Design With and Without Intelligence

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Writer's Comment: My aim with this paper is to introduce people to the concept of evolutionary design. Evolutionary design draws from a number of fields: it combines concepts from biology with tools from computer science to achieve ends in engineering. Since it is a nascent field, it often provokes the question, "What is evolutionary design?" So I often find myself going to lengths to explain what it is and why I find it fascinating. Professor Christopher Thaiss' class, Writing in the Sciences (UWP 104E), gave me an opportunity to articulate what evolutionary design is, how it differs from conventional design, and what kind of promise it holds. My hope is that this is a paper my parents can read, and say, "Oh, so that's what our son wants to do." I want to thank Professor Thaiss and Nykia Hunter for their feedback and encouragement.

—Shane Celis

Instructor's Comment: Shane's essay was one of many delights students created in my section of UWP 104E, Writing in Science, in Spring 2009. With teammates Diana Donati and Travis Scrimshaw, Shane chose "evolutionary robotics," in particular the ideas and methods of Karl Sims, as the focus of the research review that was the main assignment of the course. This focal topic sparked diverse documents from members of the team: each person's comparative rhetorical analysis of key articles, the team's full report of their review of the research literature, and each team member's article for a non-specialist ("popular") audience—the genre that Shane's essay for Prized Writing *exemplifies. Throughout the course, Shane impressed me with his rhetorical awareness: his desire to fit words and images to the understanding of different types of readers, his willingness to experiment with and revise metaphors and structural patterns. I admire his elegant comparison of "evolutionary design," "intelligent design," and "Intelligent Design," then his* *demonstration of Sims' highly intelligent use of digital evolution as a creative tool with highly practical, yet basically playful, consequences.*

—Chris Thaiss, University Writing Program

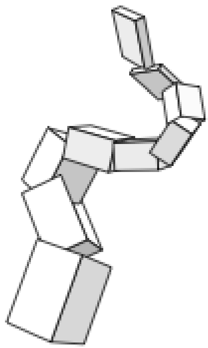

Figure 1. **Swimmer evolved by Karl Sims [6]**

A figure swims across the screen. Its tail wags and the figure pushes through what must be water. From a distance one might mistake it for a biological organism, but up close one sees that it is made of solid blocks, like idealized LEGO® bricks without any nubs or holes. It is a computer simulation. The blocks attach to form a chain with a big block at the front that looks like a head. Each following block is successively smaller, creating the impression of a tail. The tail waves back and forth to propel the creature along. The motion of its body looks natural not mechanical.

This virtual creature was not designed; it was evolved. However, it is not a product of natural evolution. It is a product of artificial evolution. Artificial evolution allows humans to harness evolution to do design work. What are the advantages of evolutionary design? What are the disadvantages? How does it compare with intelligent design? This article will show how evolutionary design and intelligent design differ and where evolutionary design can be useful.

We can break design into two camps: intelligent design and evolutionary design. Intelligent design has two different definitions, which we ought to discriminate between to avoid confusion. (1) Intelligent Design (ID) is the provocative thesis that some biological organisms are so complex that an intelligent agent must have designed them rather than their having evolved. (2) Intelligent design is the unprovocative fact that humans design things intelligently. This article will be referring to definition (2) of intelligent design exclusively.

Intelligent design is all around you, from the clothes you are wearing to the chair you are sitting on. It is ubiquitous for us. Scarcely any objects in our day-to-day lives are not products of intelligent design save for natural objects like trees and grass. Cars are products of intelligent design. Newspapers, political systems, and television shows (believe it or not) are products of intelligent design.

Evolutionary design is on conspicuous display in the natural world. Every living animal, plant, and single-celled organism is a product of evolutionary design. Evolution is an unintelligent process that produces extremely ingenious designs. Calling the evolutionary process unintelligent is no slight. Charles Darwin's insight was precisely to see how design could happen without an intelligent designer [2]. Also, to say that the process is unintelligent does not in anyway denigrate the products of that process. Natural evolution accounts for the diversity of design in the biological world, but only recently have researchers harnessed evolution to solve engineering challenges.

Researcher Karl Sims [6] evolved the swimmer shown in Figure 1. What does it mean to say that Sims evolved it? What did Sims actually design? And what did evolution supposedly design? Sims wrote a computer program that simulates physics for a simple world of blocks. Joints connect blocks, and a set of virtual genes describes the blocks' shape, how the blocks connect, and how the joints move. He then gives the computer a goal: The creature that moves the farthest wins. That is the sum of Sims' input into the process. He does not prescribe the size of the blocks nor how the blocks connect. The computer takes over from this point and begins the process of artificial evolution.

The computer randomly connects blocks together and creates hundreds of random creatures. This collection of creatures is the first generation. As one might expect, such haphazardly constructed creatures are terrible swimmers. Some are completely inert. Some move their limbs ineffectually and make no forward progress. However, perhaps one creature moves its limbs in such a way that it does move forward a short distance. It may not move much, but it does better than every other creature, so it wins; thus, it is selected by the computer to go on to the next generation. The losers are selected out and their genes are tossed into the virtual trash bin. The winners' virtual genes are copied, mutated, and even recombined with other winners' genes.

