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Design Ecology: Designing for Emergence and Innovation II

by Robert K. Logan

and Greg Van Alstyne

Introduction and Objective

In our paper "Designing for Emergence and Innovation: Redesigning Design" (Van Alstyne and Logan 2007), we explored the relationship between design and emergence within the complex series of processes and decisions that give rise to innovation. We concluded that in order for design process to produce innovation, the designer or design team must invariably incorporate "bottom-up" processes of self-organization, analogous to the emergence evident in nature that gives rise to complex phenomena including new forms of life.

In the present paper we will explore the roles of designer, client, user, and other parties essential to the design process, and the relationships between them. We will further interrogate the interactions between bottom-up processes of emergence and those characteristically "top-down" activities of the designer that together give rise to a **design ecosystem** capable of supporting the emergence of innovative design. We will begin to describe that ecosystem in which the designer operates and characterize the design ecosystem's dynamic, interdependent processes. We will try to understand the design of successful innovations of the past so we can be prescriptive about the future of design.

But why this marriage of design and ecology – doesn't ecology belong strictly to the study of natural, biological ecosystems? Well, in addition to ecology in the sense of natural science, a number of other academic and professional communities use the term "ecology" to inform and characterize their work. One such example is media ecology, the study of media as environments, including the interactions among media and users. Another example is industrial ecology, the study of the interactions among industries, the physical environment and the biosphere. In keeping with these precedents we introduce the notion of design ecology. The term "ecology" refers to the holistic study of dynamic interactions among interconnected elements and processes that make up a larger, overarching ecosystem. Such ecosystems are described as 'non-linear' because to model them mathematically we must use non-linear equations. Just as the physical environment and the biosphere form the natural ecosystem, so do communications media and their human users form the media ecosystem; while industries and their material and energetic inputs, outputs and waste form the industrial ecosystem. In the same way we can say that designers, their clients and users, along with the surrounding technosphere and the natural environment, together form the design ecosystem.

Simply put, design ecology is the interdisciplinary study of that design ecosystem, consisting of the designer or design team; their design or innovation project; their client; the potential users of their innovation and the technosphere of current and past products, services, processes and systems. The design ecosystem also includes the creativity of the design team as well as the clients' engineering, manufacturing, financial, management, marketing and distribution capabilities and resources. We use the term design ecology because we are interested in the interdependencies of the designer, the client, the users, and the other elements of the design environment we have just identified. It is out of this ecology that innovations emerge which are more than the sum of the parts of the elements that go into their design. The emergent innovation or final product of the design process cannot be derived from, predicted from or reduced to the elements that came together to create the innovation.

An ecological approach to design is justified because the design process is highly dynamic, involves the construction of niches, and operates within the context of a rich network of interactions with and among clients, users, engineers, financiers, marketers, sales agents, competitors, collaborators, and suppliers. The Chicago-based innovation consultancy Gravity Tank, Inc. captures the spirit of this approach to "shaping innovation," which it describes in the following terms: "Innovation is not a theoretical pursuit. To impact your business, innovation efforts need to result in real, everyday stuff that delights customers and drives sales: things like products, packaging, store layouts, service training and business models. It is only through the tangible stuff that innovation succeeds." (add citation)

While we agree it is not the theoretical pursuit itself but the tangible stuff that makes for innovation, we believe that our efforts to describe the innovation process within the context of design ecology will help designers and their clients to achieve tangible results. As Clayton Christensen says in *The Innovator's Solution*, theories are useful as trustworthy explanations of cause and effect. For Christensen, "theory is consummately practical…. Every time managers make plans or take action, it is based on a mental model in the back of their heads" (Christensen, 2003, 12). We would like our readers to acknowledge that designers, clients, and users are agents, that is to say, living organisms in a biological ecosystem, and as such they themselves function as complex, adaptive systems that are capable of learning. Likewise, a successful innovation consisting of "tangible stuff" also operates as a complex adaptive system, not solely within the biological ecosystem, but within the design ecosystem.

The next question that presents itself is, why is it today we increasingly think in terms of ecology and ecosystems? The reason is simple. After many centuries of linear, mechanistic analysis of the world we have come to realize that many phenomena occur within systems that are inherently complex and nonlinear. Chaos theory, complexity theory, emergence, interdisciplinary studies, the Innis-McLuhan school of media studies, environmental studies, and industrial ecology, all point in the direction of an ecological approach to understanding the dynamics of complex systems. In our work, including this paper, we attempt to apply this approach to the field of design, the work of designers, and the development of innovation.

Before continuing our analysis it is important to take a moment to describe what it is that the designer or design team designs. (Hereafter for simplicity we'll refer to this role as "the designer" whether this represents an individual or a team.) The designer is the creator of the concept and implementable plan for a product, service, system, or process, each of which may be considered to be a tool or a technology. The term technology stems from the ancient Greek word *technologia*, which means a systematic treatment, which itself is derived from *techne*, meaning art, and *logos*, meaning guiding principle. Tools are forms of technology and technologies function as tools, facilitating certain objectives of their users. We will use the terms tool and technology interchangeably. The distinction between products, services, systems, and processes can also be fuzzy. A product is usually an object that the user takes possession of, whereas a service is a function facilitated for the user by another party or agent. A process is a series of operations to create a product or service, and a system is a collection or amalgam of products and/or services that provides a certain functionality.

Biological Background of Design

In our analysis we will treat human design as a biological process, in the sense that design activity is evolutionary, closely tied to life, and “natural.” We take comfort in the fact that the eminent evolutionary biologists John Maynard Smith (2000) saw, just as we do, a relationship between biology and design, namely, that there is a parallel between non-intentional design by natural selection and design by human intention. He wrote:

> I have become increasingly convinced that there is no way of telling the difference between an evolved organism and an artifact designed by an intelligent being. Thus imagine that the first spacemen to land on Mars are met by an object, which appears to have sense organs (eyes, ears) and organs of locomotion (legs, wings). How will they know whether it is an evolved organism, or a robot designed by an evolved organism? Only, I think, by finding out where it came from, and perhaps not even then.

What is Design Ecology?

Like Maynard Smith we see innovative design as a biological process that parallels evolution and natural selection. Furthermore we see design ecology as an appropriate way of approaching and enriching our idea that emergence is a necessary process in innovative design. By design ecology we mean the study of design ecosystems, that is, the holistic and systems-based investigation of the interrelated agents, elements and processes that give rise to innovative design.

Our use of the term design ecology should not be confused with the way the term is sometimes used to mean the design of an ecology or ecosystem, whether it is one in nature or one that is a human work or living environment. We believe this activity is better described as ecological design or ecosystem design rather than design ecology. Examples of this kind of project may be found in the field of industrial ecology. As Kevin Kelly reports in *Out of Control*, the term industrial ecology was popularized by Robert Frosch and Nicholas E. Gallopoulos in a 1989 *Scientific American* article that stated,

> In an industrial ecosystem … the consumption of energy and materials is optimized, waste generation is minimized, and the effluents of one process … serve as the raw material for another process. The industrial ecosystem would function as an analogue of biological systems. (Frosch and Gallopoulos, 1989 quoted in Kelly, 1994)

Industrial ecology overlaps with design ecology in the sense that the design of closed-loop industrial systems, and their degree of success as innovations, may be analyzed through the lens of design ecology – as is the case with any design process. The overlap is significant because a successful industrial ecosystem certainly represents an exemplary case of applied design ecology – such a project would be large in scale and its design is likely to show a high degree of awareness and utilization of relational, systems-centric thinking, that is to say, ecological thinking.

