A Conceptual View of Organizational Evolution

by Dr. David Gould

January 2024

A Conceptual View of Organizational Evolution

Nothing in organizations makes sense except in the light of evolution.

Paraphrasing Theodosius Dobzhansk's comment on biological evolution,
"Nothing in Biology Makes Sense Except in the Light of Evolution"

ABSTRACT

Evolution is a well-established biological theory, and basic concepts can be abstracted and applied to nonbiological domains such as organizations. There is a gap in the literature regarding how evolutionary processes can be applied to domains other than biology. While this gap is closing, it is still debated and argued. This paper includes a general evolutionary algorithm and an abstract limits-to-success network model to explore examples of how evolution is applicable to nonbiological systems. This paper provides a theoretical approach to generalizing evolution rather than closing a gap in the literature.

Keywords: Adjacent Possible; Evolution; Limits to Success; Organizations; Systems

INTRODUCTION

This early-stage research-in-process paper explores primary evolutionary metaprocesses and relates them to organizations using the limits-to-success archetype among other systems concepts. A limited literature review is provided, along with some analysis. A set of definitions, examples, and models are provided and explored. Examples of organizations going extinct are many and a few will be covered. Some of the concepts in this paper were previously introduced by Gould and Cleveland (2018). The paper concludes with some parting thoughts.

RESEARCH METHOD

This study is a research-in-process approach to abstracting biological evolution concepts to nonbiological domains, in this case, organizations. Secondary data collected are from a review of the literature as well as historical and current observations of organizations. Analysis is comparative, explored via an adjacent possible, and a networked limits-to-success model is developed to provide an explanation regarding generalized evolution.

LITERATURE REVIEW: CONCEPTS OF EVOLUTION

Forrester (1971) and Meadows (2008) argued that a system is a set of components or parts that function together to achieve some purpose. A network of interactive nodes or agents is part of a system and these agents may interact with each other as well as with their environment. Relationships between agents may be strong, weak, somewhere in between, or null; or static or dynamic, among many other types. The type of network or networks illustrate systems structure as matter, energy, and messages (information +) flow into, though, and out of these systems via agents and their interconnections; systems exhibit behavior, and some systems exhibit some form of change or dynamics over time such as transitional, transformational, adaptation or learning, or evolutionary.

Mobus and Kalton (2015) offered a formal definition of a system as a 6-tuple, described by a set of subsystems, a network or networks, the set of nodes inside and outside the system, the boundary conditions, the interactions among the nodes, and the history of the system. While there is no specific consensus on the definition of a system, there is some convergence about some of the properties. Some fundamental principles noted by Mobus and Kalton are that systems (biological and nonbiological) are bounded, contain subsystems, are composed of networks, exhibit behavior, interact with other systems, have a life cycle, and evolve.

Hull (1988) and Aldrich et al. (2008) argued for a concept called generalized Darwinism. That is, the general principles of Darwinism apply not only to biological evolution but to the evolution of many nonbiological domains as well. This argument is consistent with Ziman (2000), who noted that theories, laws, and organizations evolve by processes of mutation and/or recombination.

Fichter, Pyle, and Whitmeyer (2010) noted "if we define evolutionary change as any process that leads to increases in complexity, diversity, order, and/or interconnectedness then there are at least three distinct mechanisms, or theories of evolution: elaboration, self-organization, and fractionation" (p. 59). The authors concisely identified the general evolutionary algorithm as the cycle of elaborate diversity, select from the diversity, amplify the selection, and repeat. Beinhocker (2010) further described these key processes as variation, selection, amplification, and repeat.

Evolutionary theory notes that nature experiments, yet few are successful as argued by Fichter, Pyle, and Whitmeyer (2010). The authors continued "elaborating evolution begins with a seed, an ancestor, or a randomly generated population of agents (individual interacting units, like birds in a flock, sand grains in a ripple, or individual units of friction along a fault zone), and evolves by generating, and randomly mutating, a large diversity of descendants which are evaluated by an external fitness function; those that do not measure up are selected out" (p. 59). Certainly, this is true for organizations as well as they experiment through new products, processes, algorithms, managers, technologies, and such as they adapt and/or mitigate changes in their environment. This same principle can be applied to systems of knowledge. That is, multiple variations may be generated, with selection reducing the number that are successful. For example, organizational learning is a critical factor for change and innovation in organizations and results from knowledge acquisition, information distribution, information interpretation, and organizational memory. Corporate performance is improved with the conversion of explicit to tacit knowledge as Nonaka et al. (1995) noted.

