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Natural Order: The Case for Applying Biomimetic Design Principles to Mass Communication Technology Design

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NATURAL ORDER: THE CASE FOR APPLYING BIOMIMETIC DESIGN PRINCIPLES TO MASS COMMUNICATION TECHNOLOGY DESIGN

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ABSTRACT

In this paper I tested the effectiveness of a biomimetically designed classifier algorithm in an effort to support a new argument for the systemic application of biomimetic design principles to mass communication technology. To supplement the purely system-level test, I conducted a series of interviews with interface-level designers regarding their own design strategies, generally accepted design strategies in the field of mass communication technology design, new design strategies, and the landscape of the field in general.

The findings of my test lend strong credence to biomimicry's potential systemic contribution to mass communication technology design, and the tone of the interview responses suggests that the practices of interface-level design are congruent with this contribution. I argue that the placement of biomimetic design principles at the systemic level would enhance the user-interface design practices already in place, given their congruency with biomimetic design principles. I argue that to improve usability, interactivity, and security, and to improve our consumption, storage, and transmission of information on a massive scale, the most prudent course of action is to concentrate biomimetic design strategies systemically--into our hardware, networks, and systems in general--and that user-interface design would not only accommodate the changes to our system-level designs, but that it would thrive on them.

1. INTRODUCTION

At the intersection of computer science and mass communication, there is a question: what kind of technological design has a positive effect on our mass transmission, consumption, and storage of information? In this paper I examine the connection between our information systems and nature's information systems, survey biological design strategy, test an algorithm designed after one of nature's most effective systems, conduct a series of interviews with interface-level designers, and ultimately argue that the answer to that question is the systemic application of biomimetic design principles.

We are increasingly noticing the consequences of our information technology's design. The Internet, our ubiquitous avatar of information technology, has not sustained a magical info-democracy in which users have access to a standard free-flow of the world's information but instead is starting to breed a machine filling itself with dangerous monopoly over information. In the form of general outrage over threats to net neutrality, for example, the public has recently seen and reacted to one of the potential consequences of this design.

In a popular video segment of his television show, John Oliver (2014) explained net neutrality simply as the equal treatment of data, regardless of who created it. He explained the dangerous monopolistic practices that Internet service providers (ISPs) could engage in if the way information is transmitted, consumed, and stored on a massive scale is not correctly protected. For instance, he pointed out the dangerous precedent that could be set by ISPs like Comcast charging streaming services like Netflix more money for higher bandwidth speeds--a fast lane, so to speak. He warned that this kind of control over information transmission speed would lead to an uneven playing field, allowing "big companies to buy their way into the fast lane, leaving everyone else in the slow lane" and preventing start-ups from supplanting established brands (2014). Oliver maintained: if ISPs could control the speed of information's flow and charge higher prices for higher speeds, that kind of ownership would create barriers to entry--by making large businesses the only ones who could afford to provide reasonable speeds for their services--into what was supposed to be our great democratizing force: the Internet.

So many users responded to Oliver's call to leave comments on the FCC's website that the Commission's site crashed. Too, President Obama (2014) has responded to this outrage and issued a statement urging the FCC to protect net neutrality:

> An open Internet is essential to the American economy, and increasingly to our very way of life. By lowering the cost of launching a new idea, igniting new political movements, and bringing communities closer together, it has been one of the most significant democratizing influences the world has ever known.
>
> “Net neutrality” has been built into the fabric of the Internet since its creation--but it is also a principle that we cannot take for granted. We cannot allow Internet service providers (ISPs) to restrict the best access or to pick winners and losers in the online marketplace for services and ideas. That is why today, I am asking the Federal Communications Commission (FCC) to answer the call of almost 4 million public comments, and implement the strongest possible rules to protect net neutrality. (2014)

His statement urges the FCC to classify the Internet as a utility and to prohibit ISPs from blocking access or slowing down or speeding up access--especially warning against granting higher speeds to higher paying users--and calls too for increased transparency on the part of ISPs. He even acknowledged the issue's importance in the most recent State of the Union Address, saying, "I intend to protect a free and open Internet, extend its reach to every classroom, and every community, and help folks build the fastest networks so that the next generation of digital innovators and entrepreneurs have the platform to keep reshaping our world" (Obama, 2015).

The outrage, the reaction, the plan--these are all great, heartwarming things--but the increasingly apparent problem, I argue, is that our technological design likely dictated this inevitable monopoly over information and that we need to focus on a design that does not encourage this monopoly. The FCC's legislation has met opposition from both Republicans, who are drafting legislation to curb the FCC's regulations, and telecommunications companies, who have formed trade groups and filed lawsuits against the FCC (Bautista, 2015; Risen, 2015). What needs to happen, in addition to this legislation, is an overhaul of our problematic mass communication technology design. Google's current search algorithm is an example of this problematic design.

In *The Filter Bubble* Pariser (2011) discussed the effect the change in Google's algorithm had on mass information consumption as a whole. In December 2009 Google changed the algorithm it used to generate results for users (Pariser, 2011, p. 2). Pariser explained that as of December 2009, Google began to offer personalized search results based on 57 signals such as the user's search history, location, and browser choice rather than show every user the same standard results based on the Page Rank algorithm, which bases search results off of other pages' links to those results (p. 2). To examine the applied consequences of this change, Pariser had two friends Google "BP" in spring 2010, during the oil spill in the Gulf of Mexico (p. 2). His friends got radically different results, one receiving investment information and the other receiving news (p. 2). Too, and more startling on face value, one friend got 180 million results, while the other only got 139 million (p. 2). That's more than just prioritizing information; that's 41 million results just disintegrated, lost into the Void--because an algorithm decided that they weren't important to that user. This is where Pariser points out the flaw in the design, calling your computer monitor in this system "a kind of one-way mirror, reflecting your own interests while algorithmic observers watch what you click" (2011, p. 3). He calls this idea "the filter bubble" (2011, p. 9).

He argues that this design creates "a unique universe of information for each of us . . . which fundamentally alters the way we encounter ideas and information," and that this growing design-level personalization directly affects users' transmission, consumption, and storage of information--that it facilitates an isolating, oppressive experience that discourages experiencing new ideas and opinions, upsetting our "cognitive balance between strengthening our existing ideas and acquiring new ones" by surrounding us with "ideas with which we're already familiar (and already agree) making us overconfident in our mental frameworks" and by removing "from our environment some of the key prompts that make us want to learn" (Pariser, 2011, p. 9-10, 84).

This is just one example of design--one algorithm--dictating unhealthy transmission, consumption, and storage of information on a massive scale. So rather than simply passing reactionary laws that reign in the consequences of our technology's design, we need to give prior attention to a design that will yield information transmission, consumption, and storage that does not need such regulation. That is this paper's purpose and place--at the intersection of computer science and mass communication, arguing for mass communication technology design that will improve our transmission, consumption, and storage of information.

No system transmits, consumes, and stores information better, more accurately, more fairly than nature. Furthermore, there is a strong link between our information systems and nature's flow of information that is growingly impossible to ignore. It is my argument, then, that we should turn here, to nature's information system--to biology--for guidance on how to design ours.

Aside from the study given to the almost physical nature of information as a link between technology and biology, there is a field--biomimetics--that explicitly theorizes that we can imitate nature to most efficiently solve design problems and catalyze technological innovations. In this paper I ultimately argue for biomimetic design in our information technologies as the fix to our information transmission, consumption, and storage related design problems.

To make the argument that biomimetic design, a design based on nature, could be the answer when designing systems for the transmission, consumption, and storage of information, first I explore the study of information as a link between nature and technology. Then I review the study of biomimetic design--both the purported elements of nature we should emulate according to these theorists and examples of successful biomimetic designs.

Then, I test the effectiveness of one specific biomimetic design--a classifier algorithm called an artificial neural network--compared to four non-biomimetically designed classifier algorithms called support vector machine, nearest neighbour, decision tree, and random forest classifiers. Though artificial neural networks are not a brand-new concept in computer science, the application of their use as an argument for biomimetic design is, and the argument for their use in mass communication technology especially is.

Finally, I present the results of that test together with the results of a series of interviews with interface-level designers regarding their thoughts on their own design strategies, generally accepted design strategies in the field of mass communication technology design, new design strategies, and the state of the field in general; and I make the argument that the placement of biomimetic design principles at the systemic level would enhance the user-interface design practices already in place, given the practices' congruency with biomimetic design principles suggested by the interview responses, thus improving usability, interactivity, and security of mass communication technology, and improving our consumption, storage, and transmission of information on a massive scale.

2. LITERATURE

The first section of this chapter explains the connection between technology and nature in terms of code. The second surveys and analyzes the literature on biomimicry. The third presents the principles of biomimetic design applied specifically to technological design.

Code

The idea that technology and nature are not separate is making its way from the aether and into the concrete, and the link between the two is the transmission, consumption, and storage of information--or, *code*.

Gleick (2011), in an excerpt--published by the New York Times--of his book *The Information*, described the path our concept of "information" took to get to where it is now. In particular, the excerpt discusses one huge milestone in that path--of the work of information-theory pioneer Claude Shannon. As Shannon (1948) developed a mathematical theory of communication, he also developed a unit for measuring the information transmitted during communication. In his paper, Shannon said:

> The choice of a logarithmic base corresponds to the choice of a unit for measuring information. If the base 2 is used the resulting units may be called binary digits, or more briefly bits, a word suggested by J. W. Tukey. A device with two stable positions, such as a relay or a flip-flop circuit, can store one bit of information. (1948, p. 379).

More than discussing Shannon's work, Gleick (2011) discussed the history of information-theory's development. On that development, he said that "Every new medium transforms the nature of human thought. In the long run, history is the story of information becoming aware of itself" (2011).

Wright (2007) too discussed in his book *Glut* the way in which information has both itself evolved and been connected to biological evolution--specifically, the ways in which information travels through different kinds of hierarchies and networks. He discussed the idea that the structured relationship of networks and hierarchies that "not only coexist but are continuously giving rise to each other" we observe on the Internet may closely resemble the structured relationship of networks and hierarchies "woven into the fabric of life itself" (2007, p. 8-11). This interaction between networks and hierarchies observed on the Internet--when made analogous to the interaction of networks and hierarchies observed in biological tribes like "an insect colony, a flock of birds or a school of fish"--carries important implications for the idea of a biological machine: that this machine could be our step toward synthesis, evolution, the quantum, the singularity, the edge--our step toward becoming a "biological superorganism" pooling its information to be preserved and passed for eternity (2007, p. 12).