Design Ecology and Biomimetics

A comparison between design ecology and biomimetics reveals similarities as well as a striking set of differences. Biomimetics, also known as biomimicry or bionics, is a research-intensive branch of design and engineering in which solutions are inspired by and developed in conscious emulation of precedents from organic nature. Frequently cited examples of biomimicry include Velcro, a fastening system modeled on the Burdock burr; shatterproof ceramics that mimic the nacre or mother-of-pearl of mollusks; underwater glues that work like that of the barnacle; and "self-cleaning" coatings that repel water as efficiently as a lotus leaf.

There is a natural affinity between biomimetics and design ecology. Table 1 lists several affinities:

1. Similiarities Between Biomimetics and Design Ecology

Seek to generate innovation
Utilize systems thinking in order to grapple with complex interdependent factors
Draw heavily from the natural sciences while articulating a synthesis of art, science, engineering and design

However significant differences suggest that the two discourses are not parallel. Table 2 highlights the distinctions:

2. Differences Between Biomimetics and Design Ecology

Key Concerns in Biomimetics	**Key Concerns in Design Ecology**
Ideas inspired by nature	Ideas drawn impartially from nature, from precedents in the technosphere, literally from anywhere
Primarily engineered components, subsystems and materials	Products, services, methods, systems
Individual innovative results	Multiple processes and interrelationships that create and drive innovation
Performance	Creation, diffusion
Minimization of energy and material use (quantitively evaluated sustainability)	Maximization of value (qualitatively evaluated experience)

While the purview of biomimetics is not intrinsically limited to these key concerns, such characteristics are predominant in the literature and conferences to date. Design ecology as we have seen is a nascent discipline that has no comparable indicators at present. Still we can state that its concerns, while sympathetic with those of biomimetics, are broader, more inclusive, more process-oriented, more closely allied with business outcomes and less closely tied to scientific or engineering outcomes.

How Design Ecology Can Help

Innovative design cannot be reduced to a formula. Given the complex factors involved, it is not possible to predict ahead of time what the next innovation might be, and success can sometimes be due largely to chance, serendipity or accident. The argument that the evolution of technology cannot be prestated or predicted may be stated as follows (Kauffman, Logan et al. 2007):

> We cannot write down causal laws with a prestated set of (collective) variables for the evolution of the biosphere… The same incapacity to prestate the evolution of the economy and its technology also arises, as does the incapacity to prestate the evolution of human culture. But all this has the deepest implications. Reductionist science is powerful, but is limited. This sets us free in astonishing ways, for organisms live their lives forward, they do not deduce them. We appear to live in a universe in which our reductionistic world view is inadequate: there is the emergence of life, and value... Human language and culture also represent propagating organization (Logan 2006 & 2007). Moreover we live in and partially co-create a ceaselessly “creative” biosphere, economy, and human culture. This glimmers a new scientific world view, beyond reductionism with broad potential societal ramifications (Kauffman 2006).

Notwithstanding this caveat, we believe that efforts in evolutionary biology, ecology, chaos theory, other interdisciplinary fields are beginning to reveal key aspects of complex systems behavior in increasingly lucid ways. And so by seeking to grasp and apply principles of design ecology, designers, clients, and other parties in the business of innovation can significantly increase their chances of success.

Earlier Notions of Design Ecology

To the best of our knowledge the notion of design ecology has not yet had a systematic treatment in the design literature, and although the notion of design ecology has been entertained from time to time, until now it has not been explicitly formulated.

One of the authors flirted with the notion of design ecology when he wrote:

> The evolution of the six languages suggests a model or theory for the development of communication and information-processing systems, based on the idea that all innovations have a cognitive, social, and technological component. They are the three basic dimensions of the process of cultural change. (Logan 2004, 123)

The other author collaborated on the articulation of design ecology and ecosystems as part of the Institute without Boundaries (IwB) research project “Massive Change in Action.” The project was designed to enable high school students to interrogate cultural change through design ecological thinking, and offers a learning activity entitled “Mapping Design Ecologies,” which states:

> Nothing on Earth exists in isolation. Everything depends on something else to function. Think of an ecosystem: humans depend on oxygen produced by plants. Plants rely on carbon dioxide, soil, and light from the Sun. Both plants and humans depend on water, and so on. We can use this kind of thinking

> to understand how designed objects also operate within systems. (Institute without Boundaries, 2005)

Van Alstyne continues to undertake design ecology projects with undergraduate students at the Ontario College of Art & Design (OCAD), for example, as outlined in the following excerpt from his course outline for “Think Tank”:

> Working individually, you will begin with a product, service or experience and outline the web of connections that surround it and make it possible – its “design ecosystem.” Your first project is to create an annotated map, diagram, or narrative of this system, articulating your own place within it, using any medium you choose. (Van Alstyne, 2007)

In the realm of economics and business we have identified a precedent bearing resemblance to our concept of the design ecosystem. James F. Moore (1993 and 1996) defined the “business ecosystem” as follows:

> An economic community supported by a foundation of interacting organizations and individuals--the organisms of the business world. This economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organizations also include suppliers, lead producers, competitors, and other stakeholders. Over time, they co-evolve their capabilities and roles, and tend to align themselves with the directions set by one or more central companies (Moore 1993).

More recently we were alerted to the importance of design ecology in a talk given at OCAD by interaction designer Bill Buxton, on the nature of research in the field of design. Buxton made reference to the ecology of the design process in his talk and indirectly within a number of papers, from which we take the following quotations:

> Mozart's [talent] did not emerge from a vacuum. He was a product of a culture that had evolved to reflect a particular set of values, with or without him. But it was also a culture that embraced a talent like Mozart's when it appeared. All of this cultural ecology was in place before Mozart's birth; he came into a world where music and the culture that it represented was highly respected. (Buxton 2006)

> We have a notion of ecology in terms of what we need to do in terms of the rainforest, gases, global warming and so forth. But our social and cultural ecology is just as important. (Buxton 2005a)

> The complexity of today's business and the ecology within which it functions demands high standards of depth and competence among a broad range of specialties, of which design is (an all-too-neglected) one, but only one of many. (Buxton 2005b)

In Buxton's attention to the connections, interrelationships and homologies within and across human culture, creativity, design, business, and social life, we find much to admire and to build on. Our efforts are directed in similar fashion toward increasing ecological thinking and awareness across disciplines, and leveraging the communicative power of design to align development around the creation of new and valuable experiences.

What is Essential About Design Ecology?

We believe that Van Alstyne's use of the term design ecosystems and Buxton's use of the term cultural ecologies portends something very important for understanding emergent design.

Rather than talk about design ecologies we have found it more accurate and useful to refer to "design ecosystems" as the objects of study, and to use the term "design ecology" as the umbrella term for the entire methodology.

