview; the "clockmaker" God simply establishes the laws and lets the universe run on its own. However, science in the past century has radically altered theological views. Newtonian science has been challenged by quantum mechanics, which asserts that certain interactions are inherently unpredictable;[35] by chaos-complexity theory, discussed below; and by the recognition that there is much that remains unknown in the universe, such as dark matter and energy.

There have been some, albeit limited, applications of scientific theories to the study of evil. Field theory has been used by Wolfhart Pannenberg mostly as a model for the action of the Holy Spirit, but he also suggests that evil spirits may operate as fields of force.[36] Robert John Russell has used entropy (the theory that all matter and energy tend toward increasing disorder) as a model of evil. He notes that both evil and disorder increase chaos in the world and that both are dependent on being: "as in theodicy, entropy is parasitic to natural processes."[37] He does not discuss demonology. The new science of chaos-complexity has not, to my knowledge, been applied to the study of evil and demonology.

Solution 2: Chaos-Complexity Theory

Put simply, three types of systems can be described: simple (a recipe, which follows an easy formula), complicated (a rocket ship, which requires multiple formulae as well as expertise), and complex (interpersonal relationships or the weather, which are generally unpredictable, influenced by multiple variables, and not amenable to formulaic analysis). It is this last category, highly intuitive but only relatively recently studied, which is of interest here. Chaos-complexity theory is based on observations that many systems (e.g., insect colonies, stock markets, weather) are nonlinear and do not obey simple laws. Chaos theory developed from the pure sciences in the past half-century; complexity theory, which is related to chaos theory, is a more recent development. They are similar enough to be combined.[38]

In chaos theory, simple laws can have complicated consequences; in complexity theory, complex causes can produce simple effects, or complex systems exhibit can simple behavior. Chaos can be defined as a system in which small changes in the initial condition of processes produce big changes in the outcome; complexity can be defined as a system that is chaotic and develops through a process of feedback on itself.[39] A complex system is "a system that is made up of several simpler components interacting with one another."[40] Edward Lorenz, a meteorologist, postulated the now famous "butterfly effect": a butterfly flapping its wings in Brazil can cause a tornado in Texas.[41] Weather results from an interaction of multiple factors such as collisions of millions of miniscule molecules of air and water.

Both chaos and complexity are nonlinear, arising through the interaction of small numbers of simple components, and challenge the assumption that complicated behavior arises from complicated rules or as a result of interactions of simple components. Nonlinear systems are "neither ordered nor random but combine elements of both kinds of behavior in a very elusive but striking manner."[42] They are flexible and open to novelty. The primary characteristics of chaos-complexity can be discussed under the headings nonlinearity and self-organization.

Nonlinearity

In nonlinear dynamic systems, interactions are not proportional, often following exponential growth curves with a consequent growth of uncertainty. The relationships between variables are unstable and as the number of components increase, the number of interactions between them increases faster. Complex systems are extremely sensitive to small changes in initial conditions (two points starting out close become exponentially further away) as well as being sensitive to ongoing feedback. Minor changes produce maximal effects. The maxim "the straw that broke the camel's back" illustrates this well. When chaos is present, negligible effects are no longer negligible. Although we can observe the effects, we cannot know all the variables. In addition, continuous positive feedback into a system results in exponential and complex behavior. Common examples of such systems include traffic jams, stock markets, child development, and population growth.

Self-Organization

Aspects of self-organization in chaos-complexity theory include self-similarity, attractors, boundedness, stretching and folding, bifurcations, self-organized criticality, and emergence. Self-similarity describes repetitive and similar patterns within complex systems. This is known as a fractal, "a geometric form with fine structure on all scales of magnification."[43] These nonsmooth and ubiquitous geometrical structures appear to be an inherent characteristic of nonlinearity, can be produced by simple mathematical formulae, and are evident in a wide variety of natural phenomena (e.g., a coastline).

Attractors are theoretical components of a complex system to which other aspects are drawn. These are postulated to explain the convergence of components in a system close to a particular point. There may be one attractor or several attractors within a basin of attraction. Some systems start out similar but end up very different. In the long term, the system selects, or settles down to, the simplest set from all possibilities (e.g., a marble in a bowl settles to a position of minimal energy; water on the top of a cliff will run to either valley). Any complex system settles at the equilibrium point between forces of attraction and repulsion. It can also be described as *bounded*, in that all points remain within certain boundaries, and as *adaptive*, in that the components respond collectively to changes in circumstances.

A similar characteristic of complex systems is the notion of stretching and folding. Systems expand to a certain point and then fold into the basin of attraction. When exponentiality and uncertainty get too large, the system folds back on itself, thus increasing its stability. Stretching and folding describe two conflicting tendencies: components are torn apart, but because they are bounded, they fold back. This appears to be a basic component of complex-chaotic systems. A related aspect is the phenomenon of bifurcation. Systems that are developing in a nonlinear manner become unstable, and once they reach a critical point, they will often split into two more-stable systems. In addition, these successive bifurcations will "nest" into each other and become self-similar fractals (e.g., the flow of a tap represents an endless process of bifurcation).

Following from bifurcations are the self-organizational tendencies of chaotic-complex systems. As a system extends far from equilibrium, it tends to self-organize to states of greater stability; this often occurs at critical bifurcation points. There is thus the emergence of simplicity on a large scale; dynamical systems have the capacity to generate stable structures. This is known as self-organized criticality because the system arranges itself at a certain critical point. In the light bulb experiment, a network of bulbs programmed to turn on or off with simple rules will settle into a limited and stable pattern out of the thousands of possibilities. This phenomenon can be observed in a pile of sand which will topple when only one more grain is added. Schools of fish self-organize by following two simple rules: follow the fish in front and keep pace with the fish beside.[44] Self-organization can also be observed in "swarm intelligence," insects which can organize without a leader, especially if they have similar goals. Paradoxically, order exists within most forms of chaos.

Chaos-Complexity and Philosophy

Chaos-complexity theory has been applied to and transformed many fields and subfields of diverse disciplines, including anthropology, biology, business management, chemistry, economics, and psychology. It has provided a new framework or model with which to understand many aspects of life. Interestingly, this shift in scientific worldview, from linear/deterministic to nonlinear/chaotic has coincided with a similar shift in sociology, from modern to postmodern.[45] Both contemporary sociology and science recognize the contribution of multiple variables to a system, and that most phenomena in life are irreducibly complex. Chaos-complexity theory can be seen as a paradigm shift, although critics are concerned about its over-application (e.g., one cannot postulate small changes as an explanation for evolutionary processes; a sand pile may change but it never becomes a cube).

Not surprisingly, many scientists have noted the philosophical implications of chaos-complexity theory. It is generally agreed that reductionism is no longer adequate as a way of viewing reality.[46] The whole is greater than the sum of its parts and nonreductionist strategies need to be employed; the context as well as the content is important.[47] Newtonian science viewed the universe as a web of causalities; now it is considered more helpful to look for patterns, not isolated steps of causality; convergence, not contingency, is emphasized.[48] Scientist-theologian John Polkinghorne concludes that "the nature of the causal nexus of the world is ultimately a matter for metaphysics rather than physics."[49] Ian Stewart rephrases Einstein's famous assertion that God does not play dice into a question and suggests that a better question is, "given some particular subsystem for the real world, is it best modeled by a deterministic mathematical system or a random one?"[50] He further notes that only the model is truly random or deterministic, since chaos is multifaceted. There can be no truly fundamental theories, only approximations within a defined domain; the result is a "pluralistic patchwork of locally valid models."[51] Leonard Smith believes that this increases human responsibility as we need to distinguish between models and reality and decide whether they are similar enough; having the wrong model leads us to ask the wrong questions.[52]

Chaos-Complexity and Theology

Chaos-complexity theory has been applied to theology, mostly with respect to the God-world relationship, and the determinism-free will debate. Many scientist-theologians stress the openness of creation and believe that God acts in the world through the small changes characteristic of chaotic-complex systems. Polkinghorne, perhaps representative, claims that God interacts through "information input" into dynamic processes.[53] God's activity may be discernible only in hindsight as it is hidden "within the unpredictable flexibility of cosmic process."[54] With respect to evil, he believes that God respects the freedom of both the creature and the creation and is self-limited by the degree of openness of the process.[55] Polkinghorne does not address demonology.

Boyd follows Polkinghorne in arguing that God is sovereign but can tolerate risk in creation. As chaos-complexity theory describes how the world can be predictable without being meticulously coercive, so God does not have to be omni-controlling.[56] This reconciles the idea that God can accomplish his purposes but still allow significant freedom to his creatures. Boyd also points out that sensitivity to initial conditions may explain the unpredictability of evil "natural" events.[57] Uniquely, he suggests that because evil spirits have free will, they can influence so-called "natural" evil events, like tornadoes.[58] However, as discussed earlier, he seems to describe evil spirits in a linear, deterministic manner and does not consider that evil spirits themselves may be a complex system.

Sjoerd Bonting more deliberately develops a "chaos theology."[59] He equates scientific chaos with primeval chaos, which he believes to be uncreated and morally neutral, but a source of creativity and evil.[60] In creation, God orders this chaos, but some chaos remains and continues to threaten creation in the form of evil (this can also explain "natural" evil arising from the chaotic behavior of complex systems). He agrees that God can act through chaos events. Bonting briefly dismisses Satan as having no relationship to evil. The application of chaos-complexity to theology is still in its infancy, and there are likely many other potential applications, one of which is demonology.

Chaos-Complexity and Demonology

The different facets of this theory can be applied to demonology in many ways. Although it may be intuitive that evil spiritual forces constitute a chaotic-complex system, the limitations of this comparison should be recognized. Unlike ant colonies, evil spiritual forces are unseen; therefore there is little hope of ever "proving" such a theory through experimental observations. Chaos-complexity theory can only be used as a model. However, as discussed above, models are capable of depicting reality.

The first application of chaos-complexity to evil is the potential influence of demons on complex systems. All natural systems are open and dynamic, involving multiple interactions with their environment, and are inherently unstable. This has been discussed by Bonting, and more explicitly by Boyd. Demons can be considered as having a large effect by influencing small factors. This has implications for discernment. If evil is viewed as a result of a complex interaction of multiple factors, including diabolical persuasion, demonic affliction, human choice (sin), and possibly random factors, then discernment involves not simply a "black-and-white" decision about whether demons are the cause of a problem, but a consideration that demons may be one of many possible factors which affect the complex systems characteristic of most of the world.

A second application of chaos-complexity is to view evil spiritual forces as a complex system. Previous scholarship has likely been operating within a Newtonian worldview, viewing demonology as a linear system and using rules that apply only to complicated systems, not complex ones. Thus there have been attempts to describe hierarchies of evil spirits. Recognizing that demons cannot be described with precise formulae explains the diversity of the biblical verses and the problems with classification attempts. Although not referencing chaos-complexity theory, some theologians have intuited that evil forces are chaotic, disorganized, and destructive. Nigel Wright, for example, believes,

> It is surely mistaken to conceive of the demonic realm as well organized and highly structured. Its essence is not reason but unreason, not organization but chaos.[61]

With Stewart we should question, are evil spiritual forces best modeled by a linear, deterministic system or a chaotic-complex one? I believe that the latter is the best model with which to understand demonology. Both biblical and scientific chaos are nonlinear, dynamic systems which are part ordered, part random, and contain multiple components that interact with each other.

Specific aspects of chaos-complexity can elucidate demonology. The idea that evil forces are self-similar may help explain the diversity, but interrelatedness, of biblical metaphors. For example, "legion" in the story of the Gerasene demoniac is a metaphorical term, meaning a large number; the "one" equaling the "many" can be explained by the fractals of chaos-complexity theory.[62] Demons, darkness, and chaos can be seen to be similar. Perhaps individual demons "nest" together to form darkness.

The concept of attractors and resistors can be helpful. The story of the "restless" demon who seeks to reside in a human "home" illustrates the concept of attractors; perhaps sin acts as an attractor (Matt. 12:43–45; Luke 11:24–26). This may explain many of the anecdotal reports of sin providing an "entry point" for demons. Yet an attractor is not a direct cause, as in a linear system. Perhaps demons of guilt cluster around a basin of guilt. Perhaps prayer and godly behavior could be viewed as a force of repulsion. This could have obvious implications for ministry; identifying attractors and resistors could be helpful. This idea may also satisfy Wink's desire to maximize human responsibility: evil spiritual powers can cluster around sinful human organizations.

Attraction relates to the idea of boundedness, the tendency of complex systems to stay within basins of attraction. The biblical vagueness regarding the limitations on evil forces can be better understood by viewing this restriction as nonlinear and complex. Demons could have a large degree of freedom, but by nature (and God's design), they tend to remain within certain bounds. Their behavior is complex, but it is only a result of obedience to simple rules. They may stretch far but eventually are pulled back. Using chaos-complexity as a model for demonology can help reconcile the tension between determinism and free will: demons are not completely controlled by God, but they are limited by restrictions he places on them.

Finally, the notion of self-organization is helpful to demonology. Observations of demons "clustering" fits well with a chaos-complexity model. Perhaps the Pauline powers can be conceived of as self-organized demons. The apparent organization of evil spirits is not necessarily due to the fact that they are intelligent, willful, autonomous beings, but that they have the same tendency as other complex systems, to exist in a state of maximal stability. As a group, they can appear greater than the sum of their individual parts and can demonstrate swarm intelligence. In the story of the Gerasene demoniac, the behavior of the demons when in the herd of pigs can be explained by swarm behavior. Self-organization has implications for ministry, too. Perhaps both individual demons and the "superorganism" of evil need to be considered.

Chaos-complexity theory can elucidate the ontology of evil. Demons can be viewed as insects (well-studied complex systems): they lack individuality and intelligence, but nevertheless, they can self-organize into a powerful force. They may appear to be intelligent, but they are only exhibiting self-organizing behavior. The biblical description of demons as scorpions and locusts is apt. Self-organization confirms the maximizers contention that the demonic world is organized, but it does not support the notion of individual personalities. This theory may explain the tension between the apparent power of evil spirits and their limitations. It can also reconcile the ontological maximizers (evil forces can have real effects and appear organized) and minimizers (evil forces in reality are no more significant than insects). Viewing demonology as a chaotic-complex system may illuminate Barth's confusing notion of "nothingness." Chaos-complexity theory in some ways confirms that "nothingness is not nothing." Demons have minimal ontology, but they can nevertheless exhibit powerful behavior when they cluster around a basin of sin.

Some aspects of chaos-complexity are difficult to apply to demonology. For example, there is no biblical suggestion that the number of demons is increasing at an exponential rate, which occurs in chaotic systems, or that their number is not fixed. This theory does not explain the relationship between Satan and the demons. Furthermore, in contrast to chaos-complexity theory, there is indication that the ancient world viewed spiritual beings in a linear manner. However, this view is not necessarily normative to the Bible, and there is evidence that regard for evil spirits was greatly reduced in both the Old and New Testaments.[63] Obviously, the ancient world would not have considered a contemporary scientific theory as a model for evil, but doing so can nonetheless assist our conceptualization of evil. All metaphors and models should be used cautiously and not over-extended.

Conclusions

The difficulties and inconsistencies with respect to the literature on demonology discussed previously can be addressed and perhaps diminished, first, by recognizing the value of metaphor and, second, by recognizing the contributions of chaos-complexity theory. We need to acknowledge that metaphors and models are the primary, if not the only way to describe and discuss evil spirits. It is the main method used in the Bible and, I believe, should be the main method used in theology. Demonology is best discussed using metaphorical truth rather than propositional truth. By affirming the power of metaphors to depict reality, we can avoid unhelpful discussions about whether a term is "metaphorical" or "literal." The linguistic contributions of metaphors and models can also further our understanding of demonology by providing incentive to search for appropriate models.

One such model which has proved helpful is chaos-complexity. Aspects of this theory such as nonlinearity, attractors, boundedness, and self-organization can provide a new perspective on demonology as well as offer a way to reconcile some of the apparent ambiguities in biblical studies and theology. Chaos-complexity theory fits well with biblical metaphors such as chaos, theological metaphors such as nothingness, and anecdotal descriptions of demonization. As metaphors cluster in the Bible, evil spirits can cluster around a basin of sin. "Broad" metaphors such as darkness and powers can be conceived of as a swarm of precise metaphors such as demons. Chaos, the biblical metaphor for evil, is also chaos, the scientific term for nonlinear dynamic systems. Evil forces are generally chaotic and disorganized with minimal ontology, but they can self-organize into powerful forces. They can be seen as "barely" real but can attain reality as they cluster or self-organize around basins of sin. Understanding evil forces as a complex system can help explain the diversity of both biblical metaphors and experiential reports. Although not all facets of chaos-complexity apply to demonology, chaos-complexity, along with metaphor theory, can provide a fresh perspective on this difficult but important subject, and may pave the way for further study, such as more specific applications to counseling and deliverance ministries. In addition, it may suggest other models which can be applied to demonology and deliverance.

Notes

[1]This division is for convenience only; it is recognized that many scholars are more nuanced. A somewhat similar point has been made by Nigel Scotland who refers to "maximizers" as "expansives" and describes a second group as "moderates"; he does not discuss "minimizers" ("The Charismatic Devil: Demonology in Charismatic Christianity," in Peter G. Riddell and Beverly Smith Riddell, *Angels and Demons: Perspectives and Practice in Diverse Religious Traditions* [Nottingham: Apollos, 2007], 84–105). James M. Collins uses the term "enthusiasm" to describe contemporary deliverance practitioners (*Exorcism and Deliverance Ministry in the Twentieth Century: An Analysis of the Practice and Theology of Exorcism in Modern Western Christianity* [Colorado Springs, CO: Milton Keynes, 2009], 1, 2).

[2]For example, Joel Marcus points out that "we should not look for too much consistency when dealing with things as ambivalent and protean as demonic spirits" (*Mark 1–8: A New Translation with Introduction and Commentary by Joel Marcus* [New York: Doubleday, 1999], 342).

