Jonathan Bartlett, Dominic Halsmer, and Mark R. Hall

ENGINEERING AND THE ULTIMATE

An Interdisciplinary Investigation of Order and Design in Nature and Craft

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Engineering and the Ultimate:
An Interdisciplinary Investigation of Order and Design in Nature and Craft
Proceedings of the 2012 Conference on Engineering and Metaphysics

Published in the United States by Blyth Institute Press in Broken Arrow, Oklahoma

ISBN: 978-0-9752838-6-8

For author inquiries, please send email to info@blythinstitute.org. For more information, please see www.blythinstitute.org.

Information about the 2012 Conference on Engineering and Metaphysics (including videos of the original conference presentations) can be found at www.blythinstitute.org/eandm2012

1st printing

Blyth Institute Press

Engineering and the Ultimate

An Interdisciplinary Investigation
of Order and Design
in Nature and Craft

edited by
Jonathan Bartlett,
Dominic Halsmer,
and Mark R. Hall

Proceedings of the 2012 Conference on Engineering and Metaphysics

this book is dedicated to the search for truth in all places—both expected and unexpected

We think the question is not whether the theory of the cosmos affects matters, but whether in the long run, anything else affects them.

— *G. K. Chesterton*

Acknowledgements

Putting together a volume like this requires a significant amount of hard work from a large number of people. This book began as a conference, and we would like to begin by thanking Oral Roberts University for hosting the original 2012 Conference on Engineering and Metaphysics which serves as the foundation for this volume. Next we would like to thank those who provided assistance in producing the book—Heather Zeiger for providing additional copyediting, Robert Lamar, for providing design assistance, Goran Marasović, for the cover design, and Eric Holloway and Winston Ewert for providing additional help with typesetting. We would like to especially thank all of the authors in this volume for following us down an untrodden road to blaze new trails, and we would like to thank our readers for the same.

—Jonathan Bartlett, Dominic Halsmer, and Mark R. Hall

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Introduction

Jonathan Bartlett

The Blyth Institute

1 Philosophy and Pragmatism, Science and Engineering

When engineering comes to mind, people usually think about bridges and computers, math and science—in other words, a practical application of technology to life. Seldom do they connect engineering with philosophers and theologians. However, the truth is that these ultimate things are thoroughly embedded within engineering, even if they are rarely reflected upon. The act of construction relies on certain assumptions about the nature and limitations of the world as well as the nature and limitations of the builders. The *purpose* of a building or software program is just as important to its structure as its materials or design. These considerations are closer to philosophy or theology than they are to math and science. However, the reasoning involved in such considerations is hardly ever formalized or even made explicit.

On the flip side of the coin, engineering is often used as the ultimate test of knowledge. In America, at least, a thing is not really considered true or authentic or of value unless someone can use it to build a better product, e.g., a better phone. This concept reflects the philosophical heritage of William James, the father of the pragmatic school of philosophy. In pragmatism, the ultimate test of ideas is their "cash value"—what people can *do* with the ideas. For pragmatists, the search for *truth* for its own sake is somewhat misguided because truth cannot be apprehended until it is applied to real-world problems. For better or worse, this tends to be the philosophical framework by which most modern people live. Therefore, the ultimate test of knowledge is whether or not we can build something out of it. This pragmatic philosophy makes *testability*, the cash value of scientific ideas, so fundamental to the practice of science. It evaluates one or more scientific models based on their *practical* consequences. This is why quantum mechanics (which is testable) holds a much firmer place in science than string theory (which is not).

Such an emphasis on practicality has caused modern humanity to all but abandon speculative pursuits such as philosophy. Some recent scientists, most notably Stephen Hawking and to a lesser extent Lawrence Krauss, have openly rejected philosophy (Warman, 2011; Andersen, 2012). However, such an attitude disregards the great contributions that such speculative endeavors have had on even the most practical concerns. Modern science, in fact, is based on the rigorous and unremitting application of ideas which originated in philosophy. The conservation laws in physics are really nothing except a practical expression of the philosophical idea of *ex nihilo nihil fit* (out of nothing, nothing comes), also called the "principle of sufficient reason," which dates back to before Aristotle (Melamed & Lin, 2011).

Pragmatism itself is an outgrowth of philosophy. Although pragmatism often represents itself as being outside of speculative philosophy, its very nature arises out of speculative reasoning. Pragmatism is the outgrowth of Liebniz's concept of "the identity of indiscernibles," which was first put forth in his *Discourse on Metaphysics* (Forrest, 2012). The identity of indiscernibles states that if two things are distinct from each other, there will be some property or group of properties which will also be distinct. Pragmatism is merely the act of looking for properties that make two theories distinct from each other, or makes reality identical or distinct from some theory. If a theory is identical with reality, then the properties which hold in the theory should also hold in reality. Testing is merely probing reality to determine, on the basis of the identity of indiscernibles, whether or not the theory is identical with reality.

So, as it turns out, science, testability, and the fundamentals of physics all draw directly from speculative philosophy. Rather than science or pragmatism getting rid of the need for speculative philosophy, they prove its importance. What modern scientific thought has actually demonstrated is that sound philosophy, over time, generates rock-solid principles, principles that are so solid that most practicing scientists simply assume their truth as self-evident, often unaware that these ideas have had a history within philosophy and are the result of centuries of reflection, debate, and development. It is true that not everything in philosophy is as sound or solid as these principles. However, to reject philosophy just because newer ideas have not achieved the status as the more well-developed ones is simply to reject the general advance of knowledge because philosophers have not achieved certainty yet. Rather than dismissal, what is needed is more active engagement and development.