The reader at this point might ask why we are introducing the notion of design ecology. Based on our previous paper "Designing for Emergence and Innovation" (Van Alstyne and Logan 2007) we are interested in identifying the elements, influences, mechanisms and environment that give rise to innovative products, services, systems and processes through emergent design. We want to understand the secret of innovation which we believe is dependent on the advent of emergent effects within the design ecosystem.

Design ecology is the study of the environment, behavioral roles, interrelationships and processes that enable the design of an innovation, or "an invention that makes a difference." The ecology of design, as Buxton points out above, embraces cultural ecology, but it also includes the ecology of the designer and their department or firm, the client organization that will bring the new product or service to market, and the expectations of potential users whose desires and needs the innovation will fulfill. The elements or components of the design ecology that we have identified are listed in Table 1.

Table 1. Principal components of design ecology:

Primary actors
Users with their needs, desires and expectations
Client as commissioner, producer, distributor
Designer as catalyst and pattern provider

Essential activities
Researching, studying
Imagining, envisioning, creating

Engineering, prototyping, testing
Managing, capitalizing, marketing
Manufacturing, performing, distributing
Using, enjoying, criticizing

Key environmental elements
Societal, cultural and behavioral norms
Market conditions
Legal and regulatory codes
Technosphere: prior products, services, systems, processes
Biosphere: the web of life and the natural environment
Material and energetic inputs
Constraints of natural law

While these components and their interrelationships represents a wide range of possibilities, we will try to describe configurations that support familiar cases from design and material culture. We will develop insight by characterizing these relationships and dynamics in contemporary design ecosystems, as well as examples from earlier historical epochs. In this way we'll seek to build perspective in order to draw foresight concerning the future of design and innovation.

We noted earlier that the design role might be filled by an individual or a team. The role may be filled by an in-house department under the same roof as the client, or by a separate business. The client is customarily an organization that commissions and then commercializes, through manufacturing and marketing, the innovation. Whether in-house or not, in most cases the design team will be a separate unit from the one commercializing the design. In some instances, as was the case with Cyrus McCormick, the inventor of the reaper, or more recently with the inventors of Google, the designer will start a company to exploit the invention.

Identifying the components of the design ecology is only the first step in understanding its importance in the development of innovation. The core challenge lies in understanding and describing the dynamic interrelationships, including complex interactions between client organization, design team, and potential users. These will differ from case to case depending on whether these roles are filled by players from similar or widely divergent cultures.

Further complicating the result is the degree of interaction or interdependence between environmental elements and essential activities, particularly when these are massively iterated. For example,

We believe an ecological approach to design is appropriate precisely because the complex interactions, cross impacts and co-evolutionary dynamics within a design ecosystem rival those of a biological ecosystem with its myriad organisms, physical features, and environmental conditions. A few examples will illustrate this point. The waterwheel came into widespread use in the Middle Ages many centuries after its initial development, when the increasing cost of labour made it viable. At that point, undertaking the capital cost of constructing a waterwheel was a worthwhile investment because of the savings that would be realized over the lifetime of the facility. In a similar sense, the personal computer achieved modest success because of its usefulness as an isolated information processor but the largest jump in demand for PCs occurred with the advent of the World Wide Web, when the radical connectivity and ease of use of the Web revealed the PCs effectiveness as a communications tool.

Whatever the relationships that the designer must catalyze we believe that the emergence of innovative design is the result of a team effort of all of the players we have identified and not the result of the genius inventor who has often been mythologized. We do not claim that we have totally succeeded in our objective of describing the complex process of innovative design but we feel we have made a start and hope that our modest beginning will lead to a dialogue with our readers.

Emergent Design, the Autocatalysis of the Components of Design Ecology, and the Role of the Designer

We wish to develop the hypothesis that innovative design is an emergent phenomenon that arises as a result of the interaction of components in the design ecosystem. Furthermore we contend that the mechanism by which this occurs may be described by borrowing from chemistry the term *autocatalysis,* meaning a chemical reaction in which the result is a further catalyzing, or speeding up, of the reaction. Appendix I presents a detailed argument that there is a direct analogy between A. The emergence of innovative design through the interaction of components identified in Table 1, and B. The formal criteria for recognizing emergent phenomena within a complex system. Readers who are not interested in formal arguments and accept the isomorphism that we are proposing can skip Appendix I without losing the chain of our argument about the nature of design ecology.

We posit that the role of emergence in the development of innovative design is analogous to that of emergent phenomena in nature which give rise to living, evolving organisms, human language, conceptual thought, and ever-changing human culture. These examples further explored in Appendix II which, like Appendix I, may be skipped without losing the flow.

Life, language, conceptual thought and culture all arose in the biosphere without the benefit of the intentional design of a designer. The subject of our study concerns the development of innovations in the technosphere that arose from the intentional behaviour of their designers. It is our contention that all the elements we have identified as part of the design ecology play a seminal role in the emergence of innovative design. That is not to say that the designer is explicitly aware of each of these components. We believe in fact in many cases some of the elements of the design ecology are intuited by the designer. Whether through intuition or by conscious design the designer becomes the instrument through which the needs and desires of society combine with engineering, marketing, financial, and organization resources at hand to create an innovative and emergent design. We believe that unless all of these factors or components of the design ecology are taken into account consciously or by intuition an innovative design will not emerge.

A careful examination of the history of the successful introduction of innovative products, services, systems and processes will reveal that each of the elements that comprise design ecology as identified in Table 1 came into play. We will support this claim by reviewing a number of successful innovations momentarily. But now we turn to an examination of the components of the design ecology and the dynamic relationships among them.

The Components of Design Ecology and the Dynamic Relationships Among Them

In this section we will describe each of the ten components of the design ecology we identified in Table 1, describe their contribution to the emergence of an innovative design and indicate the dynamical relationships among them. We begin with the most important element in the design process, namely, the designer.

1. The Role of the Designer as the Primary Catalyst

The first mover

It is the actions of the designer that are critical to the emergence of innovative design and is the key factor, which distinguishes human design from the design of Mother Nature. The principle role of the designer is that of the creator of the design but the designer is also the catalyst for the all of the other elements that make up the design ecology. It is the responsibility of the designer to make sure that all the elements of the design ecology are taken into account in the their final version of their design before the design is passed on to the client whose responsibility is to commercialize the design. Too often consideration of engineering, marketing, finance, the business model and the price point are taken into account after the design process is finished when it is too late to come up with a viable product.

The emergence of innovation in nature consists of three basic elements, namely, descent, modification and selection. The component of modification or variation is random or serendipitous and certainly not intentional. In emergent human design the generation of variation comes from the designer and is intentional. Although the process of design begins with the designer who continues to play a central role utilizing his or her intelligence, experience and imagination, the designer still plays the role of a facilitator catalyzing the other elements of the design ecology bringing together the science and engineering, with the practical needs and desires of the users as well as the constraints of the marketplace.

