AC 2008-792: THE APPLICABILITY OF ENGINEERING DESIGN PRINCIPLES IN FORMULATING A COHERENT COSMOLOGY AND WORLDVIEW

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The Applicability of Engineering Design Principles in Formulating a Coherent Cosmology and Worldview

Abstract

Recently, concepts from the field of design engineering have been found extremely useful in many areas of science. From the very large aspects of the universe (i.e. big bang cosmology and galactic and stellar evolution) to the very small (i.e. the fitness of the chemical elements and the life-codes found in DNA), the cosmos is so readily and profitably reverse-engineered as to suggest that it may have been engineered in the first place. The linking of extraordinarily complex, but stable functional structures with the production of value provides a strong impression of the action of a transcendent, yet calculating, intentionality. The most coherent view of the cosmos appears to be that of an engineered system of interdependent subsystems that efficiently interact to prepare for, develop, and support advanced life, subject to various constraints. Considerations of intention and purpose in natural science have recently been disallowed, and yet our world seems to be infused with purpose. The cosmological quest benefits from the integration of knowledge from all areas of study, including those that consider questions of purpose, such as design engineering. The synthesis of this knowledge that provides the most satisfying answers for the human condition is one that admits the recognition of purpose, and possibly the existence of an (as yet, not-well-understood) engineering influence.

In a course for engineering majors at our university, students are encouraged to integrate their knowledge of science and engineering with the development of a coherent cosmology and worldview. A major component of this course includes the recognition of engineering design characteristics in nature. Characteristics such as stability, predictability, reliability, transparency, controllability, efficiency, and optimality are found in nearly all human-engineered systems. These characteristics are also prevalent throughout the integrated and finely-tuned systems that make up the cosmos. Examples of such are studied by the students, and presented in what follows. Students are challenged to weigh the evidence supporting various explanations for the current structures and resulting values found in the universe. In so doing they make the most of their technical education, and find motivation for a fulfilling and hopeful life of meaning, purpose, and service to humanity, as a deep-thinking engineer.

Engineering Impact on Worldview

As early human beings discovered the basic workings of nature, they also learned how to use their creativity to put those discoveries to work in solving the everyday problems of life. Hence the fledgling field of engineering was born. Throughout the millennia, scientific discoveries have continued to fuel the fires of engineering industry. In recent years, the closely-related fields of science and engineering have enjoyed enormous success. The maturity of these fields has enabled current practitioners to deliver a potential productivity and quality of life which was hardly dreamed of a hundred years ago. Nature has proven to be incredibly bountiful and profoundly deep in providing mankind with an array of challenging puzzles to solve. Human mental capacity and insatiable curiosity make it difficult to resist these mysteries, especially after repeatedly experiencing how their unraveling results in such incredible satisfaction, fruitfulness, and profitability[1,2]. Could it be that the realm of nature and the human mind were, in some sense, made for each other; possibly for the purpose of communicating important truths? This idea goes a long way toward explaining the fine-tuning of the cosmos for life, and the success humans have had in reverse engineering the cosmos.

It is proposed that engineering design principles, along with "the engineering mindset", can be profitably applied to establish a coherent understanding of the fundamental nature of the cosmos and the place of humanity within it. This paper represents the start of an ambitious project which necessarily draws upon many fields of knowledge, but what better way to use the diverse and abundant resources of the university setting. An interdisciplinary course has been introduced to assist and encourage students to incorporate techniques and information from technical courses in the formulation of a comprehensive and coherent worldview. Engineering graduates who have wrestled with these concepts are believed to be better equipped and motivated to live a fulfilling life of hope, purpose and service to humanity.

The Philosopher Engineer

It is particularly important for engineering students to begin to establish a coherent worldview upon which to base their life's work. Sir Eric Ashby, a British scientist and educator wrote that

> The engineer is the key figure in the material progress of the world. It is his engineering that makes a reality of the potential value of science by translating scientific knowledge into tools, resources, energy and labor to bring them into the service of man ... To make contributions of this kind the engineer requires the imagination to visualize the needs of society and to appreciate what is possible as well as the technological and broad social age understanding to bring his vision to reality.[3]

This idea was echoed recently by Domenico Grasso, the Dean of Engineering and Mathematical Sciences at the University of Vermont, in an article entitled "Is It Time to Shut Down Engineering Colleges?" Consider the following exert.

> …engineers need to grow beyond their traditional roles as problem-solvers to become problem-definers. To catalyze this shift, our engineering curriculum, now packed with technical courses, needs a fresh start. Today's engineers must be educated to think broadly in fundamental and integrative ways about the basic tenets of engineering. If we define engineering as the application of math and science in service to humanity, these tenets must include study of the human condition, the human experience, the human record.[4]

When the engineering mindset is complemented with a broader education in the humanities, it becomes a valuable asset for assessing various views of the world, and greatly informs problem solving activities. In his book, *The Introspective Engineer*, Sam Florman writes that the universe presents itself to us as a mystery to be studied and acted upon. Later he adds that "…although engineering relies upon science and mathematical verities, in the end it responds to the demands of the human spirit."[5] The broadening of engineering education, and its implications for the areas of worldview formation and philosophy, will better equip engineers to meet the needs and desires of the human spirit.

