PERSPECTIVES on Science and Christian Faith

JOURNAL OF THE AMERICAN SCIENTIFIC AFFILIATION

In This Issue …

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

VOLUME 69, NUMBER 2 **JUNE 2017**

(US ISSN 0892-2675) (CPM #40927506)

Perspectives on Science and Christian Faith (USPS 28-3740, ISSN 0892-2675) is published quarterly by American Scientific Affiliation, 218 Boston Street Suite 208, Topsfield, MA 01983. Periodicals postage paid at Topsfield, MA, and additional mailing office. POSTMASTER: Send address changes to: Perspectives on Science and Christian Faith, 218 Boston Street Suite 208, Topsfield, MA 01983.

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Editorial

James C. Peterson

Asilomar II: The Ongoing National Academy of Sciences Report on CRISPR

The possibilities and risks of recombinant DNA triggered the famous Asilomar Conference in 1975. Geneticists agreed there on safeguards for their research with recombinant DNA. A second such formative conference was held in Washington, DC, in December of 2015. This one was triggered by an even more transformative new genetic technology called CRISPR Cas9. Instead of clumsily working proteins, CRISPR Cas9 (and now Cas13) makes possible uniquely specific deletions and additions in RNA. The National Academy of Sciences and the National Academy of Medicine of the USA, the Chinese Academy of Sciences, and the Royal Society of the UK, called together a gathering of the founding scientists with some advisors to work through the best direction for this strikingly efficient, precise, and inexpensive method to edit DNA. At that conference, I saw first hand the challenge of developing ethical consensus. The conversation went from 7:00 each morning to 7:00 in the evening with food brought in for three days. The resulting statement was heralded on all the major television and newspaper networks, but largely missed by the public. It was released at the end of the conference, December 3, 2015, while the news stream was dominated by the San Bernardino massacre.

The agreed communiqué begins: "Scientific advances in molecular biology over the past 50 years have produced remarkable progress in medicine." It continues, "The scientific community has consistently recognized its responsibility." Of course, the subtext here is that we geneticists are doing work that should be supported, and we will regulate ourselves. There is no need for governments to clumsily intervene. Granted research funding is still most welcome and productive. Keep that coming.

The document then advocates four conclusions:

1. *Intensive basic and preclinical research is clearly needed.* We are only beginning to realize the opportunities with CRISPR to extend our understanding.
2. *Clinical applications at this point should be intended to affect only the presenting patient.* Every word in a document such as this, counts. The key word here is "intended." Participants know that treating the presenting patient (somatic) often has implications (germline) for any children that they might have. We have already somatically tested and treated for PKU long enough to see its incidence increase. That is a germline effect, from a standard of care, somatic, effort.
3. *Deliberate germline editing should not be pursued until safety and efficacy issues have been resolved, and there is broad societal consensus that such editing is appropriate.* The key word here is "until." Participants expect that germline editing will eventually be welcome, but realize that it is not yet. That awareness leads then to the fourth conclusion.
4. *There should be ongoing discussion that is inclusive among nations and from a wide range of perspectives* "including biomedical scientists, social scientists, ethicists, health care providers, patients and their families, people with disabilities, policymakers, regulators, research funders, faith leaders, public interest advocates, industry representatives, and members of the general public."

The dialogue has indeed continued globally, and will extend to Golden, Colorado, this July. At the 2016 Annual Meeting of the American Scientific Affiliation, Douglas Lauffenburger of MIT ably began our discussion in a premeeting workshop. At the 2017 Annual Meeting, I will continue that conversation with a plenary on the ongoing proposed guidelines concerning somatic, germline, curative, and enhancement uses in human beings, and will include Christian insights and purpose that might shape our response. I look forward to thoughtful discussion and what we will discern working together. ✠

James C. Peterson, *editor-in-chief*

Medicine and Miracles: Cancer and Cures

Michael A. Birbeck and Douglas A. Lauffenburger

Michael A. Birbeck

Douglas A. Lauffenburger

Among the complicated interfaces of science and faith is the question of the relationship between human medical practice and transcendent actions of God in the treatment of disease and injury. As Christians, we pray in faith to our Creator and Lord for his providential intervention to bring about healing. At the same time, we generally trust that there can be benefit from efforts to heal by physicians, and that investment in research might usefully develop improved methods for medical practice. While there need not be conflict between these two approaches, their relationship often is not considered explicitly. Our article here offers some basic thoughts about how prayer and medicine can be concomitant partners in a Christian's perspective on one of the central health problems in contemporary society, that of cancer and its treatment. (Note: This article has its origins in a lecture given by one of the authors at the Faraday Institute [Cambridge, UK] in November 2014.)

Albert Einstein offered an insightful metaphor to describe his view of the relationship between science and religion: "Science without religion is lame; religion without science is blind."[1] While this metaphor does not resolve all the difficulties of integrating science and religion, it nevertheless affirms a cooperative relationship between these realms of approach to understanding our world and our lives. In the long-standing dialogue between science and religion, an abundance of attention has been devoted to topics in which historical and philosophical realms of approach to understanding our world and our lives meet. Among popular examples can be found the origin of the universe, the emergence of humankind, the source of knowledge, and the nature of free will.

In our own work and conversations, we two authors—one a pastor and one an academic biomedical researcher/teacher—have frequently landed on a more contemporary topic of mutual interest as scientifically interested believers of the Christian faith: the relationship between the human science endeavor of medicine and the human faith endeavor of prayer. There seems to be a much thinner body of literature delving into this area of dialogue. Our hope here is to offer several ideas from our personal viewpoints, especially as refined by valuable discussion. We will focus on a limited sector of human disease, that of cancer, for contemplating how Christians might usefully consider the integrated roles of medicine and prayer in the hope of overcoming this oft-tragic malady.

Receiving the diagnosis of cancer is a common experience for vast numbers of us. Almost everyone has a loved one who has suffered, or is suffering from, cancer of one kind or another. And we all trust in modern medical practice for the most effective possible treatment, yet at the

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same time we pray to our Lord God for a favorable outcome. The specific question we aim to address in this article is, How do we reconcile, integrate, or at least comprehend concomitant roles for human medicine and for providential intervention in the treatment of cancer patients?

It is worth explicitly noting here what we leave beyond the purview of this article. We do not aim to analyze efficacy of prayer per se in a meta-data manner, for that is a separate topic clearly meriting its own consideration. Instead, we focus on how potential efficacy of prayer in any individual instance may be understood, as it is surely appreciated as a vital aspect of Christian faith in all circumstances, including cancer treatment. That being said, it is heartening to remember an enriching insight from Reverend Martha Giltinan, who taught that "God always heals but does not always cure."[2]

Motivation: The Medicine/Faith Interface

From our perspective, modern medicine can be understood as an extension of humankind being made in the image of God. Genesis 1:27–28 says,

> So God created humankind in *his image*, in the *image of God* he created them … God blessed them, and God said to them, "Be fruitful and multiply, and fill the earth and *subdue* it; and *have dominion* over the fish of the sea and over the birds of the air and over every living thing that moves upon the earth." (NRSV, emphasis added)

A consensus on the meaning and significance of the *imago Dei* concept has not been reached. However, many agree that the concept expresses both humankind's unique relationship to God—in contrast to all the other creatures on Earth—and humankind's unique relationship to creation as a whole. Included in the manifest of imperatives God gives to humankind in Genesis 1 is the command to "subdue" the earth and to "have dominion" over what we might call a list of ancient taxonomic categories. Given the agrarian culture these words were originally communicated to, it makes sense for this message to be transmitted via concepts that made sense to that ancient culture. Biblical scholar Kenneth Mathews discusses the mandate to subjugate:

> This appointment by God gave the human family privilege but also responsibility as "caretakers" (2:15). The Hebrew love for life and emphasis on sacredness of all life assumed a linkage between righteousness and the welfare of the earth. In the agrarian economy of ancient Israel, this was best expressed in the care for its livestock.[3]

In our modernized, specialized culture, of course, caretaking as part of the *imago Dei* is different from what it was in that ancient culture. Hence, seeking to alleviate cancer and all other diseases is a type of God-honoring caretaking that we see flowing out of humankind. Modern medical practice can be seen as fulfilling God's mandates to subdue and have dominion over the created order.

A redemptive quality may also be perceived in medical practice. Not far from Douglas Lauffenburger's church in Cambridge, Massachusetts, the words of Revelation 21:4 are etched on the base of a forty-foot-tall monument that sits in the shade of overhanging tree branches in the verdant Boston Public Garden: "Neither shall there be any more pain." The monument commemorates the discovery that the inhaling of ether causes insensibility to pain; this was first proven to the world at the Massachusetts General Hospital. The monument implicitly connects the accomplishment of Dr. William Morton and Dr. John Warren, who performed the first painless surgery, using ether, in 1846, to the consummated new creation of Christ that is yet to be fully realized—as attested to in Revelation 21:4. Commonly referred to as the Ether Monument, it is also known as the Good Samaritan, because atop its capital the Good Samaritan from Jesus's well-beloved parable kneels down to care for an injured stranger. The stranger is propped up against the thigh of the Samaritan, who is holding a cloth, allegedly doused with ether, in his hand.

While we believe that ultimate redemption will occur only through Christ's second coming and the consummated new creation that will result, we also believe that Genesis 1:28 strongly affirms that our lives and work at present greatly matter. Medical researchers and practitioners strive toward the ideal of the consummated creation, when there will be no pain or illness (Rev. 21:4), by working against the disease and death that tragically grip our fallen world in this present age. A significant part of Jesus's ministry involved healing those afflicted with disease and congenital defects. In this vein, medical scientists and researchers join in Christ's earthly ministry and God's ultimate plan to redeem creation. We do this by identifying the observable and measurable laws

of nature and utilizing those findings to develop medical treatments that alleviate adverse medical conditions. This alleviation, from a theological perspective, is redemptive.

Admittedly, we aim to accomplish this God-honoring, human endeavor as imperfect and finite beings, with acknowledged dependence on him. This confession takes us to our second point. As Christians, we believe that God providentially works through prayer and calls us to pray for those who suffer from sickness. The gospel writers attest to a multitude of occasions when the prayers of Jesus and his disciples healed persons suffering from various diseases and congenital defects. A well-known scripture that urges Christians to pray for those who are sick is found toward the end of the Epistle of James.

> Are any among you sick? They should call for the elders of the church and have them pray over them, anointing them with oil in the name of the Lord. The prayer of faith will save the sick, and the Lord will raise them up … (5:14–15, NRSV)

Thus, on the one hand, the human science endeavor of medicine both fulfills the creation mandate to "subdue" and "have dominion" over the earth (Gen. 1:28), and joins with God in his ultimate plan to redeem all of creation (Rev. 21:4). Yet, on the other hand, Scripture commands us to pray for favorable outcomes for those facing adverse conditions, such as cancer. In scriptural words, we confess our humility, or possibly simply express our confusion or even our frustration: God's thoughts are not our thoughts, neither are God's ways ours (Isa. 55:8). Yet, is there a way to reconcile, integrate, or at least comprehend concomitant roles for human medicine and for providential intervention in the treatment of cancer patients? Is there a way to hold the two realms of approach together, without sacrificing one for the other?

The words of the sixteenth-century theologian John Calvin give some insight into this question.

> It is very absurd … to dissuade men from prayer, by pretending the Divine Providence, which is always watching over the government of the universe is in vain importuned by our supplications, when, on the contrary, the Lord himself declares, that he is "nigh unto all that call upon him, to all that call upon him in truth" (Ps. 145:18). No better is the frivolous allegation of others, that it is superfluous to pray for things which the Lord is ready of his own accord to bestow; since it is his pleasure that those very things which flow from his spontaneous liberality should be acknowledged as conceded to our prayers.[4]

While medical scientists utilize observation of natural laws in their work to overcome adverse medical conditions, we believe that the God who established those laws can work through them with unparalleled power because he is the originator of the natural world and transcendent over it. As Calvin notes, God displays, through our prayers, his "spontaneous liberality."

Background: Cancer Biology and Treatment

Although our interest in learning how to integrate prayer and medicine should apply broadly across the entire range of human health problems, we will focus on cancer as a central example. It is unfortunately a highly prevalent and consequential disease; data from the American Cancer Society shows that, in the United States in this current decade, there are typically more than 1.5 million new cases each year and more than 500,000 deaths—nearly 25% of the fatalities in this nation.[5] It is important to note that cancer is not a monolithic disease, but rather it exhibits tremendous diversity with respect to type and underlying causes. Accordingly, there is a wide range of prospects for outcome, depending on the type of cancer. For instance, average 5-year survival rates for patients diagnosed with breast or prostate cancers are relatively more favorable, when compared to those for patients diagnosed with lung, pancreatic, ovarian, or brain cancers. And within each cancer type, outcome prospects can vary significantly among different subtypes. These subtypes are increasingly identified with disparate genetic characteristics, and their treatment approaches are similarly influenced by these specific associated molecular properties.

The critical role of specific genetic characteristics is a key feature of cancer, in that it is well established that mutations in chromosomal DNA are at the root of the dysregulation of cell functions that yield pathological behaviors of tumor cells. The "hallmarks" of cancer are generally agreed upon by bioscientists, and include a number of aberrant cell behaviors leading to tumor growth and spread: cell proliferation in contexts where it should not occur; resistance to

cell death in contexts where it should occur; migration of cells into contexts where they should not be; induction of growth-supporting contexts where they otherwise would not be extant; suppression of death-promoting immune responses where they otherwise would defend effectively.[6] Each of these aberrant behaviors arises from chromosomal mutations that result in operations of intracellular or extracellular protein gene products that are different from what they ought to be under healthy physiological conditions. The number of genetic mutations present in a given tumor may cover a wide range, from as few as a dozen in leukemia to as many as thousands in colon cancer. How the multiple mutations work together to cause aberrant cell behaviors is a vigorous research area in cancer biology, and how to ascertain the most-effective therapeutics corresponding to the particular set of mutations found in any given tumor is at the forefront of cancer treatment—representing the aspiration for "personalized medicine," or "precision medicine," in which molecular information characteristic of a certain patient helps determine treatment plans.

Turning to treatment, we noted earlier that prospects for outcomes may be viewed as "more favorable" or "less favorable," depending on the tumor type (as well as on the therapeutic approach). These prospects are generally estimated in terms of probabilities: for instance, the 5-year survival probability is based on prior clinical data for previous patients possessing at least categorically similar tumor types and who were provided with fairly comparable treatments. One might ask what the roots of this uncertain nature of outcome prospects are. We can offer four categories of issues underlying uncertainty in cancer patient treatment outcome prospects:

1. "Discovery"—Outcome uncertainty may derive either from lack of scientific knowledge concerning key currently unknown biological mechanisms involved in how tumors respond to various treatments, or from lack of technological knowledge about how to treat them more effectively. For instance, if a patient's tumor is characterized by dozens of genetic mutations, further complicated by heterogeneous distribution of those mutations within the primary tumor or across multiple metastatic secondary tumors, bioscience does not currently have complete information as to how these mutations integrate to yield aberrant cell behaviors nor what must be done therapeutically to ameliorate this aberrance.
2. "Wisdom"—Outcome uncertainty may derive from inadequate understanding by the physician/caregiver about the treatments available for the patient. Although not always, there often exist multiple alternative therapeutic options for a given type of cancer, and at the present time, the rules for selecting the best option are not generally well established. While key tumor characteristics are being increasingly identified for many types of cancer, and these discoveries have accelerated over the past decade-plus with the advent of genomic and proteomic technologies in clinical research, firm associations between these characteristics and effective treatments remain elusive.
3. "Accessibility"—Outcome uncertainty may derive from questioning whether the physician/caregiver can feasibly determine the most effective treatment. Whether due to limitations related to capabilities, cost, policy, or location, a given patient may not be in a position to have key tumor characteristics analyzed that may be decisive concerning the selection of the best treatment.
4. "Randomness"—Outcome uncertainty may derive from known biological mechanisms, in relation to available treatments, that respond in an unpredictable manner to a selected treatment. That is, even if/when we gain complete information concerning patient tumor mutation distribution along with therapeutics that perfectly correspond to address that particular genomic status (point 1, Discovery, above), we can imagine that the response of the tumor cells might nonetheless be stochastic and thus unpredictable in any specific case, even if probabilistic expectations can be quantified.

The first category must be considered largely a matter of time and human endeavor, for the pace of biomedical knowledge accumulation continues to become ever swifter. In the decades to come, information helpful to producing more and more effective treatments can be expected to grow inexorably. Nonetheless, the history of biological science is such that surprising new mechanisms involved in the processes of human pathophysiology arise regularly, and there is little reason to believe that we are anywhere near completing comprehension of tumor

cell dysregulation and how to decisively and safely overcome it in general or specific terms. The second and third categories derive mainly from human cognitive abilities and human cultural contexts, thus residing at a relatively ambiguous level with respect to expectations. From a scientific perspective, the fourth category is of greatest interest because it connects a fundamental phenomenological feature of our natural world to the practical understanding of medicine. Thus it is deserving of greater elaboration here in our discussion.

A Fundamental Principle: Stochasticity in Molecular Processes

In physics, the phenomenon of stochasticity is well known; one definition is that a stochastic process involves at least some effects operating randomly, such that the observed outcome of any individual instantiation cannot be predicted other than as a representative from a probabilistic distribution of numerous instantiations. We note that a stochastic process is not the same as a chaotic process. In the latter, if initial conditions were precisely known the outcome of an observation could be predicted. In the former, the outcome remains uncertain even with precise knowledge concerning the initial conditions.

An example commonly used for illustration purposes is that of radioactive decay of an elemental atomic particle. For instance, a Carbon-14 atom possesses a nucleus of 6 protons and 8 neutrons, but when one of the neutrons transitions to become a proton (via "beta particle decay") a Nitrogen-14 atom is produced. Observations of large numbers of Carbon-14 atoms produce a firm scientific law that the decay "half-time" is 5,730 years. Thus, for any particular individual Carbon-14 atom, there is a probabilistic expectation of approximately 10^{-4} that within the next year it will decay to a Nitrogen-14 atom—but we cannot predict with certainty whether it will or not. If we follow a large number of atoms, the time at which they decay will form a distribution characterized by some decaying relatively swiftly and others decaying relatively slowly, with a tiny proportion decaying exceptionally swiftly and another tiny proportion decaying exceptionally slowly—but averaged all together producing the established half-time law.

Another example is the diffusive motion of an object, due to forces acting on it. Observations of large numbers of objects of any given size produce a firm scientific law for the expectation of how far a distance half the objects will have moved from their original locations within a specified time-period—but, for any particular individual among these objects, we cannot predict with certainty how far it will have moved in that period. It is important to emphasize that, with respect to both of these simple examples and others, and for discussion to ensue later in this article, that these unpredictable individual entity events transpire within an associated scientific law that reliably characterizes the average behavior of a very large number of entities and events. Nonetheless, a behavior influenced by a fairly small number of events can be observed as a low-probability outcome yielded by those events happening in a sufficiently skewed sampling (e.g., faster vs. slower) from within the large-number distribution.

The question then is how this general principle of stochasticity might be relevant to cancer treatment. It is well appreciated that the key cell behaviors involved in the established hallmarks of cancer (e.g., proliferation, apoptotic death, migration) appear random across individual cells within a population. Some cells might divide into two cells sooner or later than other cells under the same conditions, while other cells in that population will not divide at all. Similarly, some cells within a population might be killed by a drug sooner than or later than other cells, whereas others are not killed in the very same treatment. Tumor spread via invasive migration and metastasis is likewise random, with a small proportion of cells departing the primary tissue location, and subsequently only a fraction of these surviving in a new tissue site elsewhere in the body.

Contemporary research in all of these areas of cell biology not only recognizes the phenomenon of stochasticity in the respective cell behaviors, but is also giving increasing attention to its study in normal cell function as well as in cancer-associated dysregulated cell function. Indeed, investigators have been able to elucidate explanations for how disparities in behavioral responses among cells in a population may yield benefit to robust organism physiological function.[7]

As one highly germane example, the behavioral process known as apoptosis, or programmed cell death, has been subject to numerous experimental studies over the past few decades. A number of reagents,

both natural (factors produced in an inflammation, for instance) and synthetic (such as cancer chemotherapeutic drugs), can induce cell death via enzymatic degradation of cellular components crucial to maintaining viability; these components include chromosomal DNA and structural proteins. These degradative enzymes are activated by biochemical and biophysical reaction pathways within the cell, elicited by the stimulatory reagents. Whether a given cell undergoes the death process, or instead recovers from it by means of mitigative biochemical and biophysical mechanisms, is governed by this myriad of actors and actions with respect to their amounts and rates. Using any of a battery of experimental methods, following a given treatment condition, some fraction of a treated cell population can be observed to undergo apoptosis whereas the remaining fraction is not.[8] Moreover, even for the subpopulation that does die, the timing at which the death execution transpires for any particular cell can vary widely across a time period of many hours following treatment.

In the same manner as the radioactive decay and particle diffusion processes described above, average apoptotic response properties can be quantified for the population; thus, this cell biological phenomenon reliably follows a scientific law derived from observation. Similarly, an observer cannot predict for any individual cell whether, or when, that cell might die in response to the treatment. The reader should readily appreciate the relevance of this randomness to the uncertainty concerning the outcome of cancer therapy used to destroy tumor cells, and then multiply this in additional dimensions for each of the other cancer hallmark cell processes as they are comparably stochastic.[9]

What is the source of this randomness in biological cell behaviors? A partial answer is that there is heterogeneity among the cells within a tumor population (or, for that matter, within any population of normal, healthy cells), as all studies of cellular protein levels consistently demonstrate. This heterogeneity can generally be characterized by cell-to-cell variation in the numbers of any of the myriad proteins governing cell behavior, such as proliferation or death or migration. This number variation may arise from mutations present in some cells but not in others. Even if the genome sequence is absolutely identical across all cells in the population, the mechanistic processes of expressing those genes into their corresponding proteins can operate in stochastic fashion, with some expression processes taking place faster in certain cells than in others. And, of course, the presence or absence of any particular genetic mutation among cells in a population is stochastic, due to the nature of the molecular processes giving rise to changes in any given DNA site in a chromosome. Not surprisingly, then, exhibition or acquisition of resistance to an anti-cancer drug is similarly stochastic, whether due to gene expression heterogeneities and/or gene mutation heterogeneities—both of which are subject to the underlying mechanistic process of stochasticity.

Accordingly, in our view, it is inescapable that the prospective outcome of therapeutic treatment of cancer will ever remain unpredictable for any given patient, regardless of how far biomedical science continues to progress in knowledge about cancer biology and in capabilities for therapeutic approaches. It is not a matter of incomplete knowledge on the part of human beings, but instead a matter of the fundamental nature of our natural world.

Analysis: Transcendence and Chance

We have already identified four categories of issues underlying uncertainty in cancer patient treatment outcome prospects: discovery, wisdom, access, and randomness. We want to see a favorable outcome for loved ones who suffer from cancer. It is easy enough to see how Christians can pray for such an outcome in regard to the first three categories:

1. "Discovery"—While this category likely will not help a loved one diagnosed with cancer today, we can certainly pray that medical and scientific discovery would continue to advance and new and better treatments emerge for future cancer patients.
2. "Wisdom"—We can recall times when we found ourselves in a hospital room praying for wisdom to guide our loved one, and for the physician and medical team to make wise decisions concerning medical treatment, utilizing the best resources available.
3. "Accessibility"—We can pray both on a personal and societal level that access to the very best cancer treatment would be made available to those suffering from cancer.