[3]Keith Ferdinando, "The Spiritual Realm in Traditional African Religion," in Riddell and Riddell, *Angels and Demons*, 21–41.

[4]Based on a 1972 statement by the Bishop of Exeter. See, for example, Andrew Walker, "The Devil You Think You Know: Demonology and the Charismatic Movement," in Tom Smail, Andrew Walker, and Nigel Wright, *Charismatic Renewal: The Search for a Theology* (London: C. S. Lewis Centre/SPCK, 1993), 89.

[5]See, for example, Frank Hammond and Ida Mae Hammond, *Pigs in the Parlor: The Practical Guide to Deliverance* (Kirkwood, MO: Impact Christian Books, 1973), 12.

[6]Merrill F. Unger, *Biblical Demonology: A Study of the Spiritual Forces behind the Present World Unrest* (Wheaton, IL: Van Kampen Press, 1952), 52, 72.

[7]Ibid., 72–3.

[8]Ibid., 64–7. Similarly, popular author Neil Anderson concludes the following about the "personality of demons": they "can exist outside or inside humans," "they are able to travel at will," "they are able to communicate," "each one has a separate identity," "they are able to evaluate and make decisions," and "they are able to combine forces" (based on his understanding of Luke 11:24–26). Anderson, *The Bondage Breaker* (Eugene, OR: Harvest House, 1990), 102–5.

[9]Charles H. Kraft, *Defeating Dark Angels: Breaking Demonic Oppression in the Believer's Life* (Ann Arbor, MI: Servant Press, 1992), 18–19. Fellow missiologist C. Peter Wagner has been vocal with respect to encouraging Christians to combat territorial spirits, the existence of which is extrapolated from "gods of the nations" and cosmic powers. Wagner, *Confronting the Powers: How the New Testament Church Experienced the Power of Strategic-Level Spiritual Warfare* (Ventura, CA: Regal Books, 1996). For a helpful critique of "territorial spirits," see René Holvast, *Spiritual Mapping in the United States and Argentina, 1989–2005: A Geography of Fear* (Leiden: Brill, 2008).

[10]Michael Scanlan and Randall J. Cirner, *Deliverance from Evil Spirits* (Ann Arbor, MI: Servant Books, 1980), 84, also 96–7. Similarly David Brewer, in his discussion of demonology and psychiatry, describes different types of demons which tend to cluster in groups of six ("Jesus and the Psychiatrists," in Anthony N. S. Lane, *The Unseen World: Christian Reflections on Angels, Demons and the Heavenly Realm* [Grand Rapids, MI: Baker, 1996], 142–3).

[11]Based on Mark 3:22. Bruce K. Waltke with Charles Yu, *An Old Testament Theology: An Exegetical, Canonical and Thematic Approach* (Grand Rapids, MI: Zondervan, 2007), 231.

[12]Gregory A. Boyd, *God at War: The Bible and Spiritual Conflict* (Downers Grove, IL: IVP Academic, 1997), 194, also 182.

[13]Ibid., 141, 182, 186, 191, 199.

[14]See, for example, Walker, "The Devil You Think You Know"; Robert J. Priest, Thomas Campbell, and Bradford A. Mullen, "Missiological Syncretism: The New Animistic Paradigm," in Edward Rommen, ed., *Spiritual Power and Missions: Raising the Issues* (Pasadena, CA: William Carey Library, 1995), 9–77.

[15]Walter Wink, *Naming the Powers: The Language of Power in the New Testament* (Minneapolis, MN: Fortress Press, 1984); ———, *Unmasking the Powers* (Minneapolis, MN: Fortress Press, 1986); ———, *Engaging the Powers: Discernment and Resistance in a World of Domination* (Minneapolis, MN: Fortress Press, 1992).

[16]Wink, *Naming the Powers,* 4.

[17]Wink, *Unmasking the Powers,* 4. He views demons as the "real but invisible spirit of destructiveness and fragmentation that rends persons, communities and nations" (*Naming the Powers,* 107).

[18]The German term, *das Nichtige,* implies nihil, null, or nonexistence. The editors chose "nothingness" with the proviso that its meaning is as explained by Karl Barth, *Church Dogmatics,* trans. G. W. Bromiley and R. J. Ehrlich (Edinburgh: T&T Clark, 1960), 3:289.

[19]Ibid., 352, 523.

[20]Ibid., 300, 307–8, 310. Barth does not explain how they arise from nothingness, but insists demons are not created.

[21]For example, Wolf Krötke claims it to be "an ontological impossibility" and an absurdity (*Sin and Nothingness in the Theology of Karl Barth,* 2nd ed., trans. Philip G. Ziegler and Christina-Maria Bammel, in *Studies in Reformed Theology and History* [Princeton, NJ: Princeton Theological Seminary, 2005], 39, 42, 48–51).

[22]The view of metaphor as cognitive was originated by I. A. Richards, *The Philosophy of Rhetoric* (New York: Oxford University Press, 1936), expanded upon by Max Black, *Models and Metaphors: Studies in Language and Philosophy* (Ithaca, NY: Cornell University Press, 1962), esp. 25–47, and applied to theology by Paul Ricoeur, *The Rule of Metaphor: Multi-disciplinary Studies of the Creation of Meaning in Language,* trans. Robert Czerny (Toronto: University of Toronto Press, 1977) and Janet Martin Soskice, *Metaphor and Religious Language* (New York: Oxford University Press, 1985), among others.

[23]The idea of conceptual metaphors was developed by George Lakoff and Mark Johnson (*Metaphors We Live By* [Chicago, IL: University of Chicago Press, 1980]) and has been very influential. They argue that metaphors are based on conceptual correspondence between ideas, not simply similarities. Metaphors are largely irreducible and non-translatable; they are neurological and not just linguistic, permeate thoughts and actions, and reflect our worldviews.

[24]Black, *Models and Metaphors,* 236.

[25]Ian G. Barbour, *Myths, Models and Paradigms* (London: SCM Press, 1974), 6.

[26]G. B. Caird, *The Language and Imagery of the Bible* (London: Duckworth, 1980), 16. Paul Ricoeur concurs that, especially in religion, metaphor has the power to define reality (*The Rule of Metaphor,* 215–56).

[27]Walter Brueggemann, *Theology of the Old Testament: Testimony, Dispute, Advocacy* (Minneapolis, MN: Fortress Press, 1997), 534.

[28]Clinton E. Arnold, *Powers of Darkness: Principalities and Powers in Paul's Letters* (Downers Grove, IL: IVP Academic, 1992), 218. Belial is used in the Second Temple Literature and assumed to be the same Beliar as used by Paul.

[29]Ibid., 54. Wink notes that the language of the powers is "imprecise, liquid, interchangeable and unsystematic." He also recognizes the importance of figurative language in his claim that demons are "images whose reality can be experienced only at the imaginal level" (*Naming the Powers*, 9, 145).

[30]He believes that Satan should be viewed as "one manifestation of the Devil" and that the myth of the devil expresses profound truth (Jeffrey Burton Russell, *The Devil: Perceptions of Evil from Antiquity to Primitive Christianity* [Ithaca, NY: Cornell University, 1977], 3, 52, 252).

[31]Black, *Models and Metaphors*, 219–39.

[32]Barbour, *Myths, Models and Paradigms,* 30.

[33]The classic example being light as both particle and wave (Ibid., 75–7).

[34]Jack Cohen and Ian Stewart, *The Collapse of Chaos: Discovering Simplicity in a Complex World* (New York: Penguin Books, 1994), 19.

[35]Quantum physics points out that certain aspects of the universe (primarily the very small and the very large) function in terms of probabilities and uncertainty. The position and velocity of subatomic particles cannot be known simultaneously; they spin in a superimposed state with a 50% chance of being either up or down (the Heisenberg Uncertainty Principle), and the act of measurement affects the system. There are multiple potential interactions between subatomic particles and the forces between them. Nature is inherently random and unpredictable. See Cohen and Stewart, *Collapse of Chaos,* 44–45, 266; Peter Coles, *From Cosmos to Chaos: The Science of Unpredictability* (Oxford: Oxford University Press, 2006), 121–135; Dan Hooper, *Dark Cosmos: In Search of Our Universe's Missing Mass and Energy* (New York: HarperCollins, 2007), 43–58.

[36]Wolfhart Pannenberg, *Systematic Theology*, trans. Geoffrey W. Bromiley (Grand Rapids, MI: Eerdmans, 1994), 2:79–129. See also discussion and critique in Mark William Worthing, *God, Creation and Contemporary Physics* (Minneapolis, MN: Fortress Press, 1994), 117–23. Amos Yong also describes both the work of the Holy Spirit and evil spirits as force fields (*Discerning the Spirit(s): A Pentecostal-Charismatic Contribution to Christian Theology of Religions* [Sheffield: Sheffield Academic Press, 2000], 127). Neither elaborates on this idea.

[37]Robert John Russell, *Cosmology: From Alpha to Omega* (Minneapolis, MN: Fortress Press, 2008), 233; see also 226–41.

[38]Chaos-complexity theory evolved in diverse ways through different researchers and its origins can be traced to Henri Poincaré in the late nineteenth century. Some of the classic experiments include the pendulum (if there is just one, it obeys Newtonian laws, but if a second is attached, it exhibits chaotic behavior), dripping faucets (at first regular, then if the tap is opened more, irregular), and simple computations which diverge greatly if the decimal points are rounded off differently (calculators have different rules for rounding off). For a scientific textbook, see Massimo Cencini, Fabio Cecconi, and Angelo Vulpiani, *Chaos: From Simple Models to Complex Systems,* Series on Advances in Statistical Mechanics 17 (London: World Scientific Publishing, 2010); for lay-level accounts, see James Gleick, *Chaos: Making a New Science* (New York: Penguin Books, 1987); Cohen and Stewart, *The Collapse of Chaos;* Ian Stewart, *Does God Play Dice? The New Mathematics of Chaos,* 2nd ed. (New York: Penguin Books, 1997); John Gribbin, *Deep Simplicity* (New York: Random House, 2004); John Polkinghorne, *Exploring Reality* (New Haven, CT: Yale University, 2005), 7–37; Coles, *From Cosmos to Chaos*; Leonard Smith, *Chaos: A Very Short Introduction* (Oxford: Oxford University Press, 2007); Len Fisher, *The Perfect Swarm: The Science of Complexity in Everyday Life* (New York: Basic Books, 2009).

[39]Gribbin, *Deep Simplicity,* 255.

[40]Ibid., 143.

[41]The title of a paper Lorenz presented in 1972 was, "Does the flap of a butterfly's wing in Brazil set off a tornado in Texas?" Gribbin, *Deep Simplicity,* 60.

[42]Stewart, *Does God Play Dice?,* 368.

[43]Cohen and Stewart, *The Collapse of Chaos*, 23.

[44]A similar computer simulation describes three rules: avoidance (keep separate from each other), alignment (move in the average direction of the closest others), and

attraction (or cohesion, move toward the average position of those closest). Known as Reynolds's boids, Fisher, *The Perfect Swarm,* 26.

[45]For example, N. Katherine Hayles, ed., *Chaos and Order: Complex Dynamics in Literature and Science* (Chicago, IL: University of Chicago Press, 1991).

[46]For example, Stuart A. Kauffman, *Reinventing the Sacred* (New York: Basic Books, 2008), 3; Cohen and Stewart, *The Collapse of Chaos*, 221.

[47]Cohen and Stewart, *The Collapse of Chaos,* 246.

[48]Ibid., 400–1.

[49]Polkinghorne, *Exploring Reality*, 33.

[50]Stewart, *Does God Play Dice?,* 281.

[51]Ibid., 376.

[52]Smith, *Chaos,* 15, 154–7.

[53]John Polkinghorne, *Quarks, Chaos and Christianity,* 2nd ed. (New York: Crossroad Publishing, 2005), 89.

[54]John C. Polkinghorne, *Science and Providence: God's Interaction with the World*, 2nd ed. (Philadelphia, PA: Templeton Foundation, 2005), 52.

[55]Ibid., 62, 69–79; Polkinghorne, *Exploring Reality*, 136–46.

[56]Gregory A. Boyd, *Satan and the Problem of Evil* (Downers Grove, IL: IVP Academic, 2001), 151–8.

[57]Ibid., 218–9.

[58]Ibid., 282–4.

[59]Sjoerd L. Bonting, *Creation and Double Chaos: Science and Theology in Discussion* (Minneapolis, MN: Fortress Press, 2005), esp. 95–101.

[60]This is somewhat similar to Barth's claim that evil arises from chaos, except that Barth views chaos/nothingness as evil, not neutral.

[61]Nigel Goring Wright, *A Theology of the Dark Side: Putting the Power of Evil in Its Place* (Downers Grove, IL: IVP Academic, 2003), 116.

[62]Only named in Mark's (5:1–20) and Luke's (8:26–39) versions. The term is similar to "myriad" (Karel van der Toorn, Bob Becking, and Pieter van der Horst, eds., *Dictionary of Deities and Demons in the Bible* [Leiden: Brill, 1995], 507–8).

[63]The Old Testament seriously undermines and minimizes Ancient Near Eastern "gods": e.g., when the ark is captured, Dagon cannot survive in the presence of the Lord (1 Sam. 5:1–5); Elijah taunts his opposition, suggesting Baal is taking a trip or asleep (1 Kings 18:27); many "gods" are neutralized, e.g., the Canaanite god Yamm becomes the sea, Mot becomes death. Likewise, in the New Testament, compared with Greco-Roman culture, demons are not named and there are no elaborate exorcism rituals or prescription of amulets, also suggesting they are diminished in stature. See van der Toorn, Becking, and van der Horst, eds., *Dictionary of Deities and Demons.*

Environment

CARE OF CREATION: Christian Voices on God, Humanity, and the Environment by Joseph Coleson, ed. Indianapolis, IN: Wesleyan Publishing House, 2010. 203 pages. Paperback; $14.99. ISBN: 9780898274516.

This is the fifth book in the Wesleyan Theological Perspectives series, all edited by Joseph Coleson, professor of Old Testament at Nazarene Theological Seminary, Kansas City, MO. The eighteen authors, most on the faculties of Wesleyan academic institutions, met to plan their contributions, resulting in a coherent, unified presentation. An introduction by the editor summarizes its structure and the themes to follow.

Part 1, "Creation, Alienation, Redemption," has four chapters, each by a theologian. Referring to Genesis 1 as "a narrative so beautiful it often is called exalted or poetic prose," with "a series of three pairings" (days 1 & 4, 2 & 5, 3 & 6), Coleson himself expounds the biblical account of the creation of humanity and the mandate for care and stewardship. Next, other writers continue with discussions of sin and then redemption. The effects of human sin are characterized as "de-creation," described not only in Genesis but also in the rest of the Pentateuch and in prophetic and apocalyptic scripture passages. The chapter on redemption begins with a warning against the Gnostic idea that the life to come will be only spiritual, without the material basis that Christian belief in the physical resurrection of the body affirms; it continues with citations from the New Testament and from Wesley's writings looking forward to the perfection of the new creation. Part 1 closes with biblical reasons why Christians must care for God's creation, but we can only do this rightly if "we obey his call to separate ourselves absolutely to him."

Part 2, "Care for Humanity," comprises three chapters, the first two coauthored by a theologian and a scientist. Ethical challenges of genetic engineering include genetically modified food, on which "we must move cautiously, seeking to do the least amount of harm while effecting the greatest good," as well as frozen embryos, each of which represents a human life. The chapter "Choices between Life and Death" explains why abortion and euthanasia are wrong, with information on their legal status in the United States and the position of the Wesleyan church, in the light of scriptural teaching on how "each human being, no matter the stage of development, bears God's image" and on reliance on God's strength to endure suffering. Jo Anne Lyon, a general superintendent of the Wesleyan church, contributed the final chapter in Part 2, "Living by the Golden Rule," which focuses on crimes against women and children around the world, especially human trafficking, and "environmental disaster as violence against the poor"; our response must include both prayer and practical action.

Part 3, "Care of the Environment," has four chapters that continue to unite biblical themes and science, by theologian-scientist teams. Contributors include ASA members Richard Daake and Martin LaBar. Conservation of land, water, and natural resources requires an end to waste and respect for God's creation. Animals we raise as pets or for food must have humane treatment, which modern industrialized agriculture may not provide; eating less meat is a Christian option. The concern God has for every creature motivates Christians to preserve endangered species and habitats; obstacles to this are "the recent rapid increase in human population, giving world-wide impetus to habitat destruction," and also global warming. Part 3 ends with a fifth chapter, "A Call to Action" by Matthew and Nancy Sleeth, founders of the Christian organization Blessed Earth. They describe their conversion experiences and use the parable of the Good Samaritan to encourage Christians to put the ways for conserving water, energy, and materials into practice, using savings to advance God's kingdom.

While not comprehensive, *Care of Creation* contains accurate information on the topics it discusses. Although it avoids any mention of evolution as the process through which life and humanity came into being, it does direct the reader to Francis S. Collins, *The Language of God*: "If you have wondered whether science and Christian faith are compatible, this book is for you." The reference for a definition of "species" is Ernst Mayr, *Populations, Species and Evolution*. Each chapter of *Care of Creation* has "Suggestions for reflection and action," which make it particularly suitable as a resource for study groups; "For further reading" follows, listing several books with a brief comment on each. Wesleyans will especially value the emphasis on John Wesley's writings and sermons, and on the distinctives of the Wesleyan church. ASA members will appreciate this book as a brief account of reasons why Christians should care for humanity and the environment, with the use of scripture in every chapter as a real strength.

Reviewed by Charles E. Chaffey, Natural Science, Tyndale University College and Seminary, Toronto, ON M2M 4B3.

General Sciences

THE FALLACY OF FINE-TUNING: Why the Universe Is Not Designed for Us by Victor J. Stenger. Amherst, NY: Prometheus Books, 2011. 341 pages. Hardcover; $90.00. ISBN: 9781616144432.