Not only do many modern scientists reject philosophy, but the manner in which these higher ideals are treated by the mainstream culture demonstrates the belief that everything not directly rooted in pragmatism is a mere matter of opinion. Thus, in discussions about society and social governance, any attempt to include reasonings based on the nature, purpose, and ideals of humanity, tend to be met with ramblings about how ideas such as these are private, personal matters, and not suitable for public inquiry and discourse. Rejecting such philosophical reasoning in public discourse and deeming such knowledge as a matter of personal preference is as irrational as saying, "The principle of sufficient reason doesn't apply to me." It may be true that people don't know or agree on the ideals of humanity, however, this should not be taken as an excuse to reject them as targets of public discussion, but rather a reason to explore them further and deeper.

2 Reintegrating Philosophy into Science and Engineering

As has been previously demonstrated, science's great progress has been the result of the continual and unrelenting application of sound philosophy, such as the principle of sufficient reason and the identity of indiscernibles, into all areas of inquiry. It seems reasonable, then, that additional progress can be made by explicitly recognizing the link between these fields and encouraging more cross-disciplinary dialog. While some progress in this has been made, more is desperately needed.

In 2000, Baylor University held a conference called *The Nature of Nature*. Its goal was to bring scientists, philosophers, and other academic disciplines together to talk about the ultimate nature of reality. Specifically, the question was whether *naturalism*, the idea that all of reality is a self-contained physical system, was a valid presupposition in the pursuit of science (Gordon & Dembski, 2011a). If naturalism is true, then any phenomena must be, at least in theory, describable by references to physics. Therefore, any idea not reducible to physics should not be considered a valid explanation. In such a view, for instance, *design* might be a description, but it cannot be a cause. A soul might be a useful fiction, but it cannot be a reality. Free choice is an illusion.

The *Nature of Nature* conference included the very people who built many modern scientific fields, including Francis Crick (who discovered DNA and the genetic code), Roger Penrose (whose contributions to physics are similar to Stephen Hawking's), Guillermo Gonzalez (who pioneered work on galactic habitability zones), and many other experts and professionals in science and philosophy. While the conference did not come to any particular conclusion, it was successful in moving the question concerning the ultimate nature of reality from the periphery to a more central position. Alvin Plantinga's contribution to the conference, for instance, eventually culminated in his book, *Where the Conflict Really Lies: Science, Religion, and Naturalism*, published by Oxford University Press (Plantinga, 2011b,a).

The conference eventually resulted in a book named after the conference, *The Nature of Nature* (Gordon & Dembski, 2011b). One thing, however, was markedly absent from the list of topics—any discussion of the practical consequences of any of the theories of reality offered by the conference attendees. In other words, many interesting ideas were put forth, but nothing concrete enough to result in the building of a better phone.

Since the *Nature of Nature* conference, at least two conferences which dealt with the relationship between the nature of nature, science, and engineering have been held. The first was the Royal Academy of Engineering's *Engineering and Metaphysics* seminar in 2007. The focus of this conference was the relationship between ontology (philosophy of being) and process engineering (the act of doing). In addition, a conference in 2009 titled *Parallels and Convergences* at Claremont Graduate University tackled a variety of questions focused around the large-scale goals of engineering—including space exploration and transhumanism—and their integration with the purposes of humanity.

In 2011, a conference was planned to address two major areas of integration between engineering, philosophy, and theology. The first was to examine how philosophical and theological ideas can be directly integrated into the practice of engineering. The second was to investigate how the tools of engineering can be retrofitted to analyze philosophical and theological questions. This resulted in the 2012 Conference on Engineering and Metaphysics, whose proceedings is contained in this present volume.

3 The Engineering and Metaphysics 2012 Conference

The papers in this volume, for the most part, follow the talks given in the Engineering and Metaphysics 2012 Conference.[1] Between the participants, presenters, and authors, there exists some overlap between this conference and the original *Nature of Nature* conference which inspired it. The authors come from a variety of backgrounds—academically, spiritually, and socially. Since the participants included philosophers, theologians, engineers, computer scientists, and liberal arts professors—a truly interdisciplinary group—the book has been subtitled "an interdisciplinary investigation into order and design in nature and craft."

The conference was indeed focused on investigation, an intense desire to look deeper, to search in a number of different directions as evidenced in the Table of Contents. Nature was investigated from an engineering perspective, and engineering from various perspectives on nature. Even the investigation was investigated. At the conclusion of the conference, what was produced were not finished masterpieces but new ways of holding the brush and painting the canvas, analyzing problems in engineering, philosophy, and theology through new lenses. Some ideas and approaches surely will be more successful in the long run than others, but each one benefits the discussion by looking at old questions in new and unfamiliar ways.

Some questions asked include the following: Can theological questions be asked mathematically? Can nature be rigorously analyzed in terms of purpose as well as by matter in motion? Can the human spirit be integrated into science? Can it be

[1]If you want to see the original talks, they are all available online at the Blyth Institute website: http://www.blythinstitute.org/eandm2012

used to analyze engineering outputs? Does it leave a distinctive mark on nature? How does theology change the goals and processes of engineering? Which of these questions are ill-posed and unworkable, and which have lasting value?