The designer, whether individual or team, must have a wide variety of skills. They must understand and empathize with the emotional and rational experiences and expectations of the target user. They should have a grasp of scientific and engineering principles to assure the compatibility of their design with natural law. They also need to be able to visualize how the basic properties and principles that underlie their project can be implemented in order to achieve the functionality they envision. And finally they must be able to match the functionality of their innovation with the needs and desires of their potential customers in a way that is practical for the manufacturer (or builder), distributor and user of the innovation. They must also be able to develop a business model of how their design can be commercialized.

The essential skill of the designer is the visual one both literally and metaphorically. The designer must be able to see how the innovation will work and where. As pointed out by Basalla (1988, 97), "visual, non-verbal thought dominates the creative activity of the technologist — a kind of thinking that is done with images."

In D4E&I (Van Alstyne and Logan 2007) we developed the position that while human design is largely practiced as a top-down activity, it is most successful when the design and innovation process is able to mobilize powerful, bottom-up processes analogous to those that underly the emergence of new forms in the biosphere. We intend to advance this hypothesis further through our consideration of design ecology.

While the design process is increasingly seen, appreciated, and practiced as a team effort, innovations and inventions are nevertheless invariably attributed to the solo "genius" inventor. One step toward overturning the "genius" myth is the recognition of the many creators and solutions that lay the groundwork for every breakthrough design. Basalla seeks to explain the obscurity of such antecedents:

> The prevalence of artifactual continuity has been obscured by the myth of the heroic inventive genius, by nationalistic pride, by the patent system, and by the tendency to equate technological change with social, scientific, and economic revolutions. However, once we actually search for continuity, it becomes apparent that every novel artifact has an antecedent.

2. The Role of the Client as the Secondary Catalyst

A design is only as good as its implementation

It is the role of the client to commercialize the product or service of the designer or to implement the designer's system or process. In order to achieve this goal there are a number of engineering, marketing, financial and organizational conditions that the client must fulfill in collaboration with the designer to realize the success of the designer's innovation. These conditions that must be met for success will be discussed below. The client and the designer must work closely together to catalyze the elements of the design ecology needed to insure the success of an innovation. In most cases the designer will be commissioned by the client but there is always the possibility, as has happened in the past that the designer recruits the client in the sense of building an organization to commercialize the designer's innovation as was the case with Edison, McCormick, Marconi and more recently Jobs and Wozniak with the creation of Apple or Brin and Page with the creation of Google.

3. Explicit and Latent Needs, Desires and Expectations of Potential Users

The primary driver

> While success can be generated by exploiting new technologies and or creating new operational efficiencies, deriving our inspiration from a focus on customers is more efficient and predictable. (Rhea 2003, p. 154)

No matter how brilliant the engineering no new tool or new design of an existing tool will succeed as an innovation unless it addresses the explicit or latent needs, desires and/or expectations of its potential users. These needs can be either explicit or latent as is often the case. In the case of tapping into latent needs the innovation creates a new need that only arises with the new invention. For example there was no need for the automobile when it was first introduced. It was basically a toy for the rich, which in its initial stages was not as efficient as a horse and buggy.

On the other hand, the history of inventions is littered with beautifully engineered or designed tools or techniques which fell by the way side because they did not address anyone's needs, desires or expectations.

Pip Coburn (2006) in an article based on his book *The Change Function: Why Some Technologies Take Off and Others Crash and Burn* provides an important insight into the need to understand the consumer's needs, desires and expectations as well as their adversity to change or disruption.

> Why do people adopt new technologies? People change habits when the pain of their current situation exceeds their perceived pain of adopting a possible solution. I call that the 'change function'… Change is an emotion-laden process. Disrupting… technologies? No way. Most of us despise being disrupted.

The needs, desires and expectations of potential users include the consideration of popular culture, fashion, aesthetics, novelty and pleasure of use as was pointed out in ToolToys (Manu 19xx).

4. The Technosphere of Current and Past Products, Services, Systems and Processes

The technosphere - an idea pool

The technosphere of all current and past products, services, systems and processes is an important source for ideas, inspiration and methods for the creation of new tools. As pointed out by Basalla (1988, p. 22) , “The accumulation of novelties stimulates innovation because the number of elements available for combination has grown. Soon the accumulated novelties reach a critical point and a chain reaction takes place greatly accelerating the rate of inventive activity.”

A similar chain reaction took place in nature and the emergence of biomolecules. It is estimated that the biosphere began with only 10,000 organic molecules and now some 3.8 billion years later there are trillions of such molecules. Kauffman (2000) also explains the emergence of many new biomolecules when a critical number of biomolecules is achieved. It was at this point that living organisms emerged as a result of autocatalysis and the creation of even more new biomolecules took off exponentially first with prokaryotes (single cell organisms) and then with eukaryotes (multi-cell organisms).

A similar pattern can be seen in the technosphere which began with the first appearance of Homo genus made tool, the Oldowan hand axe which remained more or less the same for 2 million years until the explosion of new tools that appeared 50,000 years ago followed by the explosion of tools with the Neolithic revolution 10,000 years ago, the Industrial revolution 300 years ago, the electric revolution 150 years ago and the digital revolution that we are currently in the midst of.

Before examining the period after the chain reaction of inventive activity took place let’s pause for a moment and describe the advent of human toolmaking which actually began with our homind ancestors. The first thing to note is that no technology is created de novo but always begins with something from the past. For example the first hominid tools were found tools. One can easily imagine that with the experience of using found tools the first tool makers Homo habilis began to reshape found objects to better achieve their objectives. The first made tool the Oldowan hand axe was created by knapping or flaking chips from a suitably shaped and malleable stone. So the first made tools were derived from found tools but we can take this process a step further backwards because the inspiration for using a found tool came from using one's body parts as tools to achieve needed tasks. As McLuhan pointed out all tools are extensions of our body. The hammering function of the hand axe is an extension of our fist and the tearing and cutting function an extension of our hands and teeth. Animal skins fashioned into clothing became extensions of our own skin.

The Oldowan handaxe morphed into the Acheulean handaxe which then became the model from which other tools emerged circa 50,000 years ago including scrapers, knives, spears, and arrows. The next step in the evolution of homid/human technology was the use of tools to make other tools. For example knives and scrapers were used to trim animal skins. Clothing and shoes emerged from these treated skins, which were stitched together with leather straps through holes drilled with stone awls. One tool led to another creating the technosphere and duplicating the process of Darwinian evolution in the biosphere in which new forms emerged by descent, modification and selection.

The mechanism of descent in the technosphere was cultural transmission whereby the techniques for the manufacture and use of tools was passed from one generation to another. The modification occurred through the activities of the designer who modified the tools that were handed down to them through their culture taking into account the various factors that make up the design ecology. Finally selection took place in the market place in which the newly designed tools were used. The division of function between the designer, client and user had not occurred at this early stage in the development of technology. An individual was the designer, manufacturer and user of a tool.