Reverse Systems Engineering of Nature

What might lead one to suspect that ideas from the field of engineering can be helpful in developing a coherent worldview? Well, normally, information from scientific discoveries is funneled into the development of engineered products for the benefit of humanity. But recently an unusual turnabout in the flow of practical information is being realized. Concepts from the field of design engineering, and the engineering mindset, have been found to be extremely useful in areas of science such as cellular biology. As an example, consider a leading microbiology researcher with the Scripps Institute, Dr. Gaudenz Danuser, who was trained as an engineer, but as a graduate student, became fascinated with the way engineering principles were so useful in understanding the inner workings of the cell. Now he successfully conducts what he calls "reverse systems engineering of dynamic cellular processes"[6].

The concept of "reverse systems engineering" that he employs in describing his approach is significant. Systems engineering is defined as "an interdisciplinary approach and means to enable the realization of successful systems"[7]. Reverse engineering is the design analysis of system components and their interrelationships within a higher level system[8]. Basically, it is the process of extracting the engineering knowledge or design blueprints from anything that has been engineered[9]. Thus reverse systems engineering can be described as a multidisciplinary endeavor to extract engineering design knowledge from a complex system consisting of multiple interacting subsystems that have been synthesized to work together as an integrated unit. A simple version of this type of activity is often seen in children when they take things apart to see how they work, and is illustrated by the following quote by Kathryn Ingle, a systems engineer,

> As long as people have wanted to understand what makes things work, there have been those curious enough to tear apart that which is a mystery to them. To fully understand a design it is important to disassemble the original item and then try to put the puzzle back together. During the disassembly stage one hopes to discover the hidden secrets by finding the mechanism, or mechanisms, that make it work. Whatever it is that makes it valuable stirs the human imagination which desires to possess its secrets by seeking and finding the keys to unlock its magic.[10]

Methods and techniques for reverse engineering are described in texts such as *Product Design: Techniques in Reverse Engineering*[11] by Kevin Otto and Kristen Wood. Such techniques are proving to be useful when applied to natural systems, although they were originally intended for man-made systems. Could this be because the molecular machinery found in living systems so closely resembles man-made technology such as "motors, drive shafts, pipes, pumps, production lines, and programmable control systems"[12]. Author Mike Gene carefully documents this recent convergence between biology and engineering in his book: *The Design Matrix: A Consilience of Clues*[13]. Indeed, natural systems at all levels are so readily and profitably reverse-engineered by the human mind as to suggest that such systems were intelligently engineered in the first place. The idea of a transcendently engineered world is investigated in what follows. The notion of transcendence is not being used here in a religious sense, but rather to indicate that we detect an engineering capability that is above and beyond the limits of ordinary experience, and possibly beyond the familiar dimensions of our material world.

Recognition of Order

The concept of order is fundamental to engineering. Based on knowledge and wisdom, engineers arrange things into a certain order, in both space and time, so as to solve a problem or achieve a goal. When attempting to reverse engineer such an arrangement, a distinction should be made between teleology (referring to purpose or goals) and eutaxiology (referring to order and harmony in complexity). Eutaxiological elements may be easily observed by a thorough investigation of the arrangement. The fact that order has been established is typically easy to discern (although this is not necessarily the case). However, it may be much more difficult, even impossible, to discern the teleological elements associated with a particular artifact. Who knows what the original engineer had in mind in terms of purpose? On the other hand, a careful reverse engineering study may reveal function and utility that points to one particular purpose, rather than others. A bulldozer is not very convenient to use as a paperweight, but it sure is good for moving lots of dirt, assuming you know how to use it. This thinking leads to the crux of the matter. How much evidence is needed to establish that something has indeed been engineered? How much functionality is needed to establish purpose? It really depends on two things: the nature of the artifact in question, and the intelligence and experience of the investigator. (Fortunately, this is the kind of CSI-type work that modern college students find particularly intriguing.) If the capabilities of the investigator don't, in some ways, match up with the nature and complexity of the artifact in question, the reverse engineering process will have a hard time getting off the ground. Isn't it interesting that humans so enjoy, and benefit from, the comprehensibility of the cosmos? Vatican astronomer Guy Consolmagno describes this compatibility between the human mind (investigator) and nature (artifact) with the following observation:

> We scientists and engineers start with the assumption that truth is logical, self-consistent, and not arbitrary. Furthermore, truth often follows patterns… For example, I have seen over and over again in the physical universe that a true description of what's going on is neither stupidly simple nor hopelessly complicated. Instead it achieves…a complex beauty from the interplay of a few simple principles.[14]