Victor Stenger is an intelligent person, so I am puzzled why he wrote a book with so many logical fallacies. Either he is trying to mislead the reader through dishonesty or else he is badly mistaken himself. Taking his book at face value, he does not even know how to define the fine-tuning of our universe, which is the anthropic principle. The correct brief definition is that many of the universal constants of our universe have just the right values to allow atoms, stars, planets, and eventually life to exist. It does not pertain to the fine-tuning of limited things in our universe, such as our earth, which could also be fine-tuned. It is the fine-tuning of our universe as a whole which points most strongly to the existence of a Creator God. Beginning in the preface, he immediately misleads the reader on this point by talking about the unique events in the lives of his grandparents and parents that led him to be born. By treating this as an analogy to the fine-tuning of the universe, he discounts fine-tuning as evidence for a Creator, attributing it all to chance.

His worst atrocity is seen in the way in which he discounts the fine-tuning of the fundamental constants of our universe. In section 3.3, titled "Space, Time, and Reality," his first sentence is, "Most people, including most physicists, believe that models and laws of physics directly describe reality." He then goes about discounting this belief. Later in this section, he says, "Now, none of this should be interpreted as meaning that physics is not to be taken seriously. When I say physical models are human inventions, I mean the same as if I were saying that the human camera is a human invention." This is a precursor to his illogical treatment of the fundamental constants of nature, which he prefers to call "parameters." To lead the reader into his argument, he states, "But if they are human inventions then they need special attention of a human to come out 'just right.'"

Next, he explains that the speed of light, c, along with time measurements, is used to define the unit length of a meter. A meter is defined as the distance light travels in 1/299,792,458 seconds, which fixes c to the value 299,792,458 m/s. Thereby, he concludes, "The quantity c cannot be fine-tuned. It is fixed by definition." He then discusses Newton's constant, G, and Planck's constant, h, and concludes, "The values of G, like c and h, depends on the system of units being used and likewise is not a universal constant." Here, of course, he is inverting the dependence. It is not the fundamental constants depending upon the units but rather the units depending upon the values of the fundamental constants. Scientists chose this definition of a meter in terms of c because it gives them a more precise unit of length, recognizing that elapsed time can be measured much more accurately than spatial length. Within this section, he makes other misleading statements. The relative strengths of the fundamental forces of nature are fine-tuned, and Stenger points out that they "are not even constant in our universe, but depend on the energies of the particles interacting with one another," thereby discounting their importance. In reality, this energy dependence of the forces would only universally come into play when the universe was a fraction of a second old. The strengths of the fundamental forces are essentially constant during the formation of atoms, stars, planets, and eventually life. Rather than discounting the fine-tuning of these constants, we should actually add additional constants, which may also be fine-tuned, describing the forces during the first second of the universe's history.

Later in the book, there are three primary approaches Stenger takes to try to discount the fine-tuning of the fundamental constants of nature. He argues that it is coarse-tuning, rather than fine-tuning, and that their actual values can be varied by large amounts and still allow an interesting universe. Secondly, he argues that there are many fewer fundamental constants than claimed which significantly affect the properties of the universe. Thirdly, he argues that the fundamental constants are not all independent and that either their relative values can be explained or else the adverse effect of changing one of the parameters can be corrected by adjusting other parameters. He is very wrong on all of these points.

On page 90, Stenger mentions the twenty-six constants of the standard model of elementary particle physics, but fails to acknowledge that there is no theoretical connection between any of their values, and that, therefore, they must be treated as all being independent. About ten years ago, I heard a particle physicist give a talk at Fermi National Accelerator Laboratory on the fine-tuning of these constants. He marveled at the fact that slight changes in the values of any of them would make our universe uninteresting—without atoms, stars, etc. At no time did he use the term anthropic principle, raise the question of a Creator, or give any indication of what his religious beliefs are.

Let us consider one of the constants, the strength of the strong interaction. Its value could not change by even one percent up or down without having catastrophic consequences for our universe. Because of its fine-tuning, some deuterium, helium, and lithium can form quickly, early in the Big Bang expansion of our universe, leaving mostly hydrogen, which is necessary for stars. The strength of this force helps dictate the fusion rate of hydrogen in making heavier elements in stars, allowing stars to use this process for billions of years before dying. It explains such things as the production and abundance of carbon and oxygen and other essential elements. Stenger talks about deuterium, carbon, and oxygen abundance, but he does not talk coherently about them together. By looking at one specific feature of our universe, Stenger can argue for coarse-tuning or even interdependence of the constants. Looking at one narrow property of our universe, it may be possible to correct for the adverse change in this property, which was caused by a change in one constant, by modifying other constants. Such an attempt will adversely affect other features of the universe, making this type of compensation between constants impossible.[1]

In 1951, physicists were puzzled as to why carbon could form in stars, but not in the Big Bang. Fred Hoyle predicted that there must be a resonance in carbon, based upon the strong interaction, to allow carbon to form in stars. Shortly thereafter, the resonance was discovered. Since this is an example of fine-tuning, it is claimed that Hoyle's prediction is a successful prediction of the anthropic principle. Stenger makes a big issue that further study of the strong force could have predicted such a resonance, thereby discounting this so-called "anthropic prediction." Stenger includes a lot of physics theory in his book in a way which clouds the real issues about fine-tuning. He goes off on tangents such as his deity debates with William Lane Craig, discounting the origin of the universe as a "First Cause" or "Something from Nothing." He brings up the issue of multiverse theory. One of my biggest complaints about this book is that the reader will not get a good idea of the claimed breadth and strength of the fine-tuning argument. Although Stenger gives references to many publications describing the anthropic principle, these are not a substitute for his deficient description.

Note

[1]Wheaton College's physics department has introduced several weeks of quantum mechanics in its first-year physics course for majors. The last lab in this course is a study of the fine-tuning of the strong force. The lab approximates the strong force in nuclei by a square well potential and studies much of the fine-tuning of this force on the properties of our universe. Contact the physics department to get a copy of this lab.

Reviewed by William R. Wharton, Professor Emeritus of Wheaton College; currently living in Boulder, CO 80305.

WHY GEOLOGY MATTERS: Decoding the Past, Anticipating the Future by Doug Macdougall. Berkeley, CA: University of California Press, 2011. xv + 285 pages. Hardcover; $29.95. ISBN: 9780520266421.

Every budding geology student early learns the maxim that the present is the key to the past. Doug Macdougall, professor emeritus of earth sciences at Scripps Institution of Oceanography, would certainly concur with that adage. He has written *Why Geology Matters* in part because of a "desire to share some of the excitement about what geoscientists have learned about our amazing planet in recent decades" (p. xiv); much of what we have learned does indeed concern the geologic past. The primary thrust of Macdougall's book, however, is that *the geologic past is also a key to the geologic future*. As he sees things, the Earth sciences hold "the keys to understanding and addressing many of the most pressing problems facing society" (p. 250).

Macdougall exudes great enthusiasm about what geoscientists have learned in a dozen lucid, vivid, informative summaries of significant episodes of Earth history and of some major geological phenomena. His synopses, introduced by a survey of the development of methods for deciphering Earth's past, include discussions on the origin of Earth, impact events, Earth's first two billion years, plate tectonics, earthquakes, construction of supercontinents, glaciation and ice ages, the Paleocene-Eocene Thermal Maximum, large igneous provinces, extreme volcanic eruptions, and mass extinctions. The sketches serve as gateways to consideration of some major contemporary societal concerns. What is the likelihood of sizeable extraterrestrial objects colliding with Earth? Is global climate warming, cooling, or fundamentally stable? What are the risks of global warming? How serious is oceanic and atmospheric acidification and how does it impact life forms? What is the status of earthquake prediction? Must we be fearful of a cataclysmic volcanic eruption in Yellowstone? And how widespread will biotic extinctions become? Macdougall concludes with an assessment of the future in relation to water, energy, and mineral resources as well as global climate change.

To give the reader just a taste, I offer summaries of two chapters. In chapter 3 "Close Encounters," Macdougall weaves a compelling narrative around Arizona's Meteor (Barringer) Crater, the 1908 Tunguska explosion over Siberia, and especially the great impact event believed to have triggered the demise of the last dinosaurs as well as hundreds of other organisms that brought the Cretaceous Period to a close. In piecing together a picture of past impact events, geoscientists have incorporated a host of data and theory drawn from diverse fields. From geology Macdougall brings in impact ejecta blankets, shatter cones, shock-induced high-pressure minerals, fossil meteorites in Sweden, and the "smoking gun" of the end-Cretaceous impact, Chicxulub crater, now buried beneath sediments of the Yucatan Peninsula of Mexico. Terrestrial impact sites are linked to their sources in the asteroid belt by comparison of distinctive chemical signatures at those sites with chemical compositions of specific asteroid families. Physics enters by way of shock-induced phenomena at impact sites, and solar system astronomy makes its contribution through computer simulations of asteroid collision histories and calculation of subsequent trajectories of collision fragments. Large impact events exerted profound effects on the biosphere through disruption of the food chain, resulting in extinctions. Paleoclimatology considers cooling effects in the atmosphere resulting from impact-generated dust and subsequent atmospheric heating effects created by large inputs of greenhouse gases from impact melting of limestone and smoke produced by incinerated vegetation. After painting a rather frightening picture of what may plausibly have happened during and after the end-Cretaceous impact, Macdougall poses the question of the likelihood of future collisions of large bodies with Earth in the light of our current knowledge of positions and paths of extraterrestrial objects and of the current frequency of entry of objects of various sizes.

Chapter 8 "Cold Times" summarizes our knowledge about the Pleistocene Ice Age in the light of the following: geochemical and sedimentological clues in deep-sea sediments; plate-tectonic driven reconfiguration of continents and associated oceanic circulation patterns; alteration of precipitation patterns and albedo; distribution of glacial deposits; the periodicities of precession of the equinoxes, obliquity of Earth's rotational axis, and eccentricity of Earth's orbit; changes in solar insolation; variation in seawater paleo-temperatures determined from oxygen isotope ratios of fossil shells and glacial ice; and concentrations of atmospheric greenhouse gases preserved in ice-trapped bubbles. Macdougall points out that we can now more effectively assess how the climate system might respond to future perturbations based on insights into its operation during the Pleistocene Ice Age.

Both chapters, as do the others, illustrate the interdisciplinary nature of the Earth sciences. Indeed, Macdougall is convinced that a "*holistic* [my emphasis] view of our planet is important for fully understanding the workings of the Earth today, for deciding its history, and also for using that knowledge to predict the future" (p. 250). As every geologist knows, geology "is perhaps the most truly interdisciplinary of all the sciences" (p. 249). Indeed, the broadly interdisciplinary character inherent to the geosciences is a major source of the appeal that geology/Earth science has for its practitioners. If anything, the interdisciplinary character of geology needs even greater emphasis for future students.

Macdougall's book amounts to an implicit (and occasionally explicit, see p. xiii) wake-up call for a much larger place for geoscience education. After reading his book, I was confirmed in my unflinching bias that policy makers, politicians, the general public, and, yes, scientists all need far more exposure to the Earth sciences if we are to address and mitigate successfully the global resource, natural hazard, ecological, and climate change issues that confront us.

As a Christian, I make bold to apply Macdougall's concerns more specifically to the Christian community by insisting that all Christian high school and Christian college students need to acquire substantial knowledge about the structure, composition, behavior, and history of their God-given home, planet Earth. The current situation, in which the geosciences are totally ignored, or woefully underemphasized, or grossly distorted in Christian high schools and Christian liberal arts colleges, is inexcusable and must radically improve. *Why Geology Matters* should be mandatory reading for all scientists, politicians, pastors, theologians, school board members, and academic administrators, especially those in Christian educational institutions.

Reviewed by Davis A. Young, Tucson, AZ 85737.

Health & Medicine

HUMANITY'S END: Why We Should Reject Radical Enhancement by Nicholas Agar. Cambridge, MA: The MIT Press, 2010. 215 pages. Hardcover; $32.00. ISBN: 978-0262014625.

Nicholas Agar advocates some enhancements to human beings toward peak levels that already exist among us. That is clear in his 2004 book, *Liberal Eugenics: In Defence of Human Enhancement*. However, he is against *radical* enhancement of athletic prowess beyond our current top sprinters, of intellect beyond Einstein, and length of life beyond the current record of 122 years. He sees changes of such magnitude producing eventually a new species that would leave behind much that is good about human existence. Agar unfolds his argument in engagement with four transhumanists who cheerfully call for the radical enhancement he rejects.

The first is Ray Kurzweil who looks forward to the law of accelerating returns, eventually triggering a surge in superintelligence and semi-immortality. In reply, Agar is concerned that such artificial intelligence will lose characteristics and moral commitments that are unique to *human* intelligence. Indeed, radically enhanced intelligence may become smart enough to work around any safeguards that humans program in, such as not to harm humans.

The second proponent addressed is gerontologist Aubrey de Grey. He hopes to extend the human life span. Agar thinks that success in that endeavor would shift our values harmfully toward being even more self-centered and limit our experiences to those safe enough for human beings expecting extremely long lives. There would be so much more to lose if life spans were indefinite.

The work of the philosopher Nick Bostrom is the third focus. Agar says that Bostrom is so focused on the advantages of proposed changes that he does not take into account their attendant harms.

The fourth transhumanist is the sociologist James Hughes. Hughes projects that superior beings would affirm "democratic transhumanism" that would protect all persons from exploitation whether they are human, transhuman, or other. Agar replies that if a new species is established and practices the social contract or consequentialist moralities that dominate society today, then that new species would likely persecute or even enslave those left of the human species. He sees how human beings currently treat the apes as a cautionary example. Therefore, it is in our interest as human beings to make sure that no such new species arises.

Critiquing Agar's critique, much of his concern keeps coming back to species differentiation. That is a distant threat. It is the nature of genetics to disperse and recombine traits. What is advantageous spreads throughout a population. Human beings separating into exclusive species is an unlikely occurrence unless whole populations are isolated from each other, say on different planets, or centers of consciousness are transferred to nonbiological systems that bypass the interrelatedness characteristic of genetics. Such contexts are conceivable, but far from present challenges.

If major differences somehow do start to develop, the response of limiting the abilities of others as a kind of self-defense is a devastating strategy. Would we really want a society where no one could be more healthy, athletic, thoughtful, self-disciplined, or have any other skill or attribute superior to others, lest that skill be turned against another?

Further, cumulative changes in our species would not necessarily make us less human than humanity is intended to be. Human beings have changed dramatically in even the last few thousand years. Are those of us growing taller or living longer less human? Whether looking at an evolutionary time scale or only recorded human history, it is characteristic of humans to change. That is not foreign to the Christian tradition. For example, 1 Corinthians 15 promises that there is dramatic change ahead for the members of God's kingdom. God's plan for his people is that they will someday continue in a new form. The perishable will not inherit the imperishable, for we shall all be changed. As well, the resurrection of Jesus as the first-born of the new creation into a strikingly new and capable body is not described as a travesty of the created order, but rather as its fulfillment. Substantial change of itself does not necessarily move us away from being human.

Humanity's End is thorough and precise for the philosophically inclined, yet well illustrated and accessible to any college-educated reader. I recommend it as a thoughtful contribution to a formative discussion.

Reviewed by James C. Peterson, Schumann Professor of Christian Ethics and Director of the Center for Religion and Society, Roanoke College, Salem, VA 24153.

SPIRITUAL HEALING: Scientific and Religious Perspectives by Fraser Watts, ed. New York: Cambridge University Press, 2011. 207 pages. Hardcover; $87.75. ISBN: 9780521197939.

This book is a collection of essays from theologians, anthropologists, and psychologists regarding the topic of spiritual healing. Sick patients will be influenced by various aspects during their medical care—physicians, nurses, medical technology, and pharmaceuticals. A patient's spiritual insight may play a role in influencing the healing process, and the authors of the various essays in this book attempt to address this important aspect.

It should be noted that this book is not objective on spiritual healing, but instead it provides an overview from writers who find this feature of health practice potentially beneficial. The first chapter provides an overview of spiritual healing. At the onset of this book, this particular author states that "science is gradually becoming increasingly emancipated in its ontology and the range of processes it is prepared to accept … there will be less and less reason for regarding exceptional phenomena as outside the laws of nature." In other words, the author claims that spiritual healing should be considered a scientific process that has a spiritual basis. I find it difficult to believe that most US medical schools would follow this claim.

Chapter 2 deals with the healing miracles of Jesus, and it is quite well written and helpful. The author explores the various ways critics have tried to explain away healings performed by Jesus (psychosomatic, psychological, etc.). This chapter provides wonderful apologetics material for a Christian.

Chapter 3 evaluates the way the church has regarded spiritual healing in its development through the centuries, while chapter 4 discusses mystical Judaism and its influence on spiritual healing in that specific religious community. Again, these two chapters are very well done and helpful for those needing further insight into spirituality and healing in Christianity and Judaism.

After these chapters, the book goes into great detail about various aspects of spiritual healing. Chapter 5 compares Christian versus secular spiritual healing. This chapter is fascinating in that it explains how some proponents of spiritual healing would divide their belief system into "Type 1" (described as intense caring about the subject) and "Type 2" (described as using a healing energy). Chapters 6 and 7 evaluate the psychodynamics and biopsychosocial aspects of spiritual healing. The authors argue that illness allows us to know ourselves better and to reconnect with our self-healing processes. It is true that having a chronic disease can make someone be introspective; however, the book uses phrases such as "strengthening the immune system" and "detoxify" as a side effect of spiritual healing without giving a scientific explanation.