This brings us to our fourth category, randomness, which we will now discuss in greater depth. Louis Berkhof, in *Systematic Theology*, writes,

> Providence may be defined as that continued exercise of the divine energy whereby the Creator preserves all His creatures, is operative in all that comes to pass in the world, and directs all things to their appointed end.[10]

The Laplacian determinism of enlightenment thought aided in strengthening a view that there must be a sharp division within God's providence, specifically between what has been called the natural and the supernatural. God's providence sustaining the natural world through natural law was seen as categorically different from God's special providence that violated, suspended, or otherwise manipulated those laws.

Advances in quantum physics, particularly the discovery of randomness or stochastic mechanisms, allowed for a flexible universe with a built-in potentiality allowing for the probability of anomalous divine action. William Pollard was among the first to fully articulate this view in his *Chance and Providence*, published in 1958.[11] John Polkinghorne in *Science and Providence* expressed how this view of the natural world accommodated providence:

> … recent advances in science point to an openness and flexibility within physical process—not only at the microscopic level of quantum theory but also at the macroscopic level of large systems—that began to offer hope of some understanding of how both we ourselves, and also God, can exercise our wills in the physical world.[12]

Since there is no sharp division within God's providence when providence is reconciled with this more accurate understanding of the natural world, this is not a God of the gaps theory; there are no gaps. God is active within the totality of the natural world. Speaking of quantum events, Polkinghorne went on to say, "Individual events are characterized by a radical randomness and are even spoken of as being 'uncaused.'"[13] Although beyond the scope of this article, this uncausedness inherent to the natural world would conclude that even an event as highly unlikely as the resurrection would have a very low, but non-zero probability rate.[14]

We contend, with sound scientific evidence, that stochasticity is part of the fundamental nature of our natural world. Stochasticity can be seen as a locus for God's providence where we as Christians can pray for God's influence. Taking stochasticity and providence as givens, it is on the level of stochastic molecular cellular processes that we see an area ripe for discussion about Christian prayer.

It has long been thought that chance and randomness are antithetical to purpose, thus invalidating providence. However, this need not be the case. John Hall analyzed a variety of stochastic processes in several diverse systems, including biological evolution, and demonstrated that these stochastic processes serve a global purpose within the global systems in which they occur.[15] "Local" or "subsidiary" purposes within these systems may or may not be served by any of the vast set of possible outcome prospects in the given stochastic process, but the global purpose is. Because stochasticity serves the global purpose of the global system, Hall contends that stochasticity is consistent with a Christian understanding of providence. This agrees with David Wilcox's conclusion, after he explored the unique bio-evolutionary neurological development of the human brain:

> The evidence of "random" events does not exclude providence—in fact, the meaning can be viewed as quite the opposite … However, such perception requires the acceptance of the specifying assumption that God governs natural events (the doctrine of providence) … Consequently, it is rational to hold this view, but it is not necessarily statistically demonstrable to those who cannot perceive it.[16]

Hall identifies two ways in which "God can be thought of as acting" in regard to providence:

> First, he achieves his general purposes by his uniform divine action in sustaining its orderly, coherent processes. Second, he achieves particular purposes through his special divine action.[17]

This harmonizes well with the classical distinction of general providence and special providences. General providence refers to God's guidance of the whole of creation. Special providences are "special combinations in order of events, as in the answer of prayer, in deliverance out of trouble, and in all instances in which grace and help come in critical circumstances."[18] These are not two different types of providence, but two features of providence as a whole.

Hall goes on to say, "The latter includes anomalous actions that appear discontinuous with the

more prevalent orderly processes of the creation."[19] Although none of us can claim to know the thoughts of God, we can imagine that stochastic processes on a molecular level provide a particularly vital locus—although certainly not the only one—for the type of anomalous action that is often referred to as miracle, divine intervention, supernatural occurrence, et cetera.

Peculiarly, contemporary usage of these terms too often implies that God is less engaged when sustaining the universe than when effecting a "miracle." Pollard said,

> … the majority of the miracles of healing the physico-chemical, physiological, or psychological changes taking place in the body of the person healed could all have well occurred individually in full conformance with the scientific laws governing such processes. The healing resulted from the extreme improbable circumstance that they all occurred together in just the right way to produce the final result. No objective application of known medical or psychotherapeutic could have brought on the particular combination of process required for the healing, but this does not mean that any one of them violated any of the laws known to medicine or psychotherapy.[20]

As interventions at the micro level of stochastic mechanisms transpire, nonetheless the scientific laws derived from observations of myriad events at that level can remain undisturbed. In the case of medical cancer treatments, tumor cells may respond relatively favorably on the molecular level to anti-cancer drugs, resulting in a highly desired yet low- (but non-zero) probability outcome of tumor eradication.

The understanding of miracle we present above may be viewed in context of the common, secular usage of the term. In a newsletter from the highly regarded Dana-Farber Cancer Institute, we happened to come across the following quotes regarding two different cancer patients. Regarding patient A, it read, "In early 2013, she had exhausted standard treatment. What happened next some might call a *miracle*. Much to our surprise, after about six months, her tumor had almost completely disappeared."[21] Regarding patient B, it read, "She started feeling better very quickly, and we could see her tumor mass shrink. It was amazing and must have seemed like a *miracle* after everything she had gone through."[22] In the secular world, a "miracle" tends to mean an outcome that is exceedingly unlikely—yet nevertheless hoped for and gratefully received.

We opened this article by inquiring about the concomitant roles of human medicine and of providential intervention in the treatment of cancer patients. We have decided not only that stochasticity is consistent with providence, but also that stochastic mechanisms on the molecular level are likely to be a vital locus where we might expect God to act through anomalous action. We might conjecture that God works through providential intervention or special providence, of which prayer is a powerful feature, to produce anomalous activity, or miracles, or what Calvin calls "spontaneous liberality," to influence stochastic molecular mechanisms that affect the aberrant behavior of cancer cells and their potentially curative responses to therapeutic treatments. It is not so much that God breaks into nature; he has always been there. We might speak of an intervention, a miracle, or a supernatural event. But, from God's vantage point, it always was, always has been, and always will be. Just as we use the human science endeavor of medicine to aim toward favorable outcomes in medical cancer treatment, so also we can use the human faith endeavor of prayer to aim toward favorable outcomes in conjunction with anti-cancer drugs and treatments (or even outside of anti-cancer drugs and treatment, when the prognosis is dire and further medical interventions aimed toward a cure are deemed futile by a medical professional). Both of these endeavors are guided by providence and features of providence in which God invites us, the human lot, to join him.

Conclusions

We have contended that regardless of how far biomedical science continues to progress, the prospective outcome of therapeutic treatment of cancer will ever remain unpredictable for any given patient. Randomness or stochastic mechanisms are among the issues underlying uncertainty in cancer patient treatment outcome prospects. We have also argued that randomness can be perceived as an aspect of divine providence. Finally, we have posited that God uses the human faith endeavor of prayer as a feature in his providential guidance. Rightly as the human science endeavor of medicine can be utilized toward favorable outcomes in medical cancer treatment, so can the human faith endeavor of prayer be utilized

toward favorable outcomes in those treatments, particularly in regard to asking for God's influence over stochastic molecular mechanisms. ✠

Notes

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Harry Lee Poe

Article

Creating a Medium for Exploring the Implications of Science: Edgar Allan Poe and the First Science Fiction

Harry Lee Poe

Science fiction has emerged as one of our culture's means of carrying on a broader conversation about the direction of both science and technology. It asks the questions of unintended consequences and what might be the long-term outcome of applied science. One of the first writers to develop this new genre was Edgar Allan Poe. In fact, it is in his writings that we find the first examples of many of the plots that still embody science fiction today.

Science fiction enjoys a status today that was unthinkable one hundred years ago. It is one of our culture's most popular forms of stories, and, for many people, their primary source of information about science. In order to raise the most pertinent questions about existence, science fiction taps into the fears and anxieties that people have about modern society and its direction. People with a materialist view of the world, such as H.G. Wells, have used science fiction to present their perspective on reality, and people with a Christian view of the world, such as C.S. Lewis, have used science fiction to present their perspective. Science fiction remains popular, however, because the audience becomes a participant in the discussion. Science fiction creates a venue for the exploration of the issues of existence, thus it has become the mythology of the modern world.

Western culture produced science fiction in the same way that it produced popular democracy and universal education. Every culture produces institutions and art that embody its core beliefs and values. One way to track the rate of change in a culture, and the extent to which a culture has abandoned old beliefs and values, is to take note of the introduction of new institutions and art forms. Science fiction suddenly appeared as a new art form in the early nineteenth century. It would not have a name until a century later, long after it had become accepted as one of the culture's most popular kinds of stories.

New art forms rarely appear in world history. Cultures have produced few ways of telling stories. For millennia, most cultures of the world expressed their core beliefs and values through the telling of adventure stories. Such stories glorify values such as courage, loyalty, and skill in fighting. They deplore traits such as treachery, cowardice, and fear. The Greeks modified the adventure story to create dramatic tragedy—not only a new kind of story, but a new way of telling a story. Instead of the lone storyteller or poet holding forth for hours in conjunction with a banquet, a company of actors presented the story to a vast civic audience. In counterpoint to the tragedy, the comedy appeared. Both tragedy

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and comedy present and reinforce a culture's core beliefs and values by portraying the tragic consequences of violating the values or by demonstrating the foolishness of ignoring the values. Somewhere in eleventh-century France, a troubadour invented the love story, which soon became one of the most popular kinds of stories in European culture.

In times of cultural change, old art forms fade and disappear because they no longer reflect the core beliefs and values of their culture. At the end of the classical period in the West, drama disappeared. It no longer fit with the emerging culture of the Christian West that we call Christendom or the Middle Ages. Even as drama faded, the new art form of allegory became the dominant art form for the next one thousand years throughout the Middle Ages, only to die a sudden death at the beginning of the modern period as drama once again emerged.

Given the rarity of new art forms, how do we account for the creation and development of science fiction in the West during the nineteenth and twentieth centuries? Given the function of art to interact with the prevailing core beliefs and values of a culture, what core beliefs and values of western culture does science fiction support or challenge? Given that science is concerned with the study of the physical world, how do we account for the tendency of science fiction to focus on transcendent questions of value?

Science fiction has not received a happy welcome from the literary establishment concerned with "serious" literature. The case of T.S. Eliot illustrates the problem for science fiction in the academy. Eliot delivered a particularly dismissive lecture on Edgar Allan Poe at the Library of Congress in 1948, largely to explain why Poe's enormous continuing influence on the development of art, music, and literature in Europe should not be taken seriously, and why Europeans were wrong. While he focused his attention on Poe's poetry (it had meter, rhythm, and rhyme), he commented in passing on Poe's "great influence upon some types of popular fiction," notably the detective story and science fiction. Eliot acknowledged that H.G. Wells owed a debt to Poe's science fiction, but that was the problem for Eliot: science fiction did not matter to him precisely because it was *popular fiction*. He remarked dismissively, "But I fear that nowadays too few readers open *She* or *The War of the Worlds* or *The Time Machine*: fewer still are capable of being thrilled by their predecessors."[1]

Although Eliot has enormous cachet among literary critics, his comments betray the enormous gulf between academic literature and the popular imagination. He appears to have missed the culture completely. Perhaps because he was living in England at the time, Eliot did not appreciate the extent to which the public had been thrilled by Orson Welles's radio production of *The War of the Worlds* in 1938, only ten years earlier. Its success at verisimilitude created a state of panic in many communities, and the production had to be ended in mid-broadcast to reassure the public that it was only a story. Eliot's failure to appreciate the significance of the new literary art form also prevented him from predicting the staying power of Wells's stories, for *The War of the Worlds* would become a major motion picture five years later in 1953 and again in 2005. Wells's *The Time Machine* would be produced as a movie in 1960 and again in 2002. These kinds of stories have a continuing appeal for our culture that strikes at the fundamental questions of life and survival. No kind of literature is more serious than science fiction.

The Appearance of Science Fiction

Mary Shelley published *Frankenstein* in 1817, following the tumult of the Napoleonic Wars. As a result of the wars, the map of Europe and the balance of power had changed dramatically. The world had changed in other dramatic ways during and in the years leading up to the Napoleonic period. The Industrial Revolution had transformed the production of textiles and iron through the invention of machines and processes that produced goods quickly and of a higher quality. Improved iron-making processes increased the demand for coal and iron ore which led to the introduction of steam-powered locomotives for hauling ore in Britain in 1804. Robert Fulton began operating a successful steamboat in New York in 1807. As early as 1783, hot air balloon flight had begun in France. Benjamin Franklin had ushered in an age of experimentation with electricity and its properties before the American Revolution.

In *Frankenstein*, Shelley questioned what happens when humans "play God." This first modern science fiction story assumes dramatic advances in medical,

chemical, and biological sciences that would lead to an understanding of the secret to life itself. Written over forty years before Darwin published *On the Origin of Species*, Shelley's *Frankenstein* was written long after the idea of evolution in some form had been circulating in intellectual circles. The concept of evolution has profound implications for the presence or absence of God in the story of life. The boundary between life and death, between object and person, raises profound ethical questions. Not only were the advances in science raising questions about the boundary between right and wrong; they also raised the question of whether right and wrong even exist.

Questions of right and wrong lie within the spheres of religion and philosophy. They belong to theology, law, and politics. The scientific method, however, has no way to ask such questions, much less answer them. Science merely observes and describes the physical world. Technology applies the discoveries of science to creative invention. The idea of limiting what science may explore belongs to a different realm of life. The Royal Society and the French Academy of Sciences might have provided a forum for the great minds of the age to debate the relationship of ethics and morality to science, but the general public had no voice in the debate. Whatever her intention may have been, by writing *Frankenstein,* Shelley made the role and limitations of science in the modern world a topic of general conversation within the mass public. At the moment of the expansion of the franchise in the West when popular opinion was about to matter, a new form of art appeared that prompted popular discussion about scientific matters that the average person would never have understood apart from its fictional format.

When it was first published, *Frankenstein* appeared to be just another German gothic horror story. The monster story fits well in the tradition of the old fairy stories. It belongs to Beowulf and his battle with Grendel. It belongs to St. George and the dragon. With *Frankenstein*, however, Shelley has moved out of the world of faerie and into the modern world of cause and effect. The monster is not like a vampire or a werewolf. The monster has been created by modern science. The details are obscure, but they are all written down in Frankenstein's book that documents his experiments and discoveries about the secret of life. Shelley took her monster out of the world of once upon a time and placed him in the midst of the scientific revolution. In Shelley's story, the horror does not come from the world of the supernatural but from the scientists who play God.

The Industrial Revolution accounted for the dislocation of hundreds of thousands, if not millions, of people across Europe as the economy shifted from agriculture based to manufacturing. Efficiency in mechanized manufacturing also cost the jobs of the old cottage industry. Riots took place when people felt threatened by machines and the inevitable tide of progress. To a great extent, this fear of technology and the loss of livelihood has returned at the beginning of the twenty-first century as a major dynamic of post-industrial society. Shelley's novel succeeds as horror because it touches human fear.

The Development of Science Fiction

Edgar Allan Poe maintained an active interest in science throughout his career, and he was one of the first writers to take up Shelley's new kind of story, though we have no evidence that he actually was influenced by her. While *Frankenstein* was still regarded as a simple horror story, Poe focused on what distinguished it from other stories. Shelley had incorporated scientific ideas into her story, and Poe would strive to introduce the most current scientific ideas into his stories. Poe's second science fiction story, published in June 1835, involved a trip to the moon. Over the previous few centuries, others had written of trips to the moon, but Poe saw a sharp distinction between his "The Unparalleled Adventure of One Hans Pfaall" and the earlier stories. The story was set in his own time, and it depended upon the reader's identification with the reality at the beginning of the story. In a note appended to the story when it was later published in his first collection of short stories in 1840, Poe argued that his story of a trip to the moon attempted "to give plausibility by scientific detail."[2] He explained of his science fiction,

> In "Hans Pfaall" the design is original, inasmuch as regards an attempt at *verisimilitude,* in the application of scientific principles (so far as the whimsical nature of the subject would permit) to the actual passage between the earth and the moon.[3]

Though Poe, like Shelley, came to science fiction through the door of horror, he would experiment

with a variety of story forms as vehicles for his science fiction. Poe preferred comedy and satire to all other kinds of stories, and his second science fiction tale is a comedy. A great one for experimentation, Poe wrote several of his science fiction stories as comedies, some as adventures, some as horror, some as terror, and one as romantic comedy. He also experimented with the structure in which he presented his science fiction so as to increase the air of credibility. He wrote them as letters, journals, field notes, experimental notes, and news stories in addition to straightforward narratives. What they all had in common, however, was a dependence upon real science and the exploration of transcendent questions. Poe held a lifelong interest and fascination in science from the time of his childhood in England when his foster father bought him an expensive brass telescope for viewing the heavens. His interests were broadened by studying with the Rev. Dr. John Bransby at the Manor House School in Stoke Newington. Bransby finished Cambridge, and in addition to being a Classics scholar was devoted to the study of botany.

According to Harold Beaver, who edited the anthology of Poe's science fiction, Poe placed his emphasis on logic, reason, coherent forecast, and calculation as he wove his science fiction narratives.[4] Poe created the norms of science fiction, just as he did for the short story and for detective fiction. Arthur Conan Doyle credited Poe with the creation of the mystery story, and Jules Verne acknowledged his debt to Poe. Writing in France in 1909, Maurice Renard referred to Poe rather than Verne as the actual creator of the "marvelous-scientific romance."[5]

Before ever turning his hand to science fiction, Poe had written science poetry. In his "Sonnet—To Science," written at about the age of twenty when he served in the Coastal Artillery of the US Army, Poe lamented the tendency of modern science to drag "Diana from her car," to drive "the Hamadryad from the wood," and to tear "the Naiad from her flood" and the elves "from the green grass." Worst of all, at this young age of discovery, Poe accused science of tearing from him "the summer dream beneath the tamarind tree."[6] Instead of destroying the wonder and transcendence to which nature points, Poe's study of science over the next twenty years would demonstrate conclusively to him the divine mind behind the universe.

Poe wrote "Sonnet—To Science" as the introduction to his second long poem, "Al Aaraaf." Poe set this poem within the context of Tycho Brahe's observation of a supernova that suddenly appeared and then soon disappeared. In his poem, Poe associated this astronomical phenomenon with the Islamic concept of a median realm between heaven and hell. In the realm of Al Aaraaf, souls do not suffer punishment, but neither do they enjoy heavenly bliss. The contemplation of the relationship between the physical and the transcendent, as well as wondering what lay beyond death, would form an essential aspect of the plots of Poe's original science fiction stories.[7]

The Science Fiction Plots

For Shelley in 1817, the horror story provided the bridge for her *Frankenstein* to journey into science fiction. Likewise for Poe in 1833, the adventure story wed to horror provided the bridge to science fiction for his first science fiction story, "MS. Found in a Bottle." Horror provided merely a starting point for Poe, whose philosophy of composition drove him to find new ways of telling stories. For Poe, the purpose of all art, and literature in particular, was to have an effect on the audience. He would develop a variety of plot structures that suited him in the exploration of a range of spiritual issues designed to have an effect on his audience. They remain the primary plots of science fiction today; these plots continue to have an effect on modern audiences.

The Scientific Quest—"MS. Found in a Bottle"

In this sea-faring adventure beset with tidal wave, hurricane, death and destruction, fear of the kraken, and a ghost ship, Poe's narrator finds himself borne along a rapid ocean current to the southern pole. The story appeared before anything was known of Antarctica except that it might exist. The continent had been sighted by 1820, but it would be several decades before explorers concluded that the massive ice sheets of the southern ocean formed part of a continent. Poe's narrator experienced one of the most compelling theories of the earth at the time—John Cleves Symmes's theory that the earth is hollow and accessible by openings at the poles. The story shifted from mere adventure and horror to science fiction by virtue of its treatment of one of the great unknown mysteries about the nature of the earth.

Poe evoked the danger of nature and the unknown which haunted human dreams for millennia in describing the polar region:

> All in the immediate vicinity of the ship is the blackness of eternal night, and a chaos of foamless water; but about a league on either side of us, may be seen, indistinctly and at intervals, stupendous ramparts of ice, towering away into the desolate sky, and looking like the walls of the universe.[8]

Then, in the closing paragraph, Poe turned to the quest for knowledge that excites and compels humans onward, even in the face of danger:

> To conceive the horror of my sensation is, I presume, utterly impossible; yet a curiosity to penetrate the mysteries of these awful regions, predominates even over my despair, and will reconcile me to the most hideous aspect of death.[9]

The desire to acquire such "exciting knowledge" must come at the risk of destruction. This plot (1833) would animate the voyages of the starship USS Enterprise 133 years later as that spacecraft set out "to explore strange new worlds, to seek out new life and new civilizations, to boldly go where no man has gone before."[10]

At the end of the story, the ship is caught in the whirling current of vast concentric circles within a "gigantic amphitheatre," whose walls reach up into the darkness, before the ship finally quivers and heads down into the great whirlpool. This plot has been repeated any number of times, such as in Verne's *Journey to the Centre of the Earth* (1864) or Arthur C. Clarke's *2001: A Space Odyssey*. As a mere sea adventure story, Poe's story influenced Herman Melville and formed a central element of *Pirates of the Caribbean: At World's End.*

MS. Found in a Bottle, his first science fiction stemwinder, won Poe a prize of fifty dollars from the *Baltimore Saturday Visiter* which published it. Though Poe had published three slim books of poetry, his science fiction story marks the beginning of his success as a writer and would lead to his first job as an editor for the *Southern Literary Messenger*. In terms of science fiction, however, he had written a tale that explored the imperative of the quest for scientific knowledge in spite of the obstacles—even if no one ever knew or believed what had been discovered. Such a tale climatizes a culture to value the scientific search for knowledge.

Space Exploration and Aliens— "Hans Pfaall"

For his second science fiction tale, Poe's adventurer leaves Earth and travels to the moon in a hot air balloon. Rather than another adventure/horror story, "The Unparalleled Adventure of One Hans Pfaall" (1835) is a comic tale whose aeronaut ascends the heavens on April Fools' Day. Others had written tales about the Moon which Poe had criticized for their lack of verisimilitude. Poe's satirical treatment with its absurd balloon made of discarded newspapers represents Poe's love of lambasting poor efforts in any genre. His "How to Write a Blackwood Article" and its companion piece, "A Predicament," parody the vapidness of horror stories. His "Never Bet the Devil Your Head: A Tale with a Moral" satirizes the insistence of the New England literary establishment that all literature should offer moral instruction. The absurdity of "Hans Pfaall" underscores Poe's belief that tales of this kind must have verisimilitude to be compelling. In other words, science should be taken seriously in the construction of the plot.

Poe's story not only involves a voyage into space. It also involves an encounter with aliens from another world. Poe's story is ambiguous as to whether the Lunians are friendly or hostile, and that ambiguity fuels the anxiety about how to regard creatures from other planets. For H.G. Wells, the aliens would be hostile, but for C.S. Lewis, it is the natives of Earth who alone are hostile in the universe.

Verne adapted this plot in his novel *From the Earth to the Moon* (1865). Wells tried his hand at this plot with *The First Men in the Moon* (1901). French film maker Georges Méliès adapted Verne's story to film *A Trip to the Moon* (1902), one of the first great short films and still available on Netflix. As the twentieth century progressed, the moon ceased to be the challenge that it once was, and space flight extended beyond the solar system and beyond the galaxy.

Lost in Space— *The Narrative of Arthur Gordon Pym*

Poe's only novel, *The Narrative of Arthur Gordon Pym* (1838), builds on the sea adventure story of "MS. Found in a Bottle." It elaborates an attempt to explore the southern ocean and reach the southern pole to uncover one of the greatest scientific mysteries of the early nineteenth century. Poe's characters

experience mutiny, shipwreck, hostile natives, murder and mayhem, and starvation before they are lost in the southern ocean approaching the end of the world. It is a retelling of Homer's *Odyssey*, except it is full of geographical and oceanographic details, and worst of all, the sailors do not return home.