Self-organizing theories are used to explain how networks evolve (from the World Wide Web to social networks, to ecosystems) as Barabasi (2003) noted. Fichter, Pyle, and Whitmeyer (2010) noted "self-organizing evolution begins with an initial state of random agents that through the application of simple rules of interaction among the agents (e.g. an algorithm, or chemical/physical laws) evolves a system of ordered structures, patterns, and/or connections without control or guidance by an external agent or process" (p. 60). Banzhaf (2009) noted "self-organization refers to the ability of a class of systems (self-organizing systems (SOS)) to change their internal structure and/or their function in response to external circumstances. Elements of self-organizing systems are able to manipulate or organize other elements of the same system in a way that stabilizes either structure or function of the whole against external fluctuations. The process of self-organization is often achieved by growing the internal space-time complexity of a system and results in layered or hierarchical structures or behaviors. This process is understood not to be instructed from outside the system and is therefore called *self-organized"* Beinhocker (2010) noted "this led to a further interpretation of evolution as a bootstrapping algorithm that uses free energy to create order in complex systems. In other words, evolution could be viewed as both shaped by forces of self-organization, and as a process for creating self-organization" (p. 398).

Figure 1 illustrates a conceptual model of evolution linking three principles of the general evolutionary algorithm: variation (differentiation), selection (environmental fitness), and retention (amplification or deamplification) using the limits-to-success archetype or model described by Senge (2006). While some minor differences in terminology exist regarding the abstract processes of evolution, they are useful in thinking about organizational change. Berlinski (2000) noted, "an algorithm is a finite procedure, written in a fixed symbolic vocabulary, governed by precise instructions, moving in discrete steps 1,2,3, …., whose execution requires no insight, cleverness, intuition, or perspicuity, and that sooner or later comes to an end" (p. xvii). Thus, the general evolutionary algorithm provides insight into system change as all systems vary and they change given endogenous and/or exogenous pressures. The left-hand circle is about amplification or positive feedback, which increases the number of possibilities, and the right-hand circle is about selection or negative feedback, which reduces the number of possibilities. Evolution as an algorithm is then, evolution is computation as noted by Beinhocker (2010).

Figure 1

A Conceptual Model of Evolution

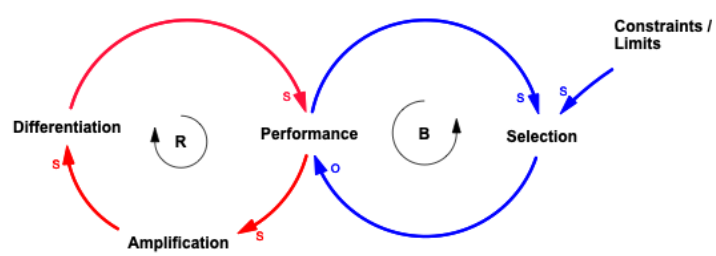


Figure 2 is an extension of Figure 1 illustrating experiments, planned or unplanned, lead to differentiation and subsequent performance. The most fit are selected to live while those less fit may decline and/or go extinct. Those selected have an opportunity to increase their numbers and may or may not need additional experimentation for some period of time. The cycle repeats.

Figure 2

An Expanded Conceptual Model of Evolution

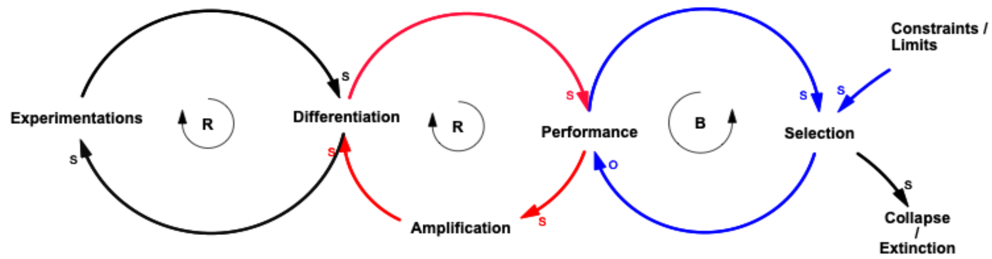


Figure 3 is a simple conceptual model of an open system illustrating inputs and outputs of material, energy, and messages (information +). As organizations are open systems, this model is inclusive as well. Organizations input resources that can be categorized as material, energy, and messages (information +). For example, material for a bakery includes flour, salt, sugar, baking pans, and such; messages or information includes recipes, customer preferences, prices of resources, and such; and energy includes electricity, natural gas, and such. Tipping points for organizations include bankruptcy, being acquired, or simply going out of business for various reasons.

Figure 3

A Simple Systems Model (Abstract Context Diagram)