The remainder of the book (three chapters) looks at spirituality and its effect on disease. Here is where the book becomes much more biased. One author claims that US physicians are using spiritual healing and prayer commonly as a standard of care by citing a study in which 13% of California physicians use prayer or religious healing (while not commenting that 87% do not!). This same author reports on the positive effect of distant healing intention (DHI), which is characterized as the mediation by a practitioner on another person's disease using meditation at a distance. Although studies have been done that suggest that DHI may enhance healing, these studies do not address confounding variables between patient groups (for example, smoking, alcohol use, family history of disease). Systematic reviews of DHI have been difficult to perform due to poor methodology in many of these studies.[1] None of these negative aspects are discussed in the book. Additionally, the authors state that spiritual healing works, based on "anecdotal reports of spiritual healing that can be found in many traditions." Although it may be subjectively true that we have all heard stories of people who have been healed through the power of prayer, such anecdotal reports fall well below established quality of evidence as outlined by the US Preventive Services Task Force.

In the end, this book's overall theme is that spiritual healing works and should be utilized in the armamentarium of the health-care provider. It may indeed work; however, the book does not provide adequate evidence for its use. There is a national debate as to whether this type of care, including all aspects of complementary-alternative medicine (CAM), can be or should be studied. Indeed, concern has been expressed as to whether federal funding should be provided for any type of CAM research, as the quality of research can be quite poor.[2] Finally, CAM, including spiritual healing practitioners, may be participating in nothing more than a useful placebo effect.[3]

This book is helpful if a reader is looking for an explanation and overview from those who believe in spiritual healing effectiveness as an adjunct in medical care. Again, some of the chapters (such as the chapter discussing healings by Jesus) are quite good. However, there is no real discussion about the lack of good medical studies regarding this type of CAM. In this aspect, the book is subjective, not objective, and provides only a limited and one-sided exposure of this subject.

Notes

[1]J. Astin, E. Harkness, and E. Ernst, "The Efficacy of 'Distant Healing': A Systematic Review of Randomized Trials," *Annals of Internal Medicine* 132 (2000): 903–10.

[2]D. Brown, "Critics Object to 'Pseudoscience' Center," *The Washington Post*, March 17, 2009 (www.washingtonpost.com/wp-dyn/content/article/2009/03/16/AR2009031602139.html).

[3]"Think Yourself Better: Alternative Medical Treatments Rarely Work. But the Placebo Effect They Induce Sometimes Does," *The Economist*, May 19, 2011 (www.economist.com/node/18710090).

Reviewed by John F. Pohl, Associate Professor of Pediatrics, Department of Pediatric Gastroenterology, Primary Children's Medical Center, University of Utah, Salt Lake City, UT 84113-1103.

History of Science

QUANTUM LEAP: How John Polkinghorne Found God in Science and Religion by Dean Nelson and Karl Giberson. Oxford, UK: Lion Monarch, 2011. 192 pages. Paperback; $14.99. ISBN: 9780745954011.

Readers of this journal will need no introduction to John Polkinghorne. He is the author of over thirty books on science and faith, including an autobiography; so it was with some surprise that I discovered this new biography. This, however, is no traditional biography. Nelson and Giberson attempt to "tell the *story* of Polkinghorne, and along the way … unfold some bigger issues" (p. 7).

We are presented with the life of Polkinghorne, from his birth in 1930, the death of his brother during World War II, his education at Trinity College, Cambridge, his career in particle physics, through the ordination process in the Anglican Church, to parish life in Kent, and back to academia in Cambridge. In between this, we are introduced to many of the key ideas of Polkinghorne. These include the relationship of science and faith, the nature of reality, the resurrection of Jesus, the role of prayer, miracles, the problem of suffering and pain, and life after death.

As I read, I kept getting a sense of *déjà vu*. There is little or no new material here, but what we have is a well-constructed summary of Polkinghorne's books interspersed with biographical details. Interviews have been conducted with Polkinghorne of which we have a few extracts, but the majority is material gleaned and edited from Polkinghorne's writings. This is a strength of the book; it provides a good introduction to Polkinghorne. It is also its weakness as it provides no new information or insight.

Unfortunately, there is a tendency toward the hagiographic—very little or no criticism of Polkinghorne is presented. This is a shame as some of Polkinghorne's views will be controversial to many Christians, particularly his view of post-mortem salvation. The strength of this approach is that the authors let Polkinghorne "speak" for himself; the weakness is that we are left wondering what Nelson and Giberson's views are.

At times, what is presented here is a rationalistic, almost evidentialistic, view of Polkinghorne. This is even suggested by the book's subtitle, "How John Polkinghorne Found God in Science and Religion." It seems to imply that we find God, rather than that he finds us: "it's the evidence that leads a physicist to believe in the equations, and it's the evidence that leads a person of faith to believe in God" (p. 183).

This well-written book will provide an *amuse-bouche* or a taster into the life and work of Polkinghorne. It is strong on description but weak on evaluation. The book is not aimed at readers of this journal who have thought through issues of the integration of science and faith; rather, it is aimed at those who think that being a Christian and a scientist involves "intellectual suicide," or is as logical as being a "vegetarian butcher" to use Polkinghorne's phrase. There are five pages of endnotes, but no index and no list of Polkinghorne's books.

For those who want to know more about Polkinghorne's life, I suggest obtaining a copy of his autobiography *From Physicist to Priest*. For more on his view of the interaction of science and faith, a good first place is his *Quarks, Chaos and Christianity* and then his *Reason and Reality*.

Reviewed by Steve Bishop, City of Bristol College, Bristol, BS16 4RL, UK.

Mathematics

MATHEMATICS THROUGH THE EYES OF FAITH by James Bradley and Russell Howell. New York: HarperOne, 2011. viii + 288 pages, with index. Paperback; $19.99. ISBN: 9780062024473.

Do mathematical concepts point beyond themselves to a higher reality? Can the idea of chance be reconciled with God's sovereignty? How do we account for mathematics being so effective in describing the world? How does giving people the capacity to do mathematics fit into God's purposes for humanity?

These are just a few of the questions tackled by the latest installment in the series Through the Eyes of Faith. This is the second collaborative work produced by the Association of Christians in the Mathematical Sciences. The first work, *Mathematics in a Postmodern Age: A Christian Perspective* (Eerdmans, 2001), is primarily a collection of scholarly articles, some of which require prior knowledge in higher mathematics or philosophy for full understanding. This recent project was undertaken with the goal of making the relationship between mathematics and Christian belief a more accessible topic. The authors have thoroughly succeeded in this task.

Chapter one is presented as hypothetical dialogue between four students in an introductory math class at a Christian college, each with varying degrees of mathematical ability and interest. Their conversation centers around the seemingly innocuous (to some) question: Could God have made a world in which $2 + 2 \neq 4$? The conversation begins at a basic level that one might expect for people with no experience in studying the relationship between mathematics and Christian faith. But then the conversation builds, through the art of skillful questioning, toward considering some of the deep and complex issues that are present in this relationship, several of which are stated above. The conversation also serves as a microcosm for the methodology of the book as a whole: pushing its audience beyond surface level questions to deep and meaningful contemplations.

Chapter two provides a brief historical context for thinking about these questions. The authors trace the relationship between mathematics and belief (be it purely philosophical or explicitly theological) from ancient Greece to modern times. Here the authors demonstrate that mathematics and faith have long been associated, as our mathematical knowledge influences our response to life's purpose in several respects: how we see our place in the universe, how we organize our understanding, and how we live our daily lives. Not until the Enlightenment did the theological significance of mathematics come to be largely ignored. But for us today, from a distinctly Christian perspective, "We have been given the opportunity to investigate God's good creation, and this understanding motivates our study of mathematics, which has at least a two-pronged purpose: to enable us to be more effective stewards of creation, and to give glory to God" (p. 240).

The rest of the book addresses various themes in mathematics and how they relate to Christian belief. These include specific mathematical topics (infinity, dimension, chance), broad mathematical characteristics (proof, beauty, effectiveness), and philosophical issues (epistemology, ontology). The book closes with an apology (in the classical sense) for mathematics as a meaningful Christian vocation.

Each chapter contains sidebars describing historical figures and noteworthy events. This helps put a face on a topic that can tend toward the abstract. Scriptural references are used often, but appropriately. The authors do not overstep their bounds by stretching the meaning of a passage too far to accommodate their topic. Each chapter closes with suggestions for further reading on the particular topic as well as numbered exercises, making this book immensely practical for a mathematics course at the undergraduate level (or simply as a stimulating activity for the casual reader). The exercises range from mathematical proofs to personal and philosophical reflections. This blend of activities serves to further emphasize the authors' message that mathematics need not be so far removed from personal application and theological convictions.

Stemming from the first piece of quoted scripture, Colossians 1:16–17, and the influence of Augustine, a running theme throughout the book is that we do not rightly understand anything until we understand its connection with Jesus Christ. "How we know something in mathematics is similar to investigating the grounds of any belief system. Were they to linger on this topic, the Christian students would realize that the philosophy of mathematics and Christian faith share a number of interesting touch points. Indeed all things exist and have their being through Christ, including mathematical objects" (p. 217).

Above, I stated that the authors have succeeded in making the relationship between mathematics and Christian belief a more accessible topic. Their success lies not in providing answers to all the questions of this complex topic, but in posing thought-provoking questions and constructing a framework of orthodox Christian belief in which the reader can pursue their own answers, or simply linger on a topic.

I strongly encourage any teacher of mathematics at a Christian institution to find creative ways to integrate this book into their curriculum; at the very least it should be required reading.

Reviewed by Joshua B. Wilkerson, administrator of www.GodandMath.com; math teacher, Navasota High School, Navasota, TX 77868; graduate student in mathematics, Texas A&M University, College Station, TX 77843.

ORIGINS & COSMOLOGY

A REASONABLE GOD: Ordinary Action in a Supernatural World by Arnie Berg. HYTEC Press (htttp://www.hytecpress.com), 2011. 238 pages, index. Paperback; $22.96. Kindle; $9.99. ISBN: 9780986801006.

A Reasonable God is an examination of intelligent design (ID). The author's stated purpose is "… to examine the scientific enterprise as it is related to a Christian worldview." Berg finds ID to be deficient both scientifically and theologically, but considers the evidence for biological diversity through natural evolutionary processes convincing. He concludes that a Christian worldview can allow for the creation of the diversity of life through ordinary natural processes while still acknowledging a supernatural purpose.

Berg, a computer scientist and consultant, begins with an introduction to the nature and practice of science, current theories of cosmology and biological diversity, and brief historical surveys of young-earth creationism and the more recent ID movement. He presents propositions advanced by ID proponents followed by critical responses from both nontheistic and theistic dissenters. A section on evidence for common descent as the explanation for the currently observed biodiversity is given as an alternative to the propositions of ID. A brief assessment of the surveyed material then leads to the author's aforementioned conclusions.

Berg defines ID as "a belief system that reacts against an increasingly secular worldview that posits ultimate natural causation for all events." He maintains the ID movement is an attempt to defend theism by questioning the scientific adequacy of the neo-Darwinian model of biological evolution. ID proponents consider the Darwinian model to be a result of, and a path toward, "naturalism" and "scientific materialism," which are perceived as threats to theism. Berg initially offers support for his description of ID by surveying themes associated with the Discovery Institute and the film *Expelled* by Ben Stein. He continues with a review of well-known ID authors such as Phillip Johnson, William Dembski, Michael Behe, and Stephen Meyer. Some of the recent court cases involving the teaching of ID in public schools are also briefly addressed.

Berg continues his discussion of ID by examining critical responses by nontheists, such as Michael Ruse and Mark Perakh, and a number of theists. Scientific concepts such as "irreducible complexity" and the inclusion of supernatural causation within natural science are criticized. The question of "bad" or "nonoptimal" design is also proposed by critics as a means of falsifying the testable portions of ID theory. Theists echo the scientific critique of the nontheists and offer additional reflection on the theological implications of ID. Some of the theists considered are Alister McGrath, John Polkinghorne, Denis Lamoureux, John Walton, John Haught, Francis Collins, and Nancey Murphy. The theological concerns expressed about ID range from comparisons with young-earth creationism to a god-of-the-gaps approach. The implications of ID for thinking of God as an illusionist and as a source of natural evil involving illness, disease, and repulsive natural behaviors within the animal world are also addressed. Berg concludes this section by stating: "… Intelligent Design is now a fringe activity with little credibility in the mainstream scientific community."

After having offered a negative critique of ID, Berg proceeds to provide supportive arguments for neo-Darwinian evolution. In this section, which addresses biodiversity and common ancestry, Berg surveys many areas of study: morphology, paleontology, biogeography, embryology, genetics, and sub-optimal design. He provides an introduction to each field of study, and then he discusses how common descent offers a better explanation than common design.

The book specifically focuses on the origin of species and limits discussion to a comparison of common design, as proposed by the ID model, with common descent, as proposed by the neo-Darwinian model. To survey this topic within a few hundred pages is indeed challenging. The result is a book which reads with the dry tone of a master's thesis. Despite this tone, the book does make progress in reaching its stated objective.

The book is recommended for anyone interested in comparing the models of ID and Darwinian evolution.

The reading level is that of post-secondary undergraduate and graduate students engaged in science studies at colleges and universities. Well-read science professors, philosophers, and theologians will also find new material in this book to catalyze their thoughtful engagement with evolutionary science.

Reviewed by Gary De Boer, Professor of Chemistry, LeTourneau University, Longview, TX 75607-7001.

CREATION AND EVOLUTION by Lenn E. Goodman. New York: Routledge, 2010. 222 pages. Paperback; $39.95. ISBN: 9780415913812.

In his brilliant work, *Creation and Evolution*, Lenn E. Goodman, professor of philosophy at Vanderbilt University, presents a sustained argument for theistic evolution. By "evolution" he means, as Darwin meant, the development of life through small, gradual changes from inert matter to a cell that reproduces itself, to life in its manifold species. By "theistic" he means that the transcendent God of Genesis worked *through* nature, not *upon* nature, to energize the process. Goodman's aim is irenic: to show that evolution and religion are complementary.

Goodman develops his argument through five chapters. In chapter 1, "Backgrounds," Goodman traces the historic clash between evolution and religion. Here and throughout the book, Goodman converses easily with ancient Greek philosophers, Jewish thinkers, and Muslim and Western philosophers. On the one hand, he faults theologians such as Charles Hodge for equating evolution with atheism, and polemicists such as Henry Morris and William Dembski for appealing to probability, "finding the odds just too high for life to have emerged by chance." On the other hand, he faults Daniel Dennett, Richard Dawkins, and others "who idealize a world without God, where only mechanism is an explanation, and natural science is the sole source of value" (p. 35). Goodman argues in contrast that humans seek an ultimate cause and that such a quest leads to a transcendent Author. But he cautions, "We defeat our purpose if we make the ultimate just another object to explain" (p. 38). For Goodman, dynamic nature is the epiphany of God.

Goodman fails, however, to make a convincing case against Morris and Dembski. He accuses Morris of dressing the argument "in flashy scientific colors," but this *ad hominem* does not address the substance of Morris's argument that the DNA code for one enzyme would need some 1,000 nucleotides of four bases each, yielding 10^{600} possible combinations, an "impossible" probability. Moreover, Dembski's argument, that complexity and specification (i.e., yielding a match to a known reality) point to intelligent design, is not refuted by saying that the Krebs cycle "*probably* (italics mine) arose from existing constituents." Goodman notes that "John Sutherland, Matthew Powner, and Beatrice Gerland of the University of Manchester have succeeded in provoking the spontaneous compounding of ribose, base, and phosphate molecules, yielding the nucleotide ribocytidine phosphate" (p. 32). But the devil is in the detail: they "provoked" it—that is to say, intelligent design was involved in the experiment. I wish *Signature in the Cell* by Stephen C. Meyer (2009), director of the Discovery Institute, had been published earlier so that Goodman could interact with Meyer's sustained argument for intelligent design. In any case, Goodman is convinced that "Darwinism in biology and creation in religious thought are here to stay" (p. 41).

In chapter 2, "Leaving Eden," he maximizes from ancient Jewish sources the opportunity to read Genesis in a way compatible with the book's thesis. In his reading, Genesis does not record "mere incidents" (p. 38). He cites with approval Leon Kass:

> Like every truly great story, it seeks to show us not what happened (once) but what always happens … its truth may lie not so much in its historical, or even philosophical veracity as in its effects on the soul of the reader. [Accordingly,] Adam is the type and figure of humanity. (p. 59)

There is truth and spiritual profit in such a reading, but again the devil is in the details: "mere" and "not so much." To be sure, for Goodman the creation story is not literary fiction, but he mostly neglects the historical facticity of Genesis.

This second chapter is the book's weakest. Jewish Midrash and ancient rabbinic comments are sometimes brilliantly insightful, but at other times they play with scripture, not engaging in the scholarly consensus that good exegesis is founded on the grammatico-historical method (i.e., determining philological issues in their historical context). Goodman handles the text similarly to rabbinic too-sharp exegesis. For example, commenting on "He [God] ceased [from his creative work] and was refreshed [Hebrew *va-yinaffash*]" (Exod. 31:17), Goodman asks, "How is that if God neither sleeps nor slumbers?" He answers, "Homilists, taking *va-yinaffash* transitively, as the causative form seems to invite, find a hint of God's breathing life and spirit into Adam's form" (p. 53). But as first-year Hebrew students learn, the form in question (*Niphal*) is a simple passive, not causative. In an otherwise excellent commentary on the Cain and Abel story, Goodman comments, "The figures are archetypal: a killer ducks responsibility. His victim need not be pure, regal or heroic. Even a simple shepherd's blood cries out to God …" But he then mars his work: "Thus the Mishnah, noting the poetic plural: 'It is written *the bloods of thy brother cry out* …' to teach us that whoever causes the death of a single soul is seen biblically as if he'd caused a world to perish." But grammarians classify the plural of "blood" as a plural of composition—like "spilled wheat" and "neck," both plural in Hebrew—denoting "bloodshed." In truth, this reviewer never heard of a "poetic plural." In any case, "bloods" (i.e., "bloodshed") is not a countable plural. A final example of an exegetical blunder: following Genesis Rabbah (23.5), Goodman glosses Gen. 4:25 by "*Adam knew his wife more* [Hebrew *'od*], taking *more* to mean more deeply." But *'od* expresses continuance (= yet, still), or addition by repetition (= still, yet, more), or a continuance limited by its nature to a single occurrence ("again," as in Gen. 4:25); it does not express a comparative sense of "more" with reference to quality.