> A biological superorganism . . . is both a network and a hierarchy; it emerges from the networked interaction of individual organisms, in turn giving rise to higher-order hierarchies. As individual organisms transmit information to each other, they strengthen the bonds that unite the group. But what, exactly, is being transmitted? Information is, after all, noncorporeal; it is not a physical 'thing' (even though it may take expression in the physical environment). Yet there is no question that animals are transmitting some kind of 'thing' to each other. So what exactly is it? (2007, p. 12)

So--return for a moment to *The Information*: one of the most important elements of Shannon's work that Gleick (2011) discussed is the notion that

Shannon's bit--the unit with which we measure information--is not some abstract *kind-of* that floats around in the Void, but rather is "measurable and quantifiable." This is the notion that information is the same as physics--that these communication technologies facilitate the passage of something real through them, that these systems have entropy--measures of chaos and order, same as the world around us. "We can see now that information is what our world runs on: the blood and the fuel, the vital principle," Gleick said (2011). He continued--

> It pervades the sciences from top to bottom, transforming every branch of knowledge . . . Now even biology has become an information science, a subject of messages, instructions, and code. Genes encapsulate information and enable procedures for reading it in and writing it out. Life spreads by networking. The body itself is an information processor. Memory resides not just in brains but in every cell. No wonder genetics bloomed along with information theory. DNA is the quintessential information molecule, the most advanced message processor at the cellular level--an alphabet and a code, 6 billion bits to form a human being . . . The cells of an organism are nodes in a richly interwoven communications network, transmitting and receiving, coding and decoding. Evolution itself embodies an ongoing exchange of information between organism and environment. (2011)

The large point to understand is--yes, that information and biology have a connection--but also that it is a very specific kind of connection, that specific kinds of codes and code-behaviors are observed in nature. "The bit is a fundamental particle of a different sort," Gleick explained (2011). "A binary digit, a flip-flop, a yes-or-no. It is insubstantial, yet as scientists finally come to understand information, they wonder whether it may be primary: more fundamental than matter itself" (2011). And those scientists observing this connection are realizing something: "The whole universe is . . . seen as a computer--a cosmic information-processing machine" (Gleick, 2011).

One of the most prevalent--and downright brilliant--of these scientists is Sylvester James Gates. During a physics debate on the elusive "theory of everything" hosted by Neil deGrasse Tyson at the American Museum of Natural History, Gates discussed the code that Claude Shannon developed and its startlingly direct connection to our universe. The following is an exchange between Gates and Tyson from that debate:

> Gates: What I've come to understand is that there are these incredible pictures that contain all the information of a set of equations that are related to string theory. And it's even more bizarre than that because when you then try to understand these pictures you find out that buried in them are computer codes just like the type that you find in a browser when you go surf the web. And so I'm left with the puzzle of trying to figure out whether I live in the Matrix or not.
>
> Tyson: Are you saying your attempt to understand the fundamental operations of nature leads you to a set of equations that are indistinguishable from the set of equations that drive search engines and browsers on our computers?
>
> Gates: That is correct.
>
> Tyson: So you're saying as you dig deeper, you find computer code writ in the fabric of the cosmos?
>
> Gates: Into the equations that we want to use to describe the cosmos, yes.
>
> Tyson: Computer code?
>
> Gates: Computer code. Strings of bits of ones and zeros.
>
> Tyson: It's not just sort of resembles computer code--you're saying it is computer code.
>
> Gates: Not even just is computer code. It's a special kind of computer code that was invented by a scientist named Claude Shannon in the 1940s. That's what we find buried very deeply inside the equations that occur in string theory and, in general, in systems we say are supersymmetric. (Tyson et al., 2011)

The pictures to which Gates referred are called *adinkras*. In Gates's (2010) article "Symbols of Power," he explained this use of adinkras (visual representations of "precise mathematical [descriptions] of calculations") in the use of explaining supersymmetrical equations (p. 36-37). In his work constructing and using adinkras for that purpose, though, he stumbled into the realm of computer science and made some interesting observations. In his article, he briefly discussed the concept of entropy--

> Modern computer and communication technologies have come to prominence by transmitting data rapidly and accurately. These data consist principally of strings of ones and zeros (called bits) written in long sequences called "words". When these computer words are transmitted from a source to a receiver, there is always the chance that static noise in the system can alter the content of any word. Hence, the transmitted word might arrive at the receiver as pure gibberish. (2010, p. 38)

--before discussing a type of "error-correcting" code (the "Hamming code") developed by Richard Hamming (1950). Gates (2010) explained that the code tells "the sending computer to insert extra bits into words in a specific manner such that the receiving computer could, by looking at the extra bits, detect and correct errors introduced by the transmission process" (p. 38). Gates found that maintaining the supersymmetrical properties in adinkra construction required a particular sequence of bits--that matched this error-correcting code--be used in their construction process. He makes the following observation:

> The part of science that deals with the transmission of data is called information theory. For the most part, this is a science that has largely developed in ways that are unrelated to the fields used in theoretical physics. However, with the observation that structures from information theory--codes--control the structure of equations with the SUSY property, we may be crossing a barrier. I know of no other example of this particular intermingling occurring at such a deep level. Could it be that codes, in

> some deep and fundamental way, control the structure of our reality? (2010, p. 39)

And before leaving the reader with a startling meditation--

> The path my colleagues and I have trod since the early 2000s has led me to conclude that codes play a previously unsuspected role in equations that possess the property of supersymmetry. This unsuspected connection suggests that these codes may be ubiquitous in nature, and could even be embedded in the essence of reality. If this is the case, we might have something in common with the Matrix science-fiction films, which depict a world where everything human beings experience is the product of a virtual-reality-generating computer network. (2010, p. 39)

--he cited John Archibald Wheeler's (1999) notion of "it from bit," the idea that every element of the universe is driven by and exists because of coded, binary, yes-no, on-off questions--bits.

> It from bit. Otherwise put, every "it"--every particle, every field of force, even the space-time continuum itself--derives its function, its meaning, its very existence entirely--even if in some contexts indirectly--from the apparatus-elicited answers to yes-or-no questions, binary choices, bits. "It from bit" symbolizes the idea that every item of the physical world has at bottom--a very deep bottom, in most instances--an immaterial source and explanation; that which we call reality arises in the last analysis from the posing of yes-or-no questions and the registering of equipment-evoked responses; in short, that all things physical are information-theoretic in origin and that this is a participatory universe. (1999, p. 310-311)

Gates (2010) did, however, aim to make it clear--in both his article and the video of the panel--that just because mathematical descriptions exist across systems does not mean the systems are connected in some kind of physical way, but does mean that computer code is present in the mathematical equations we believe to be accurate descriptions of our universe. But whether these concepts best work as descriptors or attributes or realities, the point is that there has been recognition of a connection between natural functions and technological functions.

Biomimetic Design

In addition to those who observe this connection between code and reality, there are also those who suggest that we embrace that connection--that we apply it and model our systems after biological functions. This section discusses the history and general principles of biomimetic design and some of the successful designs inspired by the theory. The next section of this review applies biomimetic design specifically to computer science.

Though the field of biomimetics has in theory been around for much longer--we can look to innovations ranging from Da Vinci's drawings for a flying machine inspired by the flight abilities of bats and birds through Paul Sperry's creating the carved grooves in the soles of his boat shoes to mimic the ease with which the grooves of his dog's paws gripped icy surfaces--it has more recently become popular largely due to Janine Benyus's 1997 book, *Biomimicry: Innovation Inspired by Nature*, as well as her lectures (Flying machine, n.d.; Our story, n.d.).

Benyus (1997) defined biomimicry as "a new science that studies nature's models and then imitates or takes inspiration from these designs and processes them to solve human problems" as well as "the conscious emulation of life's genius. Innovation inspired by nature" (p. viii, 2). Her basic premise is that in the time the Earth has taken to develop--3.8 billion years--it's created efficient design solutions for just about any kind of problem humans can come up with (Hargroves & Smith, 2006, p. 27). According to Benyus, "Nature knows what works, what is appropriate, and what lasts here on Earth" (Hargroves & Smith, 2006, p. 27). She argues for nine basic principles of biomimetic design:

1. Nature runs on sunlight
2. Nature uses only the energy it needs
3. Nature fits form to function
4. Nature recycles everything
5. Nature rewards cooperation
6. Nature banks on diversity
7. Nature demands local expertise
8. Nature curbs excesses from within
9. Nature taps the power of limits. (Hargroves & Smith, 2006, p. 27)

Essentially, the idea is to look to nature when there is a problem with efficiency or design because nature doesn't design anything superfluous--it designs things to work, and specifically to learn, adapt, and work with whatever is available. With these basic tenets, Benyus has co-founded a consulting firm, the Biomimicry Guild, which "has assisted the engineering, architectural and scientific professions as well as major international corporations . . . to learn from nature's designs" (Hargroves & Smith, 2006, p. 27). When developers in these fields have design problems and approach Benyus for a possible solution, her firm flips through nature's large design rolodex to find a biological model that may be of assistance and often takes the developers into the field to observe the natural function firsthand (Benyus, 2005).

In her lectures and writings, she cites many examples of innovations coming from biomimetic design strategies. For example, she mentioned J.R. West modeling the nose of their bullet trains after the beaks of king fisher birds to eliminate the pressure build and sonic boom created when the train entered and exited tunnels (Benyus, 2009). Because of this innovation, the train also ran "10 percent faster on 15 percent less electricity" (2009). Additionally, she noted a company--Sharklet Technologies--that modeled bacteria-resistant surfaces to decrease infections in hospitals after the skin of the Galapagos shark, the patterned texture of which prevents bacteria from landing.

In addition to Benyus's work on biomimcry, there are others that have argued for, either explicitly or not, adopting general principles of biology in design. Dayna Baumeister's work, for instance, is largely considered part of the field's core canon. Baumeister's (2014) text defines biomimicry as "the conscious emulation of life's genius" (p. 11). She suggests that successful biomimetic design mimics natural functions on three levels: natural form, natural process, and natural ecosystem--meaning that it's not enough to simply mimic a biological shape, but one must also take into account the way those shapes form and the way they fit into a natural system (p. 11-12). She explains:

> A well-adapted biological strategy must meet the functional needs of the organism in the context in which it lives in order to contribute to its survival . . . A well-adapted design must meet the functional needs of the design challenge in the context in which it must exist in order to contribute to its success (2014, p. 98).

She uses six principles, which she calls "life's principles," that are not dissimilar from Benyus's nine (Baumeister, 2014, p. 19). Baumeister's principles--with their descriptions--are:

EVOLVE TO SURVIVE
- -replicate strategies that work
- -integrate the unexpected
- -reshuffle information

ADAPT TO CHANGING CONDITIONS
- -incorporate diversity
- -maintain integrity through self-renewal

-embody resilience through variation, redundancy, and decentralization

BE LOCALLY ATTUNED AND RESPONSIVE
- -leverage cyclic processes
- -use readily available materials and energy
- -use feedback loops
- -cultivate cooperative relationships

INTEGRATE DEVELOPMENT WITH GROWTH
- -self-organize
- -build from the bottom-up
- -combine modular and nested components

BE RESOURCE EFFICIENT (MATERIAL AND ENERGY)
- -use low-energy processes
- -use multi-functional design
- -recycle all materials
- -fit form to function

USE LIFE-FRIENDLY CHEMISTRY
- -break down products into benign constituents
- -build selectively with a small subset of elements
- -do chemistry in water (2014, p. 23)

In *The Shark's Paintbrush* Jay Harman (2013) defines biomimicry as "applying lessons learned from nature to solve human problems" and calls nature "the best source of answers to the technological, biological, and design challenges that we face as humans" (p. 2-3). On the biomimetic process, he says:

> The first step . . . is to clearly define the challenge we're trying to solve. Then we can determine whether the problem is related to form, function, or ecosystem. Next, we ask what plant, animal, or natural process solves a similar problem most effectively (2013, p. 7).