The most important feature of the plot involves the journey to an unknown world from which the travelers may or may not return. In the course of the journey, however, they advance human knowledge. At the end of the world, Poe's travelers are confronted by a giant figure shrouded in white. Poe had general contempt for symbolism in literature because most symbols were arbitrary contrivances in the mind of the author to which the reader did not have access. On the other hand, he found it hard to pass up a chance to poke fun at the literary establishment by including a symbol for which there was no key. Unlike the traditional adventure story, like that of Bilbo Baggins who went "There and Back Again," this story takes its adventurers beyond their world to an uncertain future.

Arthur Conan Doyle, who had great success adapting Poe's detective plots, adapted this plot in *The Lost World* (1912), which has been translated to film and television. In one form, this plot served the television series *Lost in Space* (1965–1968) which was made into a movie in 1998. *Star Trek: Voyager* (1995–2001) also relies on this basic plot.

Apocalypse—
"The Conversation of Eiros and Charmion"

With "The Conversation of Eiros and Charmion" (1839), Poe developed a plot based on the end of the world caused by a brush with a comet. Halley's Comet had appeared in 1835 and William Miller had created a great stir with his prediction that the world would end in 1844. The conversation in the tale involves the recollections of two spirits in the next life who describe how the world anticipated the approach of the comet and how the end came. For his verisimilitude, Poe appears to have relied on *The Christian Philosopher* by Thomas Dick, who speculated that the extraction of nitrogen from the air could result in the combustion of the atmosphere.[11] The comet causes such an alteration to the chemical composition of the atmosphere that Earth bursts into flame.

The device of the comet would feature in Verne's *Off on a Comet* (1877), but the plot of the end of the world by natural disaster would become a favorite science fiction plot in recent years with movies such as *Armageddon*, *The Day After Tomorrow*, and *World War Z*. Science fiction mirrors the fears of society as informed by scientific concerns about the climate, disease, and an unstable asteroid belt. Scores of apocalyptic movies have been produced since 1970 which reflect the dominant anxieties that people feel about the survival of the planet.

Rationality and Imagination with Nature as Ally—
"A Descent into the Maelström"

In "A Descent into the Maelström" (1840), Poe turned again to a natural phenomenon for the source of danger and the cause for fear, but he also wedded human rationality and imagination for a way out. Poe regularly relied upon what he knew to be an innate fear that his audience would bring to his stories: fear of fire, water, height, earth, and darkness. People fear burning, drowning, falling, premature burial, and isolation. It is interesting to note that our greatest primordial fears became the four basic elements of the cosmos for the ancients: fire, water, earth, and air.

In this story, a fisherman recounts how he was drawn into the great maelstrom in the district of Lofoten in Norway. We know from the beginning that the man will not die because he tells his tale to another person. Despite what the reader knows, Poe still creates terror because of the reader's own fears. Alfred Hitchcock said that what Poe managed to do was tell an implausible story in such a way that the readers believe it can happen to them.[12]

Others had written stories of surviving a bout with such a whirlpool, but Poe was dissatisfied with the solutions and aimed for a more logical explanation for how a person could survive by their wits and powers of observation—the critical elements of the scientific method. The fisherman had to rely on cooperating with the laws of nature, rather than fighting them, in order to survive. Thus, nature is not the enemy, but the ally.

Wells employed this plot as the denouement of *War of the Worlds*, for the planet is saved from the invaders from Mars by the tiny microbes that decimate the invaders.

Human Depravity and Hope beyond Death— "The Colloquy of Monos and Una"

In "The Colloquy of Monos and Una" (1841), Poe turned again to global disaster, but this time to humans as the cause. Una and Monos are two people who have died and gone on to experience "Life Eternal" through new birth.[13] The colloquy explores how world civilization grew cold and callous so that the only real hope lay in being born again. Monos then describes how it felt to die and then be resurrected. In the course of this colloquy, Poe explores "the autocrats *Place* and *Time*."[14] Poe continually returned to the problem of time and space in his stories, essays, and poetry, but he found science fiction a particularly appropriate genre for exploring the boundary between life and death, which represents one step beyond Shelley's exploration of the ethics of reanimating body parts.

The boundary between life and death is the boundary between science and religion. Tolkien would explore this boundary with Gandalf's transformation from the Grey Wizard to the White Wizard. J.K. Rowling would explore this boundary with Harry Potter's visit to King's Cross station and his return in *Harry Potter and the Deathly Hallows*. Lewis would explore this boundary with Aslan in *The Lion, the Witch, and the Wardrobe*. Some might think that the similarity of these stories suggests that Poe's story belongs to fantasy instead of science fiction, but we should recall that bookstores had already placed *The Lord of the Rings* in the science fiction section of the store several decades earlier. The boundary between science fiction and fantasy is a narrow one.

The science fiction disaster story in which humans bear the blame for causing the disaster has returned during particular times of corporate anxiety. During the great fear of atomic war in the 1950s, we had *The Day the Earth Stood Still* followed by *The Planet of the Apes*. The fear of environmental disaster coincided with *The Andromeda Strain* and *The Omega Man* (earlier filmed as *The Last Man on Earth* and later filmed as *I Am Legend*).

The Relativity of Space and Time— "Three Sundays in a Week"

Originally published with the title "A Succession of Sundays" in 1841, "Three Sundays in a Week" is a romantic comedy that relies upon one of the most profound ideas of the last three thousand years for its punch line. A contrary old man in London refuses to give his consent for his daughter to marry his nephew until three Sundays fall in a single week. The daughter conceives a solution to the problem by inviting two old friends to dinner the following Sunday. Both men were sea captains who had left England on the same day a year earlier and then returned on the same day that week. One sailed east and the other sailed west. The contrary old man sat down to eat on Sunday, but one of the captains who ate with him sat down on Monday while the other sat down on Saturday. For one, Sunday had been the previous day and for the other, Sunday would be the next day. Thus, three Sundays had fallen within one week. Poe concluded the story with the remark, "there can be no philosophical reason assigned why the idea of one of us should have preference over that of the other."[15]

In *Eureka,* Poe expanded the idea that no time or space had preference on Earth to the idea that "duration" and "space" were the same thing and relative to each other. Verne adapted the plot in *Around the World in Eighty Days* (1873).

Knowledge across Time and Space— "A Tale of the Ragged Mountains"

With "A Tale of the Ragged Mountains" (1844) Poe returned to science fiction related to the mind. Psychology and psychiatry were not yet in their infancy, but Poe was fascinated by the mind and how much science did not know about it. Phrenology and mesmerism were all the rage, but Poe had serious doubts about both as science. He set this tale in the mountains around Charlottesville in 1827, the year after he left the University of Virginia. Poe loved to hike these mountains and regularly walked twenty or thirty miles a day exploring their beauty.

In this tale, the principal character describes what might be called an out-of-body experience that transported him to Calcutta in the midst of the revolt of 1780. Poe wrote the story in such a way as to allow a variety of explanations for the experience, ranging from a true psychic phenomenon to a drug-induced hallucination to a hypnotic suggestion. The story opens the question of epistemology in general and the possibility of knowledge of the past and future.

The question of what we know and how we know would take center stage in much of Poe's work in the 1840s, but this kind of science fiction would enjoy periodic popularity down to the present day. The recent films *Interstellar* and *Arrival* explore, as Poe did, what we can know as either a natural or a supernatural process.

Just beyond the Current Science—"The Balloon-Hoax"

Poe's greatest science fiction triumph came in April 1844 when the morning edition of the *New York Sun* published a brief paragraph in anticipation of its noon edition.

> By Express
>
> Astounding intelligence by private express from Charleston via Norfolk!—The Atlantic Ocean crossed in three days!!—Arrival at Sullivan's Island of a steering balloon invented by Mr. Monck Mason!!

The announcement created a sensation, and the noon edition of the paper with the full story of the trans-Atlantic aeronautical crossing sold out at scalping prices. The next day, the *Sunday Times* picked up the story. This story that appeared to be a news story now goes by the name "The Balloon-Hoax."[16] It is the primary reason that good science fiction, which had an air of believability, went by the name of "hoax" for so many decades before science fiction became the accepted name. Upon reading "The Balloon-Hoax," Verne determined to devote himself to writing this kind of story. His first science fiction tale was *Five Weeks in a Balloon* (1863).

Four years earlier, Poe had written a brief note in his monthly column on science about Charles Green's claim that trans-Atlantic balloon travel was possible using a form of hydrogen gas.[17] This kind of science fiction story depends upon tapping into a current conversation about what might be possible in the immediate future such that reasonable people might expect a new discovery at any moment. New stories about cold fusion have traction because people would like to believe that this next step has been achieved. Sandra Bullock's *Gravity* and Bruce Willis's *Armageddon* depend upon this current conversation: what might someone do who has had an accident in space, or how might we save the earth from a fatal collision with an asteroid? Matt Damon's *The Martian* is the same kind of story, for it involves questions currently under consideration by NASA. For the most successful of these stories, the challenge to humans must be enormous, and failure must mean death.

The Mind, Death, and God—"Mesmeric Revelation"

In "Mesmeric Revelation" (1844), Poe returned to hypnotism that he had only hinted at in "A Tale of the Ragged Mountains." This time, the whole story is presented as the case notes of a mesmerist who has been asked by a skeptic to place him in a trance in hopes of satisfying his mind about a troubling thought that had recently perplexed him. He feared that he might have an immortal soul. Logic alone could not settle the question for him. Poe was not impressed by the philosophical arguments for the existence of God. Poe regarded the imagination as a higher form of knowing which made both poetry and scientific discovery possible. Once under the hypnotic trance, the skeptic is free from disbelief and discovers God and the universe.

The 1840s were a period of wild religious enthusiasm. Joseph Smith, the founder of the Mormons, was killed by a mob the same year that this story appeared. Belle Baumfree took the name Sojourner Truth in 1843 after living for a time in the commune of Prophet Matthias. Transcendentalism was all the rage among the New England intelligentsia. At the beginning of the New Age Movement in the 1970s, science fiction once again employed the dialogue about the nature of God as a key element in the story with Luke Skywalker quizzing Obi-Wan Kenobi about the Force in *Star Wars*.

Resistance to Science—"The Thousand-and-Second Tale of Scheherazade"

In "The Thousand-and-Second Tale of Scheherazade" (1845), Poe crafted a comic sequel to the famous *One Thousand and One Nights*. As science fiction, the plot centers on the way that narrow-minded, ignorant, and unimaginative people may hinder the advance of science and technology. Poe picks up the story the night after the successful conclusion and happy ending of *One Thousand and One Nights*. Unfortunately, Scheherazade decides to tell the king a new tale of

Sinbad and a land he visited that had all the wonders that Americans in the 1840s had recently acquired: the daguerreotype, the telegraph, iron ships with steam engines, and a variety of other things that skeptics had laughed at only a few years earlier. The king regarded the tale as too preposterous, so he had his queen killed. This plot provides the conclusion of *Things to Come* (1936), a British film written by Wells. The film's title is the English translation of Poe's next-to-last science fiction short story, "*Mellonta Tauta*."

Reanimation of Life— "Some Words with a Mummy"

Poe wrote "Some Words with a Mummy" (1845) as a comic story, but its plot deals with the issue of prolonging life through scientific means. In this case, the party engaged in examining a mummy decided to apply an electrical charge to its brain after realizing that the internal organs had not been removed. This mummy appeared to have been a victim of premature burial. Of course, the mummy sprang to life and proceeded to critique everything wrong with modern life. Poe did not hesitate to include in the examining group George Robbins Gliddon, a noted British Egyptologist then on a lecture circuit in America.

This kind of plot has two variations. As a horror story dependent on the occult for reanimation, Hollywood has kept the plot alive with *The Mummy* (1932), *The Abominable Dr. Phibes* (1971), *The Mummy* (1999) and its sequels, and *The Mummy* (2017). As science fiction, however, the plot has moved away from a mummy to a more terrifying idea—the reanimation of Adolf Hitler through genetic science in *The Boys from Brazil* (1978). This plot also serves as the basis for *Jurassic Park* (1993) and its sequels.

The Manner of Creation— "The Power of Words"

"The Power of Words" (1845) is a dialogue that begins in the midst of a conversation between Oinos (Wine), a new immortal spirit, and Agathos (Good), an old immortal spirit. They discuss three topics: (1) the possibilities of knowledge in an infinite universe (Poe would reject the idea of an infinite universe in *Eureka* in 1848); (2) ether as the medium through which the force of creation moves (Poe would reject the notion of ether in *Eureka*); and (3) the difference between primal creation by God and secondary creation. From their discussion, love emerges as the motive for creation. The plot of the story explores what kind of universe exists and how creation occurs beyond the initial impulse of God.

This fiction of science represents ideas that Poe would develop in *Eureka*, his cosmological essay on God and the universe. It is important to note that Poe's stories about an afterlife and what that might be like were not mere intellectual curiosity. They were driven by an existential crisis, for his wife had been dying of tuberculosis since 1842, and it was not until she died in 1847 that he devoted himself to working out the relationship between science and God in *Eureka*. Science fiction continues to provide a context for pondering and discussing the great existential issues that affect people personally.

The examination of the presence or absence of God in the construction and maintenance of the universe provides the plot to Carl Sagan's novel *Contact* (1985), which was produced as a major film starring Jodie Foster in 1997. The description of the Force in *Star Wars* (1977) made it acceptable in American popular culture to talk about God/god unselfconsciously after a hiatus of several decades. This conversation is now once again common in science fiction.

Artificial Prolonging of Life— "The Facts in the Case of M. Valdemar"

"The Facts in the Case of M. Valdemar" (1845) take the plot of "Mesmeric Revelation" one step further as a horror story. In "Mesmeric Revelation," a skeptic hopes hypnotism will enlighten him about the existence of God, but he dies in the midst of the trance. In "The Facts in the Case of M. Valdemar," hypnotism is employed as a scientific experiment to prevent a man from dying. The doctors expected Valdemar to die within the night, but once in a hypnotic trance, he was kept so for seven months during which time he responded to the mesmerist's questions. At last, Valdemar declared,

> "For God's sake!—quick!—quick!—put me to sleep—or, quick!—waken me!—quick!—*I say to you that I am dead!*"[18]

As soon as the mesmerist attempted to act, Valdemar was immediately reduced to "a nearly liquid mass of loathsome—of detestable putridity."[19]

The artificial prolonging of life is Poe's flip side to the fear of premature burial that so occupied the thoughts of his era. He anticipated a different problem with the advances of science. Lewis used this plot in *That Hideous Strength*. It is the reason for creating clones to harvest body parts in *The Island* (2005). It is the horror of deciding when to let daddy die. It is existential rather than theoretical.

Future Society— "Mellonta Tauta"

Poe adapted "Mellonta Tauta" from the fictional introduction to *Eureka*. It is in the form of a letter written from the airship "Skylark" in the year 2848. Just as Plato had begun his cosmological essay *Timaeus* with the cataclysmic tale of Atlantis from the distant past, Poe began his cosmological essay *Eureka* with an optimistic take, set in the distant future.

In contrast to the Transcendentalists, Poe had no faith in human perfectibility and saw no evidence of an improvement in human nature over the previous 6,000 years. War and pestilence would be seen in the future as positive goods for controlling the population. On the other hand, he did believe that people would continue to make advances in science. His future airships could travel in excess of 150 miles per hour, and trains could exceed 300 miles per hour. In that future society, commerce with the citizens of the moon, who have a superior technology, will be commonplace. New York had been destroyed in a massive earthquake in 2050, but archeologists have found many interesting remains that the future humans misinterpret because of their new set of assumptions.

Science fiction looks to the future with a range of expectations from utopian to dystopian. This plot formed the basis for Wells's *The Time Machine* and for *The Hunger Games* books and movies. It is also the plot for *The Matrix* and *Terminator* series of movies.

The Great Scientific Breakthrough— "Von Kempelen and His Discovery"

Poe published his last science fiction story, "Von Kempelen and His Discovery," in April 1849 at the beginning of the California Gold Rush and just a few months before his death. In response to the Gold Rush, Horace Greeley, Poe's sometime friend and sometime rival, famously declared, "Go West, young man. Go West." In this story, Poe declared that the young man, Von Kempelen, should not be such a fool. Poe reports on Von Kempelen's great achievement of successfully turning lead into gold.

In the opening lines, Poe creates the impression that a host of international scholars had reviewed Von Kempelen's notes and experiments to confirm the achievement, thus reinforcing the popular notion of science fiction as hoax. Poe referenced actual scientists, including Dominique Arago, director of the Paris Observatory; Benjamin Silliman, professor of chemistry and natural history at Yale; and Lieutenant Matthew Maury, head of the Depot of Charts and Instruments in Washington, DC.

In the third paragraph, Poe stated his intention of providing details of the process which had been suggested in "The Diary of Sir Humphry Davy." Then, Poe inserted with brackets the following statement:

> [As we have not the algebraic sign necessary, and as the "Diary" is to be found in the Athenaeum Library, we omit here a small portion of Mr. Poe's manuscript. –ED.][20]

For all those contemplating an arduous trip to California to scrape for gold, Poe suggested that they not waste their time in the light of Von Kempelen's discovery. He followed the story with one of his most beautiful poems, "Eldorado."

Science fiction thrives on the great discovery that will change the world for good or ill. In Kurt Vonnegut's *Cat's Cradle,* it signals the end of the world. In Robert Louis Stevenson's *Dr. Jekyll and Mr. Hyde,* it is the cure to the violence of human nature. In Wells's *The Time Machine,* it is the secret to travelling through time. This kind of plot depends upon an audience that believes in the progress of science and that someday, with persistence, the greatest of scientific problems will be conquered—for good or ill.

Conclusion

Something of the original horror story remains in all successful science fiction. The advance of science often means venturing into dangerous territory. Sometimes the danger involves death, but as often as not it means risk to reputation or professional advancement. Science fiction has focused on the physical danger to the individual and to society that

scientific advance entails. This encounter with death makes possible the extent to which science fiction has opened a conversation about the transcendent that everyday affairs tend to avoid.

Science fiction lends itself to an unusually broad flexibility for plots when we consider that the love story only has one basic plot and the adventure story only two. Dorothy L. Sayers claimed that Poe had constructed all five of the modern mystery plots, but in all his efforts at pioneering the science fiction story, he did not completely exhaust the plot possibilities. The rich plot variety of science fiction allows the audience to experience vicariously the existential questions of existence that science fiction can raise without damage to the basic plot line or threatening the willing suspension of disbelief. This variety allowed Wells to present one view of reality while Lewis presented another. Both approaches to the questions that science fiction invites, manage to open the discussion to the whole culture, and the audience need not agree with the views of the authors. Once the question has been raised, it is out of the box and no longer under the control of the storyteller.

As the method of science does not allow for self-critique in terms of questions of ethics, morality, and superimposed philosophical considerations, science fiction has emerged as one of our culture's ad hoc means of carrying on a broader conversation about the direction of both science and technology. Science fiction asks the question of unintended consequences and what might be the long-term outcome of applied science. Science fiction lacks all of the rigor of science, but its commentary allows the nonspecialist to contemplate the future that science allows us to envision. ✠

Notes

[1]T. S. Eliot, "From Poe to Valéry," in *The Recognition of Edgar Allan Poe*, ed. Eric W. Carlson (Ann Arbor, MI: University of Michigan Press, 1970), 30.

[2]Edgar Allan Poe, "The Unparalleled Adventure of One Hans Pfaall," in *Poe: Poetry and Tales,* ed. Patrick Quinn (New York: The Library of America, 1984), 996. Three weeks after Poe published "Hans Pfaall" in 1835, Richard Adams Locke published another moon hoax that he attributed to Sir John Herschel as an account of Herschel's observations of flora and fauna on the moon by means of his new telescope. Poe criticized Locke's moon hoax on the basis of the description of the magnifying power of the telescope. Poe remarked,

> Mr. L. makes his lens have a power of 42,000 times. By this divide 240,000 (the moon's real distance,) and we have five miles and five-sevenths, as the apparent distance. No animal at all could be seen so far; much less the minute points particularized in the story. (p. 997)

[3]Ibid., 1001.

[4]Edgar Allan Poe, *The Science Fiction of Edgar Allan Poe*, ed. Harold Beaver (London: Penguin, 1976), x. Beaver has included two of Poe's works that I do not classify as science fiction. One is "The System of Dr. Tarr and Prof. Fether," an original story of the inmates in charge of the asylum. Written as a slap-stick farce, it might be counted as science fiction in the field of psychiatry. The other is Poe's lengthy (almost 150 pages) essay on cosmology, *Eureka*. While Poe's ideas of relativity, the expansion of the universe from a primordial particle, chaos, the forces of attraction and repulsion at the sub-atomic level, the equivalence of matter and energy, and a number of other modern ideas were regarded as ludicrous when Poe wrote his essay, he did not write it as fiction. I have included one story that Beaver does not include, titled "Three Sundays in a Week." This story was critical in Poe's working out his ideas about the relativity of time and space.

[5]Ibid., ix.

[6]Poe, *Poetry and Tales*, 38.

[7]Although I have discussed "Sonnet—To Science" and "Al Aaraaf" in *Edgar Allan Poe: An Illustrated Companion to His Tell-Tale Stories* (New York: Metro, 2008), 39–41 and in *Evermore: Edgar Allan Poe and the Mystery of the Universe* (Waco, TX: Baylor University Press, 2012), 135–36, a much more extensive discussion of them in terms of Poe's interest in science may be found in the recent dissertation of Mo Li, "From 'Before the Eye of the World' to 'What I Here Propound Is True': Science and Edgar Allan Poe's Building of the Universe" (PhD diss., Middle Tennessee State University, 2017).

[8]Poe, "MS. Found in a Bottle," *The Science Fiction of Edgar Allan Poe*, 10.

[9]Ibid., 10.

[10]Opening monologue for each episode of the original *Star Trek* series from 1966 to 1969.

[11]Poe, *The Science Fiction of Edgar Allan Poe*, 356 n.9.

[12]As cited by Peter Wollen, "Compulsion," *Sight and Sound* 7, no. 4 (1997): 17; and Dana Brand, "Rear-View Mirror: Hitchcock, Poe, and the Flaneur in America," in *Hitchcock's America*, ed. Jonathan Freedman and Richard Millington (New York: Oxford University Press, 1999), 123.

[13]Poe, "The Colloquy of Monos and Una," *The Science Fiction of Edgar Allan Poe*, 89.

[14]Ibid., 97.

[15]Poe, "Three Sundays in a Week," *Poetry and Tales*, 480.

[16]As a side note, the *New York Sun* is also the newspaper that printed the most famous editorial ever written: "Yes, Virginia, there is a Santa Claus" in 1897.

[17]Edgar A. Poe, "A Chapter on Science and Art," *Burton's Gentleman's Magazine* 6, no. 3 (1840): 149. Poe read voraciously on the sciences and continued to write columns that dealt with new breakthroughs in the sciences until his death. He often included observations about the sciences in his literary essays.

[18]Poe, "The Facts in the Case of M. Valdemar," *The Science Fiction of Edgar Allan Poe*, 203.

[19]Ibid., 203.

[20]Poe, "Von Kempelen and His Discovery," *The Science Fiction of Edgar Allan Poe*, 324.