On the one hand, readers should not take Goodman's Hebrew philology seriously, in spite of its antiquity and rabbinic pedigree, unless he cites Sarna. On the other hand, although he overly dichotomizes a literal from a symbolic reading of Genesis 1–9, in teaching Genesis, I will appeal again and again to his perspicacious insights.

"The case for evolution," chapter 3, essentially follows Darwin's original case in his classic, *The Origin of Species*, noting "morphology and taxonomy," "development and rudiments," "fossils and extinction," and "migration and adaptation." Goodman then addresses three questions that Darwin answered ("intricate organs," "elaborate instincts," and "sterile castes and crosses") and one that he could not (Kelvin's challenge, who formulated the Second Law of Thermodynamics). Later science met that challenge. The chapter concludes with neo-Darwinism, citing "Mendel's work," "adaptation observed," "Kettlewell's moths," "drosophila evolving," and the "DNA evidence."

In "Three lines of critique," chapter 4, Goodman addresses Darwin's insistence on gradualism: "My theory would absolutely break down," Darwin says, "if it could be demonstrated that any complex organ existed, which could not possibly have been formed by numerous, successive, slight modifications." The intelligent design movement takes up that challenge by the evidence of irreducible complexity as, for example, in the DNA molecule; "organic systems bespeak a prior plan." The argument of design, as Goodman notes, is as old as the Stoics and Aristotle. The Darwinist answers that existing organs take on new uses: "wings serve as fins and forelegs to the penguin, as sails to the ostrich, as flappers to the logger-head duck" (p. 121). But it is a big jump from this gradualism in gross anatomy to molecules that contain systems within systems, presupposing a living organism. The reality of irreducible complexity throws a monkey wrench into Darwin's gradualism. Goodman, citing Massimo Pigliucci, explains, however, that redundancy, a common feature of living organism, frees "one copy of the gene from immediate constraints and can slowly diverge in structure from the original, eventually taking over new functions." Also, Goodman, as do scientists in BioLogos—whom he curiously does not reference—fears that the argument that irreducible complexity points to a higher wisdom is guilty of *reduction ad ignorantiam* (a "god-of-the-gaps" explanation). Meyer, however, explores every known explanation of origins of life by random chance and finds none satisfactory. Meyer argues that this is not an argument from ignorance but from knowledge gained by Darwinian science.

Goodman draws the fourth chapter to a conclusion with "Beyond a God of the gaps." The power of questions about nature, he asserts, lies not in finding the answers to how they work but in the mystery, wonder, and religious awe they invite, a way to react to the presence of God. They point to a reality beyond themselves.

In the final chapter, "That has its seeds within it," he argues that science points to values. There is a teleology in natural history as organisms ever strive for what is their good. Citing Darwin, he explains that no account of species change would be adequate without explaining "how the innumerable species … have been modified, so as to acquire that perfection of structure and co-adaptation which most justly excites our admiration." Moreover, he argues that "evolution charts the emergence of new values in the rise of higher organisms … like autonomy, sensibility, and community" (p. 141). "Human beings," he notes, "distinctively, choose aims expected to give meaning to their lives … Our ends are never the mere dictates of our genes. We are always, in some measure, who we make ourselves, reaching for a good defined in part by our own efforts" (p. 155). These few citations fall far short of the profundity of this chapter.

Fortunately, Goodman grounds his theology in Genesis; otherwise, he implies a progressive theism, a God who himself is emerging into an open future. Hopefully, his work will move readers beyond theism, beyond the God of the philosophers, to the God of salvation history, the God of Abraham, Isaac, and Jacob, who on a developing historical trajectory fully manifested himself in Jesus Christ and lives a life of seeking the good of others, not self, in his church.

Reviewed by Bruce K. Waltke, Professor Emeritus of Biblical Studies, Regent College, Vancouver, BC, Canada, and Distinguished Professor of Old Testament, Knox Theological Seminary, Fort Lauderdale, FL.

PALEONTOLOGY: A Brief History of Life by Ian Tattersall. West Conshohocken, PA: Templeton Press, 2010. 240 pages. Paperback; $19.95. ISBN: 9781599473420.

Ian Tattersall's book, *Paleontology: A Brief History of Life* is a panoramic overview of life's history from the earliest conditions of Earth's formation to the appearance of *Homo sapiens*. It is an introductory text, and Tattersall's approachable, inviting prose makes this book a pleasure to read. The author does not begin his history, proper, until the fourth chapter. The first three chapters are devoted to setting up a framework for understanding and appreciating the significance of the history he later presents.

The author informs us, in the first chapter, of the three different types of rocks of concern to paleontologists and the processes of burial and fossil formation. The geologic time scale is considered and the various clues that fossils can furnish. The second chapter gives us a historical synopsis of the theory of natural selection, including a discussion of the fact and significance of mass extinctions in the history of life. Chapter three is devoted to Darwin's concept of "descent with modification," which the author ably explains employing the notion of "the tree of life." Here, he shows us what it means to claim that all living things are related by common descent.

Having established a framework, Tattersall spends chapters four through eight furnishing a general account of the history of life, from the Precambrian, through the Paleozoic to the "Age of Dinosaurs," the "Age of Mammals" right up to primates and humans. Though each section of the history is quite brief, some evolutionary episodes merit more attention, e.g., the transition from sarcopterygian fish to tetrapods; the appearance of birds from theropod dinosaurs; the origins of the three-boned, mammalian ear and the emergence of whales from terrestrial, "superficially wolf-like hoofed predators" (p. 136).

The author travels at quite a gallop and though it did leave this reader a bit breathless, Tattersall refrains from going into mind-numbing detail. Instead, his narrative so nicely mixes general history with engaging particulars that one willingly rides along.

The most interesting chapters are chapters nine and ten, the discussion of human evolution. This is not unexpected given Tattersall's eminent standing among anthropologists today. First, the author considers several possible candidates for the designation of "earliest hominid," but he confesses that the evidence is puzzling and inconclusive. Next, in considering Australopiths, he claims that these "bipedal apes" adapted both to open savannahs and arboreal habitats. Why, exactly, bipedality developed remains a contentious issue, and the author frankly admits that the sort of "pelvic adaptations" the earliest hominids had in order to accommodate bipedality remains a mystery. "Lucy," says Tattersall, is a late case, and she already possessed a pelvis and legs that were "radically altered from the ancestral condition" (p. 158). He ends this part of the discussion of Australopiths by saying, "There is still a lot to learn" (p. 158).

Throughout his book, Tattersall exercises the Socratic virtue of intellectual humility, a position I greatly admire. He often acknowledges the ambiguity of the evidence. While some, especially those unsympathetic to evolution, may view this as a weakness, it is, in fact, a great strength. Such a stance enables Tattersall to consider a panoply of alternative explanations for any body of evidence without a trace of defensiveness about what he does not know.

The author emphasizes the way in which morphological changes in the human frame and brain do not necessarily coincide with technological innovations. "From the very beginning … ," Tattersall says, these two things were "out of phase" (p. 167). A case in point is "Turkana Boy" (*Homo erectus/Homo ergaster*, about 1.6 mya) who is, clearly, a striding, obligate biped with a skull structure that anticipates many later hominid developments. He is, as Tattersall puts it, "… a total break with the past. Nothing in the fossil record anticipates the morphology of this new form …" (p. 169). And yet, such an individual is found to use the same primitive tool kits (Mode 1 or Oldowan technology) as the much earlier Australopiths. Tattersall wonders why this is so and muses that the Mode 1 technology might just be a victim of its own success (p. 170). Similarly, it is a wonder to the author how Mode 2 technology, typified by the much more sophisticated Acheulean hand axe, could have been invented in Africa and would not arrive in Europe until fully a million years later (p. 172).

Homo heidelbergensis (600,000 years old), discovered in 1976 at Bodo in Ethiopia, is "the first truly cosmopolitan species" (p. 179), having been discovered in several locations in Africa, Europe, the United Kingdom and even China. The first shelters are associated with this species (at Terra Amata, France), and they may even have made certain wooden spears found in a bog in Germany (p. 179). Although the "cognitive revolution" begins here, there is little evidence of what Tattersall calls "the critical modern cognitive feature" (pp. 179–80), namely, symbolic intelligence. According to Tattersall, a central feature of the symbolic mind is the ability to construct an alternative reality that is "literally of its own creation" (p. 180), a rival world to the world of experience. This, the author believes, is the condition for art, science, religion and philosophy. *Homo heidelbergensis*, he claims, comes closer to, but did not cross, this cognitive divide.

Homo neanderthalensis (200,000–30,000 years ago) was a species endemic to northern Europe, which had branched off from its African origins over a half-million years earlier. They were highly skilled practitioners of the Levallois (Mode 3) technique of tool making (p. 183). Such productions clearly required a mental template of what was to be produced and a great skill in dislodging, with a single blow, the completed tool from the rest of the stone. Still, Tattersall maintains that Neanderthal tool-making displayed little innovation and is much the same wherever it is found. Though they appear to have invented burial of the dead, the author denies that their burials had any sort of spiritual significance. There is no clear evidence of grave goods in any Neanderthal burial site, and even the famous "flower burial" one at Shanidar Cave is ambiguous. He believes it is "highly doubtful" (p. 186) that Neanderthals had any sort of developed language.

Anatomically modern human beings have been found in Ethiopia and the Levant, dating around 195,000 years ago and later. At Blombos Cave in southern Africa, some of the first clearly symbolic artifacts show up, dated around 75,000 years ago. Here are found "a couple of ochre plaques engraved with regular geometric markings" (p. 190). Near this site are also found "small gastropod shells" (p. 190) notched with tiny holes and strung together to make a necklace. Such early jewelry undoubtedly had social significance. Once this sort of symbolic activity appeared, a threshold had been crossed. When it reappeared,"it was expressed with a vengeance" (p. 190).

A creative explosion occurred around 40,000 years ago with new, sophisticated tools and all manner of artistic creations—painting, engraving, sculpture, decorative embellishments on weapons and tools. There was music, too—on vulture-bone flutes! (p. 191). The lives of these people, the Cro-Magnons, "were drenched in symbol …" (p. 192). According to Tattersall, the human mind was ready for symbolic thought, and it only required some sort of "cultural stimulus" to release the potentialities within it. That stimulus was the invention of language (p. 194). Tattersall does not believe that the brain was "made" for symbolic thought. Rather, it is an exaptation from a previous physical condition. In other words, the brain served some other purpose related to survival; language came along and conditions became ripe for the brain to be co-opted for this new function. This is one valid, if reductionist, way of explaining the matter.

So, says Tattersall, human beings are dual. One foot is in the biological world of instinct and survival; the other, in the cultural world of myth and symbol. Both come together in "a rather rickety general-purpose brain that happens to possess some remarkable capacities" (p. 196). The advent of symbolic thought is also at the origin of our spiritual life and yearnings. Because we are able to imagine other worlds, our thoughts and longings need not be restricted to immediate experience. Tattersall suggests that Cro-Magnon art was not only about this world, but also about an imagined world transcending this one.

Having broached the topic of religion, he completes this brief history with a statement of his belief that science and religion are not rival but complementary explanations of reality, "… underpinned by the same identical human curiosity about the universe, and about our own place in it" (p. 204).

Highly recommended for all undergraduate libraries in the sciences and humanities.

Reviewed by Lloyd W. J. Aultman-Moore, Waynesburg University, Waynesburg, PA 15370.

Philosophy & Theology

DID ADAM AND EVE REALLY EXIST? Who They Were and Why You Should Care by C. John Collins. Wheaton, IL: Crossway, 2011. 192 pages. Paperback; $15.99. ISBN: 9781433524257.

C. John ("Jack") Collins has written a timely book on the relationship between scripture and human origins. It comes in the wake of a controversy this past year at Calvin College regarding two professors who published papers in *PSCF* rejecting the historicity of Adam (September 2010: 179–95; 196–212). These papers were first presented at the 2009 ASA annual meeting at Baylor University alongside a paper by Collins defending the existence of Adam. And this book review is being written only days after the publication of a *Christianity Today* cover article entitled "The Search for the Historical Adam" (June 2011: 23–7).

Collins terms his view of human origins as "mere historical Adam-and-Eve-ism" (p. 14), echoing the famed C. S. Lewis book *Mere Christianity*. Though he states, "I am not endorsing any one scenario" (p. 14), by the end of the book, he certainly seems to hold a position. In beginning his argument, Collins is correct to deal with the critical question of the literary genre of the opening chapters of scripture. He offers four interpretive approaches:

> (1) The author intended to relay "straight" history, with a minimum of figurative language; (2) The author was talking about what he thought were actual events, using rhetorical and literary techniques to shape the readers' attitudes toward those events; (3) The author intended to recount imaginary history, using recognizable literary conventions to convey "timeless truths" about God and man; (4) The author told a story without even caring whether the events were real or imagined; his main goal was to convey various theological and moral truths. (p. 16)

Collins embraces the second category, but at this point fails to state whether "the actual events" were indeed real historical episodes. Eventually, Collins acknowledges a "historical core" of real events in the past (p. 35). However, he misses a fifth possible category, whereby "the author was talking about what he thought were actual events," *but, in fact, these events never actually happened, because the author was reconstructing history from an ancient phenomenological perspective*. In other words, this would be an ancient understanding of history similar to an ancient understanding of nature and science found in scripture. In failing to identify this fifth option, Collins loads his literary genre categories in the direction of his position.

This oversight is related to Collins's insistence that "timeless concepts" and "transcendent truths" cannot be separated stories in scripture (p. 27). He sharply criticizes my view that the Bible has inerrant messages of faith that are transported by incidental ancient elements (pp. 34, 107; e.g., 3-tier universe). Once again, Collins sets up an assumption in order that his conclusion affirming the historicity of Adam follows. With this strategy, he attempts to argue that it is necessary to have a historical Adam if we are to believe that humans are created in God's image and that they are sinful. But what are parables? Heavenly messages delivered by earthly stories. The eternal truths in the parable of the Good Samaritan are not dependent on this account being historical. This can also be the case with Holy Spirit-inspired truths in Genesis 1–3 about the human spiritual condition. A person can reject the historicity of Adam and yet believe that he or she bears God's image and is a sinner. Interestingly, Collins betrays his early assumption late in his book when he introduces the categories of "world view" vs. "world picture" (p. 134), arguing that the Bible is more concerned with the former instead of the latter. Using Collins's categories, why could the ancient world picture of human origins (the *de novo* creation of Adam) not be separated from the world view (the belief in the image of God and human sinfulness)?

The core of Collins's argument is in the fourth chapter entitled, "Particular Texts That Speak of Adam and Eve." He lists well-known passages from the Old and New Testaments, in particular from Jesus (Matthew 19) and Paul (Romans 5 and 1 Corinthians 15). He also presents Second Temple Jewish literature. Collins contends that since Adam and Eve appear throughout these ancient texts, it only goes to show that they must have been real people. But this is not necessarily true. We can review this same literature for their astronomical statements and find that they present a 3-tiered world. Using Collins's argument from consensus, does this mean then that the cosmos actually has three levels? Of course not. I am sure that in this case, Collins would separate this ancient "world picture" of a 3-tiered cosmos from the essential "world view" that God created the heavens (Gen. 1:6–8; 14–19) and that they declare his glory (Ps. 19:1). Moreover, it should not surprise anyone that these texts have Adam at the head of humanity. In the ancient world, *de novo* creation was the best conceptualization of the origin of living organisms. In addition, ancient people extrapolate from their experience of expanding families and genealogies back in time to the beginning of creation. This along with the common motif of tribal formation explains why scripture, by necessity, arrives at an original human.

Chapter 5, "Can Science Help Us Pinpoint 'Adam and Eve,'" is the most interesting in the book. Collins opens with a criticism of the "problem of concordism," pointing to the failure of aligning nineteenth-century geology with scripture (pp. 106–7). Yet he does not seem to recognize that his "mere historical Adam-and-Eve-ism" is, in fact, a concordist approach—it derives a historic Adam and Eve from scripture and attempts to align them with modern science. More specifically, Collins contends that the "historical core" in Genesis includes the following: (1) natural processes alone cannot account for the origin of humans; (2) Adam and Eve are at "the headwaters of the human race"; (3) the fall was historical and moral (p. 120). From science, Collins draws evidence from genetics, which indicates the number of humans was never below

1,000 individuals (pp. 12, 130), and paleoanthropology, which reveals that modern humans entered Australia about 40,000 years ago (pp. 17, 121, 124). Collins's concordist hermeneutic leads to a position with "humans as a single tribe" and "Adam as the chieftain and Eve as his queen" at least 40,000 years ago (pp. 121, 130). Interestingly, in the introduction of his book, Collins states that he intends to argue for a "traditional position on Adam and Eve, or some variation of it" (p. 13). But his Adam as tribal leader thesis is far from "traditional." Where in church history does this appear? In addition, the model is *ad hoc*. He accepts certain passages in Genesis as part of the "historical core," and then overlooks others. For example, Gen. 3:20 states, "Adam named his wife Eve because she would become the mother of *all* [Hebrew *cōl* means "all, whole"] the living" (NIV). Collins uses this verse in chapter 4 to establish the historicity of Eve (p. 62), but moves away from its historicity in chapter 5 because his tribe of 1,000 individuals could not possibly be descended from Eve. He attempts to mitigate the problem by focusing on the name of Eve as simply "Life-giver" (p. 125). But Collins betrays the context and ignores the explanatory clause in this verse. Eve is given her name "*because* she would *become* the mother of *all* the living." Concordism always fails because it is impossible to align ancient science (*de novo* creation) with modern science (evolutionary creation).