If the artifact in question is the entire universe, shall one "throw in the towel" because of the difficulty in fathoming anyone big enough to engineer such an enterprise? The curious thing is that humans *can* imagine such a transcendent design engineer, and this is not a recent phenomenon. From ancient times, nearly all peoples have recognized the eutaxiological aspects of nature and attributed it to some mind or deity. As philosopher Michael Corey notes in his book *God and the New Cosmology*, the eutaxiological argument predated the Christian religion by some 500 years. At that time, a Greek named Anaxagoras of Clazomenae was probably the first philosopher in the west to attribute the obvious order in the universe to the larger plan or design of a Mind. Socrates and Plato believed that in addition to providing the initial order to the universe, Mind also acted to sustain it at all times. Plato's student, Aristotle, made the jump to teleology, with detailed studies into causality and purpose. About 100 years before Christ, Marcus Cicero even suggested that various characteristics of the creating deities could be inferred from the highly ordered work of their hands[15],

> When we see some example of a mechanism, such as a globe or clock or some such device, do we doubt that it is the creation of some conscious intelligence? So when we see the movement of the heavenly bodies…how can we doubt that these too are not only the works of reason but of a reason which is perfect and divine?[16]

Throughout the ages, many great minds have expressed a profound appreciation for the incredible ingenuity of natural systems. Leonardo da Vinci, from his in-depth study of human anatomy, recorded in his notebook that "The human foot is a masterpiece of engineering and a work of art". He recognized that the intricate structures of the foot provide a synergy resulting in robust functionality without compromising aesthetic value. Scientists and engineers are familiar with the works of such great teleologists as Copernicus, Galileo, Kepler, Boyle, Newton, and Leibniz. In the 1600s, William Harvey discovered the detailed flow patterns of blood within the human body by asking himself how an engineer would have constructed such a system. The most influential design formulation of that era was probably developed by William Paley, whose watchmaker argument[17] appealed to the integrated functional complexity of living organisms as evidence of a designer. It is widely thought that this argument was soundly refuted by the later works of David Hume and Charles Darwin, but that view is now in question, due largely to recent discoveries in microbiology, as will be discussed later. In Addition, Paley's arguments also had a eutaxiological strain that was unaffected by evolutionary theories. He suggested that the orderliness and appropriateness of laws of nature, such as gravity, pointed to a designer.[18] This idea has persisted, to some degree, into the modern era as exciting new discoveries have been made regarding the life-friendly structure and order of the cosmos at all levels.

Suitable Singularity

Important for any reverse engineering process is the consideration of all information that may be gleaned regarding the origin of the artifact in question. Prior to Albert Einstein's development of the Theories of Special and General Relativity, the prevailing cosmological view was that of an eternal universe. Now there is an abundance of scientific evidence for the "big bang"; a singularity which is thought to have resulted in the existence of all the matter, energy, and space-time dimensions that make up our universe. By definition, these fundamental constituents obey the laws of nature. But they do so in a very special way, which suggests that there was another unseen element present at the beginning of the universe. There was information. As scientists have uncovered more about this intriguing event, there are several considerations which suggest that a more suitable name might be the "engineered expansion", although admittedly it just doesn't have the same ring to it.

One of the things that made Einstein so endearing was he readiness to wax philosophical. He pondered questions like, "Why is there something rather than nothing?" and "Why do we find the universe to be so comprehensible?" It is clear from his writings that he believed in a transcendent source for the rationality of the world. His friend Max Jammer recorded the following quote from Einstein:

> Everyone who is seriously engaged in the pursuit of science becomes convinced that the laws of nature manifest the existence of a spirit vastly superior to that of men, and one in the face of which we with our modest powers must feel humble.[19]

Even the most prominent physicists of today write about the philosophical implications of science. Stephen Hawking regarded the laws of nature to originate from thoughts in the mind of God, as evidenced from this passage from A Brief History of Time:

> If we discover a complete theory, it should in time be understandable by everyone, not just by a few scientists. Then we shall all, philosophers, scientists and just ordinary people, be able to take parting the discussion of the question of why it is that we and the universe exist. If we find the answer to that, it would be the ultimate triumph of human reason – for then we should know the mind of God.[20]

Notice the implicit reference to reverse engineering by suggesting that the intent of the original design engineer might be discerned from a more complete understanding of that which has been made. Why do the study of cosmology and the laws of nature often inspire scientists and engineers with such awe, wonder, and respect for a transcendent intelligence? Part of the reason may be that their training and experience afford them with an intimate understanding of the supremely large degree of difficulty associated with a project such as the origin of the universe. Design engineers are particularly well-equipped to marvel at the idea that such a vast and powerful "machine" could be devised, ultimately as a suitable habitat for intelligent life.