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Article

The Evolution of Creation Science, Part 2: Beneficial Mutations

Philip J. Senter and Jared J. Mackey

Philip J. Senter

Creation science (CS) is a discipline in which evidence is sought to support a literal interpretation of the opening chapters of Genesis. Its technical literature has existed since 1964, long enough to test for trends in positions on certain topics. Here, we present a study of CS literature from 1964 through 2015, focusing on trends regarding the topic of beneficial mutations. Acceptance of beneficial mutations was low among CS authors in the twentieth century but has risen sharply in the current century: the number of CS authors accepting beneficial mutations was approximately equal to the number of CS authors rejecting beneficial mutations in the period 2011–2015. The rise in acceptance is largely due to twenty-first-century creationist interpretations of transposons and similar phenomena as divinely programmed machinery for beneficial mutations that were allegedly loaded by God into the genomes of the originally created organisms.

According to the young-Earth creationist (YEC) worldview, the literal wording of the book of Genesis is an accurate record of past events. Proponents of the YEC view hold that the earth and all kinds of organisms were independently created about 6,000 years ago, as described by the literal wording of Genesis. Widespread popularity of the YEC view persists,[1] despite the mountain of physical evidence that the earth is billions of years old and that all organisms evolved from a common ancestor,[2] and despite abundant endorsement in the New Testament of a figurative rather than literal approach to Genesis and the rest of the Pentateuch.[3]

Creation science (CS) is a discipline in which practitioners seek extrabiblical support for the YEC view. In 1964, supporters of the YEC view launched *Creation Research Society Quarterly*, the earliest technical journal of CS. CS has since produced several such journals, a brief history of which we described in our first article in this series[4] and which will not be repeated here.[5] These journals are peer reviewed and only accept manuscripts that agree with a literal interpretation of Genesis. The YEC movement feeds information from CS journals into its popular, nontechnical publications, which refer to studies published in CS journals to lend the appearance of legitimacy from "science" to their claims.[6]

The literature from CS technical journals has now become vast enough and sufficiently long lived to test for the presence of temporal trends in positions on various topics. In our previous article, we reported an investigation into such trends in the topics of vestigial structures (as mainstream scientists understand them) and biological degeneration (as CS practitioners understand it).[7] Here, we

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report an investigation into temporal trends in the CS technical literature, regarding the topic of beneficial mutations.

A mutation is a change in the nucleotide sequence of DNA, and mainstream biologists recognize beneficial mutations as a major contributor to biological evolution.[8] Mutations are often harmful: for example, a mutation is harmful if it causes some physiological problem that is lethal at an early age. However, in many cases they are beneficial: for example, a mutation in a bacterial cell is beneficial to the bacterium if it grants the bacterium resistance to chemicals that would normally kill it (e.g., antibiotics). Many CS authors assert that beneficial mutations do not exist (tables 1, 2), thus making biological evolution impossible. Other CS authors accept the existence of beneficial mutations. Some of the latter have recently hypothesized that within the genome of each originally created organism, God placed DNA sequences that move within and/or between chromosomes, and that these mobile DNA sequences were meant to enable adaptation to environmental changes or to new environments into which organisms spread, "to genetically prepare each creature from the start of creation for future challenges."[9] For such mobile DNA sequences, hypothetically loaded by God into genomes at creation, CS authors have coined the terms AGEs (altruistic genetic elements)[10] and VIGEs (variation-inducing genetic elements).[11]

Mainstream scientists have found that mobile DNA sequences that generate mutations exist; such sequences include endogenous retroviruses (ERVs) and transposons. ERVs are DNA sequences derived from retroviruses, which sequences can be inherited by the host's offspring.[12] Transposons, some of which may be derived from ERVs,[13] are DNA sequences that can change locations within and between genomes. CS advocates of the VIGE concept consider ERVs and transposons to be examples of VIGEs.[14]

Materials and Methods

We sought to determine whether temporal trends exist in CS technical literature, in positions toward beneficial mutations. We used the methods described in our previous article, limiting the analysis to technical articles in CS literature and to conference abstracts in CS journals in which lengthy, referenced abstracts function as stand-alone articles. We searched through available PDF files of CS technical literature and searched visually through paper copies of journal volumes for which pdfs are not available.[15] For pdf searches, we used the search terms "mutation," "AGE" (case-sensitive), and "VIGE" (case-sensitive).

As in our previous article, we divided the duration of the CS movement into ten periods: 1964–1970 and nine subsequent periods of five years apiece, from 1971–1975 to 2011–2015. We then compared the number of articles and authors accepting or rejecting beneficial mutations through time. We considered an author to reject beneficial mutations if the author denied their existence or claimed that they occur rarely enough to be negligible in number or effect.

We calculated the percentage of twentieth-century articles and authors accepting or rejecting beneficial mutations, recording percentages with a precision of three significant digits; we repeated the procedure for twenty-first century articles and authors. We then ran two-tailed *z*-tests on these proportions, to test for significant differences in the proportions between the two centuries. The *z*-tests were run with alpha set at a stringent 0.01.

Table 1. Numbers and percentages of CS articles and authors rejecting or accepting beneficial mutations, through 2015.

	1964–1970	1971–1975	1976–1980	1981–1985	1986–1990	1991–1995	1996–2000	2001–2005	2006–2010	2011–2015
Articles rejecting	14	8	6	7	3	11	6	18	17	7
Authors rejecting	10	9	5	8	4	10	6	13	17	7
Articles accepting	2	1	0	0	0	2	2	8	25	16
Authors accepting	2	1	0	0	0	3	2	6	12	9
Percentage of articles accepting	12.5%	11.1%	0%	0%	0%	15.4%	25.0%	33.3%	59.5%	76.7%
Percentage of authors accepting	16.7%	10.0%	0%	0%	0%	23.1%	25.0%	31.6%	41.4%	56.3%

Table 2. CS articles in which beneficial mutations are rejected or accepted, through 2015, with indication of articles in which the authors accept AGEs or VIGEs.

Author and year	Position
Gish, 1964[1]	Reject
Lammerts, 1964[2]	Reject
Morris, 1964[3]	Reject
Tinkle, 1964[4]	Reject
Lammerts, 1965[5]	Reject
Klotz, 1966[6]	Accept
Shute, 1966[7]	Accept
Gish, 1967[8]	Reject
Lammerts, 1967[9]	Reject
Moore, 1967[10]	Reject
Tinkle, 1968[11]	Reject
Howe, 1969[12]	Reject
Klotz, 1969[13]	Reject
Lammerts, 1969[14]	Reject
Brauer, 1970[15]	Reject
Mosher & Tinkle, 1970[16]	Reject
Grebe, 1971[17]	Reject
Howe & Davis, 1971[18]	Reject
Lockwood, 1971[19]	Reject
Ouweneel, 1971[20]	Accept
Holroyd, 1972[21]	Reject
Moore, 1972[22]	Reject
Telfair, 1973[23]	Reject
Williams, 1973[24]	Reject
Gish, 1975[25]	Reject
Haines, 1976[26]	Reject
Tinkle, 1976[27]	Reject
Poettcker, 1977[28]	Reject
Tinkle, 1979[29]	Reject
Ancil, 1980[30]	Reject
Howe & Lammerts, 1980[31]	Reject
Cheek, 1981[32]	Reject
Melnick, 1981[33]	Reject
Jones, AJ, 1982[34]	Reject
Lammerts, 1982[35]	Reject
Moore, 1982[36]	Reject
Cribbs & Barrows, 1984[37]	Reject
Hamilton, 1985[38]	Reject
Leslie, 1986[39]	Reject
Lester & Bohlin, 1986[40]	Reject
Bergman, 1990[41]	Reject
Jones, JB, 1991[42]	Accept
Kouznetsov, 1991[43]	Reject
MacAoidh, 1991[44]	Reject

Author and year	Position
Wieland, 1991[45]	Accept
Bergman, 1992[46]	Reject
Lumsden, Anders, & Pettera, 1992[47]	Reject
Wile, 1992[48]	Reject
Gibson, 1993[49]	Reject
Gibson, 1994[50]	Reject
Lester, 1994[51]	Reject
Powell, 1994[52]	Reject
Wieland, 1994[53]	Reject
Bergman, 1995[54]	Reject
Bergman, 1996[55]	Reject
Wieland, 1996[56]	Reject
More, 1998[57]	Accept
Penrose, 1998[58]	Reject
Weeks, 1998[59]	Reject
Burgess, 1999[60]	Reject
Ivanov, 2000[61]	Reject
Walkup, 2000[62]	Accept (AGEs)
Bergman, 2001[63]	Accept
Bergman, 2001[64]	Reject
Mastropaolo, 2001[65]	Reject
Wood & Cavanaugh, 2001[66]	Accept (AGEs)
Batten, 2002[67]	Accept (AGEs)
Bergman, 2002[68]	Reject
Standish, 2002[69]	Reject
Wood, 2002[70]	Accept (AGEs)
Bergman, 2003[71]	Reject
Bergman, 2003[72]	Reject
Bergman, 2003[73]	Reject
Moeller, 2003[74]	Reject
Wood, 2003[75]	Accept (AGEs)
May, Thompson, & Harrub, 2004[76]	Reject
Thompson & Harrub, 2004[77]	Reject
Wilson, 2004[78]	Accept
Anderson, 2005[79]	Accept
Anderson, 2005[80]	Accept
Bergman, 2005[81]	Reject
Bergman, 2005[82]	Reject
Buggs, 2005[83]	Reject
Lightner, 2005[84]	Reject
Lightner, 2005[85]	Reject
ReMine, 2005[86]	Reject
Williams, 2005[87]	Reject
Wise, 2005[88]	Reject

Author and year	Position
Biswas, 2006[89]	Reject
Lamb, 2006[90]	Accept
Lightner, 2006[91]	Accept
Liu & Moran, 2006[92]	Reject
Liu & Moran, 2006[93]	Reject
Cavanaugh, 2007[94]	Accept
Kim, 2007[95]	Reject
Lightner, 2007[96]	Accept
Liu, 2007[97]	Reject
Standish, 2007[98]	Reject
Williams, 2007[99]	Reject
Anderson, 2008[100]	Accept
Anderson & Purdom, 2008[101]	Accept
Bergman, 2008[102]	Reject
Borger, 2008[103]	Accept (VIGEs)
Brand, 2008[104]	Reject
Lightner, 2008[105]	Accept
Lightner, 2008[106]	Accept
Matthews, 2008[107]	Reject
Purdom, 2008[108]	Accept
Purdom & Anderson, 2008[109]	Accept
Sanford, Baumgardner, Brewer, Gibson & ReMine, 2008[110]	Reject
Williams, 2008[111]	Accept
Williams, 2008[112]	Reject
Williams, 2008[113]	Reject
Bartlett, 2009[114]	Accept
Borger, 2009[115]	Accept (VIGEs)
Borger, 2009[116]	Accept (VIGEs)
Brown & Sanders, 2009[117]	Accept (AGEs)
Criswell, 2009[118]	Reject
Hennigan, 2009[119]	Accept
Larssen, 2009[120]	Reject

Author and year	Position
Lightner, 2009[121]	Accept
Lightner, 2009[122]	Accept
Lightner, 2009[123]	Accept
Purdom, 2009[124]	Accept
Shan, 2009[125]	Accept (AGEs, VIGEs)
Wise, 2009[126]	Reject
Bergman, 2010[127]	Reject
Borger, 2010[128]	Accept
Lightner, 2010[129]	Accept (VIGEs)
Lightner, 2010[130]	Accept
Carter, 2011[131]	Accept (VIGEs)
Doyle, 2011[132]	Reject
Lightner, 2011[133]	Accept
Lightner, 2011[134]	Accept
Soltys, 2011[135]	Reject
Gaskill & Thomas, 2012[136]	Accept (VIGEs)
Arneigh, 2013[137]	Reject
Jeanson, 2013[138]	Accept (AGEs)
Lightner, 2013[139]	Accept
Rupe & Sanford, 2013[140]	Reject
Terborg, 2013[141]	Accept (VIGEs)
Lightner, 2014[142]	Accept
Lightner, 2014[143]	Accept
Lightner, 2014[144]	Accept
Williams, 2014[145]	Reject
Williams, 2014[146]	Accept
Williams, 2014[147]	Accept (VIGEs)
Ingle, 2015[148]	Accept (AGEs)
Lightner, 2015[149]	Accept
Liu, 2015[150]	Reject
Truman, 2015[151]	Accept
Truman, 2015[152]	Accept
Williams, 2015[153]	Reject

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Results

We found 153 CS articles, by 124 authors, in which the authors took positions on beneficial mutations (tables 1, 2). Rejection of beneficial mutations strongly exceeded acceptance through the twentieth century. In the twenty-first century, a sharp rise in acceptance occurred, with the number of authors accepting beneficial mutations approximately equaling the number of authors rejecting it in the period 2011–2015 (fig. 1 & table 1).

The two-tailed *z*-tests found a significant difference between the two centuries in the proportions of articles and authors accepting and rejecting the existence of beneficial mutations. The rise in acceptance of beneficial mutations among CS authors in the twenty-first century is therefore statistically significant.

Discussion

CS authors have long recognized that genetic changes are called mutations, that genetic changes have caused each baramin ("created kind" of organism) to diversify into different species, that these diverse species are adapted to their environments, and that adaptation to one's environment is beneficial. It follows from those premises that beneficial mutations have occurred. Nevertheless, through the twentieth century, most CS authors rejected beneficial mutations (table 2), a self-contradictory position.

The current century has witnessed a dramatic rise in CS acceptance of beneficial mutations (fig. 1; table 2), correcting the self-contradiction. Such acceptance is more realistic than rejection is, because mainstream biologists have documented a plethora of examples of beneficial mutations in recent decades. Examples

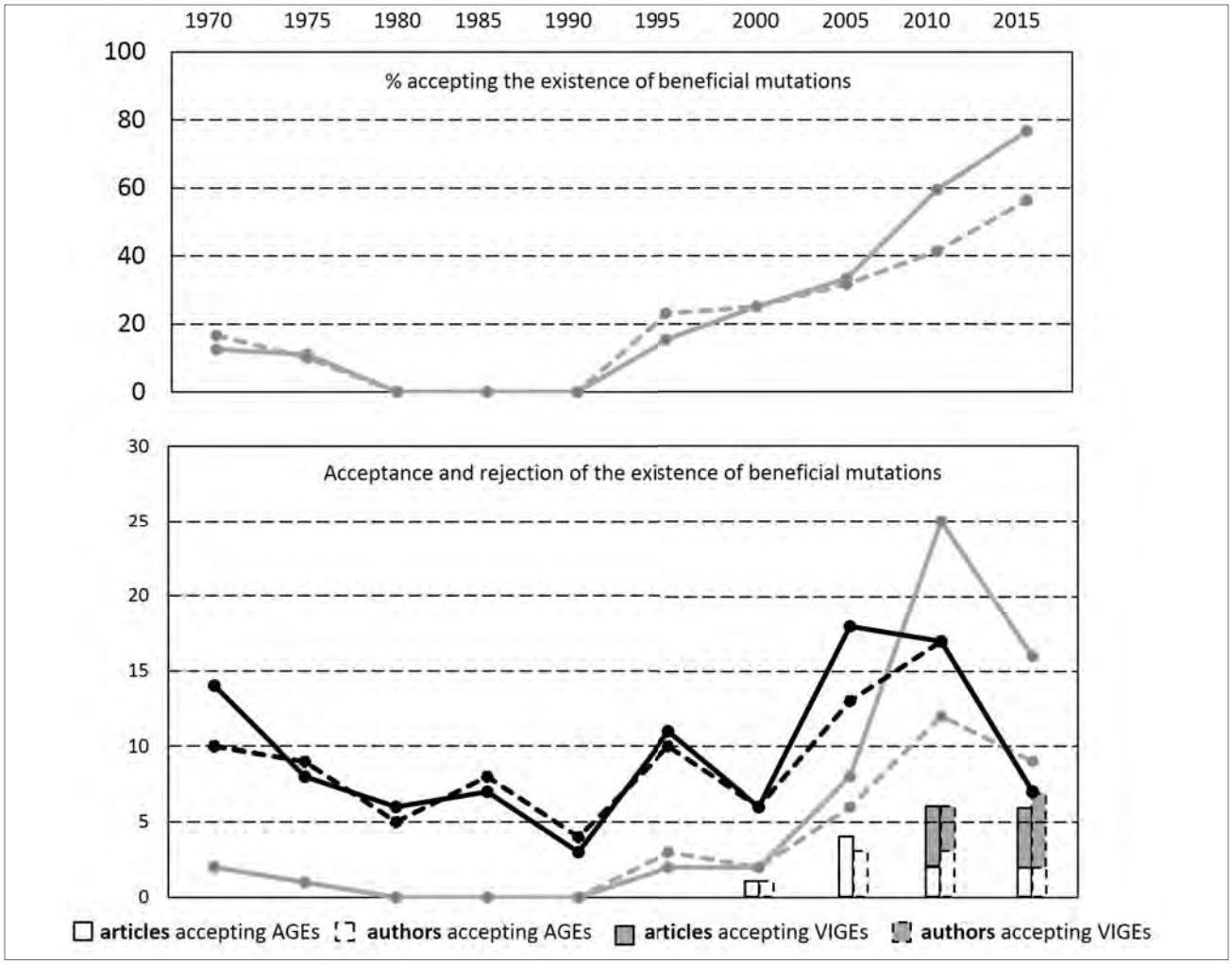

Figure 1. Temporal trends in the technical literature of creation science through 2015, regarding positions on beneficial mutations. Solid lines indicate articles, and dashed lines indicate authors; where no dashed line is visible, the number of authors equals the number of articles. Gray indicates acceptance, and black indicates rejection.

include beneficial mutations in viruses,[16] bacteria,[17] fungi,[18] eukaryotic algae,[19] plants,[20] invertebrates,[21] and vertebrates,[22] including humans.[23]

Nearly all CS authors rejecting beneficial mutations justified that position by stating that known mutations were harmful or neutral in effect. Some added that the appearance of beneficial mutations is illusory. For example, noting that geographic differences in human phenotypes make it appear that beneficial mutations have generated adaptation to local environments, one author explained it away by positing that the genetic changes happened first and then the humans moved into geographic areas where they were most comfortable.[24] Some CS authors insisted that pleiotropy (a phenomenon in which a gene has multiple effects on phenotype) would cause any mutation that had a beneficial effect to have multiple harmful effects, so that its net effect would necessarily be harmful.[25] For example, some argued that mutations in bacteria that make them antibiotic-resistant are harmful to the bacteria in some other way.[26]

Mainstream biological research has now falsified the argument that pleiotropy necessarily makes all mutations harmful. Examples of beneficial mutations without pleiotropic cost have been documented,[27] as have examples of pleiotropic mutations with multiple beneficial effects.[28] Furthermore, mainstream biologists have now documented cases in which the duplication of pleiotropic genes is followed by subfunctionalization,[29] a phenomenon in which each copy of the gene undergoes subsequent mutations that divide the gene's former functions between the copies, so that each copy now has but a single effect. Theoretically, this should allow the copies that have a harmful effect to be removed from the genome by subsequent deletion mutations or recombination. Mainstream biologists have also documented cases of neofunctionalization, in which duplicate genes undergo subsequent mutations and evolve new, beneficial functions.[30] The documentation of these phenomena falsifies the assertion of some CS authors that gene duplication cannot produce beneficial effects.[31]

Some CS authors argued that beneficial mutations do not get fixed in the genomes of organisms, because beneficial mutations are too rare[32] or would get weeded out before they can get fixed.[33] However, mainstream biologists have now documented numerous cases in which beneficial mutations have become fixed in genomes.[34] Additionally, mainstream biologists have also documented cases in which beneficial mutations occur sufficiently often to negate the effects of previous, harmful mutations.[35]

The recent rise in CS authors' acceptance of beneficial mutations is largely due to the emergence of the CS concepts of AGEs or VIGEs as generators of beneficial genetic changes. CS authors now use those concepts as convenient explanations for several phenomena. Some use AGEs or VIGEs to explain genetic variation[36] and its role in intrabaraminic diversification,[37] or to explain the rapidity with which such diversification must have taken place in only 6,000 years to generate the vast number of species recognized within some baramins.[38]

According to the CS paradigm, harmful mutations are a result of the Fall of humankind in the Garden of Eden, which introduced death and degeneration to the physical world.[39] Some CS authors hypothesize that mutations in AGEs or VIGEs after the Fall explain certain biological phenomena. One author hypothesized that the pathogenicity of viruses and bacteria (hypothetically designed as useful endosymbionts) is possibly due to mutations in their AGEs.[40] Another hypothesized that today's multicellular parasites are the mutant descendants of yesterday's beneficial endosymbionts:

> Raccoon roundworm, the rat tapeworm, and many other highly prevalent parasites provide support for the hypothesis that symbiotic animals were created to make horizontal transfer of AGEs possible and efficient.[41]

Some CS authors explain genetic diseases as the results of mutations of VIGEs.[42] Some propose that transposons and endogenous retroviruses are mutant descendants of VIGEs[43] or that RNA viruses arose by exogenization of endogenous retroviruses that are mutant descendants of VIGEs.[44] These creative applications of the AGE and VIGE concepts demonstrate the versatility and potential explanatory power of these concepts within the CS paradigm.

Interestingly, the emergence of the AGE and VIGE concepts, popular though they are among CS authors, does not seem to have persuaded many CS authors rejecting beneficial mutations to change their minds and accept beneficial mutations. Rather, the twenty-first-century rise in acceptance of beneficial mutations among CS authors is not due to the

changing of minds but is instead due to an influx of new authors who had already accepted beneficial mutations when they began writing about them, as shown in table 2. Jean Lightner, a rejecter[45]-turned-accepter,[46] is an exception.

The recent swing in CS literature from denial of beneficial mutations to acceptance of mobile genetic elements as generators of beneficial mutations, approaches concordance with mainstream biology. Mainstream studies confirm that, although in some cases transposons have harmful effects,[47] in other cases they have beneficial effects, and numerous examples of beneficial mutations resulting from transposon activity have now been recorded.[48] By considering transposons to be the molecular descendants of a mechanism that was meant to induce beneficial mutations, advocates of the VIGE concept have therefore come remarkably close to acceptance of the position of mainstream biologists.

One CS author proffered a unique explanation for the arguably beneficial advent of defense structures and attack structures (which would have been unnecessary in peaceful Eden) in organisms, without reference to AGEs or VIGEs. According to his explanation, each organism may have been created with two sets of genes: "one gene set for benign morphology and behavior (sinless contingency) and one for malignant morphology and behavior (Fall contingency) with only the benign gene sets expressed prior to the Fall."[49] As an alternate explanation, he proposed that God may instead have created organisms with malignant gene sets expressed as a preparation in case the Fall occurred but having no use prior to the Fall.

The explosion in documentation of beneficial mutations by mainstream scientists is mostly a phenomenon of the most recent three decades. Therefore, for much of the twentieth century, CS authors who rejected beneficial mutations had a point. At the time, little observational evidence for beneficial mutations had been collected. However, now that myriad beneficial mutations have been documented,[50] there is no longer any excuse to deny them. ✠

Notes

[1]Allan Mazur, "Believers and Disbelievers in Evolution," *Politics and the Life Sciences* 23, no. 2 (2005): 55–61; Jon D. Miller, Eugenie C. Scott, and Shinji Okamoto, "Public Acceptance of Evolution," *Science* 313, no. 5788 (2006): 765–66.

[2]Donald Prothero, *Evolution: What the Fossils Say and Why It Matters* (New York: Columbia University Press, 2007); Felix Gradstein, James Ogg, and Alan Smith, *A Geologic Time Scale 2004* (Cambridge, UK: Cambridge University Press, 2005).