Jack Collins is an important voice within the evangelical science-religion community. Though I completely reject his concordist view of human origins, I certainly recommend that this book be read. Regrettably, it is marred by some irritating rhetoric (e.g., the back cover comment about those who doubt a historical Adam: "rarely are those doubts humbly subjected to serious scholarship"), but looking beyond this will reveal a wonderfully committed Christian wrestling mightily with the relationship between science and scripture.

Reviewed by Denis O. Lamoureux, Associate Professor of Science and Religion, St. Joseph's College, University of Alberta, Edmonton, AB T6G 1H7.

Religion & Science

BROKEN WORDS: The Abuse of Science and Faith in American Politics by Jonathan Dudley. New York: Crown Publishers, 2011. 205 pages. Hardcover; $21.99. ISBN: 978-0385525268.

Broken Words grabs the reader's attention from the very first sentence: "I learned a few things growing up as an evangelical Christian: that abortion is murder; homosexuality, sin; evolution, nonsense; and environmentalism, a farce." With this brief outline of his book, Jonathan Dudley starts a path through rethinking the "Big Four" ideas that may serve as the best characterization of evangelicals to the larger society. He takes on each in turn, and effectively ties together these four topics by showing that for each, a "simple reading" of scripture is actually an evolved history of interpretation: for each, the modern dogma reflects reactions against social, theological, and political issues separate from the issue itself; and for each, there is an element of rejecting science as a reliable way of understanding the world.

Dudley is well qualified to address these topics. He is the child of a well-pedigreed evangelical Christian family (many family members are Moody Bible Institute graduates) who knows from personal experience the weight placed on adherence to the "right" answers to the Big Four issues. He graduated with a biology degree from the evangelical Calvin College, and earned an MA in religion from Yale University's Divinity School. He is currently a medical student at Johns Hopkins University. Thus, he is well versed (and taught) in the science underlying these topics and has clearly spent significant time learning about the history and theology of the Big Four. The book is a strong argument because of Dudley's strong qualifications in both science and theology.

The most important contribution of the book may be the broad historical view of the hermeneutics behind the Big Four, and how these interpretations have changed over time. Other authors (Francis Collins, Keith Miller, Darrel Falk, and others) have written eloquently on resolving apparent conflicts between faith and science; Dudley shows how evangelicals ended up in these seemingly intractable conflicts in the first place. As an example, in the chapter on abortion, he provides some historical surprises for the reader: "The prevalence of abortion among Protestant women (versus mostly immigrant Catholics) is widely considered by historians to be one of the main reasons that physicians, worried that immigrant Catholics were out-reproducing their mainly Protestant social group, led the campaign to criminalize abortions in the late 1800s" (p. 41). More recently, post-Roe examples of Southern Baptist Convention resolutions in support of allowing abortion in cases of rape, incest, fetal deformity, and maternal health, as well as a call for repeal of anti-abortion laws by the Christian Medical Society, show how far evangelical opinion on the morality of abortion has changed in the last forty years. Dudley suggests and provides evidence that the change in evangelical thought was an outgrowth of a desire to influence politics surrounding the civil rights movement and women's rights movement by joining forces with Roman Catholics, rather than a longstanding understanding of scripture regarding fetal life.

Similar treatments of the issues of homosexuality, environmentalism, and evolution follow in the other chapters. While I found Dudley's chapter on environmentalism the least interesting, possibly because the topic is the least contentious of the Big Four, he makes a unique argument that the Bible is neither pro- nor anti-environmental, and Christians on both "sides" of the debate are abusing hermeneutics. Those who oppose the environmental movement often read the apocalyptic passages as predicting an end to the current creation, thus negating the need to care for the earth while it still exists. Environmentalist evangelicals are re-interpreting scripture in the light of their experience in the environmental movement, but have little support from the history of the church in their call for "creation care."

There are a few shortcomings in the book. It tends to be a bit repetitive, as there is a commonality to the approaches evangelicals take to the four issues treated in the book. A more complete reference list would have been nice for readers who want to explore more of the literature that Dudley used, but with a little digging using the endnotes, one's curiosity can be satisfied.

Overall, this book is an interesting, easy read. It very nicely traces the evolution of evangelical thought on the Big Four issues, and in so doing, points out the fallacy of a "simple reading" of scripture in isolation from the culture and issues of the day.

Reviewed by Robin Pals-Rylaarsdam, Biology Department, Benedictine University, Lisle, IL 60532.

THE POLKINGHORNE READER: Science, Faith, and the Search for Meaning by Thomas Jay Oord, ed. London: SPCK, 2010. 256 pages. Paperback; £14.99. ISBN: 978-0281060535.

ENCOUNTERING SCRIPTURE: A Scientist Explores the Bible by John Polkinghorne. London: SPCK, 2010. 128 pages. Paperback; £9.99. ISBN: 9780281062539.

Is there a God? How do we know? What is the nature of this God? And how does God interact with the natural world? These are the themes that have engaged John Polkinghorne these past thirty years or so, and they are well addressed in these two volumes, which encapsulate the provocative thinking of this remarkable scientist-theologian. For the unlikely uninitiated, Polkinghorne was professor of mathematical physics and later president of Queens' College, Cambridge University, as well as an Anglican priest and Canon Theologian of Liverpool Cathedral, *and* the 2002 winner of the Templeton Prize for Science and Religion, *and* the author of numerous other books, many of which have been reviewed in these pages. Oord is professor of theology and philosophy at Northwest Nazarene University and the author of other books on the intersection of science and religion.

First, a word about editions: Both of these books were published in Britain by the Society for the Promotion of Christian Knowledge (SPCK). *The Polkinghorne Reader* was also subsequently published in the USA by the Templeton Press in a slightly different format.

Second, a word about the distinction between these two volumes. *The Polkinghorne Reader* is the more substantial, in both size and effect, of the two, for as its title suggests, it is a compilation of the author's best or most helpful writing on the intersection of faith and science. Polkinghorne cooperated with Oord in the selection of the pieces, which are arranged thematically rather than chronologically. It is organized into three parts: "The World," "God," and "Christianity," with seven or eight selections in each part. While not technical, it is written for the educated reader, one with some familiarity with theology or science. *Encountering Scripture*, on the other hand, is a shorter, more narrowly focused explication of Polkinghorne's understanding of the nature, role, and interpretation of scripture. It is written as a soft apologetic, primarily for the lay or general reader who might be intrigued to hear how a noted scientist-theologian approaches some of the thorny questions about the meaning of scripture.

In both volumes, Polkinghorne is more the theologian than the scientist, although he is continually attempting to stand between the two camps and link them together by noting common quests for truth and common patterns in their efforts. He humbly claims lay status as a theologian (see, for instance, his Gifford Lectures) but his ponderings are astute and reflect a well-read mind. Because his scientific profession addressed mathematical physics, little of that finds its way into these writings. When he speaks of science, it is largely to draw analogies between quantum theory and the epistemological challenges of knowing and understanding God. Beyond the fundamental epistemological question, his central theological concern is to understand and articulate the interactions of God in the world in terms and frameworks that are credible and relevant to a contemporary secular audience; along the way, he also addresses the corollary questions that result from that one, including how creation is to be understood, how God reveals himself, and the problem of evil (theodicy).

Regarding these central theological questions, it might be helpful to summarize Polkinghorne's thought, as presented in these volumes. First, he is an advocate for a kenotic Christology, a long tradition, recently revived (see *Exploring Kenotic Christology* by C. Stephen Evans), that stands between classical Christology (of the Chalcedon Definition and Thomas Aquinas) and process theology (of Alfred North Whitehead). Following the lead of Jürgen Moltmann, Polkinghorne's favorite theologian, who wrote of a "crucified God," Polkinghorne is attracted to an understanding of a self-emptying God who incarnates as a fully flesh-and-blood human being in Jesus. Second, Polkinghorne's attraction to a kenotic Christ runs parallel to his understanding of continuous creation, in which the Creator continues to engage and form the created world in cooperation with human beings. As to where and how such interactions between Creator and creation take place, Polkinghorne provocatively suggests that something akin to the indeterminancy that happens on the quantum level when an observer is present might occur on a macro level as well.

Third, for Polkinghorne, this image of a God who limits himself and who engages his creation provides at least a partial solution to the problem of evil, for he imagines a God who does not know the future (cf. open source theology) and who therefore encounters and addresses evil alongside of and in cooperation with humans. Fourth, Polkinghorne believes that God has revealed his presence and his character in scripture, although he eschews an evangelical or fundamentalist understanding of direct, literal inspiration for what might be best understood as a neo-orthodox hermeneutic.

There's more … much, much more than a brief review can summarize or address and, of course, the books are available for those who wish to read more and deeply. Readers of this journal will be unlikely to find *Encountering Scripture* to be very helpful, unless one wishes an introduction to biblical hermeneutics. *The Polkinghorne Reader*, however, is a well-organized and delightful volume, wide-ranging in its topics, insightful in its arguments, and marvelously edited so that the passages flow rather seamlessly and coherently, despite their different sources and chronologies. If one has all or most of Polkinghorne's writings on one's shelf, this would be an unnecessary redundancy; if, however, one wishes to have a distillation of his thought, this is an excellent, inexpensive alternative.

Reviewed by Anthony L. (Tony) Blair, President and Professor of Church History, Evangelical Theological Seminary, Myerstown, PA 17067.

INTELLIGENT DESIGN UNCENSORED by William A. Dembski and Jonathan Witt. Downers Grove, IL: InterVarsity Press, 2010. 175 pages. Paperback; $15.00. ISBN: 9780830837427.

This book is divided into two major sections: chapters 1–4 cover the basic arguments for intelligent design (ID) and chapters 5–7 focus on ID as an apologetic against materialism. There is little new here, but it is a good place to start if you are new to ID.

Chapter 1 "Fantastic Voyage" is an introductory, delightful, and fanciful voyage into the inner workings of the cell through a Sci-Fi miniaturization scenario.

Chapter 2 "The Design Revolution" is a brief description of Darwinism and particularly its alleged failure to account for the observation that the universe appears to be fine-tuned for complex life. After glibly dismissing the weak anthropic principle and multiverse proposals, Dembski and Witt propose ID as the most reasonable solution.

I was pleased to see Dembski and Witt recognize that all biologists acknowledge design. Biological structures have a function and perform a particular role in the cell. Philosophers of biology have long reflected on this. Therefore, ID has no unique claim on design. The dispute is not over whether design exists, but whether evolutionary processes could have designed the object.

Chapter 3 "The World's Smallest Rotary Engine" is the frequently seen chapter on the bacterial flagellum. Much of the chapter is devoted to refuting the criticisms of theistic evolutionist/evolutionary creationist (TE/EC) Kenneth Miller. Nonetheless, I find Miller's argument persuasive—that a subset of the flagellar machine that makes up the functional Type III Secretory System is proof that the general idea of co-option is a feasible explanation. It does not matter which came first.

Chapter 4 "The Design Test" presents the design threshold, the probability below which something is considered to be designed. It seems that the probability calculation for the cell as a whole is based on the untenable belief that the whole is assembled at random from a collection of all the constitutive molecular parts. First, there are physical and chemical properties that dictate much of the assembly process; it is not really random. Second, this approach assumes that there is no step-wise assembly. Some aspects of these structures are dependent on previous steps having occurred. To illustrate: the probability of getting two heads when two coins are flipped is 0.25, but the probability of getting two heads, when one of the results is already heads, is 0.5. Biological processes and similar processes likely to be involved in the origin of life are much more like the sequential coin flip. Third, evolutionists never say that the evolutionary process is random. Aspects of it may involve processes that approach random (nucleotide substitutions, recombination, random assortment of chromosomes, etc.), but self-organization, natural selection, environmental contingency, etc., are not random.

Dembski and Witt say that the origin of information is the critical problem in biology. They review several non-ID proposed solutions and find them all lacking. Here are two examples of rather technical arguments that they present that seem persuasive to the casual, non-expert reader, but are not to the more expert reader.

They argue that molecular phylogenies, as a general rule, are an unreliable argument for evolution from alleged problems with sequence comparisons involving the vitamin C synthesis gene (GULO). Evolutionists have argued that the existence of the nonfunctional GULO pseudogene in primates in the context of functional GULO among other mammals is strong evidence for common ancestry. Guinea pigs, far off the primate branch, also have a nonfunctional GULO pseudogene. It turns out that a larger than expected number of the mutations is common between the distantly related guinea pig and human, suggesting a mutational hot spot in this region (no one would suggest that primates and guinea pigs are close relatives, based on other comparisons). Following arguments of Jonathan Wells, they argue that, in a similar manner, each of the primate nonfunctional GULO pseudogenes could have arisen independently and that this is an equally parsimonious model. The claim for equal parsimony is suspect, even if the hot spot argument is legitimate, but to argue that this example results in doubt being cast on the whole molecular phylogeny enterprise is unwarranted.

They argue that the mutagenesis research of Douglas Axe, which concludes that functional folds in proteins are extremely rare and that it is not possible for new folds to originate from other folds, makes evolution impossible. The research of the Brian Matthews group with T4 lysozyme leads to a different conclusion. One of the reasons for the differing conclusions is that Axe uses catalytic function to assess proper folding rather than mere folding. It seems to me that functional folds (that is, folds with enzymatic function) are a small subset of properly folded proteins. (Axe seems to make the opposite assumption.) We would expect modern proteins to have evolved to be distant from each other in folding space, so that they fold up into their unique structure. Indeed, dysfunction results when proteins fold up in alternate conformations as in amyloid diseases—proof, interestingly, that some "folding islands" are not so distant from others. A less modern protein would have a lower stability (be less likely to be in the folded structure at a given time) and may even have multiple conformations. I also have serious doubts about Axe's key calculation of 0.38 as the probability of having a suitable amino acid in a given position. Our experience with T4 lysozyme mutagenesis suggests a much higher number for most positions. In addition, his assumption that that probability applies to all residues is most likely wrong.

The final three chapters are devoted to apologetics questions and are evidence that ID is motivated substantially by the apologetic agenda. There is much to commend in chapter 5 "The Poison of Materialism," for indeed, much of the modern intellectual marketplace is rooted in this anti-Christian worldview. But Dembski and Witt fall prey to the problem of not distinguishing between evolution as a scientific theory and evolution as a comprehensive worldview. It is possible to be an evolutionist with respect to some set of biological theories and *not* be a materialist. Evangelical critics of evolution and atheists both commit this error.

Chapter 6 "Breaking the Spell" is Dembski and Witt's attempt to debunk theistic evolution/evolutionary creation, which they tend to caricaturize as being deistic. Rather, most who hold this position would say that God is involved moment by moment in upholding and governing the universe he created—far from a deistic view. That this universe operates according to regularities detectable by us is evidence of faithful and regular governance, not autonomy, not materialism. There are some theists who would even claim that everything is designed. Distinguishing between such a creation and a materialistic world is a matter of theological commitment and not empirical evidence.

Chapter 7 "The Book of Nature" includes strategies for would-be ID scientists to navigate the anti-ID biased waters of today's academia. The advice is to not let anyone know of your beliefs until you have tenure ("loose lips sink ships"). This approach seems ill-conceived. Receiving tenure might guarantee a permanent university position, but it does not guarantee permanent grant support or circumventing peer review in future publications. Tenured scientists with unconventional ideas may keep their university positions, but they quickly lose the respect and support of their peers. Science is not a democracy and free speech about science in the scientific literature is not a civil right among scientists.

With such a fundamental difference in worldview, ID might be better served by building their own institutions of research, teaching, etc., similar to the Christian school and college enterprise. Even if the old guard is never convinced, the new institutions, if successful, would displace the old.

Reviewed by Terry Gray, Instructor, Department of Chemistry, Colorado State University, Ft. Collins, CO 80523.

SCIENCE AND RELIGION: Are They Compatible? by Daniel C. Dennett and Alvin Plantinga. New York: Oxford University Press, 2011. 82 pages, foreword, index. Paperback; $9.95. ISBN: 9780199738427.

This book is an extension of a formal debate between two American philosophers, Alvin Plantinga, an explicitly Christian analytical philosopher once described by *Time Magazine* (1980) as America's leading orthodox Protestant philosopher of God, and Daniel Dennett, an internationally acclaimed philosopher of mind and one of the "Four Horsemen of New Atheism." The original debate took place in 2009 at the American Philosophical Association Central Division Meeting in Chicago.

The title of this volume would, reasonably enough, lead one to expect a debate revolving around the question of whether the central claims of science and religion ultimately come into conflict or perhaps even contradict each other. This, however, is not what one actually finds. In fact, the title of the volume (and the originally billed debate) is somewhat misleading. The debate is not about whether science and religion are compatible. Plantinga and Dennett both agree they are compatible. Plantinga contends not only that science and religion are compatible, but that the rational embrace of science's claims rests ultimately upon epistemic presuppositions that derive from Christian theism; Dennett, on the other hand, thinks that the mere logical compatibility of science and religion is trivial, and argues that a truly scientific understanding of the world makes it impossible *rationally* to accept Christian theism. So this debate does not focus on science and religion's compatibility, but on two rather more interesting but much less general questions: (1) Does Christian theism deserve more rational credence than that typically apportioned to superhero tales? (Plantinga says "yes"; Dennett says "no"); and (2) Is Darwinian evolutionary naturalism (i.e., the view that the process of species descent is driven by natural *unguided* selective forces operating on random mutations) able to supply a rational basis upon which to trust the reliability of the very cognitive faculties that have led to this belief? (Plantinga says "no"; Dennett says "yes").