Although the concept of the universe as a machine-in-process may not be a very accurate depiction, it has proved to be a powerful analogy for the purposes of science. A useful working definition of a machine is a system of elements arranged to transmit motion and energy in a predetermined fashion.[21] As will be seen in the next section, various aspects of the cosmos appear to be finely-tuned to permit the existence of intelligent life. This strongly suggests the influence of a calculating intentionality that predetermined the necessary values of various features of the expanding universe. As an example, consider the perfect balance that was achieved between the expansion of space and gravitational attraction, which resulted in such stable and life-friendly structures as galaxies, stars, and planets.

A similar humanly engineered phenomenon that comes to mind (although miniscule in comparison in terms of both time and space) is a fireworks display. The shells that produce such a beautiful sight are engineered to expand to a certain size at maximum brightness. But this is not really that big of a challenge because gravitational forces between the small burning particles don't come into play in the calculations. It is difficult to imagine the engineering of a system of rapidly expanding mass and energy that would not only combine to eventually produce just the right elements for life in the interior of stars, but also sustain such stable structures as galaxies and solar systems over billions of years? Such an engineer would have to have incredibly vast resources, incredibly powerful intellectual capability, and a full and complete understanding of science, mathematics and engineering principles. Perhaps it was considerations like this that prompted Paul Dirac, one of the most accomplished quantum physicists of the 20th century, to assert that "God is a mathematician of a very high order and he used advanced mathematics in constructing the universe."[22]

Fitness and Fine-Tuning

When our children were younger, we enjoyed spending time playing with them, especially if we were engaged in some creative activity like building sand castles or models. One of our favorite activities was to build things out of Lego blocks. If you've ever played with these plastic blocks, you know that they are extremely well-engineered so that children can easily press the blocks together, inserting pins into holes, into a semi-permanent arrangement. With only a little effort from small hands, those same blocks can be separated by pulling them apart to make something new. The fundamentally great thing about Legos is not only that they come in all shapes, sizes, colors, and functional types, but that the blocks stay stuck together (within reason) so that you can play with your new creation without it falling apart on you. This semi-permanent "combinability" is not a feature of the blocks that just happens by accident. It is accomplished through skillful and meticulous engineering.

Knowing the typical strength and dexterity of children and the coefficient of friction associated with hard plastic, engineers then determined and manufactured the exact pin and hole sizes that would result in a just-right interference fit; not so loose as to easily fall apart, and not so tight as to be difficult to disassemble. It is the insight and skill of the design engineering, and the precision of the manufacturing, that is responsible for such a reliable feature that has become known and appreciated by children around the world.

In a sense, Lego blocks are very much like the elements of the periodic table that make up the physical world. These elements also join together in very specific ways by forming bonds of various strengths. However, these bonds can also be broken, and the elements separated, if the right forces and conditions are applied. Furthermore, the semi-permanent combinability of these elements appears to be absolutely reliable. We can count on certain reactions to always take place under a given set of conditions. This order and reliability at the foundation of the material world is actually a very remarkable feature of the cosmos, which was not fully recognized until the field of chemistry had sufficiently matured. Cosmologist Helge Kragh, in his book *Matter and Spirit in the Universe*, describes the impact this had on the great scientist James Clerk Maxwell:

> He [Maxwell] was impressed by the fact, as revealed by the spectroscope, that molecules of the same chemical species were all alike and had not changed the slightest "since the time when Nature began." Uniformity in time as well as uniformity one-to-another strongly indicated that atoms and molecules were created… Borrowing an expression from John Herschel, he famously (and with an allusion to natural theology) referred to the molecule as a "manufactured article."[23]

Philosopher Richard Swinburne also asserts that the orderly features of material objects and fundamental particles require an explanation:

> It is not merely that all material objects have the same very general powers and liabilities as each other… but they fall into kinds, members of which behave like each other in more specific ways. Each electron behaves like each other electron in repelling every other electron with the same electrical force… And many of these respects in which all material objects and objects of particular kinds behave like each other…are also simple and so easily detectable by human beings… God being omnipotent is able to produce a world orderly in these respects.[24]

At the start of the 20th century, in one of the first studies of its kind, Chemist and Biologist Lawrence Henderson conducted a thorough investigation into the significance of such orderliness for life, culminating in a classic book entitled: *The Fitness of the Environment: An Inquiry into the Biological Significance of the Properties of Matter*. From the properties of water and carbon dioxide molecules to the properties of the oceans, He explains in great detail how the chemical elements, their interactions, and their larger aggregations provide a most fitting environment for life. Consider the follow quote:

> Coincidences so numerous and so remarkable as those which we have met in examining the properties of matter as they are related to life, must be the orderly result of law, or else we shall have to turn them over to final causes and the philosopher… how does it come about that each and all of these many unique properties should be favorable to the organic mechanism, should fit the universe for life?[25]