[3]See Phil Senter, "Christianity's Earliest-Recorded Heresy, and Its Relevance to Christian Acceptance of Scientific Findings," *Thinking about Religion* 12 (2016), http://organizations.uncfsu.edu/ncrsa/journal/v12/SenterP_Peritomes.htm. This article expounds upon Jesus's non-endorsement of a literal reading of the Pentateuch; St. Paul's criticism of literalists, his advocacy of figurative interpretation, and his characterization of the Pentateuch narratives as "myths"; and endorsement of nonliteral interpretations by other early Church Fathers. See also Phil Senter, "Cognitive Styles Used in Evidence Citation by Ancient Christian Authors: The Psychology of a Major Ancient Controversy over the Historicity of the Pentateuch, and Its Implications for Science Education Today," *Open Library of Humanities* 3, no. 1 (2017): 1–50. This article includes a large collection of evidence that the New Testament's authors and other early Christian authors cited against the historicity of the Pentateuch. For New Testament endorsement of figurative interpretations of the Pentateuch, see Rom. 3:28–31; 1 Cor. 10:4; Gal. 3:7, 3:29, 4:24; Eph. 5:31–33; Col. 2:21–22; Heb. 10:4; and other passages discussed in the two articles mentioned above. Along similar lines, Jesus condemned anyone who broke the least of the Pentateuch's commandments (Matt. 5:17–19), yet he regularly broke them in their literal sense (Matt. 5:38, 12:1–8, 19:3–9; Mark 2:23–26, 7:14–19, 10:2–12; Luke 6:1–4, 16:18; John 5:1–11, 8:1–11); this apparent contradiction is resolved if he advocated following them in their figurative rather than literal sense. Moreover, he viewed the Torah as, at least in part, a set of veiled Messianic prophecies (Luke 24:27, 24:44; John 5:46).

[4]Philip J. Senter and Jared J. Mackey, "The Evolution of Creation Science, Part 1: Vestigial Structures and Biological Degeneration," *Perspectives on Science and Christian Faith* 69, no. 1 (2017): 27–41.

[5]But it will be useful to list here the abbreviations used in subsequent endnotes for the names of the CS journals: *ARJ* (*Answers Research Journal*), *CENTJ* (*Creation Ex Nihilo Technical Journal*), *CRSA* (*Creation Research Society Annual*), *CRSQ* (*Creation Research Society Quarterly*), *ENTJ* (*Ex Nihilo Technical Journal*), *JC* (*Journal of Creation*), *JCTS* (*Journal of Creation Theology and Science, Series B: Life Sciences*), and *OPBSG* (*Occasional Papers of the Baraminology Study Group*). The names of the CS journals *Origins* and *TJ* are not abbreviated in these endnotes, nor are the titles of the *Proceedings* volumes of the International Conference on Creation series. The current journal *JC* was previously *ENTJ*, then *CENTJ*, then *TJ*, before being named *Journal of Creation*. Likewise, the current journal *JCTS* was previously *OPBSG*.

[6]For example, Don Batten and Jonathan Sarfati, *15 Reasons to Take Genesis as History* (Brisbane, Australia: Creation Ministries International, 2006); Ken Ham, ed., *The New Answers Book 3* (Green Forest, AR: Master Books, 2009); Michael J. Oard, *Dinosaur Challenges and Mysteries* (Atlanta, GA: Creation Ministries International, 2011); Ken Ham, ed., *The New Answers Book 4* (Green Forest, AR: Master Books, 2013).

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[8]Brian K. Hall and Benedikt Hallgrimsson, *Strickberger's Evolution*, 4th ed. (Burlington, MA: Jones and Bartlett, 2008), 175; Neil A. Campbell, Jane B. Reece, Martha R. Taylor, Eric J. Simon, and Jean J. Dickey, *Biology: Concepts and Connections*, 6th ed. (San Francisco, CA: Pearson, 2009), 265; Carl T. Bergstrom and Lee A. Dugatkin, *Evolution*, 2nd ed. (New York: W. W. Norton, 2016), 6, 208, 199.

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[14]Borger, "Evidence for the Design of Life: Part 2."

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INTRODUCTION TO EVOLUTIONARY INFORMATICS by Robert J. Marks II, William A. Dembski, and Winston Ewert. Hackensack, NJ: World Scientific Publishing, 2017. 350 pages. Paperback; $48.00. ISBN: 9789813142145.

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

In this monograph, William Dembski joins his successors in the intelligent design movement to summarize three decades of publications. Their conclusion remains the same as in each of those publications: analysis of computer models of evolution show that evolution can succeed only with the input of "active information," which can come only from an external intelligent agent.

Robert J. Marks II is Distinguished Professor of Engineering in the Department of Engineering at Baylor University. He holds a PhD in electrical engineering from Texas Tech University. In 2007, Marks set up a research initiative to investigate the role of information in evolution. This work formed the basis of the Evolutionary Informatics Lab.

Dembski is well known to readers of this journal for his active role in promoting the concept of intelligent design. He holds a PhD in philosophy, a PhD in mathematics from the University of Chicago, and an MDiv from Princeton Theological Seminary. He is a Senior Research Scientist at the Evolutionary Informatics Lab.

Winston Ewert holds a PhD from Baylor University and is now a Senior Research Scientist at the Evolutionary Informatics Lab.

The authors have published numerous technical articles in the last few decades on mathematical and logical algorithms related to evolutionary searches. This book is not intended to provide any new ideas but rather to summarize and present their published work in a manner easier to understand by a larger audience than that of technical readers.

The eight-page preface provides a synopsis of each chapter and the conclusions of the book. For many, this will suffice, but others will look for the more detailed explanation in the text. In the authors' own words,

> This monograph serves two purposes. The first is explanation of evolutionary informatics at a level accessible to the well-informed reader. Secondly we believe *a la* Romans 1:20 and like verses that the implications of this work in the apologetics of perception of meaning are profound. (p. xiv)

Their conclusion is that "… all current models of evolution require information from an external designer in order to work" (p. xiii).

The first chapter is a six-page introduction with some general observations on the nature of science and the role of models and probability analyses.

The second chapter is an introduction to the concept of information. The authors make it clear that they are not limiting themselves to Shannon information which Claude Shannon developed to focus on communication. Rather, they are interested in the meaning of information, which Shannon explicitly pointed out was excluded from his engineering perspective. The authors claim to have made progress in measuring both meaning of information and design difficulty. They ignore Rolf Landauer's insight that "information is physical"; this foundation underlies the scientific field of information theory for which Shannon provided the basic tools of quantification of information entropy and communication channel capacity. Landauer's principle, pertaining to the lower theoretical limit of energy consumption of computation, has been theoretically and experimentally validated in the past 55 years. The authors favor Norbert Wiener's quote that "information is not matter; information is not energy." They interpret Wiener, the father of cybernetics, to mean that information is "… an independent component of nature" (p. xv). This chapter discusses two ways to measure and quantify information: Shannon for internal information, and Kolmogorov-Chaitin-Solomonov (KCS) for complexity, or lossless compression. Several examples are presented to show how these equations are applied. Neither approach satisfies the authors' desire to focus on meaningful information, leading them to suggest a new approach in chapter seven.

The third chapter discusses the role of search algorithms and design in evolution. Extensive discussion is offered of examples in which the goal is to design an optimal product, such as finding an optimal recipe for making pancakes and designing an optimized antenna. They introduce the concept of "active information" as the knowledge about the goal that must be provided during the search process in order to

achieve the goal in a practical number of searches. They conclude the chapter by noting that "undirected Darwinian evolution has neither the time nor computational resources to design anything of even moderate complexity. External knowledge is needed" (p. 59).

Chapter four is titled "Determinism in Randomness" and provides a useful set of examples of how to think about randomness. The authors point out that the probability distribution functions obtained as solutions to Schrödinger's equation are deterministic. They also discuss the implications of a limit of complexity of algorithms in computer models, as articulated by mathematician William F. Basener.[1] Finally, the authors analyze Thomas Ray's model of evolution called Tierra, published in 1989, and claim to show that it, as well as all other models of evolution, is limited by Basener's ceiling of complexity.

The fifth chapter is devoted to the topic of conservation of information (COI) in computer searches and, together with Basener's ceiling, is the heart of the argument presented in the book. They trace the earliest origin of COI to Lady Lovelace (Augusta Ada King), who observed that computers cannot create anything but can do only that which intelligent agents ask them to do (p. 105). Wolpert and Macready are given credit for coining the related term "No Free Lunch" (NFL) which also deals with computer search originality (p. 106). With many examples and quotes, the authors explore and demonstrate COI and NFL. They show how active information is quantified and why it is essential. The law of COI is then applied to evolution. The authors assert that "the evolutionary process creates no information" (p. 181). There must be an external source of knowledge about the goal to be achieved.

Chapter six is devoted to an analysis of two popular computer models of evolution, EV and Avida. The authors show that the success of these models depends on the explicit or implicit addition of active information by the programmers. To the authors, this supports the concept that evolution cannot be successful without external knowledge. They also discuss Gregory Chaitin's algorithmic approach, dubbed "metabiology," and attempt to refute Chaitin's claim that evolution has been validated algorithmically.

The objective of quantifying meaningful information is addressed in chapter seven. Marks has introduced the concept of algorithmic specified complexity (ASC) as a measure of meaningful information. He defines it as the internal information minus the KCS complexity information. While this may be a theoretical upper bound to the amount of meaningful information that a system can contain, his formulation provides no methodology of how ASC can be calculated in a real world system. Marks acknowledges that the value of the KCS complexity, and therefore the amount of ASC, of an arbitrary set of information, cannot be algorithmically determined, leaving it quantifiable only for some cases. Examples are given of codebooks such as ASCII or Morse code or information in snowflakes. But no guidance is offered of how to determine whether an information state really is meaningful in a biological organism. He adds notation to indicate that meaning is dependent on the context, but he does not offer a means for quantifying contextual effects. The primary conclusion is not a quantification of meaningful information; rather, it is an observation that meaningful information is extremely rare, a very small fraction of possible information.

The concluding chapter eight contains a brief discussion of intelligent design and artificial intelligence. The limitations of computer creativity, as explained in this book, indicate that the reach of artificial intelligence falls far short of that which can be achieved by an intelligent agent and may always do so. The success of evolutionary processes can be explained only by a source of external intelligent knowledge, providing active information of the goal of evolution. They conclude the book by saying that "undirected Darwinism can't work. An intelligent designer is the most reasonable conclusion" (p. 288).

In the opinion of this reviewer, while the conclusions of the authors may or may not apply to the computer models they discuss, there is no relevance to the real world of biological and chemical evolution. Four distinct differences between their models and evolution will be discussed here: (1) the limited scope of their consideration of information, (2) the role of populations, (3) the effect of selection, and (4) the consequences of the presupposition of goals.

1. Limited Scope

The first difference lies in the type of information being considered. The authors readily acknowledge that they are not working in the realm of the scientific field of information theory. Rather, like everyone except physicists and engineers, they are interested only in the meaning of information. While many a theorist has pursued an attempt to develop an analytical approach to meaningful information, none has succeeded. The bold claim of these authors to have made progress in measuring meaningful information is therefore notable. However, in restricting their attention to meaningful information, the authors misjudge the role of information—with critical consequences.

By ignoring nonmeaningful information, the authors overlook a potent source of new meaningful information. Physical information states must exist before they can have meaning. Information without meaning can acquire meaning in various ways. A simple example from the English language illustrates this point.

Consider the case of five-letter English words. With an alphabet of 26 letters there are about 11.9 million possible permutations. Up to 0.1% of these are meaningful English words, truly a rare occurrence. How can new meaningful words be generated? One way is for meaningful words to be assigned new additional meanings, dependent on the context. A more fruitful way is for words without meaning to be given a meaning, usually by consensus usage of the people. Any approach that considers only meaningful words will not be able to account for all the sources of new meaningful words. In the same way, the authors have overlooked a key source of meaningful information.

It should be noted that the intelligent design community has long recognized that there are two different types of "meaning of information," as discussed by Stephen Meyer.[2] However, the implications of the distinction have not been acknowledged. The most common form is the abstract significance assigned to a physical state of information. For example, a particular permutation of letters is assigned a meaning that is not related to the physical characteristics of the particular letters being used. Such an abstract relationship is not rooted in nature and can be designated and understood only by an intelligent agent.

The second type of meaning is a useful function in some physical context. This is the form recognized by biologists as they pursue the meaning of various information states in an organism. The meaning is the biochemical activity performed by an assembly of biomolecules which is the information state. This meaning does not require an intelligent agent. New functions can arise from a reservoir of various physical information states as the contextual environment changes.

An argument often used by the intelligent design community is that all of our experience tells us that new information can be generated only by intelligent agents and therefore biological information can be generated only by intelligent agents. That claim, however, conflates the two types of meaning of information. The only experience we have in which meaning requires intelligence is in human-designed systems which predominantly have abstract information. There is no rationale for applying that experience to information that is functional in the physical sense, as in biological systems.

Another way in which their limited scope of information inhibits their conclusion is that it leads to the application of the wrong conservation principle to evolution. The law of conservation of information (COI) as expressed in this book applies only to computer models and information searches in the artificial sense. In a real biological organism, the information states must be considered from the fundamental Shannon/Landauer perspective. The number of bits of information is dependent on the number and type of component particles and on their configuration. The only conservation principle that applies is the first law of thermodynamics, namely, the law of conservation of energy. The amount of information can be changed by adding or decreasing energy or particles, while a particular information state can be changed by a new configuration or arrangement of particles.

A biological system is not a closed system; rather, it has an influx of energy as well as dissipation of waste energy. This energy flux enables the opportunity for changes in information and the creation of new physical information. New genomic and epigenomic information can be created every time there is a rearrangement of genetic material, a point mutation in DNA, or any of the many processes that can insert or

remove segments of DNA. These changes introduce new biochemical activity which may be useful and therefore meaningful. Changes in the environment can also introduce new meaning when biochemical activity becomes useful in that context. Rarity of meaning is hardly relevant since the starting point of the genetic search is always a known successful system and the changes are usually small.[3] The authors fail to consider this primary source of new evolutionary information by restricting their focus to meaningful information.

2. Role of Populations

The second difference between the models used by the authors and real evolution is the effect of populations. The authors dismiss the effect of populations (p. 155). They reckon that a population of Q members is equivalent to a serial search of Q steps in terms of information added to the system. They consider this to be a more expensive query cost and set it aside.

However, the biotic world is composed of a large number of highly diverse species, each of which is composed of one or more populations, each of which is composed of many diverse members. In every reproductive cycle, each population produces a generation of offspring with a distribution of modifications ranging from minimal to radical. With a new arrangement of biological components in each individual and occasionally additional components, there is new information generated in each cycle. The authors average all of this into a single theoretical fitness parameter and ignore the accompanying increase in complexity and diversity. In other words, they set aside descent with modification, which is the primary driving force of complexity and new information.

3. The Effect of Selection

This leads to the third major difference between the authors' models and real evolution: the effect of selection. In a sequential serial search, such as those the authors consider, a life/death criterion cannot be used. If any step in the search meets with death, then the entire search is halted and must be restarted. Hence, any such events are washed away in an averaging parameter. However, in a real population, there is a massively parallel search with every member of the biotic world engaging in procreation from its unique information state. Each member of the offspring generation will either survive to reproduce in the subsequent generation or die in the sense that it will no longer procreate. The net effect is to have a new population, based on the parental population, with a new distribution of information states. These are the states modified from the parents which are successful, whereas the unsuccessful states are lost, never to be attempted again. In the terminology preferred by the authors, this is an injection of active information into the system.

No intelligent agent is needed to provide this active information. It is a direct result of life/death events, commonly known as "selection." Selection is not uniquely determined by fitness or complexity since numerous random contingent events can influence survival. In general, improved fitness in a changing environment will lead to a better probability of survival. The authors have therefore omitted consideration either of descent with modification or of selection, the two pillars of evolution.

4. Presuppositions of Goals

The fourth difference between the authors' models and real evolution is the assumption of a goal for evolution. Is the active information provided by selection sufficient? That depends on the goal being considered. If the goal is solely to reproduce a new successful offspring generation, then the active information from selection is sufficient. If, however, there is an ulterior motive or optimization goal for a future configuration, then it is not. It is argued here that it is the existence and nature of a teleological goal for evolution that leads the authors to the conclusion that an external source of knowledge is required. The authors point out that

> the fundamentals of evolutionary models offered by Darwinists and those used by engineers and computer scientists are the same. There is always a teleological goal imposed by an omnipotent programmer, a fitness associated with the goal, a source of active information … and stochastic updates. (p. 187)

However, such a goal is not derived from any study of nature. It is imposed externally, and it is this presupposition, and not nature itself, that leads directly to the conclusion that a source of external knowledge is required. A well-known example will illustrate this point.

Consider a dealer who shuffles and distributes a deck of 52 cards into four piles of thirteen cards each. As long as the cards are face down and equivalent, every hand looks identical. When the cards are turned over, each card has a distinctive marking. If all cards are equal in value and there is no difference in desirability of a particular arrangement, then no goal exists except to carry out the distribution which is successful in every case. However, as soon as someone values a particular arrangement, depending on the specific game being played, then it becomes possible to calculate probabilities. The more specific and rare the desired configuration is, the lower the probability that it will succeed. Very quickly, the probability drops below the plausibility level, and if a desired configuration is achieved, it could be argued that knowledge must have been transmitted to the dealer. If that knowledge affected the outcome in a positive way, the process is called "cheating." It is the goal itself that leads to the ability to calculate low probabilities, and not any inherent property of the cards or of the process of dealing the cards. It is also noteworthy that it is easy to fall into the well-known trap of a posteriori vs. a priori probabilities. Once a distribution is completed, that particular arrangement of cards can be noted. If it is applied as an a priori desire, it is easily shown that the probability is essentially zero. Yet, that arrangement was achieved.

In the real world of evolution, the change in populations of species is highly dependent on a vast complex set of environmental factors. The interaction between the biochemical activity in each cell and the environment is still beyond our complete understanding. It is easy to see that any goal with even the most modest level of specified complexity would lead to a mathematical calculation of essentially zero probability. However, nature knows nothing of such goals. The primary activity of a biological system is to reproduce in such a way as to generate viable offspring. As long as the change in the environment is relatively slow, the probability of success in each new generation is near 100% with no artificial bounds on what can or cannot happen; it is limited only by survivability. In other words, nature does not seek a specific goal: it seeks any state that survives. With the powerful role of descent with modification and selection operating in a reservoir of immense amounts of information, there are no limits to the complexity that can be achieved.

This brings us to the critical question of a teleological presupposition. The authors conclude that there is a need for an external source of knowledge. If that conclusion is due solely to the presupposition that there is a goal in the first place, which could only have come from an external source, then the conclusion is tautological and merely self-consistent rather than descriptive of the real world. On the other hand, if there is a presupposition that there is no goal, then no probability calculation is possible and the system continues to evolve without need of an external source of active information. It is noteworthy that virtually all arguments for an intelligent designer are based on probability calculations which in turn are possible only in the context of a preexisting goal. If it is assumed that there is no goal, then a self-consistent model will conclude that no external agent is needed.

The clash of major worldviews on the topic of evolution seems to center on whether evolution is purposeless and without guidance or whether it is guided with ultimate meaning and purpose. If a preexisting goal is assumed, then it is understandable that a mathematical model will conclude that information about that goal must be provided in order for the goal to be attained in a reasonable timeframe. If it is assumed that there is no goal, then it can be easily concluded that this world is meaningless and without purpose.

Which presupposition is correct? Nature cannot tell us. A preexisting goal is inherently outside the scope of this universe. On the one hand, no source or mechanism for such a goal has ever been postulated, let alone discovered. On the other hand, neither can nature tell us that such a goal or such an infusion of information does not exist. Each presupposition is self-consistent. Ockham's razor can be invoked on the side of those who argue there is no goal. On the other side, there is a sense of incredulity that the complexity of life could have come into existence without being planned. Furthermore, a common theological perspective is that God planned the current biotic world in advance. His goal can be interpreted generically with a reasonable probability of being met, either through convergent evolution or as a specific goal requiring divine guidance which may not be detectable. Evolutionary informatics will not settle the issue.

This book contains numerous examples of information, mathematics, and logic puzzles that are instructive and entertaining. However, anyone seeking insight into biological or chemical evolution is advised to look elsewhere. ✠

Notes

[1]William F. Basener, "Limits of Chaos and Progress in Evolutionary Dynamics," in *Biological Information: New Perspectives,* ed. Robert J. Marks II et al. (Hackensack, NJ: World Scientific Publishing, 2013), 87–104.

[2]Stephen C. Meyer, *Signature in the Cell: DNA and the Evidence for Intelligent Design* (New York: HarperCollins, 2010), 85–111.

[3]For a more detailed discussion of how physical information in DNA can be transformed into new meaningful information, see Loren Haarsma and Terry M. Gray, "Complexity, Self-Organization, and Design," in *Perspectives on an Evolving Creation*, ed. Keith B. Miller (Grand Rapids, MI: Eerdmans, 2003), 288–312.

Meeting Chaitin's Challenge

A Response to Randy Isaac's review of *Introduction to Evolutionary Informatics* (above)

by Robert J. Marks II, Distinguished Professor of Engineering, Department of Engineering at Baylor University, Waco, Texas.

Let my response to Randy Isaac's respectful review begin with thanks to James Peterson, the editor-in-chief of *Perspectives on Science and Christian Faith,* who, in concert with Isaac, solicited this response to Isaac's review. Such a practice is not common for book reviews. But we note that, in the venue of this journal, we are followers of Christ where we celebrate iron sharpening iron. One day, in front of our Creator, we will learn the degree to which of us is right. When this happens, I suspect the answer will matter little. Until then, let's continue to reason together.

Chaitin's Challenge

Gregory Chaitin, arguably the greatest and most creative mathematician of my generation, says: "The honor of mathematics requires us to come up with a mathematical theory of evolution and either prove that Darwin was wrong or right!" This question is answered in *Introduction to Evolutionary Informatics*: there exists no computer or mathematical model of Darwinian evolution not requiring the use of a guiding source of knowledge or oracle. Nor will there ever be an evolutionary algorithm that creates complex specified information without guidance supplied within the algorithm by one or more sources of knowledge such as oracles.

Regarding our book, Isaac concludes that those "seeking insight into biological or chemical evolution are advised to look elsewhere." We agree. But if you are looking for insights into the models and mathematics thus far proposed by supporters of Darwinian evolution that purport to describe the theory, our book is spot on.

Evolution Models: We Didn't Start the Fire

An honest attempt at computer modeling of evolution was Thomas Ray's fascinating program Tierra that, although displaying interesting properties, fell well short of Ray's goal of simulating something akin to the Cambrian explosion. Although Tierra had no explicit goal, Ray attempted to design an environment in which his digital organisms could evolve. He was not successful. After numerous failures and tweaks, Ray abandoned Tierra.[1]

More recent evolution simulations include the computer programs Avida and EV. Avida and EV pose evolution as a search algorithm with a specified goal. Engineering design has a long history of using evolutionary search with a design goal.[2] But Isaac protests that "such a goal [in evolution] is not derived from any study of nature." If true, Isaac has disqualified Avida, EV, and all other evolution models of which we are aware. For different reasons, we therefore find ourselves in agreement with Isaac: there yet exists no mathematical model that describes Darwinian evolution.

Avida is of particular importance because Robert Pennock, a co-author of the first paper describing Avida,[3] offered testimony at the Darwin-confirming *Kitzmiller et al. v. Dover Area School District* bench trial which ruled that work such as mine is religious. He testified, "In the [Avida computer program] system, we're not simulating evolution. Evolution is actually happening." If true, Avida and thus evolution is teleological, guided, and overflowing with active information supplied by the programmers.[4]

On the other hand, microbiologist James Shapiro says, "Most debates about evolution sound like the last fifty years of research in molecular biology had

never occurred"[5] and maintains that organisms teleologcally generate novelties which other organisms later adopt. Palaeontologist Simon Conway Morris's book *Life's Solution: Inevitable Humans in a Lonely Universe* makes clear from the title that evolution has a goal as witnessed by observation of evolutionary convergence. So, maybe evolution does have a goal. If so, evolutionary models and the critique of them in our book apply. If not, there exists no mathematical model of Darwinian evolution.