This process is similar to the three levels described in Baumeister's (2014) text. But perhaps my favorite biomimetic success story came from Harman's text. Harman (2013) met a mycologist named Paul Stamets, whose "talk on the six ways that mushrooms can save the world has been voted 'best TED talk of all time' by the online community" (p. 165). In his research, Stamets has used mushrooms to combat things like pollution and viruses quite effectively. The most interesting thing he's done with them in my opinion, though, is to mimic their networking capabilities to improve a Japanese transportation system.

> In experiments at Hokkadia University in Sapporo, Japan, mycelium was allowed to grow on a map of Tokyo, with tempting oat flakes representing thirty-six nearby cities. To get to the oat flakes, the fungus worked out more efficient pathways than the current Tokyo railway system reaching its suburb cities. (Harman, 2013, p. 169)

Harman (2013) says this "strategy could be adapted to improve everything from road planning to more efficient computer communications," the latter of which is revisited in the next section of this chapter (p. 169).

There are similar processes and principles to Benyus's, Baumeister's, and Harman's being described in works by researchers not dedicated specifically to biomimicry. In *Leading from the Emerging Future*, Scharmer and Kaufer (2013) used biomimetic language to call for a complete restructuring of our current system: "a shift from an *ego*-system awareness that cares about the well-being of oneself to an *eco*-system awareness that cares about the well-being of all, including oneself" (p. 2). In proposing this shift, the text explicitly argued for replicating biology in our technologies. Scharmer and Kaufer summarized a few basic ways that a system would act if designed biomimetically:

> a. *Zero waste*. Nature is designed as a zero-waste system. Every output is someone else's input. There is no such thing as waste in nature. By contrast, the human economy is full of waste: waste that is produced while sourcing from nature. Only tiny fractions of our waste are being cycled back into a closed-loop system of reuse."

> b. *Solar Energy*. Nature operates on 100 percent renewable energy. Cells, like the human economy, need an external source of energy. But unlike the human economy, which has located those sources predominantly in fossil fuels, cells turn to sunlight as their sustainable source of energy.
>
> c. *Diversity and symbiosis*. All eco-systems are based on the principles of diversity and symbiosis: different species working together in symbiotic and harmonious ways. By contrast, industrial production promotes monocultures and single-variable maximization that reduce resilience and make the system vulnerable to disruption. (2013, p.81)

Importantly, the authors argued that these systems are not just more efficient but are also healthier and more resilient if constructed with a natural, biological design.

Jenkins, Ford, and Green (2013)--despite noting distaste for biological terminology used to describe media-related interface behaviors--too seemed to champion biological features--specifically of media--as proper design. The first instance of this in their text *Spreadable Media* is their discussion of marble vs. stone. They discussed the two media mostly in terms of their effect on power. For instance, they said that stone leads to "top-down control over what information is preserved" and that the shift to papyrus resulted "in more decentralized communication" (2013, p. 37-38). They also said--on monopoly over information--that "shifts in the technological infrastructure have the potential to construct or undermine 'monopolies of knowledge' closely associated with other sources of institutional power" (2013, p. 38). This, of course, is of interest--the consequence of design--but of primary interest are the seemingly biological characteristics of Jenkins, Ford, and Green's suggested design for optimization of spreadable media:

> -*Available when and where audiences want it*: Producers, whether professional or amateur, need to move beyond an 'if you build it, they will come' mentality, taking (or sending) material to where audiences will find it most useful.
>
> -*Portable*: Audience members do not want to be stuck in one place; they want their media texts "on the go." Content has to be quotable (editable by the audience) and grabbable (easily picked up and inserted elsewhere by the audience). Audiences will often abandon material if sharing proves too onerous.
>
> -*Easily reusable in a variety of ways*: Media producers and media audiences circulate content for very different reasons, actually for very many different reasons. Creating media texts that are open to a variety of audience uses is crucial for creating material that spreads.
>
> -*Relevant to multiple audiences*: Content that appeals to more than one target audience, both intended and surplus audiences, has greater meaning as spreadable media.
>
> -*Part of a steady stream of material*: The "viral" mentality leads brands to invest all their energy in a particular media text that is expected to generate exponential hits. Blogging and microblogging platforms emphasize the importance of a regular stream of material, some of which may resonate more than others in ways creators may not always be able to predict. (2013, p. 197-198)

Though not explicitly stated, these qualities--just like the qualities of papyrus (malleability, portability, accessibility) they championed over stone's--are all qualities that emulate biological functions, and many sound similar to Scharmer and Kaufer's (2013). For instance, on their description of "availability"--it sounds like a body assigning everything that comes into it to its right place. It does not build for no reason. Rather, a biological system assigns--functionally. On "portability"--a biological system is never rigid. It is always adaptable and ready to incorporate disruptions and movements. Too, the idea of media being "reusable in a variety of ways," is similar to the idea that biology does not waste and that biological systems facilitate their symbiosis with life's forms. Similarly, the notion that the media should be "relevant to multiple audiences" is close to the idea that a biological system encourages that symbiosis with a variety of life's forms. Finally, though their description of "part of a steady stream of material" rejects a viral mentality, it goes on to describe that viral mentality in very unbiological terms (investment of all funds into one text, for instance), and it describes the desirable alternative (blogging and microblogging) in terms of a steady stream of material. This is a biological notion touched upon previously in this paper even--the pure flow of life's information, and its status as a desirable undercurrent.

Biomimetic Machines

There are researchers and designers practically applying elements of biology's design specifically to design in the world of computer science. These are the changes, I argue, that can have a positive effect on our mass communication technology and our transmission, consumption, and storage of information on a massive scale if adopted into our design on a systemic level.

One large area of study is the application of insect behavior to algorithm design--particularly the idea of swarm intelligence. Applying the "self-organized behavior of some biological systems, such as ant colonies or animal herds, with collective properties that are not easily identifiable from the dynamical features of single elements alone . . . has led to the development of many tools, such as swarm robotics, and algorithms" (Pershin & Di Ventra, 2014).

> In fact, a prototypical example of swarm intelligence algorithms is the ant colony optimization algorithm proposed by Dorigo *et al*. in 1991. This

> algorithm is useful for a variety of computational problems, which can be reduced to finding optimal paths through graphs, whether directed or not. Specific examples of such problems include the shortest path, traveling salesmen problem, etc. (Pershin & Di Ventra, 2014)

Of popularity equal to or greater than the ant in the world of swarm intelligence, it seems, is the honeybee. Karaboga & Akay (2009) surveyed the literature regarding the algorithms being developed around bee swarm intelligence and found that algorithms for many computational tasks were being optimized by modeling them after bees' foraging habits, dances, hierarchies, task selections, flight patterns, and many more behaviors. Nakrani & Tovey (2007), for instance, looked to honeybees to solve the design problem of Internet server infrastructure and unpredictable Internet request traffic and developed a "biomimetic server orchestration algorithm" inspired by the "remarkable resemblance between the honeybee colony's problem of allocating foragers amongst flower patches to maximize nectar influx and the host center's problem of allocating servers amongst host customers to maximize revenue" (p. 182).

Algorithms based on swarm patterns are not the only examples of this application of biomimetic design to computer science, and to be clear--in the cases of these insects, it is not likely purported by biomimetic design that these information storage and transmission processes are made more efficient by the large amount of organisms working on it, but rather the idea that the smaller organisms act as one big organism, the key biological function being not "everybody work together," but rather this notion of effective networks and connections among nodes that exist in natural functions. Harman (2013) noted this idea in his conversations with mycologist Paul Stamets (responsible for the previously mentioned mushroom/railroad test), stating that the "neural pathways of the human brain--and the Internet--follow a very similar construction as mycelium" (p. 168). "Paul is certain that artificial intelligence of the future can be self-educating and mimic the natural networks of fungus" (2013, p. 169). Stamets (2008) himself explains:

> I first proposed, in the early 1990s, that mycelium is Earth's natural Internet. When you look at the mycelium, they're highly branched. And if there's one branch that is broken, then very quickly, because of the nodes of crossing--Internet engineers maybe call them hot points--there are alternative pathways for channeling nutrients and information. The mycelium is sentient. It knows that you are there. When you walk across landscapes, it leaps up in the aftermath of your footsteps trying to grab debris. So, I believe the invention of the computer Internet is an inevitable consequence of a previously proven, biologically successful model. The Earth invented the computer Internet for its own benefit, and we now, being the top organism on this planet, are trying to allocate resources in order to protect the biosphere.

A self-described "shameless technophile when it comes to computers," Benyus (1997) has not overlooked computer science, stating that "even computing would take its cue from nature, with software that 'evolves' solutions, and hardware that uses the lock-and-key paradigm to compute by touch" (p. 3, 188). She also noted that that field has already "learned an enormous amount from living things, on the software side. So there's computers that protect themselves, like an immune system, and we're learning from gene regulation and biological development. And we're learning from neural nets, genetic algorithms, evolutionary computing" (Benyus, 2005).

Benyus (1997) pursued biomimetic application to computer science by seeking out Michael Conrad, head of the BioComputing Group (p. 188).

> Abandoning zeros and ones, Conrad is pursuing a totally new form of computing inspired by the lock-and-key interactions of proteins called enzymes. It's called jigsaw computing, and it uses shape and touch to literally 'feel' its way to a solution (1997, p. 187).

She explained that in the 1970s Conrad became interested in creating a new computing platform, and his goal was to create one that could evolve (p. 202). His idea came from the realization that biological systems work with shapes rather than lines--that because "molecules have a specific shape that can feel for other shapes, they are the ultimate pattern recognizers" (1997, p. 203). Conrad wondered about "processors full of molecules that recognized patterns through shape-fitting--lining up like corresponding pieces of a puzzle and then falling together, crystallizing an answer" (1997, p. 203). A key idea of Conrad's speculation that Benyus presented was the idea of self-assembly. He said to Benyus:

> Instead of being controlled from the outside, by us, each processor will mold itself to the task at hand, while together, several processors will sharpen their ability to work as a team. They will actually evolve through a process of variation and selection toward an optimal peak, the best possible system for the conditions at hand. (1997, p. 208)

But most importantly, in her meetings with Conrad, she identified several ways in which computers are not yet functioning with the same prowess as the brain. On the brain's computational ability, she said:

> If you want better computers, better stay to the brain side of the chart. First, design processors that are powerful in their own right. Fashion them in nature's image by using a material that's amenable to evolution, embedded in a system with a lot of springs. Then, when you challenge your computer with a difficult problem, it'll hitch all its horses to the problem. Efficiency will soar. And when conditions change, and it needs to switch horses, it can adapt. (1997, p. 202)

The first of eight distinctions she noted between the computer and the brain was that "Brained beings can walk and chew gum and learn at the same time; silicon digital computers can't" (Benyus, 1997, p. 189). "We perceive situations," she explained; "we recognize patterns quickly, and we learn, in real time, via hundreds of thousands of processors (neurons) working in parallel; computers don't" (1997, p. 190). She explained that simple tasks for us, such as scanning a room full of faces and categorizing those you know and where you know them from, are easy for us because of our interconnected "processors," but that computers are not yet able to process in parallel or even "guess" at faces--they simply have binary yes-or-no answers--and the "already blinding speed of modern processors can't touch the task" (1997, p. 190).