By the end of the 20th century, it had become clear that Henderson's work was only the tip of the iceberg regarding the fitness of nature for life. Biologist and physician Michael Denton provided a much needed update with his book: *Nature's Destiny: How the Laws of Biology Reveal Purpose in the Universe*, where one can find evidence from physics, chemistry, geology, and biology. For example, his in-depth study of the water molecule concludes that every single one of its many known physical and chemical properties contributes to making it the ideal fluid medium for life on Earth. Regarding the multiple amazing properties of light, he concludes that "like water, the light of the sun appears to be of optimal biological utility." Regarding the laws of physics, he asserts that they are:

> …supremely fit for life, and that the cosmos gives every appearance of having been specifically and optimally tailored to that end... There is simply no tolerance possible in the design of the celestial machine. For us to be here, it must be precisely as it is.[26]

He refers to the striking correlation between the abundance of the chemical elements and their utility for life. Even the radioactive elements which stoke the tectonic activity of our planet play a special role. In reference to the way the Earth's water cycle and tectonic cycle work together, he writes:

> The extraordinary mutual fitness of these two cycles for the maintenance of the constancy of the environment is self-evident. Like two gigantic cogwheels engineered to fit perfectly together…[they] have turned together in perfect unison

> for billions of years, ensuring the continual turnover and essential cycling of the vital elements for life.[27]

Regarding the chemical elements, his remarks are reminiscent of the Lego blocks mentioned earlier, as recognized in the following quote:

> The total number and diversity of possible chemical structures that may be constructed out of carbon, oxygen, hydrogen, and nitrogen is virtually unlimited. Almost any imaginable chemical shape and chemical property can be derived. Together these elements form what is in effect a universal chemical constructor kit.[28]

In several places, Denton uses the phrase “integrative complexity” in referring to subsystems that are integrated together to form a complex and functional system that supports life. This feature is a characteristic of engineering systems, which suggests that life is the result of an engineering influence. In concluding, he writes:

> …science has revealed a vast chain of coincidences, which inexorably lead to life… Purposiveness exists everywhere, permeating the whole universe.[29]

Much work has been conducted in this area recently. A new book entitled *Fitness of the Cosmos for Life: Biochemistry and Fine-Tuning*[30] celebrates the 1913 work of Henderson and looks at the delicate balance between chemistry and the ambient conditions in the universe that permit complex chemical networks and structures to exist.

Benjamin Wiker and Jonathan Witt, in their book *A Meaningful World: How the Arts and Sciences Reveal the Genius of Nature*, recognize a special feature of the order inherent in nature which appears to facilitate the reverse engineering process. They see a tutorial aspect of the cosmos as described below:

> As we have seen, nature is not only ordered, but ordered in a kind of tutorial fashion, so that we, the knowers, can move from what is knowable in our everyday, visible, tangible experience, downward, step by careful step, through layers of previously unseen order, to the deep order we grasp only intellectually… As the history of chemistry reveals, when we reflect on ourselves as knowers, it is clear that we are pattern-seeking and pattern-finding creatures, creatures curiously made to be curious amidst an order curiously designed to be sought.[31]

Wiker and Witt also point out a key systems engineering principle that often shows up in nature; the value of the multifunctional part or subsystem that solves multiple problems simultaneously. Simply put, it’s basically the idea of killing two birds with one stone. They note this characteristic of our atmosphere as seen in the following:

> Now the sign of a designing genius is the ability to provide a solution to a seemingly intractable problem – a solution that displays the best overall fitness, a “part” that not only solves the problem but also functions simultaneously as the

> solution to other design problems within the same system. This is what we find with our atmosphere…the Earth's level of atmospheric oxygen, the result of a complex of conditions, ingeniously satisfies several design criteria simultaneously.[32]

Multiple well-researched articles concerning the fine-tuning of the universe for life can be found in the book: *God and Design: The Teleological Argument and Modern Science*[33], edited by Neil Manson.

Guillermo Gonzalez and Jay Richards' book: *The Privileged Planet*[34] adds a new twist by showing how the same fine-tuned features of the universe that result in habitability also play a part in enabling our discovery of how the world works, thus facilitating reverse engineering. Philosopher and astronomer, David Seargent, picks up on this idea in his book: *Planet Earth and the Design Hypothesis*, focusing especially on the apparent fine-tuning of our Earth-Moon system for life. He asserts that one of the primary hallmarks of design is a property he calls transitive complexity (TC), in which "the suspected design points to a larger state of affairs beyond itself"[35]. An example of this would be a signal containing the prime number sequence emanating from a far-away planet. Such an engineered signal points beyond itself, in effect communicating the existence of intelligent alien life. Indications of TC would be evident if the fine tuning that permits the existence of living organisms also produces an environment in which one class of those organisms is enabled to fulfill certain basic desires, which in themselves haven't been determined by the struggle for survival.[36] He concludes by writing:

> …the habitability/discoverability conjunction is an instance of TC. Both habitability and discoverability converge to establish a niche for a being possessed of cosmic curiosity. Moreover, we note that this apparent purpose is fulfilled by the fact that just such a being occupies this niche; a being displaying the appearance of having been specially crafted for this very environment, not just as a survivor…but as one who fulfills his cosmic curiosity by using this special place as a remarkably efficient platform for discovery.[37]

In shifting to the arena of biological systems, the concepts of specified complexity and irreducible complexity will be added to the already developed concepts of integrative complexity and transitive complexity. All of these concepts for how to recognize an engineered system are helpful in evaluating the various worldview possibilities.