There are many modern examples of the way in which the technosphere serves as a resource for innovation. The use of water and wind power in the medieval period served as the basis for the use of steam power and the advent of the industrial revolution. The Watt steam engine that drove this revolution with its rotary motion was itself derived from the Newcomen steam engine that functioned as a pump which in turn was derived from hand pumps. One invention builds upon another and the relationship is not a simple linear one as is the case with biological systems so that a new technology can have more than one ancestor unlike the situation in biology. So that the steam engines that were the sources of power in the first automated factories were the products of a host of unrelated technologies such as the hand pump, the gears and cams of waterwheels and windmills that converted linear motion into rotary motion. Basalla points out that in the tree of life the branches diverge as is the case with a tree in nature but the tree of technology has another topology in which diverging branches can merge to form a new branch.

Can Technology and Media Be Treated as Natural Systems Subject to the Principles of Ecology?

We have shown that the technosphere emerges and evolves in a pattern similar to that of the biosphere and that the elements of the technosphere emerge like the elements of living organisms that comprise the biosphere. Furthermore we argued in D4E&I (Van Alstyne and Logan 2007) citing Christiansen (1994 & 1995), Deacon (1997) and Logan (2007) that language and culture can be treated as living organisms as far as evolution and emergence is concerned. Given that the technosphere is part of culture it follows that technologies and media can be treated as organisms and that the ecological description of the living organisms that make up the biosphere apply with equal validity to the components of the technosphere.

The reader might at first blush wonder how the elements of the design ecology listed in Table 1 could apply to the Stone Age culture where the technosphere first came into existence. The engineering resources were the tools and skills used to create new tools. Need, desires and expectation of the users and the marketing resources translated into the satisfaction of the user of the new tool compared with other tools that were available and the ability of the culture to promote the manufacture and use of that tool through its various cultural forms of learning. The management and financial resources translate into the social organization of Stone Age cultures and the way in which the division of labour was organized. The price or cost of the tool was the labour required to access and process the materials that went into the construction of a tool.

5. Creativity, Imagination and Vision

The muse of innovation

Creativity and psychological factors such as imagination and vision as pointed out by Alexander Manu are key factors contributing to the success of a designer. We have already mentioned in Section 2 that there are two visualization skills the designer must possess to be able to pull off successful innovation, namely the ability to visualize how the basic components that go into an innovation can work together and secondly the ability to envision a “killer application”. Both of these skills require creativity and a certain amount of fantasy or playfulness.

> Play is one of the constitutive processes of the material universe, and most certainly of complex mammalian development. The ludic scholar Brian Sutton-Smith calls play “adaptive potentiation”. The many games, simulations,

> imaginings, experimentations, tricks and rituals that comprise play, in their sheer fecundity and diversity, are what keeps a human capable of responding to the challenges of social living, beyond the moment of sheer survival (Kane 2007a).
>
> If play is 'adaptive potentiation' - that is, the spinning-out of possibilities, experiments and imaginings to ensure our continuing development and adaptability - then our play is as 'necessary' to our survival (and thrival) as our work (Kane 2007b).

The designer is in the business of creating new possibilities. The designer needs to take into account all aspects of the domain they wish to work in remembering that every element of that domain is subject to change. Roger Martin (2006b) using Aristotle's Analytics where things are classed as those that cannot change and those that can. "A rock is a rock and can't be anything else," but living things and human systems and tools are subject to change. In the biosphere the process of change is by descent, modification and natural selection of Darwinian evolution. A similar process takes place in the technosphere but descent takes place by designers probing past designs and innovations. The modification component requires the creativity of the designer and natural selection through the marketplace.

6. Design Research

Well designed – well researched

Research is a key factor in the design process. The research does not always have to be carried out by the designer. The designer can piggyback on the research of others in the fields of science, engineering, social studies or marketing. Industrial research teams have played a major role in the development of projects. Thomas Edison was one of the first to establish an R&D facility, which eventually became the R&D arm of General Electric. Another early example of industrial research was carried out in Germany in the synthetic dye industry (Basalla 2002).

Darrel Rhea (2003, p. 145) has identified some of the objectives of design research, namely, “the process of discovering what to make, deciding whom to make it for, understanding why to make it, and defining the attributes of success.” He also includes “research that explores the emotional benefits and psychological satisfactions of a product or service [that] can start to define the necessary ingredients of a successful user experience.”

An important aspect of planning any research effort is the decision of whether to exploit what is already known to achieve an incremental innovation or to explore for new forms of knowledge that can lead to a radical innovation. The path of incrementalism does not succeed in the long term because eventually a competitor will take the exploration route and succeed in achieving a radical innovation that will obsolesce one’s incremental innovation. This is what happened to the search engine Alta Vista eclipsed by Google’s algorith and to Digital Equipment Company (DEC) the manufacturer of the minicomputer, the Vax, which was eclipsed by personal computers (PCs). The history of the Web browsers also illustrates this point. Netscape was the first browser to be commercially available but it was eclipsed by Explorer by dint of Microsoft’s superior marketing, i.e. by packaging Explorer with Windows. But the story of Firefox is more interesting because it too eclipsed Netscape from which it originated by

Having established the importance of explorative research to achieve radical innovations does not mean that one should not exploit one’s knowledge to achieve incremental innovations but rather one’s research program should be a balance between exploitation and exploration (March 1991). If the existing products or services of the client are having a difficult time achieving a competitive advantage this is the time for explorative research.

Once a radical innovation is achieved, however, an exploitative research program is then in order (Carlisle and McMillan 2006).

7. Engineering Resources and the Constraints of Natural Law

Well designed – well engineered

The first tools were made by the hand of our hominid ancestors. After that it took the tools and/or the techniques that were used to make the older tools to create newer tools and/or techniques. This combination of tools and techniques is nothing more than the engineering resources we identify in Table 1. These engineering resources arise from the past products, services, systems and processes of the technosphere and evolve in a manner similar to living organisms. In fact engineering resources are an important part of the technosphere, for without these engineering resources no new tools or techniques could be created.

The designer is naturally constrained by the laws of nature but this does not usually present a problem unless someone is attempting to build a perpetual motion machine or a time travel machine.

8. Marketing Resources and Business Model

An innovation is a design that engenders or demands a new business model.

Marketing impacts on the success of a new design in three ways. One is the identification of what problems that the new technology will solve or what needs or desires will it satisfy. Once the product, service, system or process is designed then a business model must be generated to determine its commercial viability. The third and final step once the innovation is ready for the market place is to create the desire among potential customers to use and purchase the new innovation.

Identification of the practical application of a new tool or technology is the key factor contributing to its success. By designing starting with the needs and desires of potential users one increases the chances of a successful innovation. However, in many cases the designer starts with a technical capability and looks for a possible practical application. To illustrate this point let us consider two innovations designed by Thomas Edison. In the case of the home electric lighting distribution system Edison began with the desire and need of home dwellers to have a convenient and reliable source of lighting as was provided by the gas lighting system used in Edison's days. Edison made a very simple substitution of the home distribution of electricity that could cause a light bulb to shine instead of gas that was burned in a fixture and had an obnoxious odor and often caused fires. The practical application of his innovation was assured. The same was not true of his gramophone invention, which he thought would be used for taking dictations in an office environment. He never saw the killer application which was recorded music (Basalla 2002).