In the next generation, more creatures can move forward a short distance because these creatures are all, in a sense, *children* of the creature that moved a short distance. So to win the next round each creature must move even farther to secure a place for itself in the following generation, and so on for every successive generation. This process is repeated mindlessly hundreds of times. At the end of this process, the creatures that are produced look like they were born to swim, and in a sense they are. One can see these creatures swimming in Sims' movie, which is available online [5]. Note that if one were to rerun the process of evolution, one

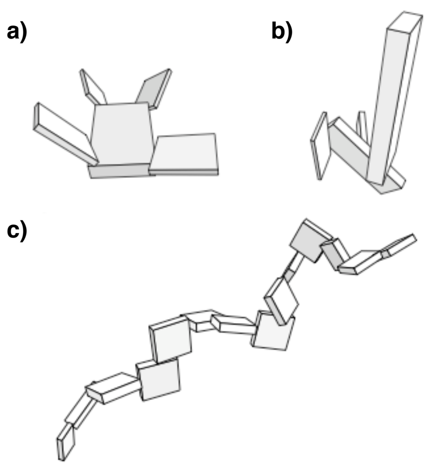

Figure 2. Different swimming strategies: a) uses flippers; b) extends forward and contracts like a caterpillar; c) uses a snake-like motion [6]

would likely produce different swimmers each time. Figure 2 shows other swimmers that were produced by the same process.

Sims' swimmer demonstrates a design for swimming that may evoke natural forms, may even be considered aesthetically pleasing, but most engineers might eschew it for its complexity. Its means of locomotion is complicated. It has many joints, which move simultaneously in a synchronized manner to achieve forward motion. Consider what human engineers have designed to swim. The submarine, shown in Figure 3, is internally complicated. For instance, many submarines are powered by nuclear reactors. However, the means of its locomotion is conceptually simple: a shaft rotates and turns a propeller. Engineers gravitate towards simplicity in design for many reasons: Simpler designs are easier to think about and easier to model; also, fewer things can go wrong. In fact, the Keep It Simple Stupid (KISS) principle makes simplicity a key design

Figure 3. Swimmer designed by humans

goal. Engineers have good reasons to adhere to KISS in their designs, but KISS is not always applicable.

With computer animation, Sims faced an engineering problem for which KISS was inapplicable. Animators sometimes want to animate large, complicated creatures; a small, simple creature will not always do. Imagine a fictitious scenario for animators creating the movie *Finding Nemo*. In the movie, a whale needs to be animated. The goal is to make its motion look visually realistic. The whale has all the downsides of the swimmer in Figure 1. An engineer might object, "Its locomotion is too complicated. It has too many joints." But the animators cannot substitute a submarine for the whale even though the submarine follows KISS and the whale does not. There are two solutions: Animators can do painstaking stop-motion animation, or engineers can figure out how to control the body of a simulated whale. Either one is time-consuming and expensive. Sims suggests a third solution: Evolve a way to control the body of the simulated whale. It only costs computer time, and it tends to produce natural-, not mechanical-looking motion. And computer time is cheaper than an animator's or an engineer's time, so the solution has some economic justification.

An important difference between the two design methodologies is that intelligent design and evolutionary design ask different questions. Intelligent design asks *how*? Evolutionary design asks *what*? Case in point, Sims does not provide any details about how the creature is supposed to swim. The lack of guidance is evident in the results shown in Figure 2 that demonstrate many different strategies for swimming. If a strategy had been prescribed by Sims, we would not see such variety. Most engineering design work consists of figuring out *how* to do something. Sims in this case passed that burden on to evolution and instead only declared what he wanted, a creature that would swim. With evolutionary design, one declares *what* one wants and lets evolution figure out *how* to do it. With intelligent design, one knows *what* one wants then spends one's time figuring out *how* to do it.

Another difference between the two design methodologies is that intelligent design is economical: it uses understanding and modeling whereas evolutionary design does not understand nor model its creations. Modeling allows one to take economical shortcuts. Consider a car factory. We know that changing the color of the car should not require retesting the car design. We know that removing the engine will produce a car that does not work. However, if evolution had control of a car factory, it might randomly change a car design, say, the color. Since it does not model or understand how cars work, it cannot discriminate between an inconsequential change like the color versus a consequential change like removing the engine. It would produce many unviable cars and run them through a series of expensive, exhaustive tests: crash test, performance test, off-road test, and real world test. Evolution would still work in theory. It would just be extremely impractical: it would take a long, long time and lots of resources. Unsurprisingly, no one envisions using an actual car factory to generate evolutionary designs for cars. Instead, one might hand evolution a virtual car factory where evolution's excesses and waste only consume computer time and may still produce some innovative car designs.