These questions are all foundational questions. This volume is not designed to be a finishing point for these types of investigations, but rather to serve as an inspiration to others to ask even better questions along the same lines. The hope is that entirely new fields will emerge at the boundaries of theology, philosophy, science, and engineering, which will ask new questions, develop new methodologies, and learn not only new answers, but also entire new ways of understanding. In short, the goal for the conference and this volume is not a final answer, but an initial inspiration. After perusing these proceedings, the reader will be challenged to reexamine the borders and boundaries of disciplines, and to think about the world in new and exciting ways.

4 Articles in this Volume

The papers in this volume are divided into four parts—Engineering, Philosophy, and Worldview; Architecture and the Ultimate; Software Engineering and Human Agency; and The Engineering of Life. Below is a short preview of each paper and its importance. While they approach very different subjects from very different perspectives, each one investigates the way in which usable knowledge can be increased by looking beyond the strict functional materialism which often dominates engineering discussions.

Reversible Universe: Implications of Affordance-based Reverse Engineering of Complex Natural Systems

This volume begins with a paper examining how scientists look at nature and suggests that reverse engineering is a fruitful methodology for natural investigations. It suggests that *purpose* is just as much of a discoverable fact of nature as is mechanism and suggests a methodology based on affordance-based reverse engineering for discovering nature's purpose as well as nature's mechanisms.

The Independence and Proper Roles of Engineering and Metaphysics in Support of an Integrated Understanding of God's Creation

The next paper analyzes the boundaries of various disciplines and shows the kinds of problems that arise from misunderstanding the proper roles and boundaries of various disciplines, including mathematics, science, engineering, and philosophy. It looks at how various spheres of knowledge do and do not interrelate, with the goal of producing a symphonic arrangement of knowledge and action.

Truth, Beauty, and the Reflection of God: John Ruskin's *Seven Lamps of Architecture* and *The Stones of Venice* as Palimpsests for Contemporary Architecture

Much of modern engineering is functional. If it works, then what more is there to do? In this paper, additional foundational considerations besides function are suggested for the practice of architecture, including moral, ethical, philosophical, and religious principles. Using John Ruskin as a plumbline, the paper provides examples of modern architecture which embody these principles and suggests ways in which these principles can be incorporated into future architectural projects.

Using Turing Oracles in Cognitive Models of Problem-Solving

Problem-solving plays a fundamental role in engineering, as one of the main tasks of an engineer is to generate creative solutions to technical problems. As such, this paper examines the question of whether humans are entirely physical or if they have a spiritual component and the impact that this has on cognitive models of problem-solving. The paper suggests Alan Turing's *oracle* concept as a way of integrating non-mechanistic human abilities into models of human insight.

Calculating Software Complexity Using the Halting Problem

Building on the previous paper, this paper gives a practical application of non-mechanistic models of problem-solving by developing a software complexity metric which is based on supra-computational abilities of humans when solving problems requiring insight. It uses the computational insolubility of the halting problem to find and measure the amount of insight required to understand a computer program.

Algorithmic Specified Complexity

The next paper in the volume considers the question of what it means for something to be engineered. Is there any property of an *engineered* system which separates it from things which are not engineered? This paper makes a technical examination of algorithmic information theory to derive a metric that the authors term *Algorithmic Specified Complexity*, which uses compressibility and context to measure the likelihood that a particular sequence is the result of intentional engineering rather than happenstance.

Complex Specified Information (CSI) Collecting

If one assumes that humans are non-mechanical and are capable of supra-computational abilities, then it may be possible to reliably harness this ability in certain applications. This paper looks at how this might be measured, tested, and harnessed programmatically. The paper includes an experimental design which, though it was not successful in this attempt, can provide a starting point for future experiments and investigations.

Developing Insights into the Design of the Simplest Self-Replicator and its Complexity

This final paper is an extended consideration of the minimal requirements for true self-replication, divided into three parts. Part 1 considers the abstract design required to allow self-replication. It analyzes what sorts of processes, components, and information is needed for any self-replication to occur. Part 2 analyzes the potential physical implementation possibilities and the various design considerations when choosing implementation materials. Part 3 compares the minimal artificial self-replicator to the self-replicators found in nature—namely cell biology. This part examines possible origin-of-life scenarios based on the analysis of the design requirements of self-replication.

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Part I

Engineering, Philosophy, and Worldview

This volume begins with two papers discussing the relationship between engineering and knowledge. In the first paper, Dominic Halsmer et al. argue that engineering is foundational to the search for truth as truth. It looks specifically at reverse-engineering and design recovery as a model for seeking truths about the natural world. These methodologies have been developed and used within engineering to recover a design when the specifications are not readily available, and Halsmer argues that they can be applied to the scientific endeavor to uncover the original design within nature.

In the second paper, Alexander Sich argues that engineering cannot be foundational in the search for truth because the engineering disciplines depend fundamentally on highly-focused natural scientific knowledge applied to the production of artifacts, while the particular natural sciences depend foundationally upon metaphysics for their first principles. Moreover, Sich contends that a failure to draw proper ontological distinctions between the objects studied by the natural sciences and philosophy leads to confusion over the character of inferences to the existence of the objects studied.