Regarding the first question, Plantinga affirms that contemporary evolutionary theory is compatible with Christian theistic belief, since contemporary evolutionary theory, properly understood, does *not* rule out the possibility that God guided evolutionary processes to yield human beings (p. 2). Dennett agrees that contemporary evolutionary theory does not prohibit theistic guidance nor can it demonstrate the absence of divine design (p. 27), and thus Christian theism and evolutionary theory are logically compatible. But Dennett insists that their mere logical compatibility supplies no rational grounds warranting appeal to deity for explanatory assistance; in fact, he ridicules such a tactic as garnering no more rational warrant than a silly appeal to Superman supervising evolutionary descent (pp. 28-9), and claims further that atheism is the tacit yet fundamental assumption required to secure the closed system of physical causes underwriting current practices of science and courts of law (p. 31). Plantinga counters, noting that holding a hypothesis that does not entail theism is very different from assuming atheism (p. 42). Dennett then claims that the only reason Plantinga takes theism more seriously than Supermanism is that his Christian faith has biased his imagination (p. 46) and compares Plantinga's biased imagination to the imaginings of a half million people who believe in the existence of the angel Moroni's golden tablets (p. 47). Plantinga responds by explaining to Dennett the important difference between necessary and contingent beings and how this difference makes no small difference when it comes to the rationality of belief in Christian theism as opposed to belief in Supermanism (p. 58).

In reference to the second question, Plantinga believes that although there is no conflict between Darwinian evolution and Christian theism, he does believe that naturalism (of the sort Dennett holds) and science are incompatible (p. 70), despite their apparent concord. One cannot rationally accept both (p. 17). Dennett's (and others') quasi-religious naturalistic worldview entails an evolutionary process entirely driven and shaped by the nonrational forces of chance (random mutations) and necessity (survival of the fittest). Plantinga argues that belief in both naturalism and evolution yields a very low probability that our cognitive faculties are reliable (p. 17), i.e., that we can trust them to track truth and not merely endow us with beliefs that improve our chances of survival (p. 19). Since beliefs do not have to be true to confer survival value, anyone who believes that evolutionary naturalism accounts for the ascent of humans with all our capacities and faculties, also has an excellent reason *not to* believe that this belief is true. (And, of course, it is irrational to believe something about the causes of all one's beliefs that make truth irrelevant to their output.) Dennett does not accept Plantinga's argument that the conjunction of beliefs in naturalism and evolution is self-defeating, because although it is true that biological evolution has (over millions of years) "designed" our belief acquisition modules to promote user survival, it is also true that *cultural* evolution has (over thousands of years) honed those survival-conducive beliefs to home in on truth (pp. 35–6).

The enduring value of this book will not come from its contribution to the debate about the compatibility of science and religion, but will much more likely come from the clarity with which it shows the epistemological import of our beliefs about the origins of our species: how what we believe about the originating causes of our beliefs seriously affects how seriously we can rationally take any of our beliefs.

Reviewed by Robert P. Doede, Associate Professor of Philosophy, Trinity Western University, Langley, BC V2Y 1Y1.

TEST OF FAITH: Spiritual Journeys with Scientists by Ruth Bancewicz, ed. Eugene, OR: Wipf and Stock Publishers, 2010. 120 pages. Paperback; $18.00. ISBN: 978-1608998944.

This book will inspire and motivate Christians in science and indeed anyone on a journey "of reconciling" their faith with current scientific understanding of the natural world. *Test of Faith* presents a collection of spiritual journey essays—selected, compiled, and organized by the editor, Ruth Bancewicz—from highly respected scientists who profess a deep Christian faith. Bancewicz is a research associate at the Faraday Institute and has spearheaded the Test of Faith project since 2006. The project aims to provide relevant resources about Christianity and science and, most importantly, to make them accessible to everyone. This book is one of those resources.

The book serves two main purposes. First, it unambiguously establishes that faith and science are compatible and, in fact, complement and inform each other in a way that strengthens both. Second, it provides people in science with examples of how their Christian faith can guide them in their daily work serving the Lord.

In an open manner, *Test of Faith* speaks to a common misperception that science and faith are in opposition to each other. With the recent rise of the so-called "new atheism" movement and the publication of many best-selling atheist books, there are people asserting that a scientific worldview is incompatible with a belief in a personal God. Yet, as Bancewicz points out in her introduction, "there are a huge number of scientists who are also Christians, and hundreds of books have been written explaining how faith and science fit together" (p. xii). This book presents a positive affirmation of faith with essays that are sincere, nonantagonistic, and respectful of other faiths and atheistic perspectives.

Bancewicz carefully selected ten prominent scientists from a range of scientific disciplines including physics, astronomy, molecular biology, neurobiology, and computing science, as well as from a diversity of upbringings; some began their career as atheist or agnostic, others as strongly rooted Christians. While simultaneously producing a well-balanced compilation of stories, this book provides counterbalance to some of the more prominent "new atheists" through contributions from Christians who are experts in the same scientific disciplines. For example, Francis Collins is a molecular biologist with a thorough understanding of evolutionary theory; he provides a Christian perspective of life's origin that counters the arguments presented by atheist Richard Dawkins. Alasdair Coles and Bill Newsome, both neurobiologists, admirably counter neuroscientist Sam Harris, author of *The Moral Landscape*. Coles and Newsome assert that morality cannot be explained on the basis of science alone, and that a person must search for a balance "… where you can be modern and intellectual and yet be open to emotional meaning that transcends the logic to some extent or at least complements the logic" (p. 50). Similarly, Ard Louis, John Polkinghorne, and Deborah B. Haarsma serve as voices against the criticisms from physicists Victor Stenger and Stephen Hawking who posit that a solely scientific explanation is sufficient to explain the origin of the universe. Polkinghorne eloquently states that "if you look at these laws, their rational beauty, their order, their fruitfulness, their 'fine-tuning,' they do seem to point beyond themselves" (p. 89). The Christian physicists each acknowledge the existence of different types of truth, different yet significant ways of knowing—what Ard Louis refers to as "deeper logic" (p. 72).

The personal stories shared in *Test of Faith* illustrate how faith influences career paths, guides research directions, and informs day-to-day interactions in the lab and classroom**.** For example, Bill Newsome coherently addresses how faith informs how he mentors students in his lab. His story sheds light on how Christian higher education may differ from non-Christian higher education and will prove useful for academics and those considering entering post-secondary education. John Bryant focuses on bioethics and how Christian ethics can help inform how we choose to respond to the momentous advances in technology and science.

While this book will appeal to anybody who has pondered the link between science and faith, readers who are interested in a deeper discussion of Christian ethics by some of the same contributors may turn to *Real Scientists, Real Faith* edited by R. J. Berry. Other resources offering a fuller exploration of some of these issues are available through the Test of Faith website (www.testoffaith.com). Nonetheless, the limited depth in this book is certainly appropriate given its purpose and target audience. Each author describes some of the resources that were personally valuable on their own journey. Yet, to strengthen this collection, the editor might have appended a more comprehensive list of useful resources on specific topics, particularly a list of publications from each author (e.g., Francis Collins's *The Language of God*).

I recommend *Test of Faith* to anyone interested in the interaction between Christian faith and science. This book has something for everyone. Christian academics may identify with the inspirational stories. New faculty members will find that the contributors make great role models. Readers who are embarking on a Christian path will appreciate the personal stories from John Polkinghorne and Deborah B. Haarsma, who both aim to find common ground among divergent faith perspectives. The book should be recommended reading for Christians who are considering a career path in science, as well as for parents and family members interested in learning where those career paths might take them spiritually. Yet most importantly, *Test of Faith* would be ideal for the lay public who are continually bombarded with the unfounded assertions of high profile atheists. Here is a valuable resource that can be used by church leaders and church groups to begin a reassuring discussion among the faithful that science is not antithetical to their beliefs and values.

Reviewed by Keri McFarlane, Assistant Professor of Biology, The King's University College, Edmonton, AB T6B 2H3.

SUPERNATURAL SELECTION: How Religion Evolved by Matt J. Rossano. Oxford: Oxford University Press, 2010. 304 pages. Hardcover; $29.95. ISBN: 9780195385816.

Supernatural Selection is an extended analysis of how humans became religious. Matt Rossano explores the topic, using recent findings from a variety of fields—anthropology, archaeology, biology, developmental human biology, neuroscience, philosophy, primatology, psychology, and sociology among others—to weave an intriguing examination of religion and human evolution. Essentially, he regards religion as a social phenomenon. At its core, he argues, it is "fundamentally relational," involving relationships between humans as well as between humans and the supernatural (pp. 19, 34). Consequently, he contends that, because of its experiential base, religion is beyond science. To support his argument, Rossano narrates the development of religion from ritual to shamanism to compelling myths.

I expected a hard-hitting dogmatic exposé of religion. What I found was much more interesting. Rossano often discusses evidence with phrases such as "this suggests that," "this study has found that," "though interpretations … differ," "we must be cautious that," "lends further support to the notion that," and "however, this does not mean that." I found that this relaxed procedure disarmed my suspicions. However, later in the book, these qualified pieces of evidences are used as givens. Depending on his or her background, each reader will question different pieces of Rossano's evidence. For example, in an attempt to describe religion's primitive traits, Rossano uses phylogeny noting that humans and chimpanzees share many traits in common. He concludes that these traits were probably present in the ancestor of both species. This is standard phylogenetic theory. However, he then uses the same logic to look at the traits of religion that are shared across human societies. This leap from biological traits to cultural traits Rossano makes smoothly, without much equivocation. Given the vast difference between cultural and biological evolution, I found it difficult to make the same jump, much less with the same ease.

In fact, creationists with a short time model ("young earth creationists") will find the first seven chapters problematic. For example, Rossano states "Sometime between … (about 100,000 ybp) and … (about 35,000 ybp), some of our ancestors thought up the idea of a supernatural world" (p. 60). Young earth creationists will want to pack all of human prehistory into a short time (less than ~4,000 years). On the other hand, creationists with a long time model will find the book extremely thought provoking. Was the supernatural realm invented or discovered (or revealed)? Rossano provides only a narrative for invention. Someone needs to use the same body of evidence and argue for an alternative hypothesis.

In the eighth chapter, "Religion and Morality," Rossano argues for importance of religion in the understanding of morality. In fact, he spends several pages on developing "moral expertise," which will be of value to anyone interested in spiritual growth. I was surprised by the amount of evidence that he amassed to support his assertion that religion was and is extremely valuable. For example, he contends that it is key to the survival of anatomically modern humans.

Furthermore, the book is scholarly. Twenty-five pages of notes plus 50 pages of references alone will have me returning many times to its pages. Chapter nine focuses on the testability of his argument. He makes five general predictions (plus a few minor ones) and notes how the evidence up to now supports elements of his predictions. In addition, he discusses how his model could be refuted. I found both the predictions and potential refutation refreshing.

However, not everything that Rossano contends is crucial for his argument. For example, he sees the super-eruption of Mount Toba as nearly wiping out humans. This idea is in contrast to the view of Michael Balter, who, in his report on a conference (*Science* 327: 1187–8) that examined the Toba eruption, notes that the experts disagreed on its impact. Rossano presents his position as unequivocal when it is not. Additionally, a more sophisticated view would see the early years in Africa as often threatening the existence of the human species (e.g., James L. Boone, "Subsistence Strategies and Early Human Population History: An Evolutionary Ecological Perspective," *World Archaeology* 34 [2002]: 6–25). However, these modifications do not detract from his overall argument.

Not only is the book scholarly, but also it is well written. Rossano entertains his readers not only with his appeal to critical inquiry, but also with his incorporation of humor. Furthermore, he often sums up his discussion and provides abundant subheadings to keep the reader orientated. As a result, the reader knows where Rossano has been and where he is headed.

Overall, this is a valuable book, and I look forward to reflecting further on Rossano's arguments and seeing how its predictions withstand future evidence.

Reviewed by Bruce Buttler, Professor of Biology, Canadian University College, Lacombe, AB T4L 2E5.

Book Reviews

SCIENCE AND THE SPIRIT: A Pentecostal Engagement with the Sciences by James K. A. Smith and Amos Yong, eds. Bloomington, IN: Indiana University Press, 2010. 217 pages. Paperback; $24.95. ISBN: 9780253222275.

This is a very interesting collection of articles that explore questions of spirituality in the light of contemporary science and technology. These are crucial issues for today with our culture seeking real answers as to how it can have an authentic and Spirit-empowered faith that is also consistent with the exciting discoveries of modern science and the challenges that arise with cutting-edge technologies. The contributors deliver insightful ideas on a wide range of topics at the interface of science/technology and Pentecostal theology. The book is divided into three sections, with three articles in "Part One: What Hath Azusa Street to Do with MIT?" There are four articles in "Part Two: The Spirit of Matter: Questions and Possibilities in the Natural Sciences," and three articles in "Part Three: The Human Spirit: Questions and Possibilities in the Social and Technological Sciences." Prior to these ten chapters, the editors provide a brief introduction to set the stage for this emerging conversation between Pentecostalism and science. The articles are meant to be comprehensible to the undergraduate student while also offering penetrating analysis of the tough questions facing this frontier from a scholarly perspective. They achieve a good balance in this regard.

In Part One, chapter one, Telford Work explores scientific knowledge in theological context. He catalogs western Christian responses to the rise of scientifically inspired cosmologies and then offers his own ideas regarding an "obscure" plan of God. He suggests a "scientific and spiritual gift exchange" and writes that the quest for holiness can benefit from evolutionary science. In the second chapter, James K. A. Smith dives into the thorny question of scientific methodology for the Pentecostal believer. After providing helpful definitions and distinctions up front, he asserts that there is nothing inconsistent about working from a Pentecostal worldview and affirming a kind of methodological naturalism (MN). However, in the light of God's activity in continuously holding all things together, a Pentecostal ontology might force one to reject MN in terms of both "closure" and "intervention." In the third chapter, Amos Yong provides Pentecostal perspectives on current models of divine action. He discusses Polkinghorne's model of God acting through chaotic systems at the quantum level, but admits that it may be a mistake to insist that divine action is even observable and measurable by humans. He proposes a pneumatological theology of divine action with several interesting theses, including the idea that the laws of nature are more loose than rigid, allowing nature to still surprise us, and the idea that divine action must be understood eschatologically and teleologically with reference to God's purposes in advancing the kingdom.

In Part Two, chapter four, Wolfgang Vondey explores the relationship between physics and theology and concludes that they need not be separate, emphasizing that methodology is the key, and referencing concepts of "spirit" held by both Newton and Einstein. He suggests that a Spirit-oriented approach may lead to a reconsideration of current methodology (MN), with the goal being to discover the role of the Spirit in the origin, availability, and distribution of reason in the universe. His assertion that the Spirit-filled physicist will operate on a different level than a "carnal" scientist, being able to discern hidden things as the Spirit reveals, will be hard for some readers to swallow. This article could have benefited from more interaction with Smith's article in chapter two and vice versa. In the fifth chapter, Steve Badger and Mike Tenneson do a good job of describing the current positions on creation, and also provide some helpful statistics indicating a shift from young earth to old earth and evolutionary creationism. However, the smaller number of respondents in the more recent poll casts some doubt on the significance of these results. They describe the positions of various Pentecostal denominations and encourage researchers to remain open to the active, ongoing, creative role of the Spirit in nature. In the sixth chapter, Frederick Ware addresses the question of whether religious experience can be reduced to brain activity. He explores the idea that "self-transcendence" may function as a telos of consciousness. He then suggests a multifaceted approach in which reductive materialism is abandoned, narrative is significant, and hypotheses are formed and tested in the light of metaphors and other structures disclosed in narratives of conscious experiences. In the seventh chapter, Donald Calbreath proposes a holistic Pentecostal approach to mental illness, exploring the issue of depression from both medical and spiritual perspectives. Causes and treatments are explained and critiqued. An integrated model is proposed with information on various options available for those dealing with depression.

In Part Three, chapter eight, Craig Scandrett-Leatherman provides a personal discussion of his participation in science, Spirit, and social reconstruction as an anthropologist and Afropentecostal. He stresses the role of participation in science and how humans are changed in the process. By exploring the cases of Frank Cushing, Michael Polanyi, and Victor Turner, he promotes healing and transformation through participation in community rituals and in the ways and disciplines of elder experts. In the ninth chapter, Margaret Poloma explores the possibility of integrating Spirit and sociology from a personal and postmodern perspective. She claims that other ways of knowing, beyond science, are valuable and measurable, and that a postmodern view can lead to more openness to Christianity. Her current research shows great potential in studying the "dynamic interaction between divine and human love that enlivens benevolence." In the final chapter, Dennis Cheek addresses the question of how Christians should approach the design, appropriation, and use of technologies to satisfy human wants and needs. Being an engineer, and convinced that engineers have significant contributions to make to the science and theology dialogue, I felt that the editors had saved the best for last. To my delight, drawing heavily from his recent doctoral dissertation on "Theology and Technology," Cheek explores God's role as a systems engineer. Recognizing our duty as creation stewards, he outlines the beginning of an appropriate Christian response to technology.

Each of these papers is helpful in addressing crucial questions at the interface of science and Pentecostal spirituality. The book is a valuable resource for those who dialogue with scientists, engineers, and interested others about the potential for a Spirit-empowered faith that is simultaneously concerned with scientific integrity and careful stewardship of technology.

Reviewed by Dominic M. Halsmer, Professor of Engineering and Dean of the College of Science and Engineering, Oral Roberts University, Tulsa, OK 74171.

THE TRINITY AND AN ENTANGLED WORLD: Relationality in Physical Science and Theology by John Polkinghorne, ed. Grand Rapids, MI: Eerdmans, 2010. 232 pages. Paperback; $30.00. ISBN: 9780802865120.

Sir John Polkinghorne is one of the leading figures in advancing the science/theology dialogue. This book, which is a collection of essays presented at two different conferences sponsored by the Templeton Foundation and edited by Polkinghorne, moves the discussion to a deeper level by examining the interplay between relational theology and quantum theory. The motivation for considering these two apparently disparate subjects resides in the concept of holism.