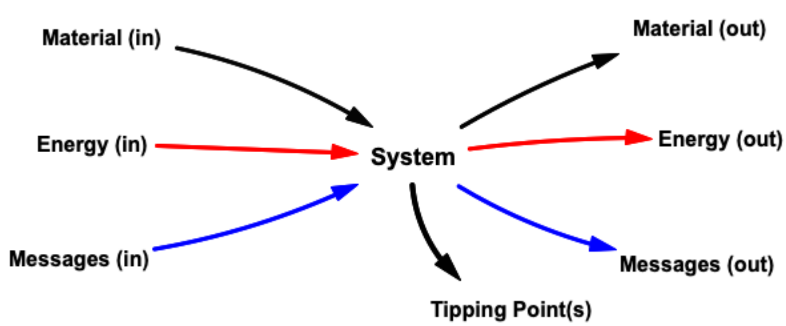
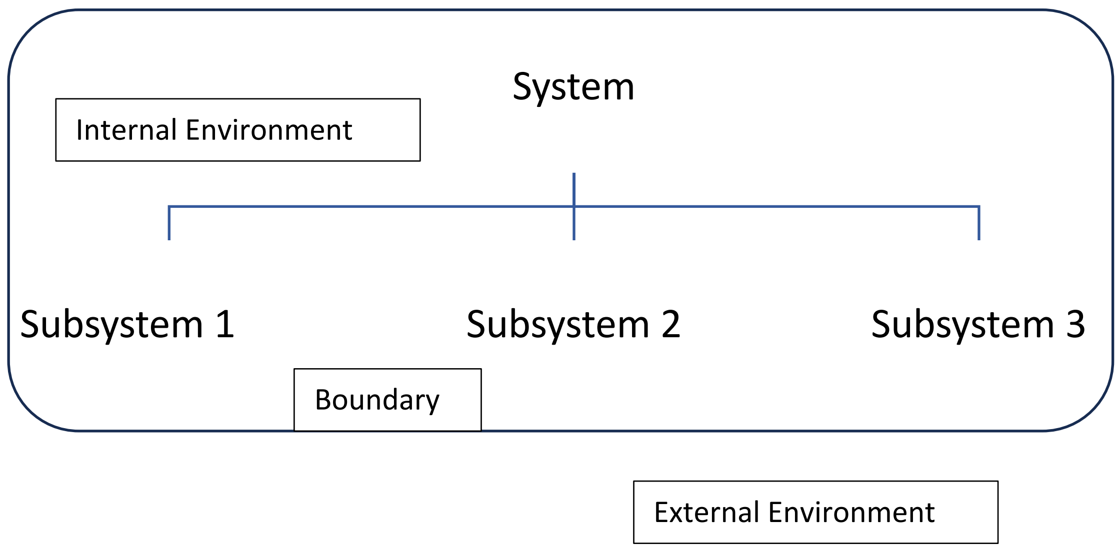


Figure 4

A System with Three Subsystems



Each subsystem may be functionally decomposed into sub-subsystems as practical (see Figure 4). At some point, functional decomposition stops. There being no practical or physical reason to continue. The boundary may be solid, porous, permeable, semi-permeable, or other type. The external environment consists of everything not included in the system.

Material, energy, or messages (information +)--MEM, are resources and are inputs (inflows) to a system, through a system, and outputs (outflows) from a system. Inflows may be stored within a system as an accumulator or stock. An organization might have several types of stock: input storage, in-process storage, and output storage. Inputs, outputs, and throughputs can be measured in units per time. For example, a small coffee shop might purchase 200 pounds of coffee per week, have revenues of $10,000 per week, have expenses of $8,000 per week, and make 1,000 coffee drinks per week.

Arthur (2009) explored technology as an evolutionary system. Consider the common or ubiquitous technological product—the widget. Once a widget is developed and commercialized, it undergoes selection in the marketplace and if it survives, it can be replicated, and its numbers may increase and it may be considered successful. Widget derivatives, or variations, may be introduced to the marketplace to capitalize on its success. Innovation operates exogenously or intentionally to create these derivatives or variations. Improving the capability to innovate increases diversity and reducing the time-to-market increases the velocity of the cycle. Arthur argued that technological evolution occurs exogenously as technologies combine or recombine to form new products or technologies. Mass production can create almost any number of identical copies given sufficient resources. Over time, one or more of these technologies can be combined with other technologies to create yet new technologies.

Aldrich, Ruef, and Lippmann (2020) restated the general evolutionary algorithm as the processes of variation, selection, and retention and summarized a set of organizational perspectives (ecological, institutional, interpretive, organizational learning, resource dependence, and transactional cost economics) mapped to these evolutionary processes. Table 1, Row 2 includes the ecological perspective. The remaining perspectives, institutional, interpretive, and others are not provided in this paper for simplicity. The ecological perspective illustrates that variation or differentiation is introduced via new organizations. Yet as existing organizations can adapt by changing products, processes, location, M&A, and so on to become something different.

Table 1

Organizational Perspectives Mapped to Evolutionary Processes

Perspective	Variation	Selection	Retention
Ecological	Variation introduced via new organizations	Selection results from fit between organizations and environment	Retention through external pressures and internal inertia"

Digiammarino (2018) described five stages or evolutionary growth stages of organizations along with some key characteristics and concerns at each evolutionary stage. These stages or processes are:

1. Idea / Concept (phases)
2. Startup
3. Growth
4. Sustainable
5. Mature

These stages map to the general evolutionary algorithm or the model of differentiation, selection, and retention/amplification where the idea/concept corresponds to initialization; startup corresponds to differentiation; growth corresponds to amplification by surviving at least one pass through selection; and sustainable and mature correspond through multiple passes through selection. Few business organizations last more than 21 years, before decline and eventually collapse and extinction occurs. Statista (2020) reported that the average lifespan of a company on the S&P 500 Index was about 21 years. The information technology industry contains many examples of business organizations that leveraged good ideas, became successful, and then collapsed and became extinct. Some recent examples include BlockBuster, Borders, Compaq, Data General, DEC, Lotus, Pan American, Tower Records, Toys R Us, and many others.