Although getting the science and engineering correct is a necessary condition for success it is not sufficient. One has to couple these factors with the correct identification of practical and desired applications. Papin, a physicist, created the first crude steam engine while investigating the nature of a vacuum but saw it only as an instrument for doing research. It was Newcomen and then Watt who identified their practical applications. The same goes for the transmission of radio waves first demonstrated by two physicists Hertz and Lodge. Lodge was able to transmit Morse code wirelessly. It was Marconi, however, who did not have a deep understanding of the physics of electromagnetic waves who found the first practical application of radio waves in ship to shore communication. The killer application of course turned out to be entertainment and gave rise to the medium that we simply call radio as though the other applications using radio waves don't count for much (Basalla 2002).

Once a potential application for a new product, service, system or process is identified the next step is to develop a business model (Fraser 2007) to ensure the commercial viability of the innovation. A business model must take into account an understanding of the dynamics of the marketplace, which includes an analysis of potential competitors as well as an understanding of what products, services, systems and processes are in demand in the marketplace. The first use of an invention is not always the one for which the invention succeeds and therefore identifying the target market for any technical innovation is essential. If one begins with the user's needs or desires this problem can be avoided.

Another factor that must be asked in determining the possible success of an innovation is to ask if one can deliver the new product or service at a price potential customers can afford and would be willing to pay. When Edison was designing his home electric lighting distribution system he carefully calculated the costs of delivering such a service to make sure that the price of electric lighting would compete favorably with the gas-based home lighting system with which he would have to compete. Price also played a key factor in the demise of the supersonic Concorde airplane despite its being a triumph of engineering. The impact of the price to the end user was not properly taken into account when the Concorde was designed. Factors such as national pride and engineering hubris blinded the designers to the practical matter of the affordability of a ticket. The cost benefit analysis for the traveler was not properly calculated.

The design of an innovation must include a first stab of a business model for the innovation, which can be later refined by client who is slated to bring the designed innovation to market. Traditionally a business model is developed for a business firm and not a product or service per se as the following definition of Osterwalder, Pigneur and Tucci (2005) indicates:

> A business model is a conceptual tool that contains a big set of elements and their relationships and allows expressing the business logic of a specific firm [or innovation]. It is a description of the value a company [an innovation] offers to one or several segments of customers and of the architecture of the firm [client] and its network of partners for creating, marketing, and delivering this value and relationship capital, to generate profitable and sustainable revenue streams.

In the above quote we have added the words in square brackets so that the definition could apply to an innovation instead of a firm or a company. This definition altered for an innovation gives a rough idea of the kind of business model that needs to be considered when designing an innovation to ensure the commercial success of the innovation one is designing. The details of the business model will depend on the nature of the innovation.

Another factor required for the success of an innovation is some good old fashion marketing or salesmanship as enthused by Coburn (ibid.).

> Great marketing causes epiphanies; it can help customers think one of two things: "Ah. I see! I really want that! In fact, I need it!"

A new product or service that does not succeed in the market place cannot be regarded as an innovation. The supersonic jet, the Concorde is an example of a well-designed technology that operated as designed but in the end failed for a lack of understanding of practical matters such as the market place and the impact of price which brings us to the next section.

9. Management, Collaboration and Finance

Well designed – well managed – properly financed

In addition to taking account the resources of the technosphere, engineering, the needs of potential users and marketing there are a number of practical concerns that also need to be addressed as well as the Concorde example demonstrated.

The process of the development of an innovative product or service from the inception of an idea to its design to its engineering or implementation to its introduction into the marketplace requires a significant amount of financing and hence risk. This is one of the elements of the management skills that are necessary to steer a brilliant idea for an innovation into a practical product or service. The greatest challenge in today's complex environment for management is to coordinate the many skills required for successful innovation and create an environment for the collaboration of the various players that are part of the innovation team.

Collaboration of the designer and the client is essential for the success of a project. The designer is like an artist concerned with the elegance and aesethics of their work whereas the client is in almost all cases a hard nosed business organization that will take the greatest risk in the project and has to make a profit to stay in business. The designer must not only design the product, service, system or process but must also design a way to sell the idea of the iinovation to the client and convince them to take the risk of bringing the innovation to market (Martin 2005). The designer must also collaborate with the client's sales and manufacturing departments so as to reduce the risk to the client (Martin 2006a).

Some Examples of Emergent Design and the Way the Design Ecosystem Operates

For each emergent design that we will examine we will describe the elements of the design ecology that gave rise to the innovation. We first describe the elements of the technosphere **from** which the innovation sprung. Next we describe the needs and desires of the uses **for** which the innovation was designed. We next describe the marketing effort that was mounted on behalf of the innovation. And finally we describe any special **management** concerns that were needed to insure the success of the innovation.

A. Graphic design: The technologies **from** which the Gutenberg movable type printing press descended were
the textile press, the grape press for winemaking and Chinese block printing press. The Gutenberg press met the needs of a new reading public spawned by the emergence of the medieval university and the Renaissance of classical learning both of which trends the printing press reinforced creating an even bigger market for it and the books that it produced. The printing press also found other applications as the producer of the family Bible and the propagation of the Protestant Reformation. The press also met the needs of scientists to capture and store their data in a reliable format that could be reproduced without errors.

The innovation was not just the product of Gutenberg but also his business partner who wrested control of one of the presses from Gutenberg in a civil suit. Fust used that press to print a 1000 Bibles which he sold in Paris for a huge profit and started the new industry of book publishing. Gutenberg continued to improve his invention and died a poor man.

Aldus Manutius invented the small portable book and the italic font to create a legible but small type font. The portable book descended from the large format books that were chained to the tables in the monastery and university libraries. The innovation answered the need of readers who wanted the convenience of a book they could read in the comfort of their domicile or while traveling. The portable book created a new market

B. Industrial design: The Watt Steam Engine
Watt's steam engine is descended from several sources in the technosphere including the pump, the windmill, the water wheel, and the Newcomen steam engine used to pump water from underground mines. The Newcomen engine was designed specifically for mining operations and was an immediate success. The Watt engine was designed to provide a convenient source of power for machinery that had been designed to exploit wind and water power with the windmill and the water wheel respectively. The Watt engine was able to translate linear motion into circular motion and hence could take advantage of the existing infrastructure used to exploit wind and water power. The Watt engine was subsequently adapted for transportation with the steamship and the steam locomotive. The needs of industrialist for a more reliable source of energy weer met with the steam engine.

The marketing of the steam engine and management of the enterprise were quite straightforward because of the enormous advantage of the technology over conventional sources of power.

C. Environmental design: Solar energy devices
One might say that solar energy devices are derived **from** green houses. They meet energy needs in an environment where non-renewable sources of energy and increasing in cost and are rapidly being depleted. They also help to slow the process of global warming. Smart marketing is required
to overcome the barrier to entry presented by the petroleum, coal and nuclear energy industries. Political action is also required to overcome government subsidies to these other sources of energy.