Biological Complexity and Information

Martin Beckerman, senior scientist at the Department of Energy, begins his recent textbook on Molecular and Cellular Signaling with the following:

> Biological systems are stunningly well engineered. Proof of this is all around us. It can be seen by the sheer variety of life on Earth, all built pretty much from the same building blocks and according to the same assembly rules, but arranged in myriad different ways. It can be seen in the relatively modest sizes of the genomes of even the most complex organisms, such as ourselves… The good

engineering of biological systems is exemplified by the…partition of cellular processes into the fixed infrastructure and the control layer. This makes possible machinery that always works the same way in any cell at any time, and whose interactions can be exactly known, while allowing for the machinery's regulation by the variable control layer at well-defined control points. Another example of good engineering design is that of modularity of design. Proteins, especially signaling proteins, are modular in design and their components can be transferred, arranged, and rearranged to make many different proteins.[38]

In studying and writing about the communications processes within the cell, he recognizes some of the characteristics of engineered systems. What are the characteristics of engineered systems in general? According to the book: *Complex Engineered Systems: Science Meets Technology*,

> The classical engineering process seeks systems whose behavior can be predicted and encapsulated by precise description. This is reflected in the characteristics that are seen as the *sine qua non* of all engineered systems: stability, predictability, reliability, transparency, controllability, and – ideally – optimality.[39]

In *The Design Matrix*, Mike Gene writes that rational design is revealed when a logical form of structural and functional decomposition is present. He argues that a rational design would have certain attributes that reflect engineering, such as efficiency, specificity, robustness, elegance, flexibility, and coherence.[40]

Microbiologist Michael Behe describes one way in which functionality might be determined in biological systems in his book *Darwin's Black Box: The Biochemical Challenge to Evolution*. The process is basically one of reverse engineering as he outlines below:

> Ultimately, in order to find out how a thing works, you have to take it apart and reassemble it, stopping at many points to see if function has yet been restored. Even this may not yield a clear idea of how the machine operates, but it does give a working knowledge of which components are critical.[41]

Another key concept that Michael Behe has introduced is that of irreducible complexity. He carefully defines this concept below:

> By *irreducibly complex* I mean a single system composed of several well-matched, interacting parts that contribute to the basic function, wherein the removal of any one of the parts causes the system to effectively cease functioning. An irreducibly complex system cannot be produced directly (that is, by continuously improving the initial function, which continues to work by the same mechanism) by slight, successive modifications of a precursor system, because any precursor to an irreducibly complex system that is missing a part is by definition nonfunctional. An irreducibly complex biological system, if there is such a thing, would be a powerful challenge to Darwinian evolution.[42]

It is thought by many scientists and engineers that several biological systems (such as the bacterial flagellum) have been identified that satisfy this definition. However, this is a very controversial subject and many scientists, especially evolutionary biologists, argue against the existence of irreducibly complex systems in biology. They suggest that there are natural processes that are capable of producing such systems. One such possibility is "co-option" (or exaptation) in which a simpler version of the system starts out with one function and then evolves into a more complex system which subsequently takes on a new function. However, philosopher Angus Menuge details the prohibitive difficulty associated with the occurrence of such an event in his book *Agents Under Fire*, where he writes,

> For a working flagellum to be built by exaptation, the five following conditions would all have to be met:
> 1: Availability - Among the parts available for recruitment to form the flagellum, there would need to be ones capable of performing the highly specialized tasks of paddle, rotor, and motor, even though all of these items serve some other function or no function.
> 2: Synchronization - The availability of these parts would have to be synchronized so that at some point, either individually or in combination, they are all available at the same time.
> 3: Localization - The selected parts must all be made available at the same "construction site", perhaps not simultaneously but certainly at the time they are needed.
> 4: Coordination - The parts must be coordinated in just the right way: even if all of the parts of a flagellum are available at the right time, it is clear that the majority of ways of assembling them will be non-functional or irrelevant.
> 5: Interface compatibility - The parts must be mutually compatible, that is, "well-matched" and capable of properly "interacting": even if a paddle, rotor, and motor are put together in the right order, they also need to interface correctly.[43]

Information theorist William Dembski, one of the founders of the field of "intelligent design", recognizes the importance of the engineering mindset in this area, as seen by the following quote from his book, *Intelligent Design: The Bridge between Science and Theology*:

> Intelligent design's positive contribution to science is to reverse engineer objects shown to be designed. Indeed the design theorist is a reverse engineer. Unconstrained by naturalism, the design theorist finds plenty of natural objects attributable to design (this is especially true for biological systems). Having determined that certain natural objects are designed, the design theorist next investigates how they were produced. Yet because evidence of how they were produced is typically incomplete (at least for natural objects), the design theorist is left instead with investigating how these objects could have been produced. This is reverse engineering… To sum up, intelligent design consists in empirically detecting design and then reverse engineering those objects determined to be designed.[44]

Through much work, documented in several books, William Dembski has made significant contributions to the relatively new field of design detection. Using information theory, he has quantified a very useful concept for this purpose called "specified complexity", as described below:

> …irreducible complexity needs to be supplemented with another form of complexity if it is to become a precise analytic tool for detecting design in biological systems. Often, when an intelligent agent acts, it leaves behind an identifying mark that clearly signals its intelligence. This mark of intelligence is known as specified complexity…Unlike irreducible complexity, which is a qualitative notion, specified complexity can be quantified and falls within the mathematical theory of probability and information….irreducibly complex biological systems can, under certain circumstances, be shown to exhibit specified complexity. But what is specified complexity? An object, event, or structure exhibits specified complexity if it is both complex (i.e., not easily reproducible by chance) and specified (i.e., displays an independently given pattern).[45]

The example of transitive complexity cited earlier, that of a signal containing the prime number sequence emanating from a far-away planet, is also an event that exhibits specified complexity. If the sequence is long enough, it is hard to reproduce by chance and therefore complex. Moreover, because the sequence is mathematically significant, it can be characterized independently of the physical processes that brought it about.[46] The fact that this feature clearly indicates the influence of intelligent causation is precisely why the receipt of such a signal would cause great excitement among SETI (Search for Extraterrestrial Intelligence) researchers.

What's more interesting is the very real and present scenario that the DNA molecule within every living cell also exhibits specified complexity. As philosopher Stephen C. Meyer notes in the book: *Signs of Intelligence: Understanding Intelligent Design*,

> …specific regions of the DNA molecule called coding regions have the same property of "sequence specificity" or "specified complexity" that characterizes written codes, linguistic texts, and protein molecules. Just as the letters in the alphabet of a written language may convey a particular message depending on their arrangement, so too do the sequence of nucleotide bases… inscribed along the spine of a DNA molecule convey a precise set of instructions for building proteins within the cell. The nucleotide bases in DNA function in much the same way as symbols in a machine code or alphabetic characters in a book.[47]

In terms of the elegance and efficiency with which DNA is processed in living systems, Bill Gates, the founder of Microsoft Corporation has noted, "DNA is like a computer program, but far, far more advanced than any software we've created."[48] In addition, distinguished Professor of Natural Philosophy, Bernd-Olaf Kuppers has made the insightful observation that

> The problem of the origin of life is clearly basically equivalent to the problem of the origin of biological information. In accordance with this, the idea of biological

> information emerges as *the* fundamental concept in the physicochemical theory of the origin of life.[49]

This is a very interesting state of affairs, considering the fact that it was also information that had to have been present at the beginning of the universe for finely-tuned life-supporting laws and orderly structures to develop. It appears as though multiple aspects of our universe, from the very large, to the very small, reflect the influence of a transcendent, yet calculating, intentionality which is concerned with at least one thing: the development and sustenance of intelligent life.

One final reference concerning the origin of life problem will be made to a rather obscure but recent book, *Origin of Life: The 5th Option*, by engineer, author, and entrepreneur, Bryant Shiller. He conducts a thorough and detailed (over 500 pages) investigation of the problem from an engineering mindset claiming the following advantages:

> An engineering background affords some distinct advantages: a) provides sufficient background knowledge to address and comprehend the technical aspects of the biological sciences; b) provides sufficient background knowledge to address the other technical disciplines such as chemistry, geology, information theory, thermodynamics, quantum theory, etc. that have come to bear on the subject; c) permits viewing the subject from a uniquely pragmatic "top-down" engineering point of view as opposed to the laboratory "bottom-up" mentality of biochemists.
>
> Engineers, by nature, are pragmatic problem solvers. Engineering traditionally employs the fruits of scientific research to address and solve practical problems and create the technology that ultimately serves the needs of mankind… In the pursuit of these goals, engineers are often called upon to combine the findings of a number of diverse scientific disciplines in order to arrive at practical solutions and to achieve specific goals. This is the traditional application of engineering principles. But those same principles are eminently suitable for the study of systems already in operation. It's called "reverse engineering". The quest for the solution to the puzzle of how and/or why life came to be on the planet earth can benefit from this kind of mentality – the engineering mentality.[50]

Although apparently not religiously motivated, he ultimately arrives at the conclusion that the system of life on Earth has been engineered by an intelligence of some kind, thus validating the reverse systems engineering approach that he employed for analysis.