Figure 5 illustrates planned (deliberate or intentional) and unplanned (nondeliberate or nonintentional) approaches to evolution. This figure illustrates planned and unplanned approaches to evolution and their directed conceptual influence on artificial, social, biological, and natural systems. Social systems contain organizations among other types of systems such as societies, teams, groups, and so forth.

Artificial systems such as artificial societies, cars, and airplanes evolve via planned approaches. Programmers tweak algorithms, observe over time, and select some for another cycle. Engineers and designers tweak car or airplane components to differentiate and evolve them. At present, I am not aware of any artificial systems evolving via an unplanned approach.

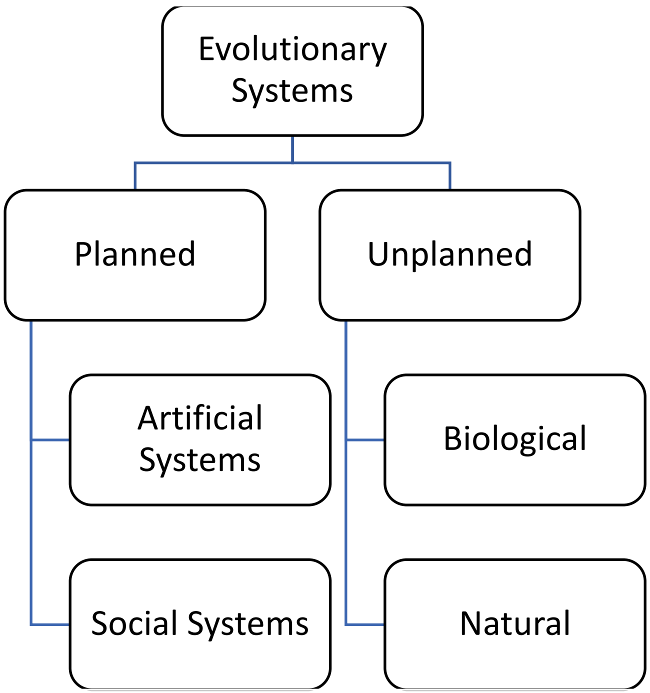
Social systems such as organizations, are influenced by both planned and unplanned behavior. Managers develop and apply strategic and long-range plans as well as short-term tactical plans to drive their organizations forward. The projected outcomes are organizational differentiation with new and updated product offerings, new and updated processes, new management, and so on. Environmental threats and opportunities may influence an organization in unplanned ways when not anticipated by organizational leadership. One notable example is Kodak, which misread environmental signals regarding the demand for digital photography, with the outcome of Kodak declaring bankruptcy. Another example of unplanned change for social systems include conflict such as competition or even war. Unplanned environmental changes to social organizations include earthquakes, fire, flooding, and climate change.

Biological evolution is essentially unplanned as seen in the biological world. Yet, there are many exceptions, primarily in the domestication of both animals and plants. For example, most agricultural products such as wheat and corn today are the outcome of years of planned evolution and today's dogs and cats are products of planned evolution, wherein sexual selection is just another form of biological selection.

Natural, but nonbiological, systems may evolve via both planned or intentional and unplanned or unintentional approaches. The evolution of the universe with its trillions of stars, solar systems, planets, comets, and such is an example of unplanned evolution. Damming rivers (technology) is a planned approach to evolving a natural system (a river) to generate electricity. Dredging a river or stream is another approach to evolving natural systems. Dams can be updated for example, thus being changed themselves and changing the natural system (river) itself.