The second distinction between computers and brains she noted was that brains "are unpredictable, but conventional computing is obsessed with control" (Benyus, 1997, p. 191). Though she said doing so may cause unpredictable and somewhat uncontrolled interactions between programs, shortening "electrons' commuting time by shrinking switches and packing them closer together" or having "thousands of processors working in parallel" would yield faster, more powerful computers--that this diversity is what would allow the systems to adapt and learn more closely to the way we do (1997, p. 191).

The third distinction was that brains "are not structurally programmable the way computers are" (Benyus, 1997, p. 192).

> When we want to learn something, we don't read a book that tells us how to change our brain chemistry to remember a blues riff or the date of Delaware's statehood. We take on information, and our neuronial net is free to structurally store the data *on its own*, using whatever mechanical

> and quantum forces it can muster. Neuron connections are strengthened, axons grow dendrites, chemicals move in mysterious ways. (1997, p. 192)

The fourth distinction was that brains "compute physically, not logically or symbolically" (Benyus, 1997, p. 192). Benyus said that "nature computes with submicroscopic molecules that jigsaw together, literally falling to a solution" and that the "driving force at this scale is . . . the push and pull of thermodynamic forces," echoing the entropy discussed so frequently in information theory--and that though a molecule "can be bent or flattened, it'll always spring back to shape" (1997, p. 192-193). On this concept, Michael Conrad said to Benyus that the "'most important conceptual journey for [him] was to go inside the neuron and slosh around at the chemical level,'" where, he said, "'three-dimensional molecules are computing by touch'" (1997, p. 195).

The fifth distinction was that brains "are made of carbon, not silicon" (Benyus, 1997, p. 195). Conrad also told Benyus that he thought physical computing would have to try materials other than silicon--like carbon (p. 195). "Matter matters," Benyus said (1997, p. 195). "And so, it seems, does the connectedness of this matter" (1997, p. 195).

The sixth distinction was that brains "compute in massive parallel; computers use linear processing" (Benyus, 1997, p. 196).

> Thoughts arise from a meshwork of nodes (neurons connected in democratic parallelism--thousands attached to thousands attached to thousands of neurons--all of which can be harnessed to solve a problem in parallel.
>
> Computers, on the other hand, are *linear* processors; computing tasks are broken down into easily executed pieces, which queue up in an orderly fashion to be processed one at a time. All calculations have to funnel through this so-called "von Neumann bottleneck." Seers in the computing

> field bemoan the inefficiency of this setup; no matter how many fancy components you have under the hood, most of them are dormant at any given time. As Conrad says, "It's like having your toe be alive one minute, and then your forehead, and then your thumb. That's no way to run a body or a computer."
>
> Linear processing also makes our computers vulnerable. If something blocks the bottleneck, that dreaded smoking bomb appears on the screen. The redundancy of net-hood, on the other hand, makes the brain unflappable--a few brain cells dying here and there won't sink the whole system (good news to those who survived the sixties). A net is also able to accommodate newcomers--when a new neuron or connection comes on line, its interaction with other neurons makes the whole stronger. Thanks to this flexibility, a brain can learn. (1997, p. 196)

Computer scientists have created algorithms called neural nets to mimic these parallel functions. Benyus explained that neural nets are programs "that run on top of old-fashioned linear hardware" to "create a virtual meshwork composed of input neurons, output neurons, and a level of hidden neurons in between, all copiously connected the way a brain might be" (1997, p. 196). She said that neural nets "digest vast amounts of historical data, then seek relationships between that data and actual outcomes" (1997, p. 196).

Some practical applications of neural nets she noted were: a campaign headquarters feeding a neural net years' worth of polling and demographic data to predict the next winner of the New Hampshire primary, or a soda manufacturer feeding it monthly temperatures, demographics, and advertising budget allocation to predict its sales in a particular town (Benyus, 1997, p. 197). At first, the neural net "ventures a wild guess," but as the correct data is fed to the neural net, it "adjusts its connections and guesses again," repeating the process until it can make correct guesses and predictions (1997, p. 197). And the neural nets do this very quickly and accurately. "The reason nets learn so quickly is that connections between inputs can be weighted, as in, this input is more important than that input, so this connection should be strengthened," much like the way our brain's networks behave (1997, p. 197). While these neural nets are quite powerful, the important next step that Benyus noted is the step that I am arguing for with this paper in its entirety--the "next step, of course, is to build net-hood right into the hardware" (1997, p. 198). Though computer scientists have been experimenting with these neural net algorithms with great result, there has been little adoption of their biomimetic properties at a systemic level into our technology design. That is the change I am arguing for.

The seventh distinction was that neurons "are sophisticated computers, not simple switches" (Benyus, 1997, p. 198). Conrad called the neuron a "full-fledged chemical computer, processing information at a molecular level" (1997, p. 198). Benyus said that

> Thinking is not the yes-or-no, fire-or-not-fire proposition that it was once believed to be . . . [there's] a cast of thousands in there, weighing and considering inputs, using quantum physics to scan other molecules, transducing signals and amplifying messages, and after all that computation, sending signals of their own. In silicon computing, we completely ignore this complexity, replacing neurons with simple on-or-off switches. (1997, p. 199-200)

Conrad said that what he wants to do is "'replace a whole network of digital switches with *one* neuronlike processor that will do everything the network does and more" and then "to connect lots of these neuronlike processors together'" (Benyus, 1997, p. 200).

Finally, the eighth distinction was that brains "are equipped to evolve by using side effects. Computers must freeze out all side effects" (Benyus, 1997, p.

200). Benyus and Conrad explained that nature builds redundancy into itself to accommodate mutations and side-effects--that the "ability to ride that riot of forceeable and unforseeable forces has allowed nature to exploit myriad effects, becoming more efficient and better equipped all the time," but that "computers can't tolerate so much as a comma out of place in their codes," that if "you add a random line of code to a program, for instance, it's not called a new possibility--it's called a bug" (1997, p. 201). In this way, Benyus said that computers can't evolve or adapt the way life does (p. 201).

> What would be a nightmare to computer engineers--quantumly small computing elements, connected catawampus in dizzying parallelism, randomly interacting and coloring outside the lines--is what gives life its unswerving advantage. (1997, p. 201)

In short, Benyus argued that because of these distinctions, "we have a machine that is thoroughly dead--inefficient, inflexible, and doomed by the limits of Newtonian physics" (1997, p. 201-202). These distinctions have not gone totally unnoticed by computer scientists. In several of the distinctions Benyus made, she made reference to neurons working in parallel. And one of the best examples of biomimetic design's success in computer science is the artificial neural network Benyus explained--a classifier algorithm designed to mimic the brain in that the algorithm is "composed of interconnected and interacting components called nodes or neurons" (Leverington, 2009). "Individual nodes in a neural network emulate biological neurons by taking input data and performing simple operations on the data, selectively passing the results on to other neurons" (Levington, 2009). In evaluating the strengths and weaknesses, computer scientists have noted the neural net's pattern recognition ability, even in datasets that are incomplete or have large amounts of noise:

> Neural networks have quite a few advantages. If we have a lot of input and output data to learn, but no idea what the function mapping the two together is, the network can learn this function without our having to explicitly provide it. Neural networks are also good with data sets that are noisy or where some inputs have missing variables. ("A gentle introduction," 2012)

Interestingly, too, are the weaknesses of the neural net noted by computer scientists:

> However, neural nets also have a key disadvantage of many other approaches: the answer that emerges from a neural network's weights can be difficult to understand (it may work, but we don't know how), and the network's training can take longer than certain other methods of machine learning. ("A gentle introduction," 2012)

This to me seems indicative of what Benyus mentioned--that system-level designers are reluctant to relinquish the control they'll have to to make machines that can function with the same prowess as nature.

Because the artificial neural network is such a direct and testable example of biomimetic design applied to computer science, this is the design I used to test the big idea--that biomimetic design at a systemic level in mass communication technology could improve our transmission, consumption, and storage of information.

3. METHOD

To test the potential performance of biomimetic design at the systemic level of communication technology design, I had a Ph. D. student in the Computer Science and Engineering department at the University of California, San Diego code and run a test in which machine learning algorithms were tasked with weeding through a dataset of images to, essentially, "learn" what they're looking at and classify it.

Five algorithms--called classifiers--were trained with machine-learning algorithms and then tested and compared in terms of accuracy. Of these classifier algorithms, one was a biomimetically designed artificial neural network. The other four models--support vector machine, nearest neighbour, decision tree, and random forest classifiers--were non-biomimetically designed.

Additionally, I conducted a series of interviews with interface-level designers in an effort to place the result of this classifier test into context and lend credence to speculation about the placement and adoption of biomimetic design principles.

In this chapter, the first section discusses the vocabulary needed to understand the classifier test. The second section discusses the test procedure itself. The third section explains the interview process.

Definitions

A classifier is an algorithm that labels, or classifies, a dataset. Datasets can be images, texts, sounds, etc. The classifier must be trained with labeled samples of the data--a training set--from outside the testing dataset. Then, based on what it has "learned" from this training set, it attempts to classify the dataset it is given.

As previously stated and explained, the biomimetically designed classifier in this test will be an artificial neural network, a classifier designed to mimic the processes of an animal's brain by running neurons in parallel. The non-biomimetic classifiers being tested in comparison to the artificial neural network will be support vector machine (SVM), nearest neighbour (kNN), decision tree, and random forest classifiers. The formal definitions of these algorithms are presented below. Before reading the definitions below, it is important to note that the vectors, or tuples, referred to are simply the collections of features that each of these algorithms takes as input and analyzes in its own way before venturing a guess at what they are attempting to classify.

Neural networks, as previously discussed, are built to mimic the function of the brain by allowing input nodes--or neurons--to take input, weight the data, and selectively pass it to other neurons. They are

> organized in a series of layers . . . where the input vector enters at the left side of the network, which is then projected to a “hidden layer.” Each unit in the hidden layer is a weighted sum of the values in the first layer. This layer then projects to an output layer, which is where the desired answer appears. ("A gentle introduction," 2012)

Support vector machine classifiers, "are based upon the idea of maximizing the margin i.e. maximizing the minimum distance from the separating hyperplane to the nearest example" (Aly, 2005). They use

> a nonlinear mapping to transform the original training data into a higher dimension. Within this new dimension, it searches for the linear optimal

> separating hyperplane. A hyperplane is a “decision boundary” separating the tuples of one class from another. With an appropriate nonlinear mapping to a sufficiently high dimension, data from two classes can always be separated by a hyperplane. The SVM finds this hyperplane using support vectors (“essential” training tuples) and margins (defined by the support vectors). (Entezari-Maleki, Rezaei, & Minaei-Bidgoli, 2009)

Nearest neighbour algorithms "are based on learning by analogy, that is by comparing a given test tuple with training tuples which are similar to it" (Entezari-Maleki, Rezaei, & Minaei-Bidgoli, 2009).