Even the production of car designs with a virtual car factory would be an ambitious undertaking, so let us return to practical and potential applications. What practical designs have been made with evolutionary design? One example comes from three NASA researchers. Jason Lohn, Gregory Hornby, and Derek Linden used evolutionary design to create an antenna design [4] to meet a specific set of requirements for a space mission. A conventionally designed antenna that met the same requirements was available for comparison. Both antennas are shown in Figure 4. The size of the antennas is the most obvious difference, but the evolved antenna also had potential power savings and required less material to fabricate. The evolved antenna was deployed with NASA's Space Technology 5 spacecraft on March 22, 2006, making it the first artificially evolved hardware in space [1].

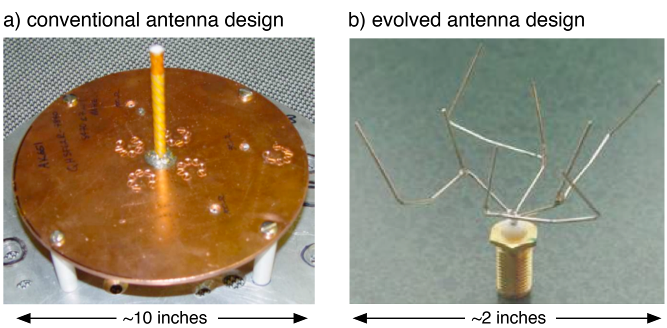

Figure 4. A conventionally designed antenna on the left, and an evolutionarily designed antenna on the right [4]

Less exotic than space-age applications, but perhaps closer to home, evolutionary design may help usher in the era of mass customization. The era of mass production has created department stores that are full of duplicates of clothes, furniture, and other goods. Mass customization is the idea that we will be able to fabricate not just duplicates but originals that suit our individual needs. Doing this with clothes is perhaps the easiest to conceive of. One would provide one's measurements and a machine would fabricate a suitable article of clothing. However, doing something similar with furniture is not as easy to conceive of. Few of us have the carpentry skill to create our own furniture designs. Imagine, instead, a web site that allows one to choose designs one liked, and the site would *mutate* that design or *recombine* it with other designs and display a new set of designs. One could continue selecting designs one liked, just as farmers have selected crops with high yields, until satisfied with a unique design. In this way evolutionary design could serve as an intermediary for those who want novel designs but do not necessarily have the expertise to create them by hand. Furniture is a simple example, but the same idea could be applied to many kinds of objects, media, and gadgets.

Intelligent design and evolutionary design should not be misconstrued as hostile methodologies, in which one camp claims supremacy over the other. Both methodologies have their advantages and disadvantages. Evolution has no foresight and every innovation must pay for itself immediately; there is no way to claim that an evolved innovation may help in the future. Humans have foresight and can make innovative leaps that they assume will pay off in the future. To use a phrase from evolutionary biologist Richard Dawkins [3]: Evolution is a blind watchmaker, while humans are sighted watchmakers. Evolution is mindless, while humans are mindful. If the methodologies were hostile, it seems that intelligent design would have a distinct advantage. However, humans must pay for their foresight by tackling the complexity of what they hope to design. The human requirement of understanding creates a bottleneck on the complexity we can permit in our designs. Because evolution never tries to understand its creations, it has no such bottleneck; this may sound like a bold claim until one considers the complexity of living creatures.

Sight has its advantages, but blindness is not solely a limitation. Blindness allows evolution to explore designs we might never consider because we have our own prejudices about what is possible, about what works, about what is desirable. Each methodology has its strengths and weaknesses, but there is no need to restrain oneself from taking what works from each methodology and applying it to one's own ends.

Intelligent design has been the diligent workhorse of human progress. It has shaped politics, math, literature, science, and more. There is good reason for us to cherish it, to uphold it as perhaps uniquely human. Computers open the door for us to use evolution as a new workhorse, to have it take on some of our burdens. Evolution does not shrink from complexity as we might because it never tries to understand anything; it merely trudges on mindlessly churning out further refined designs. And the natural world is a testament to what evolutionary design can do. Our human works show us what intelligent design can do. It remains to be seen what we might achieve by synthesizing both evolutionary design and intelligent design.

References

[1] Sandi Beck. "About ST5." *Space Technology 5*. NASA, March 2006. Available http://nmp.jpl.nasa.gov/st5/ABOUT/about-index.html

[2] Charles Darwin. *The Origin Of Species*. Signet Classics, September 2003.

[3] Richard Dawkins. *The Blind Watchmaker: Why the evidence of evolution reveals a universe without design*. Norton, New York, 1996.

[4] Jason Lohn, Gregory S. Hornby, and Derek Linden. An evolved antenna for deployment on NASA's space technology 5 mission. In *Genetic Programming Theory and Practice II*. U.-M. O'Reilly, R. L. Riolo, T. Yu, and B. Worzel, Eds. Kluwer, 2004.

[5] Karl Sims. *Evolved Virtual Creatures Movie*, 1994. Available http://www.archive.org/details/sims_evolved_virtual_creatures_1994

[6] Karl Sims. *Evolving virtual creatures*. In *Proc. SIGGRAPH 94*, pp. 15–22, 1994.