From Whence Design?

Within evolutionary models, the evolutionary process is not the source of design. The design is, rather, due to the imbedded source of knowledge in the model or simulation. For Avida and EV, our group was able to use the same resident sources of knowledge and generate results much more efficiently using simple stochastic hill climbing. Gold miners can dig using a spoon or a shovel. Evolution can be an inefficient tool for mining results from an oracle. For those interested, we have interactive GUI's (graphical user interfaces) on our website that demonstrate this.[6]

Hitting a limit called Basener's ceiling, evolutionary models such as Tierra and Avida will evolve only to the resident oracle's level of expertise. An evolutionary program written to play chess will not evolve an ability to play GO unless programmed to do so. Doing so makes the problem even more complex, necessitating even more guidance from a source of knowledge.

Some Information about Information

Measuring the algorithmic specified complexity (ASC) of a design involves defining applicable information measures. ASC does not deal directly with evolution, but is useful in assessing the meaning of end design information.

An entire chapter in *Introduction to Evolutionary Informatics* is dedicated to various definitions of information. We like Claude Shannon's take on defining information:

> It seems to me that we all define "information" as we choose; and, depending upon what field we are working in, we will choose different definitions. My own model of information theory … was framed precisely to work with the problem of communication.[7]

Isaac's claim that "information is physical" is narrow. It is like saying "squirrels are mass and energy." In the strictest sense, Shannon's definition of information is based on probability—events in the future which have not yet happened and therefore have nothing directly to do with anything yet physical. Nevertheless, we today universally assign Shannon's binary digit as the measure of physical information storage.

And then there's the Kolmogorov-Chaitin-Solomonov (KCS) information model that differs from Shannon's. Although more difficult to measure, KCS information deals with existing structures and is as much a part of the universe as energy, mass, and time. KCS information can be used as the foundation for determining the ASC—or meaning—of an object.

Here's an illustration. Consider a computer program that instructs a 3D printer to construct a bust of Abraham Lincoln in sufficient detail to see the wrinkles on his forehead and the mole on his right cheek. Contrast this with a program for printing a new bowling ball. For both the bowling ball and Lincoln bust, there exists a shortest program to accomplish the print. These shortest programs are called "elegant." The length of the elegant program is an object's KCS information content. The elegant program for the bowling ball, in bit count, will be shorter than that of Lincoln's bust. Lincoln's bust, measured by the bit count of its elegant program, contains more KCS information than the bowling ball.

However, the elegant program for detailed construction of a bumpy rock might be similar in length to the program needed for Lincoln's bust. So, assuming the details of the rock are not as meaningful as those on Lincoln's face, KCS information is seen to not measure meaning. Lincoln's bust is more meaningful because it is specified via context. Consider short 3D-printer-assisting subprograms called MOLE, BEARD, and HUMAN HEAD to which the programmer has access. When computing the length of the Lincoln elegant program, the subprograms used by the master program are not included in the bit tally. The conditional elegant program will be shorter. The ASC measure of the meaning of an object is obtained by subtracting this context-conditional elegant program length from the information measure of the

object based on chance construction by the best available theory, for example, the laws of physics. ASC appropriately bears a resemblance to Shannon's measure of mutual information.

Here are two examples from our book. A snowflake is very complex, but complex things like snowflakes happen all the time. Two arbitrary complex snowflakes have a low ASC whereas two identical snowflakes have a large ASC. In the context of poker, a two-of-a-kind poker hand has negligible ASC whereas a royal flush has an enormous ASC content.

"So You're Telling Me There's a Chance!"

… is *Dumb and Dumber*'s Lloyd Christmas's response to pretty Mary "Samsonite" Swanson who told Lloyd his odds with her were one in a million. The line is funny because Lloyd's response is clearly dumb. As I type, the odds of my right thumb quantum tunneling into my keyboard's space bar is finite but so small that saying "so you're telling me there's a chance" is also dumb.

How small must a probability be before we announce impossibility? The answer is fuzzy in the sense of Zadeh. So, to remove doubt, we must set chances beyond all argument.

Based on Landauer's contention that "information is physical," Seth Lloyd estimates the computing capacity of the universe throughout history to be 10^{120} operations on 10^{90} bits. Without guidance, 10^{120} bits is not able on average to generate unguided random creation of *any* sequence exceeding 165 Webster's dictionary words.[8] The low number of words is astonishing. For a specified phrase, the chances are smaller.[9]

Let's dwarf Lloyd's information bound. One Planck length stretched to an inch scales the diameter of a proton to several light years. A Planck time unit is the time it takes light to travel one Planck length. Consider a bit count equal to the number of Planck cubes in the universe integrated in Planck time units over 14 billion years. This number interpreted as bits is insufficient for generating any string of dictionary words as long as the Gettysburg Address. If you are astonished by this low figure, you are not alone. Even if multiplied by 10^{1000} universes in a multiverse, the resulting number, in bits, is insufficient for generating any sequence of words as long as the Declaration of Independence.

Isaac and others are critical of our use of probabilities. Even if "information is physical," these astronomical resources[10] eclipse the universe's current mass-energy parsed into single bit energies measured in von Neumann–Landauer lower energy bounds multiplied by the number of Planck time units in 14 billion years. Given the resulting staggeringly limited creativity of this bit count resource, creation requires enormous guidance to explain the ASC we see in nature, which certainly exceeds the length of the Gettysburg Address.

In a separate but related theory, the chance of generating a design decays at least exponentially as a function of the resulting ASC. The probability of a thousand bits of ASC occurring by chance is less than 2^{-1000}.

Are Meaningful and Meaningless Information Models Meaningful?

In his review, Isaac proposes his own information model to rebuke some of our research conclusions.[11] His theory consists of ideas such as meaningful information and meaningless information and the possibility of transforming the latter into the former. Isaac objects that we consider only meaninPPgful information while ignoring meaningless information. This is critical because, according to Isaac, it is possible to derive meaningful information from meaningless information.

If true, a DVD of bits generated by a quantum random number generator can be transformed into a DVD that has meaning—something like the movie *Braveheart*. Even if an enormous codebook translating random sequences into words were written, a source of knowledge in the form of human intelligence is required to establish the context required for meaning. We are simply agreeing on a new alphabet. In this sense, we concur that Isaac is correct in saying meaningless information can be defined as artificial context. In the same sense, hieroglyphics can be redefined into English without knowing hieroglyphics or caring about the meaning originally intended by some long-dead Egyptian writer.

Functional Information's Definition Is Abstract

Isaac points out that the information one might find in abstract symbols such as letters is different from functional information corresponding to a useful function in some physical context. He accepts that abstract information requires an intelligent agent, but argues that functional information does not. This begs a question: Does the instruction manual for my juicer contain functional information? No definition of functional information is given, and therefore the answer is not clear. "Functional information" needs to be defined in a mathematical sense. In molecular biology, functional information is "$-\log_2$ of the probability that a random sequence will encode a molecule with greater than any given degree of function."[12] I do not believe that this is what Isaac means. Curiously, functional information's definition according to Isaac looks to be abstract.

Isaac attempts to dismiss the applicability of our conservation of information results by arguing that one can increase meaningful information in a biological system by adding noise. But this is simply increasing the randomness of a system. Introducing randomness into a system is fully part of what is taken into account by the conservation of information. In a paper titled "Meaningful Information," Vitányi also disagrees with respect to KCS information.

> One can divide … [KCS] information into two parts: the information accounting for the useful regularity [meaningful information] present in the object and the information accounting for the remaining accidental [meaningless] information.[13]

Unlike our approach, the Kolmogorov sufficient statistic just described does not take into account context.[14] It is concerned only with the structure of an object. Nevertheless, the conclusion is the same: if you add random bits into a sequence, the pile of random meaningless information will simply be bigger. The meaningful information pile will remain the same size.

A fixed structure, such as Donald Trump's DNA, has fixed KCS information. But its ASC bound can increase as more context is found. Hieroglyphic texts were assigned more meaning when new context was provided by the discovery of the Rosetta stone. But, once successfully translated, a hieroglyphic text has no more meaning than that intended by the original writer. Likewise, the ENCODE project has given DNA more meaning than it had twenty years ago. The term "junk DNA" (Isaac's meaningless information?) is now rarely used because it has found function. DNA did not change but its meaning did. Was formerly meaningless junk DNA now meaningful? No. The meaning was always there but the context remained undiscovered. ASC, like KCS complexity, is expressed via a bound. KCS complexity is upper bounded by the shortest program thus far known. For a fixed theory of random object constrained construction, ASC is likewise lower bounded. Higher ASC can occur as more context is discovered.

Finis

If anyone generates a model demonstrating Darwinian evolution without guidance that ends in an object with significant specified complexity, let us know. No hand-waving or anecdotal proofs allowed.

We believe that Chaitin's challenge has been met in the negative and that no such model exists.

Space limitations prohibit further comment. Thanks for listening. ✠

Notes

[1]Citations for any material not explicitly referenced herein are in our book: Robert J. Marks II, William A. Dembski, and Winston Ewert, *Introduction to Evolutionary Informatics* (Hackensack, NJ: World Scientific, 2017).

[2]For example, check out the engineering journal, *IEEE Transactions on Evolutionary Computation.*

[3]Richard E. Lenski, Charles Ofria, Robert T. Pennock, and Christoph Adami, "The Evolutionary Origin of Complex Features," *Nature* 423, no. 6936 (2003): 139–44.

[4]One should not infer that knowledge sources were placed in Avida with any thought of deception on the part of the authors, who are all highly credentialed and respected researchers. Nevertheless, they are there.

[5]James Alan Shapiro, *Evolution: A View from the 21st Century* (Upper Saddle River, NJ: Pearson Education, 2011).

[6]http://evoinfo.org. See EV Ware, Minivida, and Weasel Ware.

[7]Quoted in P. Mirowski, *Machine Dreams: Economics Becomes a Cyborg Science* (New York: Cambridge University Press, 2002), 170.

[8]Eric Holloway and Robert J. Marks II, "Informational Cost of Generating Meaningful Text and Its Implications on Creativity" (in review).

[9]Marks, Dembski, and Ewert, *Introduction to Evolutionary Informatics*, 120–25.

[10]Pun intended.

[11]We could be wrong here, but Isaac provides no references concerning his model—nor are we aware of any.

[12]Jack W. Szostak, "Functional Information: Molecular Messages," *Nature* 423, no. 6941 (2003): 689.
[13]Paul Vitányi, "Meaningful Information," in *International Symposium on Algorithms and Computation: 13th International Symposium, ISAAC 2002 Vancouver, BC, Canada, November 21–23, 2002: Proceedings* (Berlin, Germany: Springer, 2002), 588–99.
[14]See Thomas M. Cover and Joy A. Thomas, *Elements of Information Theory*, 2nd ed. (Hoboken, NJ: Wiley-Interscience, 2006) or Ming Li and Paul Vitányi, *An Introduction to Kolmogorov Complexity and Its Applications* (New York: Springer Science + Business Media, 2008).

Rejoinder

by Randy Isaac

I appreciate Robert Marks's kind remarks and his taking the time to clarify his perspectives. I would like to underscore several points.

1. Any input from an intelligent source required by a mathematical model or an algorithm such as Chaitin's is due to the fact that these models and algorithms are human simulations of a natural process. It cannot be inferred that the natural process itself requires an intelligent source of information. Whatever merit the law of conservation of information—which asserts that new information can be generated only by an intelligent agent—may have in computer models, it does not apply to information in general and is not relevant to DNA information.
2. A key assumption of the information argument for intelligent design is that functional meaning of information such as DNA is identical in every way to abstract meaning of information. Hence it is claimed that since abstract meaning can be generated only by an intelligent source, it is also true for functional meaning. However, the reason that abstract meaning requires an intelligent source is the abstract nature of the meaning and not the characteristic of information itself. Functional meaning does not necessarily have an abstract component.[1] Biochemical processes transform DNA information into functional biological activity without a single step of abstract relationships. Evolutionary processes associate useful biological activity with specific DNA information without the need for an a priori abstract blueprint.
3. The way in which Marks considers probabilities implies that complex biomolecules are assembled anew by starting from a random collection of components. No such process is proposed in biological evolutionary theory. Rather, each reproductive event starts with a proven successful set of DNA information. Descent with modification has a high probability of succeeding in generating a new living organism. Biological evolution works.
4. Biology abounds with examples of DNA altered through descent with modification which changes the DNA information set and generates new biochemical functions.[2] Such creation of new information is theoretically possible without an intelligent source, and it is experimentally observed.
5. The assumption of teleology is the primary reason why some mathematical models of evolution lead to impossibly low probabilities. The existence and nature of teleology in evolution is an open question of great interest.[3] I look forward to studying it further. ✠

Notes

[1]Randy Isaac, "Information, Intelligence, and the Origins of Life," *Perspectives on Science and Christian Faith* 63, no. 4 (2011): 219–30.
[2]Dennis Venema, *Letters to the Duchess: ID and Information* (blog series), http://biologos.org/blogs/dennis-venema-letters-to-the-duchess/series/id-and-information.
[3]Sy Garte, "Teleology and the Origin of Evolution," *Perspectives on Science and Christian Faith* 69, no. 1 (2017): 42–50.

Book Reviews

Environment

A SUGAR CREEK CHRONICLE: Observing Climate Change from a Midwestern Woodland by Cornelia F. Mutel. Iowa City, IA: University of Iowa Press, 2016. 251 pages. Paperback; $14.40. ISBN: 9781609383961.

Have you had the unfortunate experience of having friends or family members learn of a medical condition that had existed long before the symptoms became apparent? How often have we commented on how well a person looked who really was very ill? Have you ever ignored medical symptoms, wishfully hoping it was not anything serious and would resolve itself without intervention?

What if you discovered that the environment in which you lived and loved was changing in gradual and subtle ways and realized that wishful thinking would not make it better? Would you be moved to speak out?

Cornelia Mutel studied the reports on climate change so she could ably edit a report on climate change effects in Iowa. She was profoundly moved by her research, coupled with changes she was seeing in her woodland, and she felt compelled to use her voice to address the issue. As an ecologist and senior science writer, she has the ability to write a book about what she learned and make that book accessible to people with little science background. Through the use of a monthly journal, we accompany Cornelia on walks through her woodland and experience with her the changes she saw taking place as a result of the extreme weather conditions that existed in Iowa during 2013. As an ecologist, she is able to point out the changes that occurred and speculate whether these were the vague symptoms of climate change.

The science of climate change is not easy reading nor readily understood by people outside the field. Mutel took an interesting approach: sharing with us a year-long journal that she wrote for her granddaughter about a woodland in which she lives, describing its ecology and natural history. Throughout this journal, she gently introduces the process of climate change by describing the changes in her woodland alongside weather events of the year. Using this approach, she shows what we might expect in a future when greenhouse gases reach a level that causes irreversible changes to our environment. To be clear, she notes that weather events described in her journal are best called weather and not climate change, but these weather events may already be influenced by climate change. If the extreme weather in 2013, in Iowa, gives us a sense of the change that could take place because of the rising heat energy in the atmosphere, it may be a way to understand the future impact of climate change. Mutel also shared personal life-changing problems that, by analogy, provide a unique way of understanding the insidious changes that are taking place.

As a reader, I was drawn into the gentleness of the book. Thinking of the effects of climate change are overwhelming for me. The future is a scary dwelling place for my mind. I am too old to see what will happen, but my grandchildren and their children will live in this changing world and it frightens me. I have read and studied scientific articles about the topic and am convinced that we are heading in a bad direction. The general warming trend is caused by human-induced increases in greenhouse gases. We have had other warm periods in the life of the earth and high CO_2 levels, but never when the earth was the home to almost 8 billion people. We all have heard about the future ramifications of this increased heat energy in the environment. Yet we do not seem to be moved by the probability of an increased frequency of extreme weather events, challenges to world food security, weather patterns that will amplify droughts that are already persistent in many areas of the world, rising sea levels that will cause mass migrations of the majority of the world's population that lives near ocean coasts, all creating world competition for space, water, and food leading to severe political unrest. Why don't we seem to care? Is it because we are told over and over that climate change is a hoax?

In 2016, the year of a national election, I saw the issue of climate change denied, ignored, and obfuscated. The general public does not know what to think. The science is hard to understand. So it takes a gentle but firm hand to introduce a nonscientific audience to the ramifications of heating the earth's atmosphere by what most would consider an insignificant change in temperature of a few degrees and to help them understand that this heating is caused primarily by greenhouse gases emitted through human activity.

My visits to national parks have always been invigorated by the lectures and tours provided by the park rangers. So, going on walks with Mutel through her journal descriptions of her woodland was a pleasure. I wanted to be there with her through the four seasons she beautifully described so that I could learn about her unique natural world. But since I could not be physically present, I read her journal chapters and compared them to my own experience, living in the urban sprawl of a metropolitan city. No woodland, just a small city lot, small house, and small perennial garden. Could I find parallels to her experiences? Or

could readers, living in different locations, identity with the changes she described to her woodland?

She made me think about the increased frequency of "100-year storms" and record-setting weather events (22 inches of rain in August) in my area. I see the changes in our urban mammal populations (e.g., skunks, rabbits, chipmunks), butterfly and mosquito populations, seasonal temperatures not following predictable patterns, and longer periods of droughts followed by too-heavy precipitation. I remembered (and liked) the warmth of an early spring only to watch the buds of emerging flowers and trees be nipped by a frost occurring on a normal seasonal date. So, yes, I found parallels, and the more I walked with her through her journal, the more connections I was able to make.

The book provides a very good explanation of climate change. Too often, the language of science gets in the way. We need a science conversant-society, but we are far from being there. We need a society that has a healthy trust of science. We are not there either. We need to have a society that believes that science and religion can be on the same side. Still, not there. What this book provides is good, understandable science and gentle reading. And, if you allow it, you will realize that the changes she describes in a woodland in Iowa are the same ones you find in your own backyard.

Mutel points out that, initially, climate change will not affect all of us the same way. Poor nations will find it more difficult to recover from severe weather events. The poorest people will be the least likely to prepare for the changes to come. I think of how difficult the recovery process was for hurricanes Katrina and Sandy or the number of deaths of elderly people during the extended heat waves in Chicago. Climate change is a social justice issue. Christians know of God's love for his creation and for all his children. As Christians, we need to mirror God in our actions.

Mutel has faith in this planet's people and in her nation, that they will act to slow climate change. She suggests meaningful ways in which people can act. She is optimistic, and she made me a little more so. However, it is difficult to be optimistic. I watch politicians continue to block basic measures to address the issue, and I see how corporate wealth influences decision making. I would like to believe that my reducing my energy footprint, and Mutel saving her woodland, is all that it will take. But I am wrong. We cannot have national elections without this issue being discussed and debated. We cannot have the world's religions ignore the symptoms. The world communities differ in their contributions to climate change, in their ability to respond to climate change, and in their ability to bear the costs involved. Whatever the imbalance, we will all suffer the consequences.

It is important to have books like *A Sugar Creek Chronicle* written for nonscience citizens. We need gentle, firm persuasion. We need a better understanding of the issues. We need hope. All of these are provided in this book. Get a copy, read it, and pass it along.

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Earth Sciences

EARTH SCIENCE: God's World, Our Home by Kevin Nelstead. Austin, TX: Novare Science & Math, 2016. xxii + 501 pages. Hardcover; $75.00. ISBN: 9780096352911.

I spent many years teaching science to young adolescents in Christian schools. Throughout those years, I generally preferred using a secular text, because I found that the science content was often stronger, even if a distinctively biblical perspective was lacking. I believed that I, as a middle school teacher, was better equipped to infuse a biblical perspective into my lessons than to develop the science content for myself, and so I made my curriculum choices along these either/or lines. Thankfully, with the ongoing development of new texts, this sort of either/or decision making may no longer be necessary. Nelstead's *Earth Science: God's World, Our Home* is a strong offering in terms of both the science content and the faith perspective. The text invites students and teachers to do "good science" while also presenting a faithful biblical worldview.

Before becoming a teacher at a Christian school, Nelstead served as Senior Cartographer, Geospatial Analyst, and Natural Resources Specialist for the United States federal government for seventeen years. His educational background is strong in Earth science, particularly in geology. He developed this text for middle school teachers in Christian schools based on three core principles: (1) Mastery: aiming for deep understanding and retention rather than the coverage approach prevalent in many science curricula; (2) Integration: deliberately uncovering the connections between the sciences and other disciplines; and (3) Kingdom Perspective: teaching students to "effectively engage issues" and "perceive God's fingerprints in creation" (pp. xiv–xvi).

The text begins with two helpful prefaces: one for teachers and one for students. In these prefaces, Nelstead explains the approach taken in the text in a way that is appropriate for each of these audiences. He includes an exposition of the faith perspective,

beliefs about science, and pedagogical assumptions that underlie the text, as well as suggestions for how to use this text, both as a teacher and as a learner.

The science content included is comprehensive and rigorous. Topics one would expect to find in a middle school science text, such as volcanoes, earthquakes, the water cycle, and climatic zones, are all present here. However, many other topics are also included to support and extend understanding of the major concepts. For example, the chapter on minerals opens with a detailed investigation of atomic structure, the periodic table, and chemical bonds, as these concepts are helpful for developing an understanding of crystal structure. Similarly, the chapter on climatology begins with topics that would be expected, such as the factors that determine climate and an exploration of climate classifications, but then moves on to more challenging topics such as climate change and the impact of air pollution on climates. These are just two illustrations, but I hope that they serve to shed light on the careful structuring of the content both to explain the underlying concepts and to provide application of the ideas in each chapter.

The content encompasses all of the major aspects of Earth science, including techniques for visualizing the earth: geological concepts, including rocks and minerals, the rock cycle, the structure of the earth, and plate tectonics; environmental science topics, such as weathering and erosion, the hydrologic cycle, and landforms; an exploration of Earth's history and geologic timescale; an introduction to oceanography; and meteorology concepts, including the composition of the atmosphere, weather, and climate. This book provides a faithful elaboration of current scientific theories, explaining the natural features of the earth and the processes at work in creation. On a quick read through the book, some of the content seems demanding for young adolescents. Exploring the overall structure of the text, however, helps one to see the thoughtful design to support students' mastery of this challenging content.

The text is very readable, and it includes appropriate graphics to illustrate concepts and provide examples. Nelstead's warm voice present in the text suggests a caring teacher behind the writing rather than the cold prose typical in many science textbooks. Each chapter begins with a historical vignette to introduce the topics to be investigated in an engaging way. A list of objectives to guide students' learning and to offer a means of self-assessment leads the text of the chapter, which is followed by a list of new vocabulary to be mastered. Each chapter is laid out in outline format, providing a deliberate structure for the content. The section headings are informative about what is included, and each section is well written with a clear introduction and conclusion. Each major section of a chapter concludes with a "learning check" composed of several questions that provide an opportunity for formative assessment, and each chapter closes with a series of exercises in various formats, including writing prompts, potential test questions, projects for application of the chapter concepts, and suggestions for further research. Eight of the fifteen chapters conclude with a suggested experimental investigation that students might conduct.