2

Reversible Universe: Implications of Affordance-based Reverse Engineering of Complex Natural Systems

Dominic Halsmer, Michael Gewecke, Rachelle Gewecke, Nate Roman, Tyler Todd, and Jessica Fitzgerald

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Abstract

Recent advances in the field of engineering design suggest the usefulness of the concept of affordance for reverse engineering of both man-made and natural systems. An affordance is simply what a system provides to an end-user or to another part of the system. With the current recognition that engineering concepts are playing a key role in deciphering the workings of complex natural systems such as the living cell and the human brain, affordance-based reverse engineering procedures should be considered as appropriate tools for this work. Such an approach may have important implications for philosophy and theology.

Procedures for reverse engineering and design recovery have become well-defined in several fields, especially computer software and hardware, where pattern detection and identification play important roles. These procedures can also be readily applied to complex natural systems where patterns of multiple interacting affordances facilitate the development, sustenance and education of advanced life forms such as human beings. Thinking about the human condition in terms of affordances leads to a new and fruitful interaction between the fields of science and theology, in which the field of engineering plays a key role in the dialogue. Proper understanding of

the interplay between both positive and negative affordances in the context of engineering design under necessary constraints leads to a clearer worldview and a better understanding of mankind's place and purpose in the universe.

1 Introduction

A worldview consists of what one believes to be true about the universe and all of reality, including "how things work."[1] Worldviews are formed by mentally processing and filing away the accumulated experiences of life. Inaccurate worldviews can prove hazardous to one's health. Although young children do not know the inverse square law of gravitation from physics, they learn very quickly to respect the influence of gravity, or suffer the painful consequences. Other aspects of reality take somewhat longer to ascertain. But from the first moments of life, human beings enter this world as little private investigators, gathering clues as to how the world works. They are truth-seekers, especially when it comes to that which brings satisfaction and enjoyment. Upon discovery of a new object, they immediately embark on a crude type of reverse engineering exercise to determine what can be known about this object and what uses it might afford. Toddlers often go through a phase where they enjoy banging a spoon against pots and pans. Perhaps this affords them an early experience of understanding that they possess the power to control their environment, to some small degree. Or maybe they just like to make the banging sound. In either case, it results in increased hand-eye coordination and knowledge of causation.

As children get older and become more adept at reverse engineering techniques, they often pass through a phase characterized by repeated dissections of both natural and man-made objects. Perhaps taking apart complex organisms/devices facilitates the discovery of hidden connectivities, or internal affordances, which sheds light on the underlying mechanisms of operation. Or maybe they just like to see if spiders can still walk around with fewer than their original number of legs.[2] In either case, this type of behavior is often seen as a precursor to a career in science or engineering.[3] This innate

[1] Ken Samples gives a more technical description, writing, "A worldview forms a mental structure that organizes one's basic or ultimate beliefs. This framework supplies a comprehensive view of what a person considers real, true, rational, good, valuable, and beautiful" (Samples, 2007, p. 20). Ron Nash defines worldview as "a conceptual scheme by which we consciously or unconsciously place or fit everything we believe and by which we interpret and judge reality" (Nash, 1988, p. 24). For a thorough treatment of the concept of worldview, see David K. Naugle, *Worldview: The History of a Concept* (Naugle, 2002).

[2] Although unproductive from the point of view of the spider, this is actually an example of the "subtract and operate" reverse engineering technique for establishing component function in complex systems, discussed in Kevin N. Otto and Kristin L. Wood, *Product Design: Techniques in Reverse Engineering and New Product Development* (Otto & Wood, 2001, pp. 159–162, 204–211)

[3] This is not to suggest that budding scientists and engineers enjoy practicing cruelty to animals, but simply that they typically possess a high level of curiosity for "how things work." For a wonderful picture book to introduce children to the concepts of stewardship and sustainability issues in the

and seemingly insatiable curiosity is a very interesting feature of all human beings, especially when coupled with the extraordinary comprehensibility of the world[4], since it results in many profitable and satisfying affordances. Both humans and the external world appear to be engineered so that interactions with the environment result in vital knowledge, which plays a key role in gaining wisdom and maturity for a full and abundant life.

This paper is an investigation into the usefulness of state-of-the-art reverse engineering concepts and techniques for accurate worldview formation, with particular interest in how the field of natural theology may be influenced by thinking of nature in terms of affordances. An affordance is simply what an object provides to an "end user." In the case where the object is a more complex multi-component system, affordances are also recognized to exist internally, between interacting parts of the system. Hence, an affordance is also what one part of a system provides to another part of the system. Traditionally, reverse engineering has focused on identifying functionality, but recent engineering design research (Maier, 2008, pp. 34–37)[5] suggests that affordance-based reverse engineering may be more appropriate for handling the complexity associated with many natural systems. It may also be more helpful in design recovery, a subset of reverse engineering that attempts to work out what a system was designed to do, how it does it, and why it works the way it does. Design recovery goes beyond simply examining a system's component parts and their interactions and attempts to identify both purpose and logical organization. Although not expected to lead to definitive results in the case of natural systems, this approach contributes to a better understanding of why the universe is the way it is[6], resulting in positive contributions to the field of Christian apologetics, and consistent with a new vision for natural theology.[7]

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animal kingdom, see Margaret Bloy Graham, *Be Nice to Spiders* (Graham, 1967).