D. Advertising: The Internet
From Hammurabi stelae proclaiming the Law

For the need to inform
It's all about marketing and management

E. Illustration:
From Da Vinci drawings and Harvey's anatomy diagrams
For the need to visually conceptualize
Marketing tool

F. Material Arts and Design: Mechanized Production of Textiles
From Basket making, hand loom
For mass market of clothing manufacturers and homemade clothes market.
Marketing and management implications of the textile industry

Propagating Organization

In formulating design ecology we have suggested that there exists a parallel between nature's design and human design. One of the motivations of this approach is the fact that both the evolution of living organisms and technology represent propagating organization (Kauffman, Logan et al. 2007). In the case of living organisms there are two ways in which organization is propagated. One is from one generation to another of the same species through replication and the other is the way in which new life forms emerge in the biosphere through Darwinian pre-adaptation. One might say that the meaning of life is propagating organization.

There are two parallel forms of the propagation of organization that takes place in the world of design. As we pointed out in our last paper D4E&I (Van Alstyne and Logan 2007):

The concepts and organization of the technology are the 'design', in the sense of plan or blueprint, for… "design is creation for reproduction (Van Alstyne 2005)."

The second form of propagating organization in the technosphere is the way in which the designs of the past are modified and evolve to meet the needs of the future. Life evolves by natural selection. Design evolves by the natural selection of the market place. Design started with tool making and the control of fire by Homo Designus.

Preliminary Conclusion

Identifying and attending to the correlation of all processes within the design ecosystem is absolutely necessary if one wants to create an innovative product or service that will make a difference. All successful innovations of the past have attended to these processes. In certain cases some processes in the innovative design ecosystem were intuited by the designer, who had the instinct to read all the components of the design ecology and incorporate them into their innovation or invention.

Appendix I

A Formal Argument for the Notion that the Relationship between Innovative Design and Design Ecology is One of Emergence

In this appendix we make a formal argument that there is a direct analogy between the elements of the design ecology that were identified in Table 1 and innovative design with the relationship between the components of a complex system and the emergent phenomenon that arises from the interactions of these components. We make use of a formalism developed by Philip Clayton (2004).

An emergent phenomenon arises from the complexity and interaction of a set of components that make up the emergent phenomenon. The design ecology provides the components that interact with each other and emerge as an innovative or emergent design. The components of the design process are precisely the elements of the design ecology listed in Table 1.

Let us define the set L1 as the set of elements that make up the design ecology as listed in Table 1. Let us define the set L2 as the innovative designs that emerge through the design ecology, L1. With this definition of L1 and L2, we suggest that the set L2 emerges from the set L1 in the classical sense of emergence since the properties of L2 cannot be predicted from, derived from or reduced to those of L1. This emergence parallels the emergence of life from organic chemistry as an example.

Using Philip Clayton's (2004) description of the emergence of a level L2 from a less complex level L1, it becomes clear that innovative design is an emergent phenomenon and L2 emerges from L1, the design ecology. Clayton describes the relationship between two levels L1 and L2 where L2 emerges from L1 as follows:

For any two levels, L1 and L2 where L2 emerges from L1,
(a) L1 is prior in natural history.
(b) L2 depends on L1, such that if the states in L1 did not exist, the qualities in L2 would not exist.
(c) L2 is the result of a sufficient complexity in L1. In many cases one can even identify a particular level of criticality which, when reached, will cause the system to begin manifesting new emergent properties.
(d) One can sometimes predict the emergence of some new or emergent qualities on the basis of what one knows about L1. But using L1 alone, one will not be able to predict (i) the precise nature of these qualities, (ii) the rules that govern their interactions (or their phenomenological patterns), or (iii) the sorts of emergent levels to which they may give rise in due course.
(e) L2 is not reducible to L1 in any of the standard senses of 'reduction' in the philosophy of science literature: causal, explanatory, metaphysical, or ontological reduction. (ibid., p. 61)

Taking L2 to be innovative designs and L1 to be the design ecology then each of the 5 conditions that Clayton articulates are satisfied.

(a) L1 certainly took place before L2.
(b) L2 would not be possible without L1 as L1 contains the pre-adaptations and pre-conditions for the innovative designs of L2.
(c) L2 is certainly more complex that L1 as L2 now contains all of L1 and the new innovative designs.
(d) One cannot predict on the basis of the products, services and technical, marketing and financial capabilities of L1.
(e) The innovative designs cannot be reduced to the products, services, systems and processes of L1 as the innovative designs satisfy the expectations, needs, and desires of the culture that were not previously addressed in any of the senses of reduction identified by Clayton in (e) above.

Appendix II
Some Examples of Emergence

The way in which innovative designs arise as emergent phenomena parallels the emergence of other emergent phenomena such as cybernetic systems, living organisms, human language, conceptual thought and human culture. Therefore before exploring the way in which the elements of the design ecology interact to bring about an innovative and emergent design let us first examine the way in which other emergent phenomena emerge from the interactions of the components of which they are composed.

In general an emergent phenomenon is one in which new patterns of behavior arise in a composite system from the interactive processes or mechanisms of the components of which the composite system is composed. As iterated above these new patterns of behaviour cannot be explained by, predicted from or reduced to the behavior of the individual components of the composite system.

The emergent mechanism by which an self-reproducing and self-regulating cybernetic systems emerges was formulated as autopoiesis by Varela and Maturana (1973, p. 78):

An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in space in which they (the components) exist by specifying the topological domain of its realization as such a network.

Varela and Maturana thought of the living cell as one example of an autopoietic system. Stuart Kauffman (1993), a theoretical biologist, described the origin of life from complex molecules as an emergent phenomenon through the mechanism of autocatalysis in which he explicitly identified the chemical mechanism whereby the living cell emerges:

At its heart, a living organism is a system of chemicals that has the capacity to catalyze its own reproduction… What I call a collectively autocatalytic system is one in which the molecules speed up the very reactions by which they themselves are formed: A makes B; B makes C; C makes A again… What I aim to show is that if a sufficiently diverse mix of molecules accumulates somewhere, the chances that an autocatalytic system—a self-maintaining and self-reproducing metabolism —will spring forth become a near certainty. Life at its roots lies in the properties of catalytic closure among a collection of molecular species (Kauffman 2000, pp. 49-50).

The terms autopoiesis and autocatalysis entail the notion of self-organizing and self-reproducing systems and are equivalent. From this point forward we will use the term autocatalytic instead of autopoietic because of the way in which the term autocatalysis conjures up the notion that the components of a composite emergent system reinforce or catalyze each other. The resulting behaviour of the composite system cannot be explained in terms of the properties of its components just as the properties of salt so vital to living organisms cannot be understood in terms of the properties of the highly reactive metal sodium and the poisonous gas chlorine of which salt or sodium chloride is composed. The term autocatalysis has also found its way into the sociology and economics literature. Our use of the term autocatalysis will therefore embrace the notion that any set of mechanisms or ideas that catalyze or regenerate each other's existence is an autocatalytic set of mechanisms or ideas.