I very much appreciated the approach to potentially controversial topics for Christians teaching science. It can be a challenge for science teachers to navigate the perceived disparity between what scripture teaches and what is observed in creation. Nelstead addresses this challenge head-on by describing a proper understanding of the nature of science:

> We need to engage thoughtfully with the scientific claims of our day. It is not a scientific claim to say that the universe got here by itself; that is a metaphysical claim based on an atheistic worldview. But it is a scientific claim to say that the universe began with the Big Bang and is now 13.77 billion years old … We do not believe it is appropriate to teach students to be dismissive of claims like this one simply because they do not line up with certain ways of interpreting Genesis. (p. xv)

Nelstead is clear throughout the text that he loves scripture and holds the perspective that the Bible reveals God as the caring, sovereign Creator. He emphasizes the perspective in this text as one that accepts "the strong evidence for an old universe" (p. xvi). However, Nelstead also encourages Christian educators to put the issues of the age-of-the-Earth debate behind them, stating, "Since Scripture and creation both come from the same God, they cannot be in conflict. And when both are rightly understood, they won't be" (p. xvi). I recognize that not all Christian educators will agree with this perspective. However, many Christian educators teach with secular texts that embody a very different worldview than that of the teacher. The fact that Nelstead is upfront about his beliefs and how they influence the writing of the book is encouraging, and a model that Christian educators might follow.

The reader should be aware that this text seems to embody a strongly essentialist philosophy of education, emphasizing the development of vocabulary, understanding of basic concepts, and memorization. This is not necessarily problematic, but it is something to be considered in the process of selecting a text. The emphasis on mastery of the material—as opposed to the "cram-pass-forget" cycle introduced in the preface (see p. xiv)—is admirable. However, the current consensus in science education is that

a constructivist approach, emphasizing exploration, first-hand investigation, and authentic inquiry along with reading and writing in science, may lead to a deeper understanding of the concepts. While eight suggested investigations are included in this text, Nelstead seems to acknowledge that this might not be enough to truly provide opportunities for students to explore concepts firsthand. Included in the preface is a short section on "enrichment activities," which includes the statement, "understanding will be enhanced and memory will be strengthened when students engage with the content in activities outside the text" (p. xviii). Teachers intending to follow best practices for inquiry-infused science teaching will still find this a very valuable text for background reading and development of conceptual understanding related to Earth science topics.

I thoroughly enjoyed reading this text, and I believe Christians teaching science will find it a valuable resource. It may prove to be an excellent textbook choice for an earth science course for students in grades 7–9, and I would recommend that science teachers in Christian schools examine it for themselves for possible adoption. Christians involved in teaching science at other grade levels or in different types of schools would also benefit from this text as a resource to keep on the shelf. I believe that anyone interested in a thoughtful elaboration of Earth science that holds a biblical perspective as integral to that study would benefit from reading this book.

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Paleobiology

CETACEAN PALEOBIOLOGY by Felix G. Marx, Olivier Lambert, and Mark D. Uhen. Chichester, UK: Wiley-Blackwell, 2016. 345 pages, including contents, preface, color plates, and index. Hardcover; $149.95. ISBN: 9781118561270.

Cetaceans, including modern whales, dolphins, and porpoises, have long been enigmatic animals. In the first edition of *On the Origin of Species* (1859), Charles Darwin speculated how natural selection could have given rise to aquatic mammals like cetaceans, but his example, which was based on observations of black bears swimming in the water and eating insects, was so ridiculed that he removed much of it from subsequent editions. Some key cetacean fossils, hinting at their terrestrial ancestry, were recovered in the mid-to-late nineteenth and early twentieth centuries, but the origin of cetaceans was largely considered a mystery well into the mid-twentieth century. Discoveries of fossils in Pakistan and Egypt in the 1970s and 1980s spurred renewed interest in the early history of these animals, and in the past several decades, the evolution of cetaceans has become one of the most widely cited examples of large-scale evolutionary change evident in the fossil record.

Cetacean Paleobiology is a detailed look at what is currently known about this remarkable evolutionary transition based on the fossil record. The book aims to provide a complete and thorough overview of cetacean evolution, including basic principles of anatomy and taxonomy, summaries of extinct and modern families, explanations of techniques and concepts used to study fossils, detailed analyses of the fossil record, and various case studies. It was cowritten by three authors who have focused on different aspects of cetacean evolution. Felix Marx has worked primarily on the fossil record of the earliest baleen whales (mysticetes), while Olivier Lambert has studied principally the fossils of extinct toothed whales (odontocetes). Mark Uhen has focused his work on the earliest known cetaceans (archaeocetes), which bridge the gap between the terrestrial ancestors of cetaceans and the first fully aquatic forms. Between the three of them, they provide expertise on virtually all aspects of the cetacean fossil record.

Chapter 1 provides a brief overview of cetaceans and how different forms are classified. It includes a short introduction to functional anatomy and a thorough discourse on the methodology that is used to infer evolutionary relationships. This chapter also introduces some of the methods that are used to infer habitat and feeding preferences in fossil animals, including a detailed explanation of stable isotope ratios, and discusses the interplay between evolutionary trends and the biotic and abiotic factors that drive them.

The cetacean fossil record is detailed in chapter 2, and it includes a brief history of exploration and some of the key early figures involved in studying whale fossils. The basics of fossilization are discussed along with its major effects on the fossil record of cetaceans. Much of the chapter is devoted to descriptions of major cetacean fossil localities in the world, including sites such as Wadi Al-Hitan in Egypt, deposits all along the southeastern coast of the United States, and the Pisco and Sacaco basins in Peru.

I suspect that, for many readers, it is in chapter 3, which involves a detailed look at morphology, that the rubber meets the road. The chapter begins with an overview of the skeleton before moving into a detailed look at the skull. The ear region, which is vital for understanding cetacean taxonomy and ecology, is described in extensive detail. Comparatively little of the chapter is devoted to the postcranial skeleton, but the discussion of osteological correlates of soft tissue structures (e.g., muscles, baleen, brain) is

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

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

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

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

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

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Philosophy & Theology

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

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

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

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

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

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

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

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

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

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

Chapter 1: "Complexity and Emergence"

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

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

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

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

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

Chapter 2: "Digital Computer Systems"

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

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

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

Chapter 3: "The Basis of Complexity"

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

Chapter 4: "Kinds of Top-Down Causation"

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

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

Chapter 5: "Room at the Bottom?"

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

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

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

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

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

Chapter 7: "The Mind and the Brain"

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

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

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

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

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

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

Chapter 8: "The Broader View"

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

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

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

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

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

Ellis closes the book with this final paragraph:

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

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

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

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

Notes

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

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

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Science & Biblical Studies

ADAM AND THE GENOME: Reading Scripture after Genetic Science by Dennis R. Venema and Scot McKnight. Grand Rapids, MI: Brazos Press, 2017. xii + 225 pages. Paperback; $19.99. ISBN 9781587433948.

The emergence of a number of books on the so-called historical Adam in evangelical Christian circles during the last decade demonstrates how conservative Protestants in particular are grappling with important issues across the theological spectrum in the light of contemporary science. The advantage of this volume is that we are treated to a way beyond "the Bible or science" impasse by the joint efforts of a biologist (Venema) and a biblical scholar (McKnight), both of whom have impeccable scientific/scholarly and evangelical credentials: Venema with a PhD in biology from the University of British Columbia and a longtime professor of biology at Trinity Western University in Vancouver, British Columbia; McKnight with a PhD in New Testament from the University of Nottingham and with three decades of service at evangelical or evangelical-friendly institutions in the Chicago area: Trinity Evangelical Divinity School, North Park University, and Northern Seminary. Northern Seminary is affiliated with the American Baptist Convention (ABC), but it is more evangelically aligned than other ABC seminaries.

The first four chapters are biological; the latter four are biblical. Venema's contributions are to introduce evangelicals to the scientific ideas related to human origins. He first explains what it means to say that evolution is a scientific theory, helping evangelicals to understand that theory in a scientific context does not signify the merely hypothetical. He then explicates genomic science, in particular, the science of population genetics and its role in helping us understand the evolution and speciation of *Homo sapiens*. Next, he elucidates the early history of hominids from a genomic perspective, showing how the interbreeding of humans leaving Africa approximately 50,000 years ago with Neanderthals (in what is now the European region) and with members of the Denisovan species (in the Asian sphere, from DNA found in the Denisova Cave in the mountains of Siberia) have produced the basic racial variations we now associate with Africa, Europe, and Asia/Oceania. Venema also shows how all members of the human family today can be descendants of the so-called Mitochondrial Eve with respect to their mitochondrial genome and DNA, yet have 10,000 or more other ancestors vis-à-vis their chromosomal DNA. Thus, he exposes the challenges that population genetics and research on the genome present to both young earth creationist and intelligent design advocates, addressing specifically the arguments of Michael Behe (whose ideas Venema embraced at one point in his studies as a young and aspiring biologist) and Stephen Meyer, both of whom represent God-of-the-gaps approaches that have waylaid prior apologetic endeavors. Some of the terrain is dense, but evangelical Christians interested in understanding better the science of evolutionary genomics will be richly rewarded for their patience.

McKnight's part of the book proceeds with the assumption that science is coherent and plausible, and that scripture is dependable and authoritative. How then can believers subordinated to the Bible square its message with our evolving understanding of human origins, including our relationship with other species that share 95% of our DNA? The four-stranded response begins. First, McKnight lays out basic hermeneutical principles of respect for the distinctiveness of ancient voices, honesty with current knowledge, sensitivity to students of science, and the primacy of scripture. Second, he moves to clarify how the ancient biblical authors, especially of Genesis, presented not a *historical Adam* (that has emerged in our modern scientific milieu) but a literary and genealogical perspective. Third, he traces the reception history of the Genesis narrative in Jewish tradition that produced interpretations of Adam as moral archetype (Sirach), as immortal/transhistorical figure (Wisdom of Solomon), as philosophical Logos (Philo), as exemplar of Torah observance (*Jubilees*), as Roman figurehead (Josephus), as fallen creature (Ezra 4), and as representative of all humankind (Baruch 2), all of which combined to produce Adam as "the paradigm or prototype or archetype of the choice between the path of obedience and that of disobedience" (p. 169). Finally, he concludes with a discussion of how this legacy of Adamic understandings illuminates St. Paul's retrieval of the literary and genealogical Adam of the inherited biblical traditions in a moral, exemplary, and archetypal direction in order to accentuate Jesus's universal relevance. By the end of the book, the argument is clear: current debates about any historical Adam are fraught with modern scientific (biological and increasingly genetic) presuppositions that are not only foreign to the biblical world but are intrusive upon a faithful approach to the sacred text considered in its original context.

As a systematician, I come away from this book more convinced than ever before that the idea that God might have picked out *Homo sapiens* from among other creaturely species (with other hominids eventually dying out) is consistent with how divine election has been shown to work (e.g., choosing Israel

from among the nations). True, the authors recognize that there is the slenderest thread of support for such a view within Genesis itself—perhaps the lone clue being that Cain's wife came from somewhere else—but the fact that this question was not one the biblical author(s) would have asked is precisely the point of the arc of *Adam and the Genome*. If the broad lines of the way forward presented in this book are deemed cogent, then the implications will be most impactful for those traditions for which notions of original sin/guilt remain prevalent, especially Reformation-oriented traditions. (I am thinking, for instance, of those associated with the churches represented by many contributors to Hans Madueme and Michael Reeves, eds., *Adam, the Fall, and Original Sin: Theological, Biblical, and Scientific Perspectives*; Baker Academic, 2014.) The big question will then be hermeneutical: to what degree is scriptural interpretation dependent on ecclesially developed frames of reference and what might it mean for ecclesial traditions that take *sola scriptura* seriously to wrestle with the Bible in a late modern world quite removed from the (sixteenth century and later) polemics that precipitated formation and nurtured development of their traditions initially?

On the science side, this book will no doubt motivate young earth creationists to master especially the sciences of population genetics, which will be an interesting development to follow. Further, Christian and evangelical intelligent design theorists (not all ID proponents are either Christian or evangelical) should surely reconsider how Venema's personal confession of "evolution as God's grand design for creating life" (p. 90) and McKnight's position of "planned evolution" (p. 96)—both of which also go by other names (theistic evolution and evolutionary creationism, for example)—might be allies as opposed to opponents in the overall theological task of reconciling science and scripture. For the foreseeable future, this book is a significant intervention in the convoluted space where modern science and biblical faithfulness meet, and I recommend it as a text for evangelical colleges and universities to be used not only in programs in the natural sciences but also in worldview, Bible, and theology courses.

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Along with all their other contributions, many members of ASA and CSCA publish important works. As space permits, *PSCF* plans to list recently published books and peer-reviewed articles related to the intersection of science and Christian faith that are written by our members and brought to our attention. For us to consider such works, please write to patrick.franklin@prov.ca.

Science and Religion

TOUCHING THE FACE OF THE COSMOS: On the Intersection of Space Travel and Religion by Paul Levinson and Michael Waltemathe, eds. New York: Fordham University Press, 2016. 280 pages. Paperback; $19.95. ISBN: 9780823272112.

Space exploration—human spaceflight in particular—has received much attention recently. New generations of telescopes promise ever more discoveries that elucidate the origin, structure, and fate of the universe. The rise of the commercial spaceflight industry leads to the hope that all sorts of people, not just professional astronauts, will eventually be able to travel to space. Elon Musk, founder of SpaceX, has ambitious plans to colonize Mars, and NASA's own plans call for a human expedition to Mars in the 2030s. Recent movies and television programs have contributed to this surge of interest: *The Martian, Interstellar, Gravity,* and the *National Geographic* series *Mars*. This interest is not misplaced, for we have never been closer to making space flight a reality for thousands, to making observations that elucidate the state of the universe soon after the Big Bang, and to leaving Earth for extended stays.

In this milieu, it is perhaps natural to wonder if there is a "cosmic" meaning to space exploration. Space is, after all, historically the realm of the heavens, the home of God, the place to where we lift our hearts in prayer, the source of manna from heaven. One cannot contemplate the immensity of the times and distances inherent to space exploration without a sense of awe and wonder, and these almost inevitably bring one to thoughts of ultimate meaning, God, and religion. Thus there would appear to be a strong natural connection between space exploration and religion. Or is there?

In the June 2015 issue of this journal, I reviewed the book *To Touch the Face of God: The Sacred, the Profane, and the American Space Program, 1957–1975*, by Kendrick Oliver; this is another book that feels almost obligated to find a connection between space and religion. Nevertheless, it reached the overall conclusion that, despite expectations, in fact there is not a strong and compelling connection between space and religion. Certainly there are people who see intimations of God in the enormity of creation, and many religious scientists see science and exploration as forms of worship that attempt to fathom God's thoughts, as Einstein put it. But there is little or no evidence of an overall religious motivation for space exploration, of a sense that those involved experience religious conversions or insights, or that space might bring us closer to God. Within this broad envelope, however,

there are specific areas in which space and religion do come into contact. Some of these are explored in *Touching the Face of the Cosmos*. It has ambitions similar to those of the Oliver book, and although it strongly endorses a final position it does reinforce (at least for me) the overall conclusion of Oliver's book. Unlike that earlier book, which presented a logical and cohesive analysis by a single author, this one is a compilation of essays and stories by various authors.

The book is a mixed bag. The essays in Part 1, in general, are not light reading. Some have a strong academic tone, some are direct and straightforward with a single simple point, and some ramble (or are wide ranging, depending on one's view). All are thought provoking, but might prove challenging for the casual reader as there is a lack of coherence, given the variety of authors and topics. The stories in Part 2 are also a mixture, and may be more approachable for the general reader or fan of science fiction. Some of the stories are reprints from science-fiction magazines, going as far back as the 1980s. One wonders if the editors are grasping at straws in putting this collection together. The stories in many cases explore common religious issues in settings other than Earth. In some cases, this is just an excuse to talk about religion in space. In others, it is a natural way to explore what might make the Earth's religions unique. Rarely is there a true commingling of the space-travel and religion aspects.

When starting the book, one wonders if the topic under discussion is actual human space travel, as the subtitle implies, or travel more broadly construed as in the virtual travel of astronomical observation. The Introduction seems to make clear that it is indeed human space flight that is the issue and contends that one reason for our slow progression beyond our current presence in low-Earth orbit is that we have not accounted for a major benefit of human space flight, namely the spiritual and religious dimension. This is an unusual hypothesis, given that such justification was never a compelling reason for space travel, even among the astronauts themselves. This line of reasoning could well lead to an interesting discussion. But that is not what this book presents. Instead, if offers a number of loosely connected chapters that seem to have as their overall goal the exploration of the intersection of space travel and religion in a myriad of different forms. Presumably this broad-based approach will strike a nerve for a broad range of people, more so than an academic discourse based on a single theme.

The book starts with an account of an interview of Senator John Glenn conducted by one of the authors. The interview is compelling in two ways. First, Senator Glenn points out that his faith was firm before his flights. Second, interviewer/author tends to ask leading questions, probably hoping to draw out the religious effects of space flight. The outcome of the interview coincides with what has been noted by others: the experience of human space flight does not typically alter astronauts in any fundamental way, while those on Earth were often driven by a desire to see flights into space in a larger and in some cases spiritual sense. Even though Glenn is a devout Christian, his practical side as a military and political figure takes priority in his assessment of the value of human space flight. Nevertheless, his own personal faith was strengthened by his space flight, a point mentioned several times in recognition of his passing in December 2016.

The rest of the book includes 28 short chapters: fifteen essays and thirteen stories. I will briefly describe a few of the more notable contributions in order to demonstrate the range of material and ideas covered.

The author of "A Catholic in Space: Coming Home" (Consolmagno) is a Jesuit priest and Vatican astronomer. His chapter summarizes observations which his unique position, straddling these communities, has made possible. In trying to resolve his faith with the enormity of the universe, he points out that humans are special because we reflect the character of the universe. If we have faith in our science and faith in our faith, then each will be universal. Although each will be challenged with new discoveries, these challenges can be met because of our belief that what we know here on Earth is true throughout the universe.

"Our Cosmic Future? How Religion Might Shape It" (Ambrosius) presents a summary of surveys showing that there is relatively little support for space exploration among evangelical Christians, due partly to a belief of Christ's imminent return and partly to a belief that humans were uniquely created (so looking for life elsewhere is wasteful and possibly even an affront to God). Given that space exploration depends on public support, these religious aspects should not be ignored by those who aim to promote space exploration and travel.

"Faith in Space: A Christian Perspective" (O'Neal) provides a simple, concrete review of how some astronauts have carried on their religious faith traditions while in space. There is a smattering of examples of the ways astronauts from the early Mercury program to more recent flights to the International Space Station have expressed their Christian faith while in space. It is interesting and brief, without much in the way of synthesis or overall interpretation except to point out that these expressions are as natural for astronauts in space as they are while on Earth.

"The Heavens Declare the Glory of God" (Waltemathe) draws on examples of religious motivations for previous voyages, such as fleeing from persecution or from impending disaster (Noah), that could well be motivators for space flights in the future. In addition, the nature of the destination plays a major role in religious motivations for these voyages, and the sense of exploring God's creation via space travel is relevant. Such a journey gives the traveler a broader perspective from which to see anew our place in the universe, which is one of the more profound outcomes of any pilgrimage.

"Space Exploration as a Religious Pilgrimage" (del Toro) also deals with space travel as a form of pilgrimage, from the perspective that the universe is a holy place where we can get in contact with the divine. The author draws parallels to Earthly pilgrimages, framed around questions such as "where do we come from?" and "what is our purpose?" Space exploration allows us to see ourselves in a different way; this is one goal of pilgrimage.

"Anticipating the Contours of Extraterrestrial Religion" (Hess) places religion in the context of human evolution, as a cultural phenomenon subject to natural selection and societal pressures (as do several other essays in this volume). This leads to a series of questions about what non-Earth religions might be like. Issues of incarnation and eschatology are examined closely. All of this is admittedly hypothetical but leads nevertheless to theological self-examination.

Overall, this book might appeal to those who enjoy reading science-fiction stories that touch on space and religion, even if tangentially. It could also pique the reader's interest in a range of space-religion interactions. Those wanting a deep exploration of any specific aspect of this topic will be left wanting more.

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A LITTLE BOOK FOR NEW SCIENTISTS: Why and How to Study Science by Josh A. Reeves and Steve Donaldson. Downers Grove, IL: InterVarsity Press, 2016. 134 pages. Paperback; $12.00. ISBN: 9780830851447.

As its title indicates, this is genuinely a little book, but there is an abundance of helpful information packed into its few, small pages. Reeves and Donaldson state clearly in *A Little Book for New Scientists* that their purpose in writing this book is to "help Christians studying and practicing in the sciences to connect their vocation with their Christian faith" (p. 13). I suspect that the primary audience for their book will be new scientists or new Christians who are scientists, and I think that these audiences will find this book helpful.

Using the popular two-books metaphor, this book begins by arguing that, because the natural world can teach us about God, we can point to a specifically Christian reason to study science. It cautions that there are limits to what the natural world can teach us about God and, although the book touches on the converse, it does not offer a similar overt caution about what scripture can and cannot teach us about the natural world.

Chapter 2 is dedicated to the history of science, making the important point that science and faith have not always been in conflict. It also briefly outlines the reasons why it was a Christian worldview that laid the foundations for the development of modern science. This chapter ends by helpfully distinguishing between methodological naturalism and scientific naturalism (scientism).

Chapter 3 discusses science as an ethical activity in and of itself. Given the limitations of a little book, I was surprised at the attention the authors gave to explaining that scientists are morally ordinary rather than ethically superior. The authors argue that the scientific method was the source of this sense of ethical superiority, which resulted in widespread trust of scientists. In contrast, scientists are not actually ethically superior because their explanations of the way the natural world works are not value free.

I found chapter 4 to be the least engaging chapter of this book. It outlines special tools for Christians who are scientists to help them avoid pitfalls and temptations. I was less engaged, not because avoiding these pitfalls is unimportant, but because I do not find these pitfalls and temptations unique to science or scientists. I appreciated the section pointing out the problem of specialization and suggest that this could have been a strong argument for learning and doing science in the context of the liberal arts.

Chapter 5 includes a welcome shout-out to the ASA and implores scientists, especially scientists who are Christians, to work toward community building. It points out the value of integrative scholarship as a means to building community. The thorough reminder in chapter 8 that many scientists are people of faith supports this call to community. Chapter 6 asks whether intellectual humility is more difficult for scientists than for others, echoing the theme of chapter 4, and I was similarly unconvinced that this is more difficult for scientists than for nonscientists.

My favorite chapter was chapter 7, and I plan to find a way to work this chapter—if not the whole book—

into some of the courses I teach. The authors do a beautiful job of arguing for as much openness and humility in our hermeneutics as in our science, for listening graciously to each other, for a deep understanding of the cultural context of scripture, and for a commitment to resolving apparent conflicts between science and faith. The appeal to seek dialogue and understanding with a commitment to graceful listening is one we certainly need today in science, faith, and beyond.

The book concludes with a call for scientists to bring science into their churches and how doing so can "positively affect the mission and ministry of the church" (p. 120). I found the arguments in this chapter to be the most compelling of the book. I loved the authors' appeal for scientists to step forward to educate their pastors and congregations, to open up and lead conversations about the integration of science and faith, and to serve as a bridge between people of faith who may fear science and those whose worldview puts science in place of God. In a world that seems more divided by the day, this message of education and reconciliation may be the most important of the book.

I enjoyed this book. It is extremely accessible. It would be very useful in first-year college or university courses for science majors, for advanced high school students in Christian schools, in adult discipleship classes in churches, or for individuals. I encourage anyone interested in science and faith to pick it up. It is well worth the short time that it takes to read its few, but valuable, pages.

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Technology

IN OUR OWN IMAGE: Savior or Destroyer? The History and Future of Artificial Intelligence by George Zarkadakis. New York: Pegasus, 2016. xxi + 362 pages, endnotes, index. Hardcover; $27.95. ISBN: 9781605989648.