In *The Design Matrix*, Mike Gene attempts to synthesize many of these ideas into a set of four criteria that can be scored and combined to quantify an indication of design or non-design for any particular system. The four criteria are:

1. **Analogy** – Does the system resemble entities that we know are engineered by humans, such as machines, codes, or other devices?
2. **Discontinuity** – Does the system exhibit irreducible complexity, or is it possible to evolve via a series of gradual intermediate functional states?

3. **Rationality** – Does the system have a function that can be structurally decomposed? Does the working hypothesis of a "purpose" explain the system? How well do engineering criteria for good design map to the system?
4. **Foresight** – Does the system demonstrate Original Mature Design (design that has remained unchanged over long time periods and is robust in the face of disturbances? Does the present state explain something about the past?[51]

While it appears that Mike Gene intends mainly for the above criteria to be applied to biological systems, his criteria are similar in some respects to the set of criteria suggested by philosopher Michael Corey in his book, *The God Hypothesis: Discovering Design in our "Just Right" Goldilocks Universe*. He asserts that the following criteria can be used to judge if any given artifact has been deliberately contrived:

1. The existence of a coherent object that is comprised of a complex concatenation of interconnected parts that all work together toward achieving some practical end.
2. A complex degree of cooperative interaction between the various internal components toward a single functional end.
3. An Aristotelian "formal cause" or intelligible design that can be laid out in a logical coherent fashion.
4. The exploitation of well known technological and engineering principles which are utilized for a common constructive end.

> By these criteria, it is evident that the universe has indeed been contrived in some fashion. For one thing, it is hard to question the assertion that the universe itself is a coherent mega-artifact which has the goal of supporting biological life as one of its "intended" functions.
>
> With the advent of modern physics, it has also become evident that there is a complex state of cooperation between the various structures of the universe and their resultant functions. The various cosmic "coincidences" themselves are perhaps the most exquisite illustration of this type of functional cooperation. Moreover, these "coincidences" are known to exploit a wide variety of technological and engineering principles in their mutual cooperation to produce a viable life-supporting universe.[52]

Cosmologist Paul Davies recognizes that the laws of nature have ended-up producing something really good in a very ingenious way, and this profoundly affects his worldview as evidenced in his quote below from *The Mind of God*:

> The essential feature is that something of value emerges as the result of processing according to some ingenious pre-existing set of rules. These rules look as if they are the product of intelligent design. I do not see how that can be denied. Whether you wish to believe that they really have been so designed, and if so by what sort of being, must remain a matter of personal taste. My own inclination is to suppose that qualities such as ingenuity, economy, beauty, and so

> on have a genuine transcendent reality – they are not merely the product of human experience – and that these qualities are reflected in the structure of the natural world.[53]

Conclusion

Dr. Walter Bradley, Distinguished Professor of Engineering at Baylor University, has produced several publications and presentations that provide insight into the idea of an engineered world. He delineates the three essential factors that are necessary to achieve design outcomes in engineering as:

1. Mathematical form that nature assumes
2. Values of the universal and local constants
3. Specification of boundary conditions

Human engineering consists of specifying the boundary conditions under which the laws of nature operate to produce a purposeful outcome. Cosmic engineering must involve specification of not only the conditions under which the laws of nature operate, but the laws themselves and the universal constants that scale the "building blocks" of matter and energy and the fundamental forces in nature to provide the purposeful outcome of a habitable universe for life, and life itself. Dr. Bradley contends that for someone to choose to believe that there is a naturalistic explanation for the precise fine tuning of all of these factors is to "believe in a miracle by another name"[53]

He also claims that his personal experience as a lecturer supports the growing openness to these ideas in the academic world, as noted below:

> Having given over 135 talks on this subject to more than 65,000 students and professors at over 65 major university campuses from 1986 to 2002, I have observed a dramatic change in audience receptivity to the idea that an intelligent designer of the universe may exist. I have noted a widespread acceptance (albeit begrudging in some quarters) that this growing body of scientific evidence demands an intellectually honest reckoning, as no exclusively naturalistic explanation seems capable of rising to the occasion.[54]

One of the learning outcomes for the engineering major at our university is that our graduates would be able to apply Christian principle of stewardship. This involves not only conservation of natural resources, but also good stewardship over personal resources and valuable information such as evidence for a coherent and life-giving cosmology and worldview. This worldview of an ingenious transcendent engineer of the cosmos is a worldview filled with hope. It just makes sense that such an extraordinarily competent engineer who cares so much for the creation would be quite capable of completing the good purposes that are designed for its realization. With this kind of knowledge, graduates will be ready to give the reason for their hope, delivered in a rational and compelling manner, especially if the inquirer is a scientist or an engineer. In addition, it has been observed over the last 15 years that our students become inspired and motivated when they discover this kind of information, thus further enabling them to engage successfully in a fulfilling life of meaning and purpose, in which they joyfully respond to the call of love and service to humanity.

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