[4]Albert Einstein famously quipped that the most incomprehensible thing about the world is that it is comprehensible. He expounded on this view by writing, "You find it strange that I consider the comprehensibility of the world (to the extent that we are authorized to speak of such a comprehensibility) as a miracle or as an eternal mystery. Well, *a priori* one should expect a chaotic world, which cannot be grasped by the mind in any way. . . . The kind of order created by Newton's theory of gravitation, for example, is wholly different. Even if man proposes the axioms of the theory, the success of such a project presupposes a high degree of ordering of the objective world, and this could not be expected *a priori*. That is the 'miracle' which is being constantly reinforced as our knowledge expands" (Einstein, 1987, p. 131).

[5]For discussion of affordance-based reverse engineering from the perspective of engineering education, see Dominic Halsmer, Nate Roman, and Tyler Todd, "Integrating the Concept of Affordance into Function-based Reverse Engineering with Application to Complex Systems" (Halsmer, Roman, & Todd, 2009b).

[6]A recent contribution in this area can be found in Hugh Ross, *Why the Universe Is the Way It Is* (Ross, 2008).

[7]An exciting vision is cast in Alister E. McGrath, *The Open Secret: A New Vision for Natural Theology* (McGrath, 2008).

2 Reverse Engineering Natural Systems

Reverse engineering is the process by which anything that has been made is analyzed to determine the original design information that went into its development.[8] Though not a major branch of engineering curriculum in academia, reverse engineering has been studied and implemented extensively in many industries where it often assists in gaining a competitive advantage. In this sense it is considered to be a mature field in practice, if not in theory. Engineering programs at some universities are now recognizing the value of reverse engineering activities as a design training exercise for students (Wu, 2008, pp. 57–59). They disassemble and analyze power tools and other man-made devices in order to see how design principles and practices guide engineers in developing a well-made product. Reverse engineering concepts are also used extensively in deciphering unfamiliar or poorly documented computer software and hardware systems (Eilam, 2005).

But recently reverse engineering techniques have proven to be surprisingly fruitful when applied to natural systems. Although the field of systems biology[9] has expanded rapidly in the past few years, there is a long history behind this approach. One of the earliest scientists/engineers to record detailed reverse engineering studies of biological systems, including extensive dissections of the human body, was Leonardo da Vinci. Concerning this work, he wrote that "the human foot is a masterpiece of engineering and a work of art." Evidently, his intimate knowledge of biological systems led him to a deep appreciation for the beautiful functionality they exhibit. 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 (Auffray & Noble, 2009).

In more recent times, scientists like E. O. Wilson and Daniel Dennett concur with the necessity of the reverse engineering approach. Wilson writes that "the surest way to grasp complexity in the brain, as in any other biological system, is to think of it as an engineering problem" (Wilson, 1998, p. 112). Dennett claims that "you just can't do biology without doing reverse engineering, and you can't do reverse engineering without asking what reasons there are for whatever it is you are studying. You have to ask 'why' questions" (Dennett, 1996, p. 213). Though Dennett may disagree with the idea of ultimate purpose, these are questions of a teleological nature, and other scientists and engineers are coming to the same conclusion. For example,

[8] Other definitions of reverse engineering emphasize the determination of specifications that allow for the reproduction of a device or system, or to provide insight into how to "reengineer" the system by incorporating updates or improvements.

[9] According to the editors of a joint issue of *IEEE Transactions on Automatic Controls* and *IEEE Transactions on Circuits and Systems: Special Issue on Systems Biology*, systems biology is "the quantitative analysis of networks of dynamically interacting biological components, with the goal of reverse engineering these networks to understand how they robustly achieve biological function" (Khammash, Tomlin, & Vidyasagar, 2008, p. 4).

Caltech researchers ask “What is/are the purpose(s) of this biological system?”[10] and suggest that biological systems be approached from an “engineer’s perspective.” Arthur Lander at UC Irvine has proposed a system for thinking in these terms and writes that “these elements can be seen as the foundations for a new calculus of purpose, enabling biologists to take on the much-neglected teleological side of molecular biology. ‘What purpose does all this complexity serve?’ may soon go from a question few biologists dare to pose, to one on everyone’s lips” (Lander, 2004).

If such teleological, yet scientific questions are being asked at the micro-scale, then it seems reasonable that such questions could also be posed at the macro-scale. Furthermore, since such profitable answers are being found by reverse engineering at the level of the cell, it makes sense that good answers might also be found on a larger scale using this approach. The idea that qualitative questions can be answered through quantitative approaches is affirmed by Lander in another article where he summarizes the lessons learned from systems biology. He concludes the article with, “They teach a lesson about biology that is as important as it is surprising: sometimes, answering the most qualitative of questions – ‘Why does the organism do it that way?’ – succeeds only through the most quantitative of approaches” (Lander, 2007). These insights from systems biology suggest that reverse engineering of natural systems may not only reveal the inner workings of the cell, but may also assist in the acquisition of a more complete understanding of mankind’s origin, place and purpose in the universe.