Figure 4

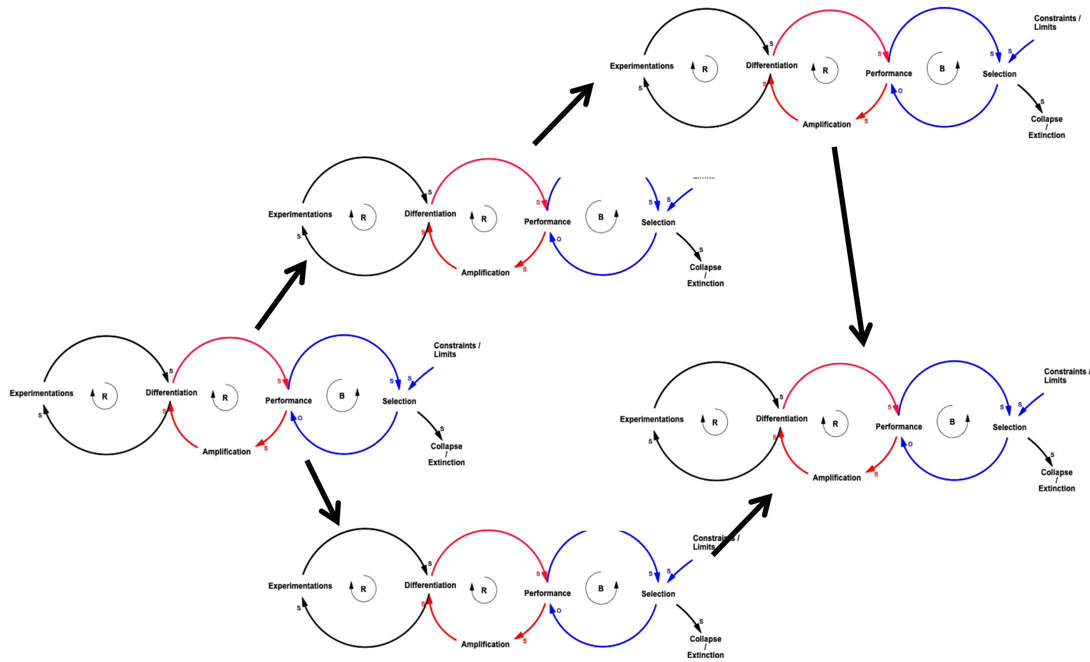
Types of Evolutionary Systems



The three meta-processes of biological evolution are differentiation (reproduction, replication, self-organization), selection, and amplification or elaboration with retention/inheritance. The key idea in these processes is that it is not the physical organisms per se that are replicated, it is the variation in the rules of development or DNA that changes due to variation or mutation. Similarly, changes in the rules for new organizations, generate new organizations subject to fitness, selection, and retention. A new organization may well adopt the template for a corporation but tweak some aspect of it (experimentation and innovation) to change it. Then, this new organization will be tested for fitness in the marketplace. There are several aspects of change: accident, innovation, response to changing environmental conditions, responding to a problem to be solved, responding to an opportunity, something to be fixed, a mandate, or addressing an opportunity or basically, improvement. See Figure 5 for a conceptual diagram of systems (organizations) that evolve, spin off new organizations in a cyclical evolutionary and perhaps coevolutionary process.

Figure 5

A Network of Evolutionary Systems



ANALYSIS

Initialization or Startup

All systems have an origin point at which it begins its evolutionary limits-to-success cycle of survival: differentiation, selection, amplification, and then another iteration and so on. That is, it begins its evolutionary journey. Along the journey, a system goes through the life cycle stages of growth, maturation, decline, and eventual collapse and extinction. An organization may have an origin point as a spin-off from an existing organization, it may start as a realization of someone's dream, it may be a merger of two or more organizations, it may be an organization morphing from something to something else, or it may have a different origin point. But, once initialized or started, organizations are subject to these three evolutionary processes as they compete to survive in the marketplace.

Differentiation / Variation

Change drives variation or differentiation. Change can be internal to an organization or external to it. A mutation will create a change in biological DNA while cultural change, teleological change, social cognition, and life cycle change affects social systems such as organizations. Change such as conflict (dialectic) and cooperation are both internal and external to social systems. External changes may be perceived as threats or opportunities, while internal changes may be perceived as strengths or weaknesses.

Inheritance is important in biology, as this process passes key traits to the next generation as a means of differentiation. Education, training, documentation, and various artifacts are used to pass on knowledge traits to the next generation in organizations as a means of inheritance. Every organization differentiates itself from other organizations over time based on its fitness in its environment. An organizational environment includes the economy, technology, society, government, its competition, and the physical environment (see Figure 6). As the environment changes, an organization changes with it (adaptation or mitigation) or it declines. This change is seen in the limits-to-success model.

Organizations differentiate by several means such as introducing variation into products, processes, technology, strategy, and such to adapt to new circumstances, to mitigate environmental situations, and/or to respond to competition. One approach to variation is to bring out new product versions every year or so as the automotive industry does or as Apple does. Many organizations revisit and update strategic plans every few years as circumstances dictate. The organizational environment continually changes as the environment, technology, economy, society, government, and competition change and interact in numerous and unpredictable ways. Differentiation is and can be generated by various means.