In quantum theory, holism is manifest in the property known as "entanglement." Entanglement expresses the idea that two systems can be more strongly correlated than would otherwise be possible were classical (i.e., nonquantum) physics a sufficient framework for describing physical law. It can be illustrated by the following example. Consider two fair coins, one held by Alice and the other by Bob. Now suppose that Alice and Bob each flip their coins 1,000 times in sequence and record the outcomes. We would see about 500 heads (H) and 500 tails (T) for each, as expected from the normal laws of probability. If we looked at them pairwise, we would see about 250 HH combinations, 250 HT combinations, 250 TH combinations, and 250 TT combinations, where the first letter is Alice's result and the second is Bob's. No surprises here either: since the coins are fair, each combination should appear about 25% of the time. Now suppose the coins are entangled. There are many ways of doing this, so for definiteness, let us pick one: we will say that when Alice gets H, so does Bob; and when Alice gets T, so does Bob. Repeating the above experiment, we will find that we get about 500 HH combinations, 500 TT combinations, but no HT or TH combinations: in this sense the correlations are not random. Yet if we consider just Alice's results alone, we will find that H and T occur in random order about 500 times each, with the same situation holding for Bob's. In other words, the entangled coins individually behave as though they were fair, but taken together, they behave as though they were biased. The pair of coins (which in actual experiments would be a pair of electrons or a pair of photons) as a system is literally greater (i.e., has richer information content) than the sum of its parts.

The Trinity is a theological concept used to express the relationship between God, Christ, and Holy Spirit, one that affirms simultaneously both the individuality of each person and their indissoluble unity. The term *perichoresis* further expresses co-indwelling, co-inhering, and mutually interpenetrating. Each person in the Trinity shares in the life of the other two, yet each has its own distinct manifestation and forms of expression.

Are there interpretative lessons that each discipline can learn from the other? Is there a meta-message that quantum entanglement has to teach us about a deeper structure to reality? Is a theology that emphasizes the relationship within the Trinity a more appropriate foundation for all of Christian faith? These are the kinds of questions this book addresses.

While the scientific contributors to this volume tend to concentrate more on explaining the basic science of entanglement than on making theological or philosophical comments about its implications, they do not shy away completely from this task. There are also essays that go beyond physics and theology, venturing into implications for sociology and cosmology.

One of the more refreshing aspects of the book is how it draws together insights from Protestant, Catholic, and Orthodox perspectives. The Orthodox perspective plays a particularly prominent role, with quite a number of the contributors commenting on the Trinitarian insights drawn from that tradition. I learned from several of these essays, and found that they enriched my faith.

While I enjoyed reading this book, I would caution that it is not an easy read. It will make a number of intellectual demands of any reader—scientifically, theologically, and philosophically. However, it is a rewarding read for those that are willing to put forth the effort.

Reviewed by Robert B. Mann, Professor of Physics, University of Waterloo, Waterloo, ON N2L 3G1.

WIRED FOR GOD? The Biology of Spiritual Experience by Charles Foster. London: Hodder, 2010. 352 pages. Hardcover; $23.95. ISBN: 9780340964422.

Readers of *PSCF* are undoubtedly aware of emerging discussions about whether (and how) findings in neuroscience and psychology bear on matters of Christian faith. Indeed, a sizeable collection of neuroscience-related articles has graced the pages of *PSCF* over the last several years. And, as Matthew S. Stanford stated in his guest editorial in the neuroscience-themed June 2010 issue, "[the] points of intersection between psychology, neuroscience, and issues of faith are immense and increasing every day" (*PSCF* 62, no. 2 [2010]: 73).

Charles Foster's *Wired for God? The Biology of Spiritual Experience* is a survey of the diverse array of human spiritual experience viewed in the light of advances in cognitive neuroscience. It is necessary to clarify, however, that the author's subject is not everyday religious belief. Instead, his focus is on what happens in the brain during profound mystical experiences and on what conditions might aid one in having such experiences. Thus, the central thesis of the book is that "[there] is undoubtedly some correlation between some of the things that go on inside our brains and the experiences we call 'religious'" (p. 11).

Some readers may instinctively balk at the idea that there are neural correlates of spiritual experiences, supposing that such material explanations obviate any genuinely spiritual content of the experiences. However, throughout the book, Foster is adamant that such a supposition would be a mistaken and misguided lapse into the wrong kind of dualism (he advocates for a different version of dualism in the appendix), arguing instead that "the corporeal and the incorporeal are intimately related" (p. 80). It should be a comfort to Christian readers that while Foster seeks to describe the material circumstances of religious experience, he pointedly allows for the possibility that such experience is still grounded in a spiritual reality.

Foster approaches the book with a combination of scientific evidence, witty argument, and philosophical musing. His chapters, each in turn, address mental states that resemble spiritual experiences, as well as various means used to attain spiritual experiences: hypnosis, meditation, mental illness, genetics, psychoactive drugs, sex, near-death and out-of-body experiences, hunger, and sleep deprivation. Additionally, he spends a chapter discussing evidence that profound spiritual experiences in ancient human history, most notably those wrought by psychoactive substances, may have been a precursor to modern everyday religion. A discussion of what Foster terms "The Terrible Problem of Consciousness" is deferred to an appendix to avoid bogging down the flow of the book with his especially technical argument.

This book is meant to be accessible to the lay reader; the writing is conversational and highly entertaining at most parts and downright gripping at others. The chapters are short, and Foster avoids overwhelming readers with nitty-gritty details of the science. In most respects, these are strengths for a book directed at an audience with a limited scientific background.

That said, it seems that in an effort not to tax the reader with too much scientific detail, Foster avoids it almost altogether. This lack of scientific detail, nitty-gritty or otherwise, is a gaping hole in this book's argument. For a book that promises to describe "The Biology of Religious Experience," it is disappointingly short on the biology. For instance, in chapter 6, "Finding God in a Garden," Foster describes the vast array of psychoactive drugs used in both ancient and modern societies and how their effects either mimic spiritual experiences—as with the consciousness-transforming effects of LSD—or are used as aids to spiritual experience—as with peyote use in the Native American church. While he says that "[it] looks very much as if drugs work through some […] of the same pathways that are used in non-drug religious experiences" (p. 129), the discussion of the underlying biology—how this is the case and what those common pathways might be—does not extend beyond the statement that "[most] of the main psychoactive drugs are either analogues of naturally occurring neurotransmitters, or change the levels of naturally occurring neurotransmitters" (p. 120). The trend is similar throughout the rest of the book; while each chapter artfully describes a particular trait of spiritual experience, it leaves unanswered the most pressing question: what actually happens to the brain during sex, seizures, hunger, cold, near-death and out-of-body experiences, for example, and what can that tell us about the biology of spiritual experience?

Charles Foster is obviously a skilled writer and his book is an entertaining and thought-provoking read. It raises a fascinating and deep set of questions relating to the nature of spiritual experience and forces the reader to ponder what it means that the "corporeal and incorporeal are intimately related" (p. 80). It is therefore disappointing that although Foster's thesis may very well be true, he neglects to discuss the scientific evidence of how and why it might be true. The promise of the book to address "The Biology of Spiritual Experience" is ultimately unfulfilled. Readers looking for an entertaining overview of the diversity yet commonality of spiritual experiences will thoroughly enjoy this book. Those desiring a discussion of the biology and the neuroscience behind those spiritual experiences had best look elsewhere.

Reviewed by Matthew J. Van Hook, Graduate Student, Brown University Department of Neuroscience, Providence, RI 02912.

EINSTEIN, POLANYI AND THE LAWS OF NATURE by Lydia Jaeger. West Conshohocken, PA: Templeton Press, 2010. 336 pages, index. Paperback; $59.95. ISBN: 9781599472478.

Let me start this review of Lydia Jaeger's *Einstein, Polanyi and the Laws of Nature* by seconding her view that "Let us not merely try to understand the extraordinary actions of the Lord, but let us also, and perhaps first and foremost try to think about how he usually acts in his creation" (p. 216). So much of the science and religion literature focuses on miracles and extraordinary interventions without first getting its bearings on how God normally acts in creation. Fixing more attention on God's normal ways of working in creation is Jaeger's best idea.

Part 1 of the book focuses on the work of Michael Polanyi. While Jaeger gives a serviceable introduction to his epistemological views for those unfamiliar with them, readers already familiar with Polanyi's thinking will find nothing new here and can skip to one of the other parts without loss. In Part 2, Jaeger focuses on Albert Einstein. The introduction to Einstein's thinking on nature, philosophy, and religion is serviceable for anyone unfamiliar with these. Anyone already acquainted with these aspects of Einstein can skip to one of the other parts of the book without loss.

It is Part 3, where Jaeger focuses on the concept of laws of nature in the Bible and science that is potentially the most interesting to *PSCF* readers. In chapter 1 of Part 3, Jaeger writes that "the Old Testament reveals the duality of its thinking about nature. On the one hand, natural phenomena are tied to rules, to a stable order; on the other, the Lord causes them through *immediate* action" (p. 139, emphasis added). As many biblical and theological scholars have emphasized, God is never pictured in the Bible as doing anything in immediate or unmediated fashion—his acts in creation are always mediated.[1] So Jaeger starts out her analysis by adopting a false dichotomy that has been very dominant in both religious and secular thinking about God and creation since the eighteenth century: Every event in nature either occurs because of God's unmediated activity or occurs due to natural processes without any influence of God whatsoever. This dichotomy is foreign to the Bible, and places any analyses of divine action and laws of natural and the created order into a straightjacket. I found Jaeger's discussion of nature, laws, and God's activity in creation in this chapter to basically be reading this dichotomy into the biblical texts (this is what many of her sources do as well). The concept of mediation has been sorely neglected in theology and hermeneutics and offers a way out of the false dichotomy.[2] Unfortunately, mediated action only gets some glancing mentions in the book (e.g., p. 144). Readers will not find the clarity and insight they seek here.

After a summative discussion of historical sources for the origin and motivation for the modern conception of laws of nature (chapter 2, Part 3), Jaeger's conclusion is that biblical revelation provided necessary conditions for the development of the modern notion of laws. In agreement with sound scholarship on the question, she acknowledges that biblical revelation does not provide sufficient conditions for the modern notion of laws. Moreover, through exploring aspects of philosophy of science as well as developments in relativity theory, quantum mechanics, and chaos (chapter 3, Part 3), Jaeger concludes that biblical usage of "law" is in terms of "everyday language" and "prescientific" as in premodern science (pp. 206–7). Yet, only those who have not read much in the literature discussing the history of science and religion will find new information on laws of nature in Part 3.

The fundamental difficulty with this book is that despite its overwhelming number of footnotes (three chapters have over 78; two more chapters, over 100; and one chapter even has 238!), it reads as if Jaeger is only first coming to terms with the science-religion literature and only has a narrow feel for what has been explored therein. The best way to read this book is to obtain it from the library and only look at the parts that interest you as this is not a book that *PSCF* readers should purchase.

A final warning: This book was originally written in French which, as with many languages, makes clear the distinction between the use of the second person plural to refer to the self—the so-called royal we—and the third person plural to refer to a group of people. Unfortunately, the translation of Jaeger's book collapses these different senses together. The translation did her a disservice by not using "I" whenever she referred to herself, or at least substituting "humans," "people," or some other elocution for "we" whenever Jaeger refers to people in general. Readers will grow tired of constantly having to ask, "Who is the 'we'?" page after page.

Notes

[1]For example, C. E. Gunton, *The Triune Creator: A Historical and Systematic Study* (Grand Rapids, MI: Eerdmans, 1998); T. F. Torrance, *The Ground and Grammar of Theology: Consonance between Theology and Science* (1980; reprint, Edinburgh: T&T Clark, 2005); and F. Watson, *Text and Truth: Redefining Biblical Theology* (Edinburgh: T&T Clark, 1997).

2Gunton, *The Triune Creator: A Historical and Systematic Study*; and R. C. Bishop, "Recovering the Doctrine of Creation: A Theological View of Science," *Scholarly Papers*, The BioLogos Foundation (January 31, 2011), http://biologos.org/projects/scholar-essays.

Reviewed by Robert C. Bishop, John and Madeleine McIntyre Endowed Professor of Philosophy and History of Science, Wheaton College, Wheaton, IL 60187.

Letters

On the Relevance of the Idea of Complementarity

I should like to thank Christopher Rios for his fascinating historical article on the idea of complementarity in discussions about the relation between science and Christian belief ("Claiming Complementarity," *PSCF* 63, no. 2 [2011]: 75–84). As an octogenarian, I have had the privilege of meeting a number of the protagonists for this idea.

However, as an engineering scientist, I have often wondered whether both scientists and theologians can forget that their specialist disciplines, such as all human knowledge, concern themselves with models of reality. In engineering, such models are constructed by selecting a small number of parameters which are of special importance for the operation of a device or system. These parameters are constructs of the human mind.

Engineers have constantly to remind themselves that their models are not the actual thing. Models can never be a substitute for a full-scale test. Moreover, useful modeling requires many different models of the same object. Thus a thermodynamic model of a gas turbine does not provide information about the price of gas in its effect on the viability of a project. Engineers who ignore economic models go out of business. This does not seem to me to be due to a philosophical principle of complementarity, but to the distinction between necessary and sufficient conditions in the solution of a problem.

A fortiori even the variety of models cannot elucidate the desirability of building a gas power station which depends on its purpose in generating electricity with its social consequences. Although Bohr's principle is undoubtedly important in the context of quantum physics, it may not be relevant to discussions between theology and science. It brings to my mind a comment attributed to Francis Bacon on William Gilbert's book *De Magnete*, "Gilbert has attempted to construct a world using material insufficient for the pins of a rowing boat."

Percy Hammond
ScD, FREng
United Kingdom

Biblical Longevities: Some Questions and Issues

Walter Makous, "Biblical Longevities: Empirical Data or Fabricated Numbers?" (*PSCF* 63, no. 2 [2011]: 117–30) presents a novel approach to analyzing Old Testament genealogies. However, his methodology raises a number of significant questions which serve to undermine his conclusions.

Most of these questions arise from his Table 1, a purported listing of all generations from Adam to Manasseh which is used for the longevity plot of Figure 1. In order to be correct, it should contain no duplications or gaps. However, it has both. For instance, ordinals 21 and 22, Ishmael and Isaac, are both sons of Abram, ordinal 20, and thus redundant. Similarly, Aaron and Moses, ordinals

28 and 29, are both sons of Amram, ordinal 27. Missing generations abound in the table. David is the only king listed from the time of the unified monarchy, leaving one to wonder what happened to Saul and Solomon. Furthermore, the time of the Judges is virtually absent. Acts 13:18–20 states that the period from the conquest to Samuel was 450 years. Yet, Eli (ordinal 31) is the only judge listed in the table. Such omissions and duplications clearly invalidate the author's L equation based on ordinal number.

The author also ignores the clear lack of expected randomness in many of the entries of Table 1. In the best example, Noah (ordinal 10) was *500* years old when his sons were born and the Flood followed 100 years later when he was 600. His son Shem (ordinal 11) became a father when he was *100* years old and he lived *500* more years, dying at the age of *600*. The chance of this being anything other than a fabricated, symbolic use of special numbers is miniscule. Also consider the ordinals 21, 25, and 27 which all list an age at death of 137 years. What is the probability that any three ages will be identical out of 7 selected randomly within a range of 54 years (the period covered by these ordinals according to the L equation)? The answer is only 0.011. It is concluded that an identical trio of ages as shown in the table is a highly improbable occurrence and a strong sign of fabrication.

One is also suspicious of unrealistic data "bunching" which occurs between the total ages of 200 and 600. Ordinals 12–14 list closely spaced ages of 438, 433, and 464. This is followed by a gap of around 200 years to ordinals 15–17 which show the ages of 239, 239 (which, according to the L equation, should be 40 years apart), and 230. Determining a natural explanation for such an unlikely spacing of numbers is very problematic. The author also argues for rounding but fails to explain table entries which are clearly not rounded, nor provide any reference to the use of this mathematical practice with regard to ages during the first millennium BCE.

The author states that all genealogical numbers used in his study are obtained by a computer search of the (Masoretic-based) NIV biblical edition. However, this method does not work for the patriarchal period since multiple texts from antiquity exist which differ in the various ages listed. These include the Septuagint and the Samaritan Pentateuch, with the Book of Jubilees and writings of Josephus providing secondary sources. To add to the problem, different versions of the Septuagint (Lucian and Alexandrian) even disagree on some of their numbers. The differences between the ages in these various texts are significant, with many corresponding numbers differing by 100 or more. The author fails to mention these other versions and how they would affect his conclusions.

A final significant issue left unaddressed by the author is how the earliest genealogical numbers were accurately transmitted. The first written Hebrew records appear in the time of the united kingdom around the eleventh century BCE. Thus, all genealogical ages prior to that time were almost certainly transmitted orally in a tribal, pastoral environment. Although it has been shown that folk tales and myths describing major events (e.g., a volcanic eruption) have been transmitted in such a way for as long as thousands of years, accurate transmission of generations of ages over such periods is undemonstrated. In fact, it has been shown that oral transmission encourages stories, including numbers, to be changed and adapted to the needs of the bard and the situation. Accurate ages from patriarchal times are thus unproven and highly questionable.

Donald A. Huebner
ASA Member
huebnerdon@aol.com

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13. Publication Title: Perspectives on Science and Christian Faith
14. Issue Date for Circulation Data Below: September 2011

15. Extent and Nature of Circulation: Worldwide		Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
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b. Paid Circulation (By Mail and Outside the Mail)	(1) Mailed Outside-County Paid Subscriptions Stated on PS Form 3541 (Include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)	1788	1774
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f. Total Distribution (Sum of 15c and 15e)		2119	2102
g. Copies not Distributed (See Instructions to Publishers #4 (page #3))		130	54
h. Total (Sum of 15f and g)		2249	2156
i. Percent Paid (15c divided by 15f times 100)		95.42	95.48

16. Publication of Statement of Ownership
☒ If the publication is a general publication, publication of this statement is required. Will be printed in the December 2011 issue of this publication.
☐ Publication not required.

17. Signature and Title of Editor, Publisher, Business Manager, or Owner: Executive Director
Date: September 21, 2011

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American Scientific Affiliation
55 Market Street, Suite 202
PO Box 668
Ipswich, MA 01938-0668

Phone: (978) 356-5656
FAX: (978) 356-4375
E-mail: asa@asa3.org
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