3 Interpreting Natural Systems

Even before the time of Christ, Greek and Roman philosophers practiced a kind of reverse engineering of natural systems, interpreting the beneficial order in the universe as an indication of a larger plan or design of a Mind (Sedley, 2009). Socrates and Plato believed that in addition to providing the initial order to the universe, this Mind also acted to sustain it at all times. About 50 years before Christ, Marcus Cicero, who brought Greek philosophy to the Romans, even suggested that various characteristics of the creating deities could be inferred from the highly ordered work of their hands. He interpreted harmonious movements in nature by referring to similarities with man-made objects when he wrote, “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

[10] In Gregory T. Reeves and Scott E. Fraser, “Biological Systems from an Engineer’s Point of View,” the authors write that “many biologists have remarked on the apparent design of biological systems, arguing that this is a false analogy. However, evolutionary theory would predict apparent design and purpose in biological systems. Therefore, regardless of the origin of this apparent design, the analogy is, at the very least, pragmatic. Keeping this in mind we can approach a biological system from an engineer’s perspective. Engineered systems were designed with a particular purpose in mind, so it would be helpful to ask, ‘What is/are the purpose(s) of this biological system?’ . . . Determining what [these purposes] are for a particular biological system is especially important in light of design trade-offs, and furthermore will provide clues to a systems molecular behavior” (Reeves & Fraser, 2009).

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?" (Cicero, *De Natura Deorum*, 2.38.97, trans. 1972)

Paul the Apostle wrote in a similar vein to the Romans when he penned the well known verse, "For since the creation of the world God's invisible qualities—his eternal power and divine nature—have been clearly seen, *being understood from what has been made*, so that men are without excuse" (Romans 1:20 NIV, emphasis added). Paul, being a highly educated Hebrew from Tarsus, would have been well aware of the prevailing philosophies of his audience. His words seem to mesh nicely with the idea of reverse engineering, which is about gleaning design information regarding an object, and if possible, also uncovering what may be known about the original engineer and his/her intentions. This is largely accomplished through a systematically obtained understanding of the object in the context of its surrounding culture and environment. In this verse, Paul may be referring to human understanding derived from observations of specific objects in nature, or the entire cosmos, or both.[11] It is suggested that modern reverse engineering techniques would find profitable application in both cases.

Nineteenth century natural theologians such as William Whewell and William Buckland practiced an early form of reverse engineering of natural systems, focusing on the implications for a Christian worldview. For Whewell, there was one Biblical teaching that stood out as a heuristic for science: that human beings are created in the image and likeness of God (Fuller, 2006, p. 283). This similarity between creator and creature, like the match between the complexity of the universe and mankind's ability to comprehend it, should facilitate the process of reverse engineering. Recognizing that one could never fully comprehend the transcendent engineering of the creator, nonetheless, for a Christian, there is a sense that science is the gift and privilege of "thinking God's thoughts after him."[12]

One of William Buckland's memorable expositions involved the design of Megatherium, an enormous extinct relative of the sloth (Roberts, 1999, p. 245). Leading anatomists of the time regarded this animal as having a poor and bungled design. But Buckland chose it to show, by "careful and rigorous anatomical description and then the application of reverse engineering," that it was "perfectly designed or adapted for its environment. . . . Here, for Buckland, design was not so much a scientific theory, but rather a metaphysical or theological outlook, which gave confidence or grounds for applying reverse engineering procedures"(Roberts, 1999, p. 248). It

[11]Recent formulations of the design argument show groups working in both directions. See Stephen C. Meyer, *Signature in the Cell: DNA and the Evidence for Intelligent Design* (Meyer, 2009) for an example of evidence from specific objects in nature, and Edward Feser, *The Last Superstition: A Refutation of the New Atheism* (Feser, 2008) for a Thomist view in which design is evident throughout the cosmos. It seems that a cumulative case for a Christian worldview, such as that described in R. Douglas Geivett, "David Hume and the Cumulative Case Argument," (Geivett, 2005) could make good use of both formulations.

[12]Often attributed to Johann Kepler. This issue is explored in Del Ratzsch, "Design: What Scientific Difference Could it Make?" (Ratzsch, 2004).

makes sense for a Christian engineer or scientist to apply such procedures in laboring under the hypothesis that the universe is an engineered system[13], without any preconceived notions about how such transcendent engineering was accomplished. This is consistent with the thinking of leading theologians of today, like Alister McGrath, who suggests that natural theology is to be understood as "the enterprise of seeing nature as creation, which both presupposes and reinforces fundamental Christian theological affirmations" (McGrath, 2006, p. 64).

McGrath also asserts that "the order of things determines how things are known . . . or, to put it more . . . formally: ontology is to be allowed to determine epistemology"(McGrath, 2006, pp. xv–xvi). Again, this is consistent with a reverse engineering mindset, which approaches the task with a certain humility, recognizing that what is discovered will in large part determine how to proceed with the overall investigation. In exploring the metaphor of nature as book, philosopher Angus Menuge writes that "a good scientific interpretation is one that allows nature to speak for itself and yet which is motivated by and connected to an overarching frame of meaning provided by revealed theology" (Menuge, 2003, p. 96).

In a response to Menuge, theoretical chemist Walter Thorson calls for maintaining a clear distinction between science and theology. He writes,

> Even the most rudimentary biosystems manifests logical organization directed to certain (limited) achievements. . . . This logical organization according to function can be explained on its own terms – as an objective aspect of a naturalistic *science*; interpretation in terms of divine agency is not essential. By such a naturalistic study of creation in its own contingent terms of reference, we would only discern the embodied logic of creaturely things themselves, not their transcendent divine purpose or design. . . . Theologically, such a situation invites the idea that God's work of creation, like his work of redemption, may be seen as the expression of a self-giving, self-emptying love: that is, creation seen as kenosis. While this view poses some difficult questions, it deserves serious consideration. (Thorson, 2003, p. 101)

But even with the attempt to keep science and theology separate, it seems likely that such theological musings will also influence aspects of an ongoing scientific approach. For those pursuing advances in both science and theology, the two fields are often found to be quite compatible, leading to many fruitful interactions.