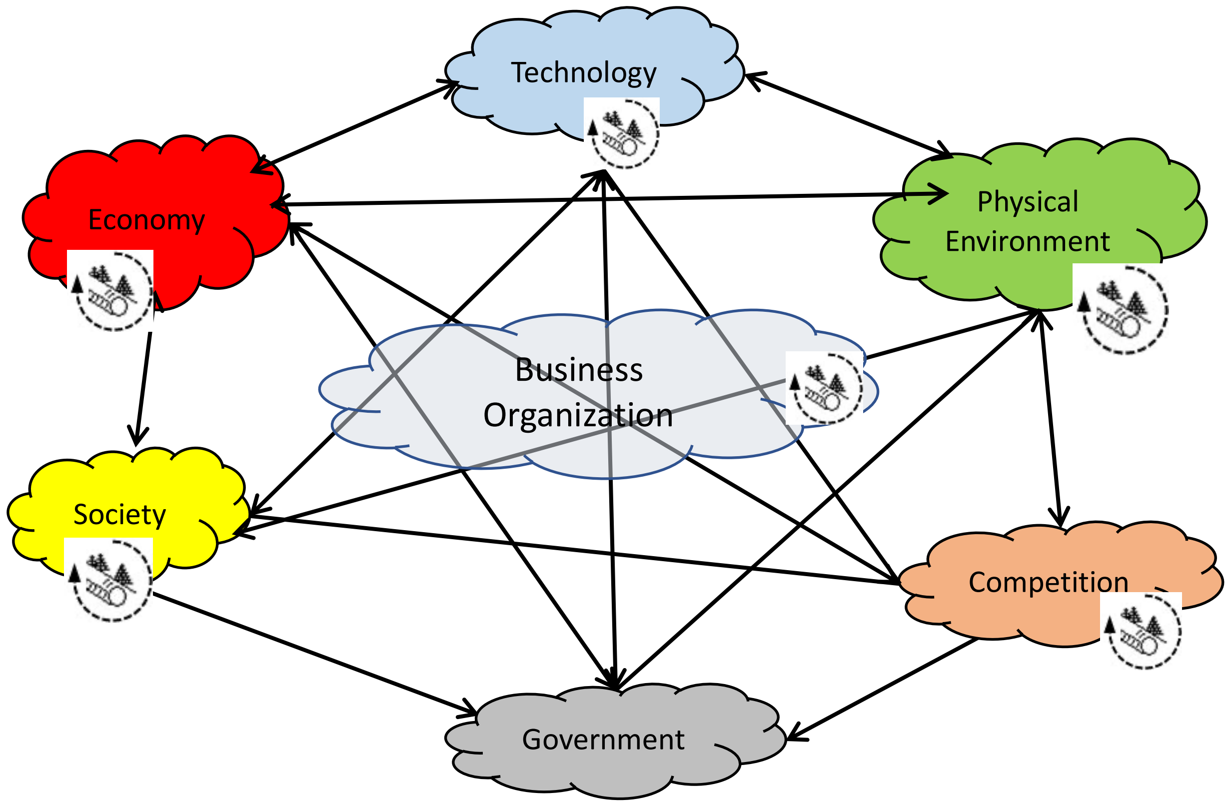
As previously noted, nature experiments drive variation, and the more fit variations are selected to reproduce and the cycle repeats. Similarly, organizations experiment to drive differentiation. Organizations experiment through trial and error to create or improve something; the more fit the creation or improvement is, the more likely it will be selected and retained for future use and/or improvement. This trial-and-error approach to learning drives the evolutionary processes of variation, selection, and retention.

Organizations have a wide variety of tools and techniques to differentiate such at strategic planning, organizational development, adaptive learning, total quality management, business process reengineering, and dozens of others. The adjacent possible is an approach for a system to differentiate and expand by changing boundaries, combining or recombining various elements, increasing or decreasing network connections, and so on. Innovation and experimentation are approaches business organizations can take to drive the adjacent possible. The innovation in products, processes, strategies, and so on are examples of the adjacent possible. The concept of the *adjacent possible* was introduced by Kauffman (2000) in evolutionary biology to explain how biological evolution is an exploration of what is adjacent possible. Essentially, the adjacent possible is a next possible step, that is, adjacent to what exists. That is, an adjacent possible is not a step to far, but a next possible step. Essentially, experimentation and innovation drive differentiation in a search through a possible design space.

Figure 6 illustrates the environment an organization lives in and is composed of technology, economic, physical environment, society, government, and competitive subsystems, each of which is a complex adaptive system and evolves. Each of these subsystems interacts with every other subsystem in an increasingly complex co-evolutionary complex adaptive system.

Figure 6

A Conceptual Model of the Organizational Environment



Consider the first desktop computers as an example. Several technologies came together to make the desktop a viable product—hardware such as disk drives, processors, and memory; software such as an operating system and applications. The convergence of hardware and software also required an affordable economic component. That is the desktop had to become affordable at a sufficient scale for companies to build it, sell it, and make a profit. Finally, there had to be a sufficient societal affordable demand for such a product. As these factors came together with the first Apple and IBM PC, a new industry was launched and within it, dozens of new companies were started, and competition developed. Over time, the PC industry developed newer technologies, improved older technologies, and combined and recombined them in novel and interesting ways (Arthur, 2010; Seba & Arbib, 2020). From the mid-1990s to the present, stationary desktop computers have increased in power, decreased in size, decreased in price, and added high-speed communications resulting in laptops and cell phones along with mobile Internet. From Bill Gates, a desktop in every home, we now have a cell phone in everyone's purse or pocket.