> The training tuples are described by *n* attributes. Each tuple represents a point in an *n*-dimensional space. In this way, all of the training tuples are stored in an *n*-dimensional pattern space. When given an unknown tuple, a *k*-nearest neighbor (k-NN) classifier searches the pattern space for the *k* training tuples which are closest to the unknown tuple. These *k* training tuples are the *k*-nearest neighbors of the unknown tuple. (Entezari-Maleki, Rezaei, & Minaei-Bidgoli, 2009)

A decision-tree classifier is one in which "an input is entered at the top and as it traverses down the tree the data gets bucketed into smaller and smaller sets" (A gentle introduction, 2012). It "is a flowchart-like tree structure, where each internal node denotes a test on an attribute, each branch represents an outcome of the test, and each leaf node (or terminal node) holds a class label. The topmost node in a tree is the root node" (Entezari-Maleki, Rezaei, & Minaei-Bidgoli, 2009). In other words:

> The tree tries to infer a split of the training data based on the values of the available features to produce a good generalization. The split at each node is based on the feature that gives the maximum information gain. Each leaf node corresponds to a class label. A new example is classified by following a path from the root node to a leaf node, where at each node a test is performed on some feature of that example. The leaf node reached is considered the class label for that example. The algorithm can naturally handle binary or multiclass classification problems. The leaf nodes can refer to either of the *K* classes concerned. (Aly, 2005).

A random forest classifier essentially layers multiple decision trees and uses averaging to improve accuracy (Random Forest Classifier, n.d.). Its creator, Leo Breiman (1999) said they "are a combination of tree predictors such that each tree depends on the values of a random vector sampled independently and with the same distribution for all trees in the forest" (p. 5). This is a method called an "ensemble approach," meaning that "a group of 'weak learners' can come together to form a 'strong learner' ("A gentle introduction," 2012). In the case of a random forest classifier, the decision tree acts as a weak learner combining with other decision trees to form the random forest strong learner ("A gentle introduction," 2012). The random forest can be "thought of as a form of nearest neighbor predictor" ("A gentle introduction," 2012).

My operational definitions were simple. For the algorithm in the test to qualify as biomimetic, it must--as discussed in the literature section--be designed to mimic a natural biological function, like the artificial neural network's mimicking the brain's neural architecture and behavior. For the algorithm to qualify as non-biomimetic, it must be the opposite: not designed with these natural functions in mind. To be clear, though the natural images of trees and forests are used in two of the algorithms presented, this nomenclature alone does not qualify their design as biomimetic. Their names derive from an analogous shape noticed after their creation. And recall that Baumeister (2014) noted that mimicking nature's shape is not enough to qualify as biomimetic, but that mimicking nature's function is the main indicator of biomimetic design (p. 11-12).

The performance of these algorithms were measured in terms of accuracy--or, the percentage of incorrect labels the algorithm applies to its testing set, discussed below.

Test

To test these models in comparison to each other, each classifier was trained on the training dataset and then attempted to label the items in the testing set. The dataset used was a set of images. The test was run in iPython notebook (Pérez, 2007).

The image dataset being used was the MNIST dataset of handwritten digits (LeCun, Cortes, & Burges, n.d.). This dataset includes a set of 70,000 images of handwritten numbers. Ten thousand out of the 70,000 images were randomly selected by IPython's built-in testing-set/training-set splitter to be the testing set that the classifier attempted to label, leaving 60,000 images with which to train the classifier algorithm. This ratio of 60,000 training images to 10,000 test images is consistent with the intentions of the dataset's creator. Each classifier algorithm was trained and tested on the same training and testing sets, respectively.

To measure the performance of each algorithm IPython measured the error rates of each algorithm's labeling attempts at various training marks. Each algorithm received part of the training set--6,000 images for instance--and was then tested on the full 10,000 test images. The error rate for that training mark--6,000 images--was noted, and then the algorithm was given more of the training set--for example, 6,000 more images to make the next training mark 12,000 images--and tested on the full 10,000 testing image set again, IPython recording its performance at that mark. Each time an algorithm was tested, it did not "remember" the 10,000 image testing set it had seen--the only learning it did was from the increasing exposure to the training set. In all, each algorithm's error rate was tested and recorded at ten training marks: 6,000 images, 12,000 images, 18,000 images, 24,000 images, 30,000 images, 36,000 images, 42,000 images, 48,000 images, 54,000 images, and 60,000 images.

In short, as the tests were run in IPython, the performance of each algorithm at 10 designated training marks was evaluated in terms of accuracy--essentially how many incorrect labels the classifier applied to its target image set. This measure of accuracy was given as an error percentage at each mark for easy comparison across the five classifiers. IPython itself generated these percentages, as each item in the dataset belongs to a category that the classifier algorithm doesn't "see"--a right answer, so to speak--so that IPython can give the number of correct and incorrect labels in the output form of an error percentage. Thus, each classifier ended up with 10 error percentages for the testing dataset they attempted to label--one for each training mark--which were then compared to each other.

Interviews

To supplement the purely system-level test of the effectiveness of biomimetic design, I also conducted a series of interviews with interface-level designers, the results of which I interpreted qualitatively using a method of thematic analysis similar to the approach described by Braun and Clarke (2006). I use the term interface-level designer to distinguish the designers I interviewed--who work in the realm of graphic design, web design, and interactivity--from those who work building technological systems or hardware at the system level.

I emailed eight interface-level designers inquiring about an interview, and six responded with interest in participating. I scheduled in-person meetings with five of those designers and a phone interview with one of them. Thus, a total of six interviewees participated. Each participant was an interface-level designer working in the Baton Rouge area for either an agency, a university or both. I asked them variants of nine interview questions meant to gauge their views on their own design strategies, generally accepted design strategies in the field of mass communication technology design, new design strategies, and the landscape of the field in general. The full list of these interview questions can be found in Appendix C. Interviews usually lasted about a 45 minutes, but their tone was conversational, leaving room for follow-up questions and general discussion, so sometimes they went longer or shorter and the order of the questions asked varied. However, each interviewee was subject to at least all nine scripted questions in some form, and responses that answered those questions were the ones that were formally coded and included in this study. The only omitted responses were those categorically unrelated to any of the nine questions. For instance, if a participant started a conversation about something like Russian literature, that was not included in the responses I coded. To code the responses, I followed steps similar to Braun and Clarke's (2006), in which I first read through my data and assigned open--"initial"--codes, then searched for themes in those codes and organizing the themes into groups, or "theme-piles," before finally naming and defining those themes (p. 19 & 35).

So, I recorded and later transcribed each interview. After I organized the transcripts from each participant into categories based on the nine script questions (for instance, question number three--How do you think about the user when you are designing/programming information technology? As a consumer? As part of an interactive system?--was a category, and in that category I placed each participant's responses following that question), I went through the categorized transcriptions and open-coded each response in each category with descriptors of the response meant to get at the essence of the response. It is worth noting that the subject's responses in a particular category did not always answer that particular question and that I created the question categories simply for organizational purposes when coding. If an interviewee talked about the way he or she thought about the user (an answer to question two) in his or her response to question one, I still coded that response in the question one category, simply because the response was given to that question. So for instance, the fifth respondent's first question category was coded with descriptors such as *design guides the user through interactive experience* and *guiding the user can be part of the message* even though they could be considered answers to the second question. Line by line I coded the portions of the transcript that I included in these question categories (essentially the entirety of every transcript--

again, the only things eliminated were those things categorically unrelated to any of the nine questions) with descriptors such as those.

Once I finished the open-coding of every question category, I organized all of the descriptors similar enough to be considered repetitions into specific categories, or themes. So for instance *design for specific function*, *design for specific application*, and *design for specific use* were grouped as part of a repetition category, but *simplicity*, *clarity*, and *do not create frivolously* were placed into different repetition categories. Only six out of the countless amounts of descriptors applied to the transcripts had no repeats and were unable to be categorized.

Once all of the repetitions were noted and organized, I examined the relationships between those categories to form broader thematic codes. For example, the *guide user to information* repetition category (made up of many repeated descriptors) was placed together with the *user-dependent design* repetition category (also made up of many repeated descriptors) to form the thematic code *importance of considering user*, which encompassed those two categories plus six others.

Once I had all of my thematic codes, I examined the relationships between them in an effort to find common ground between them, thus generating a final statement on the overall tone of the interviews--my finding or result.

4. RESULTS

This chapter is broken into two sections. In the first section, I present the results of the classifier algorithm test, meant to test how biomimetic design might perform at the system-level. In the second section, I present the results of my interviews with interface-level designers, meant to gauge the possibility and effect of the systemic adoption of these biomimetic principles on the user-interface level.

Test

The results of the classifier test are presented graphically below:

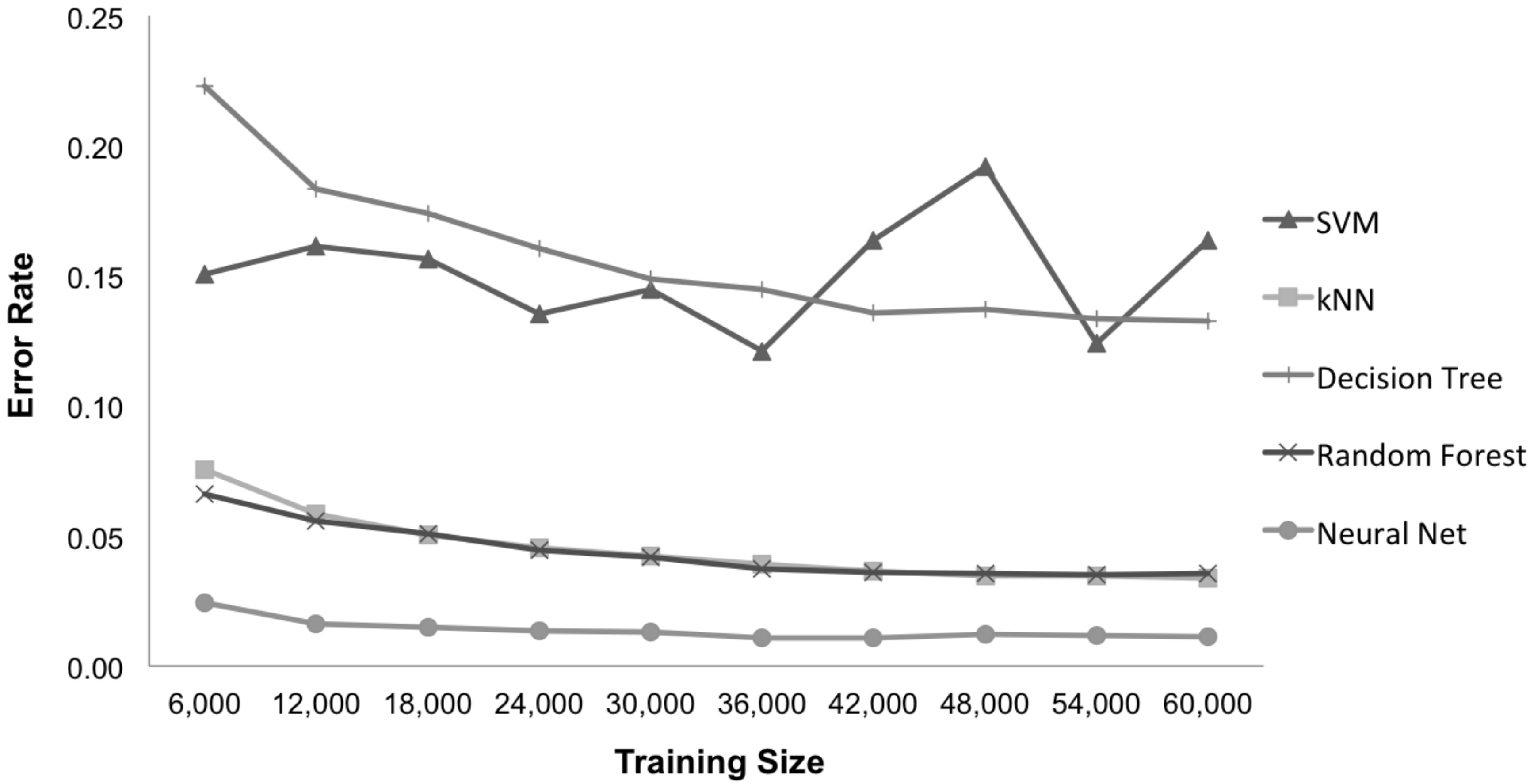

Figure 4.1 - Classifier Algorithm Performance

On the plot, the error rates are presented for each algorithm at the different training levels. So for instance, at 24,000 of the training set images, the neural network had an error rate of 0.0135, but at 60,000, it had an error rate of 0.0114, meaning that it got only 1.14% of the 10,000 attempted labels incorrect. All of the algorithms showed general improvement from the beginning of training to the end except for the SVM, the error rates of which spiked at 48,000 with an error rate of 0.1921 before improving its error rate to 0.1242 at 54,000 training images and then finally climbing back up to 0.1639 with the total 60,000 training images. Most of the other algorithms improved with some small fluctuation. The random forest algorithm for instance saw a small increase in error percentage--from 0.0350 to 0.0355--between the 54,000 and 60,000 marks, but otherwise showed steady improvement. The neural network's error rate climbed from 0.0108 at the 42,000 mark to 0.0124 before decreasing steadily to 0.0114 at the 60,000 mark. The kNN was the only algorithm that showed only decreases in error rate at every mark.

However, the superiority of the neural network's performance is apparent from the start of the test, the kNN's error rate of 0.0757 being the closest competitor to the neural network's 0.0243. Too, the closest any error rate came to the neural network's final error rate of 0.0114 was the kNN's 0.0336--another sizeable difference. In other words, on the full 60,000-image testing set, the neural network performed three times as well as its closest competitor, and at any given mark, it performed at least twice as well as any competitor--but often greater than that even. This can be seen in the full list of error rates at their evaluative marks presented in the table below:

Table 4.1 - Error Rates

	6,000 images	12,000 images	18,000 images	24,000 images	30,000 images	36,000 images	42,000 images	48,000 images	54,000 images	60,000 images
SVM	0.1507	0.1614	0.1565	0.1356	0.1446	0.1212	0.1636	0.1921	0.1242	0.1639
kNN	0.0757	0.0585	0.0504	0.0456	0.0424	0.0394	0.0363	0.0349	0.0346	0.0336
Decision Tree	0.2229	0.1835	0.1739	0.1607	0.1489	0.1448	0.1359	0.1370	0.1335	0.1326
Random Forest	0.0660	0.0560	0.0509	0.0447	0.0419	0.0375	0.0361	0.0354	0.0350	0.0355
Neural Net	0.0243	0.0163	0.0150	0.0135	0.0131	0.0108	0.0108	0.0124	0.0118	0.0114

These numbers analyzed in SPSS yield results supporting the assertion that the difference between the means of the neural net's error and the means of each competitor's error is not only large, but is also statistically significant at a 95% confidence interval. This output of each t-test is presented in the tables below containing the means of the neural net's and its competitor's error rate percentages, the differences between the two means, and the statistical significance of that difference:

Table 4.2 - T-Test (SVM and Neural Net)

	Mean Error Rate	**Mean Difference**	**Significance**
SVM	.151380	.1374400	.000
Neural Net	.013940		

Table 4.3 - T-Test (kNN and Neural Net)

	Mean Error Rate	**Mean Difference**	**Significance**
kNN	.045140	.0312000	.000
Neural Net	.013940		

Table 4.4 - T-Test (Decision Tree and Neural Net)

	Mean Error Rate	**Mean Difference**	**Significance**
Decision Tree	.157370	.1434300	.000
Neural Net	.013940		

Table 4.5 - T-Test (Random Forest and Neural Net)

	Mean Error Rate	**Mean Difference**	**Significance**
Random Forest	.043900	.0299600	.000
Neural Net	.013940		

Interviews

After organizing the open-code descriptors by repetition, I found 25 unique repetition categories. From those 25 unique categories, I formed four thematic codes by grouping similar repetition category codes together. Those four thematic codes are presented in the table below with the repetition category codes that make them up. After the table, I explain each thematic code and give examples of quotes that are indicative of the general tone of that theme in the responses.

Table 4.6 - Thematic Codes

Repetition Category Codes	Thematic Codes
Guide user to information User-dependent design Design for specific audience/user Usability/Interactivity Easy access to information desired by user Emotional resonance Shareability User as part of interface/system	Importance of considering user
Consider system when designing Design for specific purpose Design for device Speculation about moving past senses/interfaces as system changes	Importance of considering system

Table 4.6 - Thematic Codes (Continued)

Repetition Category Codes	Thematic Codes
Function over form Harnessing noise Integration of multiple disciplines/mediums/technologies Adaptability/resilience Simplicity/clean design Do not create frivolously Clarity Template-based access to creative tools	Congruency with biomimetic design principles
Can make connections between nature and information technology Biomimetic design--had not heard of it Biomimetic design--had heard of it Biomimetic design--can align past work/principles with biomimicry Biomimetic design--should pursue	Application of biomimetic design principles

The main finding of the *importance of considering user* code was that considering the user is paramount in the minds of interface-level designers. Every designer in some form or another indicated that they would consider a design that could not reach its target audience or accommodate the user's demands a failure. One designer said:

> Everything is about the user. If you can't accommodate the user in your design, then you're not going to be able to achieve your client's goals or your goals . . . sometimes you really have to bend over backwards to accommodate for the user, but if you're not willing to do that, then you should probably go do something else. Everything really is about accommodating to the user.

The most consistent statement in this category was that not only is the user the most important thing to consider when designing at the interface level, but specifically that guiding the user to the appropriate information by providing intuitive pathways through that particular system was the primary goal of design at this level. The same designer continued:

> The user is also part of the interface and part of the experience. And for a long time people misunderstood usability and would say usability means let's give the user all the options we have available to us and let them decide . . . Well now you've seen a big shift, and it's a shift that I've really sort of taken hold to, where you remove a lot of those options and really guide the user down a specific path that we've decided we want the user to go down, that helps us achieve our goals that we've set forth in developing the site.

And another said:

> We look at the user--everything that we do, we look at from an end-user perspective. I get this, what do we want them to do? How do we want them to interact with it? And really, it impacts the design.

He continued:

> [We] designed these tiles that would always be at the bottom that we could rotate out whatever we had going, and we had what we call that sticky header, where no matter where you went on the site, or where you scrolled, there was always a menu button and a reservations button because those were the two things that always had to be there because that's what the majority of traffic was looking for.

Of almost equal importance in the opinions of the designers was the consideration of the system in which they were designing. The most prevalent aspect of the *importance of considering system* code, again, was making sure that pathways to and from the information users need are constructed intuitively, one designer saying, "it can look good; it can do cool things, but if the user can't get to it . . . it's kind of worthless" and another saying it's "the most important thing--having the technology to then give them the information when they request it. That's a big thing."

The designers also mentioned the importance of knowing the parameters of the system for which they were designing, the devices to be used on the system, and the interface's placement in the system in general. The figure below is what one designer called a "technical schematic," which shows the pathways through a website they designed for a client (a construction equipment company) and to all relevant connections to and from that website, such as warranty information and equipment rentals, among other resources. Black bars have been placed over the names of all brands present on the schematic.

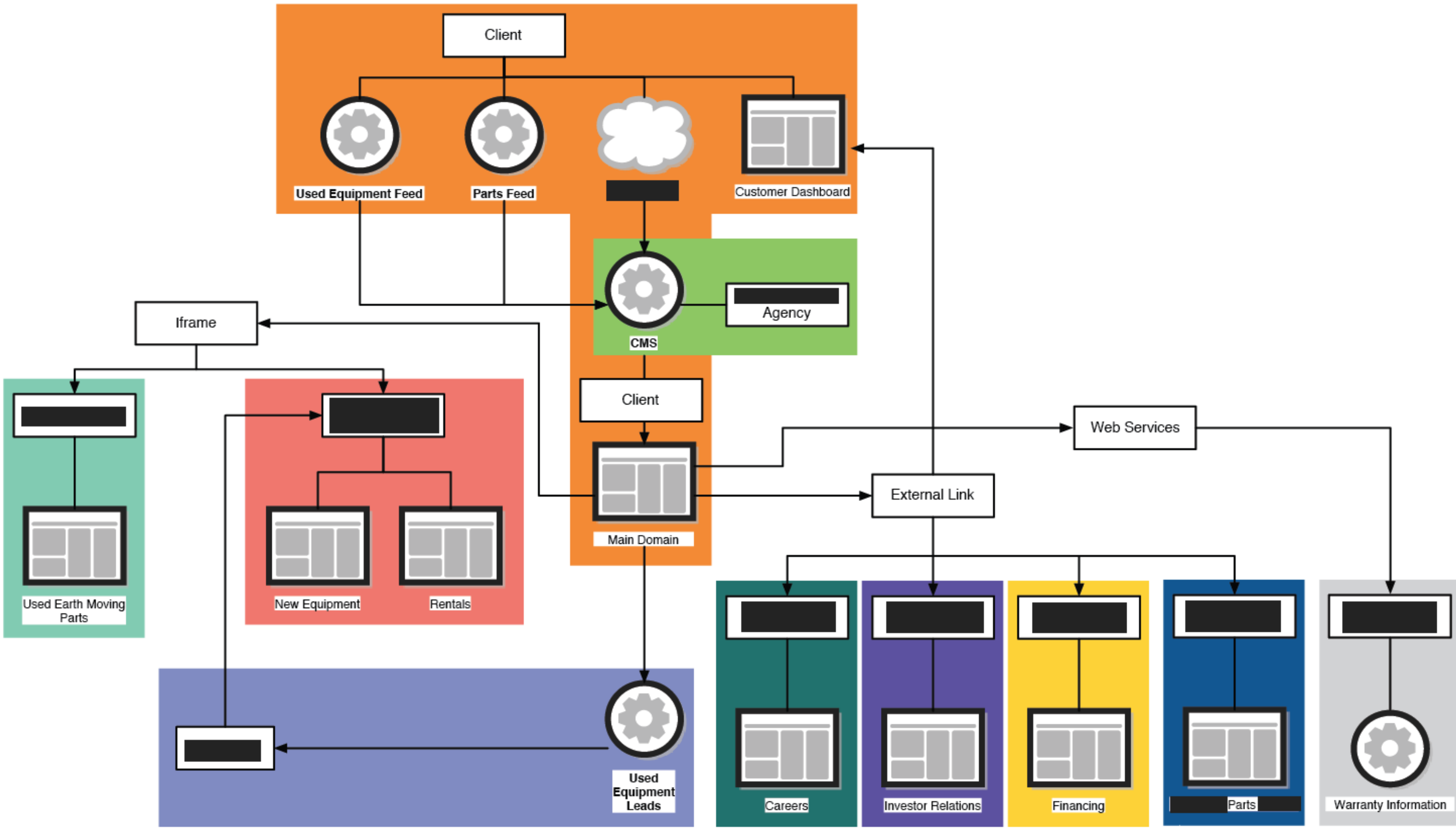

Figure 4.2 - Technical Schematic

As I was examining the category codes, I noticed that several aligned with the principles and strategies of biomimetic design I cited in the literature chapter. I created the thematic code *congruency with biomimetic design principles* after finding a total of seven category codes that aligned with biomimetic design principles almost directly. The finding of this code, then, is that many of the principles these designers use to accomplish their goals are similar to the principles a designer using biomimetic design strategies would use.