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[13]For explorations into the idea of the universe as an engineered system, see Dominic Halsmer et al., "The Applicability of Engineering Design Principles in Formulating a Coherent Cosmology and Worldview" (Halsmer, Halsmer, Johnson, & Wanjiku, 2008), and Dominic Halsmer et al., "The Coherence of an Engineered World" (Halsmer, Asper, Roman, & Todd, 2009a).

Figure 2.1: The Antikythera Mechanism at the National Archaeological Museum, Athens—Giovanni Dall'Orto

4 The "Artifact Hermeneutics" of Daniel Dennett

An example of a philosopher who applies reverse engineering techniques to the works of "mother nature" is found in the philosopher Dennett. He proposes that the same "artifact hermeneutics" be used when reverse engineering is applied to both man-made and biological systems (Dennett, 1990, p. 177). He further asserts that optimality considerations should be used, rather than attempting to analyze the intentions of a designer. As an example, he cites the Antikythera device, a complex geared mechanism discovered in an ancient shipwreck in 1900. Dennett contends that "it was—almost certainly—an orrery or planetarium, and the proof of that is that it would be a good orrery. That is, calculations of the periods of rotation of its wheels led to an interpretation that would have made it an accurate (Ptolemaic) representation of what was then known about the motion of the planets" (Dennett, 1990, p. 180). Dennett is correct, as far as the function of the device, but many other interesting questions might be addressed through a more complete approach to reverse engineering.

Jo Marchant details the entire story of the reverse engineering of the

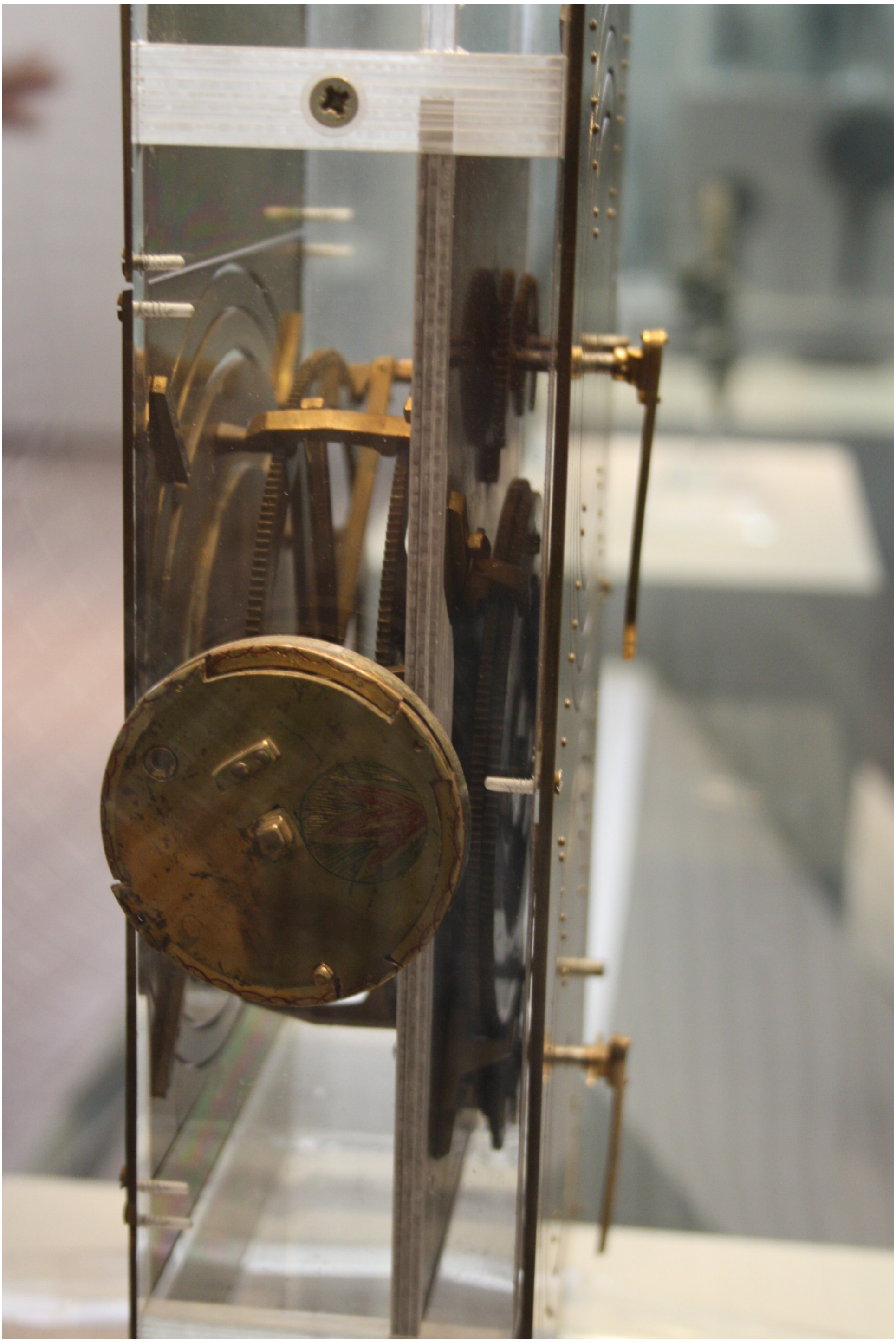

Figure 2.2: Reconstruction of the Antikythera Mechanism at the National Archaeological Museum, Athens—Giovanni Dall'Orto