From Figure 3, material, energy, and messages (information +) are input to organizations and transformed into different material, energy, and messages (information +) that are called products or services and sold in the marketplace. As new materials, energy, and messages (information +) become available at affordable prices, organizations adopt them, and throughput processes change to produce new products or services. If existing organizations are slow to adopt, new companies may start-up and without an installed base, adopt new materials, ideas, and energy sources to disrupt and potentially replace existing organizations (Christensen, 1997) as recently seen with Kodak. The camera and film industry were disrupted and mostly replaced by digital technologies.

Performance

Organizations compete in the marketplace, explore new opportunities, fight off challengers, exploit strengths, and repair weaknesses. Not all organizations will be successful. Many organizations will fail as noted by McKinsey (n.d.). Organizational performance leads to selection. The marketplace, not natural selection, is the process organizations experience. Successful performance is rewarded while not-so-successful performance is not. Better performance is the path to success and survival.

Selection

The process of selection, based on some fitness criteria such as performance, is negative feedback and acts to reduce the numbers of competing organizations. Science and decision making are examples of a selection process in action as they both generate alternatives and select among the most fit among them according to Hull (2001). For example, scientific experiments may generate several possibilities, from which testing and evaluations may select one or two of the best or fittest. Some, but not all cyber security variations in processes, products, or algorithms will be successful. Instead, they will fall on some continuum of failure to successful. Assessment is needed here to find those variations most successful. Selection in this sense is a filtering process, screening out the best from the not-so-best based on some fitness criteria.

Selection acts as negative feedback on populations thus reducing the numbers. Selection takes current limits in the physical environment, economy, and so on, as well as competition among entities within a population. As Beinhocker (2006) noted “business faces two basic demands: it must execute its current activities to survive today’s challenges and adapt those activities to survive tomorrow’s” (p. 77). Given that few business organizations survive more than 20 years, few organizations successfully adapt to the future, as McKinsey (n.d.) noted that within the Standard & Poor’s 500, the average life-span was 61 years in 1958 and today it is less than 18 years.

Selection may include competition, cooperation, adaptation, and mitigation processes. Each of these subenvironments: technology, the economy, the physical environment, society, government, and competition (see Figure 6) are complex adaptive systems and are evolving, interacting with each other, and co-evolving with each other as well. Thus, selection in terms of organizations is a complex process and difficult to predict or forecast in terms of time.

Amplification/Elaboration/Retention/Inheritance

Retention is about keeping what works. The most successful systems or organizations that survive the selection process live to amplify, reproduce, or replicate or to at least remain the same before beginning another cycle of differentiation, selection, and retention. The cycle continues until a system is no longer selected by its environment, at which point it will no longer exist. Thus, organizations must perform well and increase their market share during this evolutionary process as well as perform for both short and long-term survival.

Limit(s)

Limits influence the selection process in several ways such as the laws of physics, the availability of resources and talent, financial limits, physical environmental limits, and such. Some limits may be raised at times such as the discovery of new resources, the development of new technologies, improved financing, and such. A simple approach for increasing sales by changing the limits was noted by Baghai, Coley, and White (1999):

- Increase sales to same type of customer by varying the price
- Sell the same products to new customers
- Develop and sell new products / services
- Change the delivery system or approach
- Expand into new territories or geographies
- Change the industry structure (M&A)
- Look outside the industry for opportunities

Other innovation approaches may lead to changes in other limits such as limited resources or talent. For example, an organization's innovative education and training program may reduce the limits to talent and improve management and technical capabilities. While limits exist, innovation may help to alter the limits to improve chances of survival.

Extinction (death)

As systems depend on resources such as material, energy, and messages (information +) to survive, interruptions in the rate of input and/or output, the required amount required for survival, and/or the quality and quantity of these resources may cause a system to decline and at some point, become extinct. Adequate resources are required to leverage or adapt to new opportunities or challenges in a changing environment and to counter threats, as threats from the external environment may overwhelm a system. For example, larger organizations may acquire smaller organizations such as documented with Apple, Microsoft, Alphabet, and other companies buying smaller companies. Weaknesses within a system may cause it to collapse as seen at Kodak, wherein management did not respond to environmental changes from analog to digital cameras.

Essentially organizations fail or collapse when a survival-threatening problem cannot be solved, whether from threat or weakness or possibly both. Bardi (2017) described a collapse in network terms; that is, a collapse is a change in network nodes and/or links such that a new network is no longer the original network or system. This collapse may be slow or fast. For example, some organizations may go through a few years of decline followed by collapse, and some become bankrupt quickly. Threats for example, include conflict, environmental damage, acquisition, loss of customer base, economic collapse, among others. A weakness may be something such as not having the time, money, or talent to survive a situation. Yet, from organizational ashes, new organizations may emerge and begin their own lifecycle and along the way, merge, spin-off, and spawn new organizations.