The Emergence of Language and Conceptual Thought as an

Autocatalytic Set of the Elements or Mechanisms

Logan (2006 & 2007) suggests that spoken language arose as an emergent phenomenon because hominid existence became too complex to be handled by perceptual thought alone. Language emerged as a form of conceptual thought in which our first words were our first concepts. “A word is a strange attractor for all the percepts associated with the concept represented by that word. A word, therefore, packs a great deal of experience into a single utterance or sign (ibid.).” From the interaction of all the percepts associated with a certain concept a word emerges as a concept. Furthermore as a result of all the words interacting with and catalyzing each other language arises as an emergent phenomenon, a semantic web. In addition language and conceptual thought form an autocatalytic set because language catalyzes conceptual thought and conceptual thought catalyzes language. With language the human brain which was originally a percept processor before language bifurcates into the human mind which is both a percept processor and an analytic machine capable of abstract symbolic thought and dealing with objects and situations not immediately available by direct perception. This latter capability makes planning possible, a skill which is uniquely human.

We claim that language is an emergent phenomenon that emerged from the autocatalysis of the various mechanisms that make speech possible including: vocal articulation, vocal imitation, phonemic generativity, lexical creation, morphology, conceptual representation, comprehension, a theory of mind, joint attention, altruistic behaviour, syntax especially recursion, grammaticalization, and generativity of propositions. Speech also serves two functions, that of social communication, and conceptualization or a medium for abstract thought. The skills of linguistic representation and abstract symbolic thought are truly emergent phenomena in that they cannot be derived from, predicted from or reduced to the percepts nor the mechanisms listed above which when combined in the human brain gave rise to language and the human mind.

The Autocatalysis of Culture

Culture is also an emergent phenomenon in which the lessons learned by the individuals of a society become the components of which it is composed. As suggested by the anthropologists Boyd and Richerson (1985, p. 14):

Individual learning... can be costly and prone to errors. Learning trials occupy time and energy that could be allocated to other components of fitness, and may entail a considerable risk to the individual as well… When these costs are important, selection ought to favor shortcuts to learning—ways that an organism can achieve phenotypic flexibility without paying the full cost of learning. Cultural inheritance is adaptive because it is such a shortcut. If the locally adaptive behavior is more common than other behaviors, imitation provides an inexpensive way to acquire it.

The lessons learned in a society build one upon another to create a constantly evolving and progressing culture which Tomasello, Kruger and Ratner (1993) have dubbed "the ratchet effect." Culture also emerges as a result of the interactions of the members of a society in the form of "a system of inherited conceptions expressed in symbolic forms by means of which men communicate, perpetuate and develop their knowledge about and attitudes towards life (Geertz 1973)." A culture is a semantic web of these conceptions and an emergent phenomenon in which the web exhibits properties not possessed by individuals or individual cultural conceptions. Each of the elements of the culture autocatalyze each other. A design ecology is a particular subset of a culture and hence also an emergent phenomenon which is focused on the expansion of the technosphere, the set of all the technologies, methods and processes of the culture.

References

Basalla, George. 2002. The Evolution of Technology. Cambridge: Cambridge University Press.

Boyd, R. and P. H. Richerson. 1985. Culture and the Evolutionary Process. Chicago: University of Chicago Press.

Buxton, Bill. 2005a. First Annual Alberta Ingenuity Lecture. Innovation Alberta. (www.innovationalberta.com/article.php?articleid=669)

__________. 2005b. Innovation vs. invention? Rotman Magazine: Fall 2005**.** (www.bill**buxton**.com/innovationInvention.pdf).

_________. 2006. What if Leopold didn't have a piano? Rotman Magazine: Spring/Summer 2006. (www.billbux**t**on.com/leopold.pdf)

Carlisle, Ysanne and Elizabeth McMillan. 2006. Innovation in organizations from a complex adaptive systems perspective. Emergence: Complexity and Organization 8(1): 2-9.

Christiansen, Morten. 1994. *Infinite languages finite minds: Connectionism, learning and linguistic structure.* Unpublished doctoral dissertation, Centre for Cognitive Studies, University of Edinburgh UK.

Christiansen, Morten. 1995. Language as an organism - implications for the evolution and acquisition of language. Unpublished manuscript, Washington University.

Clayton, Philip. 2004. Mind and Emergence: From Quantum to Consciousness. New York: Oxford University Press.

Coburn, Pip. 2006. The change function. Fast Company 115: 27 (May 2006).

Deacon, Terrence W. 1997. The Symbolic Species: The Co-evolution of the Brain and Language. New York: W. W. Norton & Co.

Fraser, Heather 2007. Private communication. The idea to include a business model explicitly in the design ecology emerged from a conversation with Heather Fraser at Design Works in Toronto on April 30, 2007.

Frosch, R.A. and N.E. Gallopoulos. 1989. Strategies for manufacturing. Scientific American 261: 144-152.

Geertz, Clifford. 1973. The Interpretation of Culture. New York: Basic.

Kane, Pat. 2007a. The implicit game. http://blog.game-play.org.uk/?q=PAT_KANE. Accessed April 26, 2007.

_________. 2007b. The power of play. http://www.lwbooks.co.uk/journals/articles/kane06.html Accessed April 26, 2007.

Kauffman, Stuart A. 1993. The Origins of Order: Self-Organization and Selection in Evolution. New York: Oxford University Press.

_________. 2000. At Home in the Universe: The Search for the Laws of Self-Organization and Complexity. New York: Oxford University Press.

Logan, Robert K. 2004. The Sixth Language: Learning a Living in the Internet Age. Caldwell NJ: Blackburn Press (1st edition 2000. Toronto: Stoddart Publishing).

_________ 2006. The extended mind model of the origin of language and culture. In Nathalie Gontier, Jean Paul Van Bendegem and Diederik Aerts (Eds). Evolutionary epistemology, language and culture. Dordrecht: Springer.

_________ 2007. The Extended Mind: The Origin of Language and Culture. In press.

Maturana, Humberto and Francisco Varela. 1973. *Autopoiesis and Cognition: the Realization of the Living*. In Robert S. Cohen and Marx W. Wartofsky (eds.). Boston Studies in the Philosophy of Science 42. Dordecht: D. Reidel Publishing Co.

Moore, James F. 1993. Predators and Prey: A New Ecology of Competition. Harvard Business Review May/June 1993.

_________1996. The Death of Competition: Leadership and Strategy in the Age of Business Ecosystems. New York: HarperBusiness.

March, J. G. (1991). "Exploration and exploitation in organizational learning," Organization Science, ISSN 1047-7039, 2(1): 71-87.

Osterwalder, A., Y. Pigneur and C. Tucci. 2005. Clarifying business models: Origins, present, and future of the concept. Communications of the Association for Information Systems 15: 1-40.

Rhea, Darrel. 2003. Bringing clarity to the “fuzzy front end”. Brenda Laurel (ed) Design Research: Methods and Perspectives. Cambridge MA: MIT Press. [page range]

John Maynard Smith. 1995. Genes, Memes, & Minds. New York Review of Books. Vol 42, #19 (November 30. 1995).

Van Alstyne, 2007 [create entry here based on unpublished forthcoming course outline for Think Tank 1]

Van Alstyne, Greg, Tobias Lau and Britt Welter-Nolan. 2005. “Mapping ‘Design Ecosystems’” in *Massive Change in Action*. Canadian Heritage Information Network (www.massivechangeinaction.virtualmuseum.ca/toolkit/activities)

Van Alstyne, Greg and Robert K. Logan. 2006. Designing for Emergence and Innovation: Redesigning Design. Artifact [get full citation]