Some of the codes match up to Benyus's nine principles almost exactly. For instance one of the category codes, the *integration of multiple disciplines/mediums/technologies* category code recalls Benyus's (1997) "Nature banks on diversity" (p. 7). Similarly, *function over form* is quite similar to "Nature fits form to function" (1997, p. 7). One designer said, "It may not be the best looking way to do something, but the function usually comes first, then the form" before explaining:

> OK, I need them to click on this button, that's what I need the user to do. If the button has to be orange, and it doesn't really look that good orange, but it gets more clicks, then we have to make it orange.

And another designer said:

> As a designer you might say, "I want to do this because it looks good." Well, that's great, but if it doesn't solve the issues that we're having with navigation, usability, all the other things, then the design is for naught.

Not all the category codes directly matched one of the nine principles Benyus explained, but all of the codes that built this category matched the end goals of biomimetic practices and strategies. For instance, the *harnessing noise* category code recalls the things Benyus (1999) said about our current computer systems and their inability to do embrace noise in the system. Relatedly, the *adaptability/resilience* code describes the way Benyus (1999) argued a system ought to be designed. For instance, on designing something as part of a system, one designer said, "you have to think about how it may adapt as things change." Another said:

> I think design is always evolving. And so if you say 'well this is who I am as a designer'--but you have to be able to evolve . . . if the environment is demanding something else, you have to adapt.

I created the *application of biomimetic design principles* thematic code to encompass all of the direct statements made by the designers about biomimicry. Despite the designers' principles' alignment with those of biomimetic design, and despite the at times biomimetic language they used to describe their own practices (more than one designer, for instance, called the systems for which they were designing "ecosystems"), none but one designer had actively considered connections between nature and information technology before I asked them to. In addition, all but two had not heard of biomimicry before I defined it for them. Yet all could come up with similarities between nature and information technology, and all could apply biomimicry to their own work or to the field, and every designer saw benefit in pursuing the incorporation of biomimetic design strategies either as a standalone method or in conjunction with other methods. One designer said:

> Humans, with all of our accomplishments are not as evolved and not as smart as mother nature . . . if it has that sort of a positive effect, then it's something that must be researched and must be considered.

Other designers expressed their support for exploring different methodologies in general, and some speculated on specific applications of these design strategies that could improve their work. For instance, one designer suggested biomimetic design strategies could potentially aid in recognition software and also in the analytics of users' movement through systems.

> We look at a lot of analytics. So we look at a lot of website analytics of mass amounts of people coming into sites and where they're going and what they're doing. I think you could create some models that could maybe predict where you think users could go . . . like I've seen like hurricane or flood models where they show 'OK well this is where a hurricane hits' and then they have these visual models of where water would go, and it would be great to see where users would go.

It may be interesting to speculate that effective designers seem to do design this way without thinking about it, lending support to the idea that biomimetic design needs to be applied systemically rather than ground up--that individuals already do this innately, and the system should behave in a way that accommodates this innate design thinking, or in other words, that designers already design biomimetically; what they need is a system that can enhance these designs.

Searching for a final result--a general tone or finding regarding the responses--and considering the thematic codes together, the biggest overall theme was that interface level designers consider their job to be a communicator or bridge between the user and a system of information--that by their own estimates, they exist to connect users to a system of desired information. To do this, they must consider both the user and the system as they design on an interface-level, and because of this, they all seem to champion simple, resilient, focused design, made in the interest of the synchronization of the user and the system. Many of the principles that help them achieve their goal are congruent with the established principles of biomimetic design. Nothing in the results suggests that they did this intentionally. Rather, they independently deemed these principles the best way to create interfaces that accomplished their goal--which they identified as facilitating the interaction between users and the information system.

In other words, the final finding of the interviews was that the landscape of user-interface level design is itself already congruent with biomimetic design principles and therefore would likely be congruent with and thrive on a system designed by those same principles.

5. DISCUSSION

We don't leave our houses without our phones anymore. We feel naked without the possibility of being connected not just to each other, but to all of humanity's information. Our mass communication technology has mutated from a neat gadget and into a necessity. Have we begun our evolution into a superorganism--inescapably connected to one another, in constant flux and subject to info-entropy? Does this assign issues like net neutrality and the digital divide a much higher stake than we realized, make them a matter of biological importance--will those who don't or can't connect be left behind: fossils, missing links to homo erectus from whatever we become as coded avatars in our network? What damage do security breaches and undemocratic structures cause to us when this technology is as integrated as it's become?

There are tremendous ethical concerns latent in the fact that we rely every day on a mass communication system that is not as secure or accurate as it could be to distribute mass quantities of information. Journalists and news outlets are depending on a stunted system for accurate and secure access to and distribution of information, and more than that, they depend on users' ability to create content on and access content from that stunted system. Because norms and routines in the mass communication industry dictate resistance to new business models and systems, journalists and users are stuck using a sub-optimal and often dangerous information system. Below, I discuss the theoretical and practical implications of this research to this system relative to mass communication, as well as speculate on possible future developments and research regarding biomimetic technology design in mass communication.

Theoretical Implications

Considering the results of the interviews together with the results of the test, I contend that my general finding and contribution is that biomimetic design strategies would have a positive effect on our mass communication technology design and that the application of these principles should be focused specifically at a systemic level--into our hardware, networks, and systems in general. I argue that the time for this systemic change is now--that user-interface level designs, usability, and security would thrive on a system designed biomimetically, and that our consumption, transmission, and storage of information on a massive scale would be optimized.

Because only one of the four classifiers I tested had biomimetic properties, when it significantly outperformed all the other models, it was reasonable to infer that its biomimetic design was a contributing factor. The machine-learning test, applied to images in the context of an argument for biomimetic design in mass communication technology, yielded results that can be examined beyond the field of computer science. Because the test used a biomimetically designed algorithm, and because that algorithm was tested on a class of information content consumed by a massive base of communication technology users, this seems to support the idea that biomimetically designed mass communication technology could improve the way we transmit, consume, and store information on a massive scale. In other words, since the results of this test illustrated the superiority of biomimetic design in mass communication technology--by illustrating the superiority of the biomimetically designed classifer's interaction with a form of data our system is becoming increasingly dependent on--then one must buy the argument that this design will improve the way our mass communication technology interacts with information.

Despite the successes of neural networks, we have seen little to no adoption of biomimetic design principles at a system level into everyday hardware, networks, and systems. I speculate that this is due in part to the unwillingness to yield control that Benyus mentioned--that system-level designers would be reluctant to let these complex and sometimes unpredictable architectures run in parallel, let alone massive parallel.

But--more importantly and substantially, the results of the interviews show that design on the user-interface level is more than ready for these systemic changes and would likely greatly benefit from them. Biomimetic design works at the user-interface level. The interview responses suggest that designers have either already figured this out, or that they inherently design this way anyway: that humans have a tendency or desire to create in their own image, nature's image--and that users interact with such designs more intuitively. Change is inevitable--user-level designers have made a habit of adapting, taking systems into account as they design bridges between them and users; system-level designers ought to put effort into creating hardware, networks, and systems that can do the same rather than break every time a "mutation" occurs, thus demanding an update, and then necessitating universal interface re-design. If the system can adapt, our interface-level designers are more than practiced in making designs that can too.

For instance, the head of MIT's Media Lab Joi Ito (2014) gave a talk at the 2014 MIT-Knight Civic Media Conference on "The Open Internet . . . and Everything After," in which he presented the nine principles with which he guides the lab's work:

1. Disobedience over compliance
2. Pull over push
3. Compasses over maps
4. Emergence over authority
5. Learning over education
6. Resilience over strength
7. Systems over objects
8. Risk over safety
9. Practice over theory

He explained a few of the principles individually, such as "Resilience over strength" meaning to design expecting and embracing change and failure rather than building walls around yourself and "Learning over education" meaning learning how to learn rather than learning facts (Ito, 2014). "Disobedience over compliance" he explained by saying that to create a resilient institution or network, you have to embrace the noise of members of that network doing things in an unpredictable way; and "Pull over push" he explained as pulling "from the network as you need it rather than stocking and centrally controlling it" adding that having "printing presses and lines of code and IP" give people reasons not to shift course, stunting our design's resilience and efficiency and that "all the things that we think are assets are actually liabilities when you think about it from the perspective of agility" (Ito, 2014).

The bulk of his talk, though, he dedicated to the media lab's general design philosophy, which--like those nine principles--seemed to demand systems that can accommodate biomimetic designs. He suggested several times that our system should be thought of more like an "ecosystem," all of us working with each other and our technology, and that the solution to our big ideas--journalism, civics, government--is "going to be some combination of pieces in a network that sort of start to become resilient and start to grow"--that the future of design is going to require a system not bound by the "Newtonian, Euclidean laws of before Internet when you could predict things," but instead that can foster design that feels

> a lot more like life, like growing, like giving birth to a child in an environment that you don't have control of . . . And for that, I think the open Internet . . . is essential because as those people who try to close the system go in there, it's really like gunking up an ecosystem with pollution, trash, or constraints that you don't really want. If you think about it as a gardener, I think the open Internet is the water, the openness, the air that you need, and then I think all of us are the organisms that live there that try to make this thing vibrant. (Ito, 2014)

The neural nets are to my mind a clear indicator that biomimetic design works at the systemic level--the neural net simply performs, and it is reasonable to think that similarly designed algorithms and architectures would work, especially in parallel, and especially in an info-system as dependent on images as ours. We, and our interfaces and their designers, are ready for the implementation of biomimetic principles at a systemic level: into our hardware, into our networks and systems, into our mass communication technology design.

Yet--we are still relying on a system with higher error rate percentages, and more security flaws than we need to be relying on. The accuracy and security of this system--that journalists use every day to both access, create, and disseminate information--is not optimized. Too, they depend on users to access, create, and disseminate on this system. Again, this carries with it ethical concerns--but many of them, I argue, can be addressed in the practical implications of this systemic adoption of biomimetic design principles into mass communication technology design.