Antikythera device in a fascinating book (Marchant, 2009). A significant amount of design recovery was accomplished in terms of the purpose of the device and the identity and thinking of the original engineer(s). Referring to Greek letters engraved on the casing of the device, she writes, "[The reverse engineer] also noted that the letters were so precise they must have been engraved not by a labourer but by a highly trained craftsman" (Marchant, 2009, p. 55). She also recognized that the incorporation of historical and cultural information from the time period was valuable for unlocking some of the mysteries of the device. As an example, consider the following passage: "Archaeologists also studied the rest of the salvaged cargo. Their discoveries help to paint a vivid picture of when the ship sailed, where her load was being taken, and the sort of world from which she came. From there we can guess at the origins of the Antikythera mechanism itself, and how it ended up on its final journey" (Marchant, 2009, p. 61). Thus, it is clear that reverse engineering is most effective when all pertinent information is brought to bear. This is accomplished by looking at the "big picture" instead of limiting the study to the narrow set of data obtained by simply dissecting the specimen.[14]

Dennett's approach to reverse engineering through optimality considerations has recently been criticized from a couple directions. Philosopher Robert Richardson contends that such an approach to evolutionary psychology lacks the standard level of evidential support enjoyed by evolutionary biology (Richardson, 2007).[15] A second criticism, that gets more to the heart of the matter, looks specifically at Dennett's insistence on optimality as the guiding beacon of the reverse engineering enterprise. Philosophers Krist Vaesen and Melissa van Amerongen have recently published an extensive analysis of Dennett's artifact hermeneutics. They argue that "Dennett's account is implausible . . . [and] conclude that, quite in contrast to Dennett, intentional considerations play a crucial role in artifact hermeneutics, and even stronger, are necessary for the sake of simplicity and precision" (Vaesen & van Amerongen, 2008, p. 779).

Vaesen and van Amerongen claim that artifacts should be interpreted by relying both on optimality and intentional considerations, recognizing that this hampers Dennett's strategy of reverse engineering artifacts and organisms in the same way (Vaesen & van Amerongen, 2008, pp. 794–795). Their thoughts on how Dennett's unified approach might still be achieved leads to an interesting final paragraph. They write,

[14]For more details on this idea, see Dominic Halsmer and Jessica Fitzgerald, "Metaphysical Considerations Enhance Reverse Engineering Studies," presented at the ASA Annual Meeting, North Central College, July 29-August 1, 2011 (Halsmer & Fitzgerald, 2011), and for a discussion of the incorporation of the concept of corruption, see Dominic Halsmer and Sean McDonough, "Affordance-based Reverse Engineering of Natural Systems with Possible Corruption," Proceedings of the 2011 Christian Engineering Education Conference (CEEC), Trinity Western University, June 29-July 1 (Halsmer & McDonough, 2011).

[15]Refer to his recent book, *Evolutionary Psychology as Maladapted Psychology* (Richardson, 2007) for details of his criticisms.

> Of course, it still might be possible to establish a generic interpretive program, including artifacts *and* biological items . . . What is needed to argue for the importance of intent in the interpretation of organ(ism)s, is a proof that intent reveals things that remain hidden under an optimality account or that it is beneficial to ignore optimality and dig for a designer's – i.e., nature's – intentions instead. It is far from evident that such things can be done without entering the waters of creationism. Fortunately, the burden of proof is on, if any, those who think our understanding of biofunctions is – or should be – linked to "Mother Nature's" intentionality. (Vaesen & van Amerongen, 2008, p. 795)

Vaesen and van Amerongen's demand for a *proof* that intent reveals things that remain hidden under an optimality account is quite a stringent requirement. In the remainder of this article it should become clear that, although short of a proof, there is a significant amount of evidence that this is the case. Considerations of intention while conducting affordance-based reverse engineering of natural systems do reveal valuable things that remain hidden and unrealized under Dennett's approach.

5 Reverse Engineering and Design Recovery Techniques

If reverse engineering really is a profitable method for studying natural systems, then this approach should be fully explored to ensure that maximum benefit is achieved. A valuable resource that discusses function-based methods for hardware systems is *Product Design: Techniques in Reverse Engineering* (Otto & Wood, 2001).[16] However, a more concise, yet detailed description of the process is found in an article entitled "On Reverse Engineering" by M. G. Rekoff, Jr (Rekoff, 1985). He describes a method for systematically conducting the reverse engineering activity, noting that it "is not really greatly different from that of detective work in a criminal investigation or of conducting military intelligence operations."(Rekoff, 1985, p. 245) In a nutshell, Rekoff recommends the decomposition of existing structural hierarchy in developing functional specifications until the mechanism-of-operation is completely understood. This is unpacked in the following steps of his grand plan for conducting a reverse engineering effort . . .

- "System-engineer" [analyze the interconnectivity with an engineering mindset] first to establish hypotheses based on the information presently at hand and to identify the measurement/test needs.

[16] This book details function-based techniques for reverse engineering of man-made hardware. See Denis L. Feucht, "Design in Nature and the Nature of Design,"(Feucht, 1999) for a discussion of the relevance of functional theories to the design of living organisms.