The origins and possibilities of near-ubiquitous and transformative AI (artificial intelligence) constitute the important subject of this clearly written, often insightful, and provocative work. The book consists of sixteen chapters, framed by an introduction and an epilogue and timeline. This is ambitious popular science writing that weaves together often-contested or speculative ideas and disciplines from history and cognitive archaeology, mathematics, sciences (from quantum theory to psychology), philosophy (expositions here are one of Zarkadakis's strengths), religion (not so much), engineering, and science fiction (he cites many morally serious science fiction stories, novels, and movies). A problem with multidisciplinary attempts, of course, is that one cannot have expertise in everything or be familiar with all the relevant scholarship; the science fiction references, for example, are interesting but far from comprehensive. To his credit, the author, a computer scientist, argues that "essential aspects of being human" remain beyond technological reproduction; our intelligence "cannot be captured in formal rules" and is distinctively *embodied*; and biological consciousness cannot be reduced to computational machines (pp. 278–79). He is doubtful about an imminent, apocalyptic "singularity" of artificial *super*-intelligences.

The book begins with two chapters on deep history. Between 150,000 and 50,000 years ago—before religion or science—language birthed intelligence; we created a symbolic "world of animals and things" endowed with spirit, mind, and meaning. This was "the [cognitive] big bang" that, with naturalistic Paleolithic painting, let us come to terms with inevitable death and ultimately imagine making "robots … as intelligent as ourselves" (pp. 15–16). Zarkadakis zips through millennia of thinking (Aristotle: good; Plato and Descartes: bad), rejecting any hint of nonmaterial life forces or uploadable minds, with helpful discussions of the roles and implications of metaphors, analogies, and narratives in scientific thought about AI. (See chapters three and six on limits to our knowledge.)

Science fiction readers will enjoy the discussion in chapter four, including the old trope of superior robots/androids rising up to exterminate their human creators (see also pp. 270–75). Chapter five, "Prometheus Unbound," further examines fictional anxieties and fears, especially Mary Shelley's incomparable *Frankenstein* (1818); the familiar analysis does not engage the scholarly literature, however. We are becoming cyborgs (chap. six) and could create "digital gods" of "infinite wisdom" but we would lose our humanity in merging with them, Zarkadakis cautions.

Chapter seven discusses questions of mathematics, mind, and more philosophy. Chapter eight argues against mind/body dualism, which contradicts physics and disallows humanlike AI (pp. 118–30). The author criticizes Ray Kurzweil's singularity thesis (after about 2045, AI will be utterly beyond our comprehension) as a "quasi-religious" belief inspired by Teilhard de Chardin's evolutionary theology (as is the cosmic anthropic principle, pp. 126–28). Scientific claims are verifiable or falsifiable; religious ones are neither (p. 130). Chapter nine again contests philosophical dualism; Daniel Dennett's 1991 reductive/

materialist explanation of consciousness is highly regarded (pp. 143–46). Chapter ten unpacks the meanings of "consciousness" following Francis Crick's claim—in his 1994 *Astonishing Hypothesis*, "a book that changed everything"—that it is "entirely due to the behavior of cells … and the atoms … that make them up" (p. 155). Chapter eleven regards cybernetics as omnicompetent, if not omniscient and omnipotent: "ultimately" it could "show us how to govern the evolution of life and the universe," including fully conscious AI (pp. 172–91).

Chapter twelve is a careful discussion of logic from Aristotle, through Boole, Gödel, Turing, and others. Next comes a chapter on the Victorian background to AI, dependent on unnamed historical studies. Chapters fourteen and fifteen move through Colossus and ENIAC to Watson and true machine learning. Zarkadakis suggests that there are reasons to mistrust governments and corporations using AI against citizens, yet AI may turn out to be our savior. Chapter sixteen wonders whether mimicking the structures, connectivity, and feedback loops of human cortical neurons could result in artificial consciousness. Perhaps swarms of self-organizing and reproducing nanorobots could evolve into intelligent organisms. In his Epilogue, Zarkadakis asks if AI will create a utopia. Will we become more human, post-human, more machine-like, or superceded?

Zarkadakis's views of Christianity are often ham-fisted. For example, in Genesis, God creates the first humans, endowing them with free will, resulting in their disobedience. This "stands as a cautionary tale for the … future of Artificial Intelligence. We would not want to repeat the mistake God made with us." As a solution, he references science fiction writer Isaac Asimov who "like a biblical prophet" used his three (hardwired) laws of robotics to restrict the freedom of intelligent robots, preventing them from harming humans (p. 58). Actually, there were four laws, and the most famous three were suggested by Asimov's editor, John W. Campbell. In any event, "we know that the biblical version of humanity's origins is wrong" (p. 217; as if Genesis were a scientific monograph).

According to Zarkadakis, body/mind dualism is the self-contradictory dead end and bane of rational discourse on AI and consciousness: a matter of unverifiable faith, not falsifiable knowledge (e.g., pp. 129–31). Nevertheless, Descartes's separation of the mental and spiritual from the material "liberated" science "from the shackles of the Church." Scientists could now explore what the world was "*really* made of." *Cogito ergo sum* shifted "the debate from 'what is true?' to 'how can we be certain about anything?'" Thus certainty, rooted in biblical revelation, was "shattered beyond repair" (pp. 113–14) and "the scientific method" provided explanations superior to "divine providence" (p. 102). "Most" Christians, says Zarkadakis, believe that at death "the soul goes directly to heaven and that the body perishes forever." And "many scientists with Christian beliefs" still uncritically accept mind/brain, soul/body dualism (p. 126). Scientific explanation is necessarily materialistic, so it is surpassingly strange that "even many practicing scientists" believe in God (p. 134). Lastly, he claims that in order to create AI we "must reject" any version of dualism and "must accept" that "there is no soul"; "there is only matter"; intelligence in any form is "purely material"; and if brains can be conscious, then other material objects can as well (p. 152).

Apart from some typos (e.g., the misspellings of "Planck" on p. 127), there are errors to be noted. Zarkadakis vastly underestimates the number of cells in our body at "several billion" (p. 152). We have far more just in our brains; and if we count the many microbial species we host, the estimated numbers move from hundreds of billions to tens of trillions. William Paley's 1802 work that put forward a watchmaker analogy for design was actually titled *Natural Theology*, and was not the first such argument; and it was not so much negated by Darwin as it was a significant influence on him in the *Origin of Species* (p. 289). Zarkadakis writes that "ten years after [Charles] Babbage's death [in 1871], George Boole demonstrated" the automation of thinking via symbolic logic (p. 229); but by 1881, Boole—whose application of logic to theology is ignored—had been dead for seventeen years.

Zarkadakis often provides helpful social and intellectual context, but his concept of invention does not reflect its complex social nature and contexts. For example, he refers to Bell and the telephone (1876) and Edison and the incandescent light bulb (1879) as simple fact (pp. 230, 319). To be fair, at p. 340, note 14, he refers to historians Robert Friedel and Paul Israel, who identified twenty-two inventors of electric lights before Edison, including Joseph Swan who received a British patent in 1878. (Their study is not identified; see *Edison's Electric Light: Biography of an Invention*, Rutgers University Press, 1986. Even Wikipedia has reliable, up-to-date, nuanced articles on the origins of both the telephone and electric light.) Karel Čapek (not "Capek," p. 319) did not coin the term "robot" in his play *R.U.R.* in 1917; his brother Josef did—and Karel's play appeared in 1921.

A final comment about the book's misleading title, which may be due to the publisher or editor, not the author: *In Our Own Image* alludes to Genesis 1:26, so one might expect a bit more than the book's minimal

biblical/theological content. *Savior or Destroyer?* is a fallacious dichotomy; the two may be mutually exclusive, but together they do not exhaust the possible roles of AI in society. And the book offers *a* history and *a brief possible* future of AI, not *The History and Future* of AI. This is not a definitive history and philosophy of mind, nor of AI science and technology, much less of related science fiction and theology.

Readers interested in a more skeptical treatment of the subject than can be found in Kurzweil's *The Age of Spiritual Machines: When Computers Exceed Human Intelligence* (1999); *The Singularity Is Near* (2005); and *How to Create a Mind* (2013) will appreciate Zarkadakis. I would also recommend Noreen Herzfeld's *In Our Image: Artificial Intelligence and the Human Spirit* (2002) and *Technology and Religion* (2009), chap. 3; James Barrat, *Our Final Invention: Artificial Intelligence and the End of the Human Era* (2013); Murray Shanahan, *The Technological Singularity* (2015); Nick Bostrom, *Superintelligence: Paths, Dangers, Strategies* (2016); Yuval Noah Harari, *Homo Deus: A Brief History of Tomorrow* (2016); and Hector J. Levesque, *Common Sense, the Turing Test, and the Quest for Real AI* (2017).

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TECHNOLOGY VS. HUMANITY: The Coming Clash between Man and Machine by Gerd Leonhard. Kent, UK: Fast Future Publishing, 2016. 172 pages, index. Paperback; $15.95. ISBN: 9780993295829.

Technology vs. Humanity is a call to arms against the adversary of *dehumanizing* technology. An influence of tech futurists such as Ray Kurzweil, Alan Turing, Alvin Toeffler, and sci-fi writers such as Ray Bradbury, is evident. Leonhard extrapolates present trends far into the future, but his call to arms is not readily dismissible. If he is correct, we surely must respond. By the time you read this review, it may already be too late, because in Leonhard's view, 2016—the year of the book's publication—is the critical year to take action.

There is a lot to ponder in this book—including but not limited to Leonhard's claim that we reached the pivot point in 2016 (*this* is the very moment when exponential increases are starting to really matter); his ability to envision future technology-generated scenarios and to support them with believable rationales ("What makes us think (these things) won't happen? We simply must consider these unpalatable what-ifs because this is the road we are on—fueled by exponential technologies," p. 83); his account of androrithms (a neologism, or word that Leonhard made up to describe those unique qualities that make us human); his assertion that we will be held responsible for the decisions we make at this very moment (responsible to whom, he doesn't say); and his boldness in attempting to get the conversation started.

Leonhard explains that the pivot point is an inflection point of an exponential curve in many fields of science and technology; now we are moving at "warp speed" toward a blend of hell and heaven that he labels "HellVen." Even if Moore's law eventually ceases to apply as far as microchips are concerned, many fields of technology, from communications to artificial intelligence (AI) and deep learning, are still likely to grow at least exponentially and with combinatorial effects—the changes reinforcing one another. Engineers would call this "positive feedback."

Mathematically speaking, exponential curves do not have an inflection point. Perhaps Leonhard is thinking of the so-called "hockey stick" curve of global temperatures vs. time. Is energy use really rising exponentially? Are food production and consumption, and transportation? Perhaps he is using "exponential" metaphorically, not mathematically. But the concept is central to the argument, so I wish he were more rigorous on this point.

By 2020, Leonhard writes, almost everything will be perceived or defined as a service because everything will be digitized, automated, and "intelligized." This will have huge economic impact as it

> progressively creates abundance in almost every sector of society—first music, movies, and books, followed by transportation, money, and financial services, and eventually, medical treatments, food, and energy. (p. 79)

By 2030

> technology and pharma will have converged almost completely. Mankind's biggest diseases, including cancer, diabetes, heart disease, and AIDS are being tackled by advanced bioengineering. We will very rarely take pills to fight sickness or diseases; instead, we will increasingly use technology and genetic editing to observe, predict, and prevent the onset of diseases. (p. 157)

Leonhard cautions that we should not anthropomorphize our technologies too much or confuse our priorities when it comes to making important societal choices and decisions, and we should not forget our responsibility as we venture out to create technology that may end up surpassing us. Unfortunately, slow but systematic reduction or even discarding of androrithms is already underway. Distinctly human traits include the ability to ask questions, to imagine that something could be different, to be critical, to look at things from different angles, to read between the lines, and to see what may not yet be there. If

we don't spend as much time and resources on androrithms as we do on algorithms, not only will technology end up running our lives, but we will also be forced, tricked, or otherwise cajoled into becoming technology ourselves. We shall become "the tools of our tools."

Technologies with potentially catastrophic consequences such as geo-engineering or artificial intelligence, Leonhard writes, should be guided and supervised by those who have been proven to possess practical wisdom, what the ancient Greeks called *phronesis*, and not by technology developers, corporations, or military bureaucrats. In particular, we should not attempt to mend, fix, upgrade, or eradicate what makes us human; we should design technology to know, respect, and protect andorithms (p. 113).

Profit-and-growth-driven open markets will only escalate the challenges. The prevailing Silicon Valley ideology of "Why don't we just invent our way out of this, have loads of fun, make lots of money while also improving the lives of billions of people with these amazing new technologies?" could prove to be just as lazy—and dangerous—as Luddism. If something can be done, does it mean it should be done? Should we consider *not* doing things because they might also have negative side effects on human flourishing?

Leonhard suggests that precaution and proaction—the two principles often deployed to date as possible mitigation tools—are both insufficient to deal with this combinatory, exponential scenario where waiting will be as dangerous as firing ahead. Too much precaution will stifle progress and innovation, and too much proactivity will free some powerful and likely uncontrollable forces. He does not mention technology assessment, intelligent trial-and-error, Hippocratic engineering, responsible and appropriate technology, professional codes of ethics, or Lanny Vincent's *innovation in the company of God*.

Environmental issues receive scant mention—except (in passing) for geo-engineering, and the prediction that food, transportation, and energy supply will be abundant by 2020. But global climate change, scarcity of clean water, strategic minerals, species extinction, farmland conversion, sanitation, power distribution, flood control and irrigation are not mentioned as threats. Certainly these issues also demand attention.

Civic and political leaders must develop a deep understanding and personal foresight about technology in the context of humanity, and become stewards of our collective future. Across all sectors of all industries, we will need a new kind of hyper-collaboration, not hyper-competition. (To this reviewer it seems that political conservatives and many evangelicals miss this point.)

In sum, Leonhard believes we must: (1) put our collective human flourishing first and above all other concerns; (2) allow those uniquely human things such as imagination, chance, mistakes, and inefficiencies to continue to matter even if they are undesired by or incompatible with technology; (3) fight the spread of machine thinking, i.e., not change what we stand for and need as humans simply because it might make it easier for the technologies that surround us; (4) not be tempted into preferring technological magic (i.e., great simulations of reality over reality itself) and getting addicted to technology; and (5) not prefer relationships with screens and machines over those that we can have with fellow humans.

For Leonhard the meaning and the purpose of life, the aim of human existence—is *happiness*. The only way to create lasting benefits in business as well as in society is by putting human happiness and well-being at the heart of decision making and governance. Technology should be guided toward human well-being or *flourishing*—the state of being comfortable, healthy, or happy. The Greek word *Eudaimonia*—central to Aristotelian philosophy and commonly translated as happiness or welfare—captures the point.

Religious approaches are deliberately ruled out because "they are not universal and are often regressive." Biblical higher calling—such as *imago Dei*, creation care, or the kingdom of God—is ruled out a priori. Thus Leonhard misses a very large body of work by biblical scholars and theologians who have developed equally profound insights and urgent calls to action. At least twenty-five books on the topic, in addition to my own, reside on my bookshelf.

If we want to master those imminent clashes between humans and machines, Leonhard says,

> We will need a new kind of global stewardship backed up by ever more prescient foresights. We will need the ground rules to be decisive yet flexible enough not to inhibit progress. Daunting? Yes. Impossible? No. Alternatives? None. (p. 160)

Drawing from Greek philosophy, the Buddhism of the Dali Lama, and humanism, Leonhard develops his "digital age philosophy" of *exponential* humanism. In my view, however, the questions he raises are beyond the reach of secular and humanistic reasoning.

Leonhard's grasp of the meaning and purpose of life is bigger than mere "happiness," but his approach is basically humanistic and anthropocentric. As a Presbyterian elder, I am compelled to suggest a

higher calling as set forth in the *Westminster Shorter Catechism*: "Man's chief end is to glorify God, and enjoy Him forever."

If the issue is as urgent as Leonhard believes, I think that publishing this book (or any book) is totally insufficient to draw attention to the threat. A massive marketing campaign is required. The church might undertake such a task, if so inclined. But the church is sleepwalking in this arena. Some are struggling with trusting science, let alone steering it.

Even with these limitations, however, I strongly recommend *Technology Vs. Humanity*. Why? First, because Leonhard alerts us to the dimensions and urgency of the problem. Second, he proposes semi-tangible approaches, which he says are only conversation starters. Third, he sets forth fifteen *shall-nots*, five *core human rights* that should be incorporated into digital ethics, five *elements* of what it means to be human, and eight *must-do* actions in order for us to become stewards of our collective future. Finally, he appeals for action, not just another forum!

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ALGORITHMS TO LIVE BY: The Computer Science of Human Decisions by Brian Christian and Tom Griffiths. New York: Henry Holt and Company, 2016. 368 pages, bibliography, index. Hardcover; $30.00. ISBN: 9781627790369.

In *Algorithms to Live By: The Computer Science of Human Decisions*, authors Brian Christian and Tom Griffiths offer an answer to "the oldest question of all: how to live" (p. 4). Their bold recommendation is to live "by the wisdom of computer science" (p. 6).

In the introduction, Christian and Griffiths announce that they will demonstrate that "applying the lens of computer science to everyday life" reveals "the algorithmic underpinnings of our daily lives" (p. 4). They define an algorithm as "a finite sequence of steps used to solve a problem" (p. 3), and they contend that computer science algorithms offer us "practical, concrete suggestions for how to solve specific problems" (p. 4) in life. The authors contend that many of life's dilemmas actually correspond to "solved problems" in the field of computer science, which, "unlike most advice," is "backed up by proofs" (p. 6). Indeed, the authors go so far as to suggest that many people "don't need a therapist; they need an algorithm" (p. 3). Moreover, they claim that "as computers become better tuned to real-world problems," they also provide "a better standard against which to compare human cognition itself" and, therefore, can reveal the "meaning of rationality" and the very "nature of the human mind" (p. 4).

Algorithms to Live By is subtitled "The Computer Science of Human Decisions." Indeed, a number of the algorithms considered in the book for application to human decision making are associated with the discipline of computer science. For example, chapter 3 considers how sorting algorithms might lead to recommendations for organizing a library of books or designing an athletic tournament. Chapter 4 looks at caching algorithms and how they might assist us not only in organizing the clothes in our closets but also in understanding our own human capacity for memory. Chapter 10 explores what the design principles underlying the technologies driving the Internet might imply for how we think about and conduct our communications with other humans. However, in the remainder of *Algorithms to Live By*, the authors employ algorithms from other disciplines so often that a reader might question how well the subtitle describes the contents of this book. In these other eight chapters, most of the algorithms under consideration are not so much computer science algorithms as they are formulae from other fields, particularly mathematics, that a computer scientist might draw upon in attempting to construct a computer model, simulation, or analysis of a given real-world human phenomenon or data set.

The authors acknowledge in the introduction that the design of algorithms for computers requires theories not only from computer science but also from mathematics, engineering, statistics, and operations research. Moreover, they suggest that the application of computer algorithms to human minds requires looking "to cognitive science, psychology, economics and beyond." Christian and Griffiths also share how their own multidisciplinary academic backgrounds have assisted them in the fundamentally interdisciplinary task of writing this book.

Regardless of the disciplinary origins of the algorithms, the authors do cover an impressive range of topics in their text as they work to develop their central argument in favor of a computer-science-like, algorithm-oriented approach to human life. In the process, their recommendations for the employment of a particular algorithm are variously descriptive, predictive, and prescriptive.

The authors' argument is perhaps most compelling when they recommend the *descriptive* use of algorithms. They demonstrate how algorithmic models can provide insight into complex real-world phenomena that might be difficult to describe otherwise. For example, in chapter 3, they provide a superb explanation of "Big-O notation" and its usefulness

in describing why certain human tasks are more algorithmically complex than others. The descriptive limitations of certain algorithms are also acknowledged. For example, chapter 7 describes how what they term an "idolatry of data" can lead to "overfitting" data, resulting in overly detailed models that actually become less useful for describing real-world phenomena.

More often, the authors recommend not only the descriptive use of algorithms but also the *predictive* use of them. Indeed, the subtitle of chapter 6 is "Predicting the Future," and it is an indication of the degree to which the authors evaluate algorithms in terms of their ability to predict future events. In chapter 7, the authors' concern in regard to the overfitting of data is not merely that it may lead to a less descriptive model but, more importantly, that it "may make our predictions dramatically worse" (p. 155). The authors do acknowledge a degree of uncertainty that persists in the predictive use of algorithms. For example, in chapter 10, the authors underscore the futility of algorithmically predicting the actions of other humans by trying to guess their thoughts. However, at other times, the goal of using algorithms predictively is sometimes stated in terms that might make many Christians uneasy. During the consideration of caching algorithms in chapter 4, one computer scientist quoted by the authors suggests that the key question is: "if you don't know the future, how *close* can you come" to clairvoyance, to "God's algorithm, if you will," to the "algorithm in the sky?" (p. 98). The authors go so far as to assert that "every decision is a kind of prediction," and that, while "computer science can't offer you a life with no regret," it can offer "a life with minimal regret" (p. 43). In contrast, many Christians would profess a belief that certain decisions should not be based upon human or computerized algorithmic predictions of the future but, rather, should be made prayerfully, entrusting the unknown future to God, not so much in the hope of minimizing regret as a way of acting based upon faith.

The authors of *Algorithms to Live By* also recommend the *prescriptive* use of certain algorithms. Computer algorithms, they suggest, can tell us "how to think and decide, what to believe and how to behave" (p. 4). For example, chapter 5 examines scheduling algorithms that usefully prescribe the order in which to complete a set of tasks in accordance with a particular overall goal, such as minimizing the lateness of the most overdue task. However, in the Introduction and chapter 1, the authors insist that "the 37% rule" prescribes precisely how long to look for a parking space, an apartment, a new employee, or a spouse before making a choice, that is, after considering 37% of the available options or after 37% of the available time has passed. "Mathematically," the authors claim, "these are solved problems." The 37% rule "is not merely an intuitively satisfying compromise between looking and leaping" but, rather, "the *provably optimal* solution" (p. 2). The authors' prescription to put one's trust in a mathematical algorithm when making such important life decisions as where to reside, whom to employ, and whom to marry is difficult to reconcile with faith in a God who knows the future, has a plan for our lives, and hears our prayers for guidance and patience.

In a similarly prescriptive manner, the authors advocate redesigning library systems in accordance with sorting algorithms. However, such insensitivity to the local knowledge is one of the factors that can make computer software so frustrating, when users are expected to reshape their mental models of their tasks in accordance with computer science algorithms that have been used to design the software modeling these tasks. In contrast, Egbert Schuurman suggests in his *Faith and Hope in Technology* that "human beings ought not to have to adapt themselves to computer systems but vice versa," and that "respect and love for one's neighbors means not allowing computer systems to rule their lives."

Interestingly, toward the end of the text, the authors use the famous quote from Sartre that "hell is other people" to describe the complex recursive algorithms in games that require players to guess their opponent's thoughts. However, this utterance by Sartre is often interpreted instead as a comment upon the tendency of humans to objectify each other. Indeed, the hazard inherent in the authors' recommendation of looking at the world algorithmically, through the "lens of computing science," is a tendency to regard the world—including other people—as problems to be solved. However, humans tend to resist such an objectifying gaze, and rightly so. A contemporary and French compatriot of Sartre, the Catholic existentialist Gabriel Marcel, contended in his *Being and Having* that we are called to regard one another not as problems to be solved, but as mysteries which exceed technical understanding and require a more conversational engagement by our whole self. Accordingly, if we do undertake to look at the world through the lens of computer science, we need to remember the reductive nature of algorithms and avoid the inappropriate application of them, particularly in situations involving other persons.

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Volume 69, Number 2 **June 2017**