Practical Implications

Practically applied, imagining the possibilities on the user's end after this systemic change become awesome. Specifically on the application of neural networks: if this algorithm works not just to classify things more accurately, but to learn to classify things and provide accurate results even just based on images--this could perhaps radically improve user's searches for and subsequent consumption of information. A more accurate search algorithm, capable of actual deep-learning and classification built on a flexible system of weighted patterns (in contrast to our algorithms that learn based on arbitrary user signals) and equipped with the ability to harness noise in its pattern recognition, could more fairly provide bits to its users and maybe shrink the filter bubbles we've built around ourselves. In other words, by harnessing the noise in our entropic information systems, it is possible for us to not only reduce it, but to reduce it accurately, leaving intact both the results we search for and things that are related to it in all directions rather than just one. If our search algorithms are capable of making sense of disparate searches, our filter bubbles expand to include information that was previously eliminated from our experience. Say a journalist who usually covers sports needs to cover a natural disaster. As he searches for sources for his article, a neural network would more quickly recognize his unusual searches and find patterns in them, connecting him to his searched for information. The neural net could easily create a bridge from his sports bubble to the rest of the Internet's information each time he needs to cover a new kind of story and eventually create a large system of patterns covering all types of stories, nearly eliminating his bubble but still retaining the power to connect him to information that is relevant to him.

And once we can train these biomimetic algorithms on both text and image-based data, they'll be able to offer improvement in searching for particular kinds of results by perhaps combining the two. For instance, combining captions of images with image searches could yield great improvements to media professionals' and users' access to information discussed above. But more importantly, improved analysis of text alone--but especially in parallel with images--offers important possibilities for tone perception in text-based data. A journalist or user might be searching for sources that don't contain bias, for instance, and if these algorithms could offer insight into algorithmic detection of tone in text, images, or a combination of both, it may be possible for the algorithm to filter results with bias in the tone or give a label that indicates in which direction the tone leans. Similarly, this could aid on the editorial level. If the algorithm worked--if it could detect bias in the text and images of articles--media outlets could legitimately claim to be bias-free and share their source code to prove it. Both media professionals and users could be generating and consuming information they knew was objective.

And imagine the security in a system that could adapt to new threats--viruses, hackers--without needing an update from its creator. Rather than build walls and bars around these systems, when building and coding them, designers could expose them to viruses and breaches and let them learn what they are and how to control for them, training the machine to recognize the symptoms of an attack, virus, or glitch--similar to vaccinating our bodies at a young age to strengthen our immune systems to many kinds of threats. Instead of a cloud server being breached and its developers scrambling to update it with a fix, the machine would already have been exposed to the types of viruses and breaches the designers could think of, would have found patterns across the breaches and viruses, and would now be able to recognize and neutralize new threats. At the very least, should the new threat make it through and the system become damaged or breached, it would be a momentary sickness--the machine has been exposed to viruses before and its "body" knows what to do. To the machine's security system, this would just be one more virus it was exposed to before finding a way to neutralize it--the machine would have a cold lasting a few days, rather than need to be rushed to the emergency room and be operated on by a team of designers.

The performance of the neural net's interaction with visual data lends support to the shape-based computing and parallel processing Benyus mentioned. If these types of algorithms were adopted into our systems and hardware, interfaces could become as easy for the average user to experience as movies are compared to books. Too, the same way people joke that the TI-83 calculator has more processing power than the computer that landed Apollo 11 on the moon, devices that we could develop to interact with a system that's able to process in the massive parallel that nature can would make our iPhones look like calculators. If our systems were truly designed in our natural images, if we had a real structural connection to our machines, the logic of usability would become instinct, and the scope of usability would become infinite. We could, each of us, be our own creators--intuitively able to both access and manipulate all the world's information for ourselves reliably and safely in a world of computing that accommodates our innate biological strengths and limitations--rather than live at the mercy of those who develop that world. Through these new devices, we could all be speaking the language of creation--we simply need the system designed to accommodate those interfaces.

Limitations and Future Research

It is worth noting that this study was limited in its resources and therefore was not able to dedicate the time or machinery to the classifier algorithms' performance on text-based data, which--given the number of input features for every single attempted label--takes significantly more time and computing power than was available. I believe that the neural net's superior performance on visual data is a strong argument for biomimetic integration into our hardware given the nature of the information stored on and transmitted through our systems and the neural net's potential in shape-based computing. However, I cannot provide in this study the same substantive results on the neural net's performance with other types of datasets. In addition, it is a limitation of this study that the neural net could not be tested on hardware specifically designed for its prowess. This hardware does not exist--as it is the nature of this research to argue for its creation--but because of that, I had no biomimetic system, network, or even interface to test against a non-biomimetic counterpart; I had only a biomimetic algorithm, which is enough to offer substantial speculation, but not enough to say the hardware or systems will definitely be able to be harnessed.

These are both future research directions I suggest. I believe a completed test of the prowess of the neural net algorithm--or other biomimetically designed algorithms--on text-based data in the context of an argument for the implementation of biomimetic design principles in mass communication technology would not only compliment this paper, but would open doors for practical implementations even in our current system. Biomimetically designed algorithms like neural nets could offer possibilities or improvements in the realm of machine-automated coding of tone in text-based data such as online comments or news articles, as well as the benefits previously discussed regarding search and bias. As a start, future research could test neural nets or other biomimetically designed classifiers on the 20 Newsgroups dataset, which includes 18,000 newsgroup posts, each belonging to one of 20 categories such as sports, politics, religion, etc. (Rennie, n.d.). This, again, could improve access to information searched for by journalists and users--creators of more information.

Perhaps most importantly, research into building hardware equipped to accommodate these biomimetic designs--for instance, building something like the parallel processors Conrad was interested in--would be quite promising. A paradigm shift in the way we design our mass communication systems is now necessary. Though some systemic biomimetic concepts may still be out of our reach, creating hardware and systems that compute in massive parallel is attainable, and on those systems, we could truly test the prowess of these types of algorithms, as well as others. We can simulate the prowess of systemic biomimetic design by testing biomimetic algorithms on traditional machines, but all of the benefits discussed above come to fruition when we have the hardware capable to harness these algorithms. Research on biomimetically designed hardware and systems yields nearly endless benefits to mass communication, including the accuracy and security improvements discussed above, which have positive effects on the quality of our information disseminated by media professionals and users, and therefore is necessary.

Conclusion

My argument in short is that the classifier algorithm test supports biomimetic design's performance on a systemic level and that my analysis of the interview responses suggests that the user-interface level would benefit from this systemic adoption as well. I argue that to improve usability, interactivity, and security, and to improve our consumption, storage, and transmission of information on a massive scale, the most prudent course of action is to concentrate biomimetic design strategies systemically--into our hardware, networks, and systems in general--and that user-interface design would not only accommodate the changes to our system-level designs, but that it would thrive on them.

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APPENDIX A
IRB APPROVAL

ACTION ON EXEMPTION APPROVAL REQUEST

Institutional Review Board
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Mass Communication

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: February 11, 2015

RE: **IRB#** E9181

TITLE: Natural order: The case for applying biomimetic design principles to mass communication technology design

New Protocol/Modification/Continuation: New Protocol

Review Date: 2/11/2015

Approved X **Disapproved**__________

Approval Date: 2/11/2015 **Approval Expiration Date:** 2/10/2018

Exemption Category/Paragraph: 2b

Signed Consent Waived?: No

Re-review frequency: (three years unless otherwise stated)

LSU Proposal Number (if applicable): __________

Protocol Matches Scope of Work in Grant proposal: (if applicable) _________

By: Dennis Landin, Chairman DLandin

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE:**

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

APPENDIX B
CONSENT FORM

1. Study Title:	Natural order: The case for applying biomimetic design principles to mass communication technology design
2. Performance Site:	Louisiana State University and Agricultural and Mechanical College
3. Investigators:	The following investigators are available for questions about this study via email. Will Glass (wglass1@lsu.edu) Lance Porter (lporter@lsu.edu)
4. Purpose:	The purpose of this research project is to examine the connection between our information systems and nature's information systems and to evaluate the application of biomimetic design principles to technologies related to our mass transmission, consumption, and storage of information.
5. Subjects:	Computer scientists, designers, programmers and experts age 18 and over.
6. Number:	Up to 20 subjects.

7. Study Procedures: For approximately thirty minutes to an hour, the subjects will be asked a series of approximately eight to ten questions about common design practices, user-interface interactivity, and the possibility of incorporating biomimetic design strategies in their work. The interviews will be recorded and later transcribed.

8. Benefits: The study may yield valuable information about information technology design.

9. Risks: The only study risk is the inadvertent release of the interview recordings and therefore the names of the interviewees. However, every effort will be made to maintain the confidentiality of the recordings and transcriptions. They will be kept in a password-protected file only on the interviewer's personal computer.

10. Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which they might otherwise be entitled.

11. Privacy: Results of the study may be published, but no names or identifying information will be included in the publication. The names of the interviewees will be kept confidential and pseudonyms will be used in any publications. Subject identity will remain confidential unless disclosure is required by law.

12. Financial: There is no compensation for participating in this study.

13. Signatures: The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects' rights or other concerns, I can contact Dennis Landin, Institutional Review Board, (225) 578-8692, irb@lsu.edu, www.lsu.edu/irb. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of this consent form.

Subject Signature: ______________________________

Date:___________________

APPENDIX C
INTERVIEW QUESTIONS

1. Do you have any general design "philosophy" related to your work?

2. Do you think about the user when you are designing/programming information technology? If so, how? As a consumer? As part of an interactive system?

3. Do you consider the overall information technology system when you are designing information technology? If so, how?

4. Why do you think information technology is designed the way it is in general?

5. Do you have a design or idea you consider to be your best? Is there one you're most proud of?

6. What are some problems you see currently in information technology design? Do you have any ideas to fix those problems?

7. In what ways, if any, do you see similarities between information technology and natural, biological functions?

8. Are you familiar with biomimetic design? (Explain biomimetic principles if negative response). Have you ever used biomimetic design strategies, intentionally or otherwise? How might you use them?

9. Do you think information technology would be systemically improved, harmed, or unaffected by incorporating biomimetic principles into system-level design strategies?

VITA

William C. Glass is a Master's student at Louisiana State University's Manship School of Mass Communication where he will receive his degree in May 2015. As a graduate assistant, he worked for the Reilly Center for Media and Public Affairs and for the dean of the Manship School, Jerry Ceppos. Presenting his research ideas to Alberto Ibarguen helped to secure the Manship School a $150,000 grant from the John S. and James L. Knight Foundation, the application of which he assisted Dean Ceppos and Lamar Visiting Scholar Steve Buttry in overseeing. He was also invited by Alberto to attend the 2014 MIT-Knight Civic Media Conference on "The Open Internet . . . and Everything After." He received his Bachelor's degree in print journalism from the Manship School in 2012.

Professionally, he has worked in his hometown of New Orleans as an assistant investigator at a private investigation firm where he developed the social media procedure for all investigations. He has also done research for the Innocence Project in the Orleans Parish District Attorney's Office, preparing case files for discovery. In his free time, he writes, coaches youth cabbage ball, and is the guitarist, singer, and songwriter for local New Orleans and Baton Rouge-based rock band Pig Lizzard. After graduation, he plans to marry fellow scholar Ashley Hesson and move back to New Orleans to work.