CONCLUSION

As organizations evolve through the processes of differentiation, selection, and amplification/retention, both the external and internal environments change and at some point, an organization will fail to pass the selection process and begin the decline to collapse to extinction phase. Yet, before it dies or simply declines, it may spawn a new organization or organizations as elements within it combine or recombine in new ways and do things differently creating a new organization subject to evolutionary processes. For example, a few managers may leave one organization, join with a few others, and start a new organization. From the early days of business organizations through today, the start of small family businesses to mid-sized companies and beyond to nonprofits, LLCs, partnerships, large corporations, and so on, new forms of organizations form, change, and evolve. Over time, a web of organizations may emerge (see Figure 5) and continue to evolve.

This paper included an approach to leveraging concepts from biological evolution to social systems such as business organizations. An exploration of the evolutionary algorithm with a mapping to the limits-to-success archetype expanded to a web of organizations on an evolutionary journey of one limits-to-success life to another. Future studies could focus on expanding this paper, consider other nonbiological systems, systems in general, or approach the topic from a quantitative research perspective. Additional studies could explore applications of evolutionary systems in diverse fields such as education, manufacturing, or travel or whatever. One takeaway is that anything that is differentiated, selected, and amplified repeatedly, evolves.

REFERENCES

Aldrich, H. E., Hodgson, G. M., Hull, D. L., Knudsen, T., Mokyr, J., & Vanberg, V. J. (2008). In defense of generalized Darwinism. *Journal of Evolutionary Economics*, *18*(5), 577-596.

Aldrich, H. E., Ruef, M., & Lippmann, S. (2020). *Organizations evolving (*3rd ed.). Elgar.

Arthur, W. B. (2009). *The nature of technology: What it is and how it evolves*. Free Press.

Baghai, M., Coley, S., & White, D. (1999). *The alchemy of growth*. Perseus.

Banzhaf, W. (2009). Self-organizing Systems. In: Meyers, R. (eds) Encyclopedia of Complexity and Systems Science. Springer. https://doi.org/10.1007/978-0-387-30440-3_475

Bardi, U. (2017). *The Seneca effect* (The Frontiers Collection). Springer.

Barabasi, A. (2002). *Linked: The new science of networks*. Perseus.

Beinhocker, E. D. (2007). *Origin of wealth: Evolution, complexity, and the radical remaking of economics*. Harvard Business School.

Beinhocker, E. D. (2010). Evolution as computation: Implications for economic theory and ontology. Retrieved from http://www.santafe.edu

Christensen, C. (1997). *The innovators dilemma: When new technologies cause great firms to fail*. Harvard Business.

Berlinski, D. (2000). *The advent of the algorithm*. Harcourt.

Digiammarino, P. F. (2018). Five stages of organization evolution and key characteristics. http://Five Stages of Organization Evolution and Key Characteristics.pdf

Fichter, L. S., Pyle, E. J., & Whitmeyer, S. J. (2010a). Expanding evolutionary theory beyond Darwinism with elaborating, self-organizing and fractionating complex evolutionary systems. *Journal of Geoscience Education*, *58*(2), 58-64.
Fichter, L. S., Pyle, E. J., & Whitmeyer, S. J. (2010b). Strategies and rubrics for teaching chaos and complex systems theories as elaborating, self-organizing, and fractionating evolutionary systems. *Journal of Geoscience Education*, *58*(2), 65-85.
Forrester, J. W. (1971). *Principles of systems*. Productivity Press.
Gould, D. & Cleveland, S. (2018). Evolutionary systems: Applications to cybersecurity. *Proceedings of the Thirteenth Midwest Association for Information Systems Conference*, Saint Louis, Missouri.
Hodgson, G. M., & T. Knudsen (2013). *Darwin's conjecture: The search for general principles of social and economic evolution*. University of Chicago.
Hull, D. L. (1988). *Science as a process: An evolutionary account of the social and conceptual development of science*. University of Chicago.
Kauffman, S. (2000). *Investigations*. Oxford University.
Mayfield, J. E. (2013). *The engine of complexity: Evolution as computation*. Columbia University.
Meadows, D. H. (2008). *Thinking in systems*. Chelsea Green.
Mobus, G. E., & Kalton, M. C. (2015). *Principles of systems science*. Springer.
Mobus, G. E. (2022). *Systems science: Theory, analysis, modeling, and design.* Springer.
Nonaka, I., & Takeuchi, H. (1995). *The knowledge-creating company: How Japanese companies create the dynamics of innovation.* Oxford University
Ormerod, P. (2007). *Why most things fail: Evolution, extinction, and economics*. Wiley.
Santa Fe Institute. (n.d.). Glossary. http://complexityexplorer.org
Seba, T., & Arbib, J. (2020). *Rethinking humanity: Five foundational sector disruptions, the lifecycle of civilizations, and the coming age of freedom.*
Senge, P. (2006). *The fifth discipline*. Doubleday.
Statista. (2020). Average company lifespan on Standard and Poor's 500 Index from 1965 to 2030, in years. https://www.statista.com/statistics/1259275/average-company-lifespan/
Ziman, J. (2000). *Technological innovation as an evolutionary process*. Cambridge University.

APPENDIX A: DEFINITIONS

Adjacent possible: Kaufmann (2002) described the adjacent possible as a concept wherein biological systems morph into more complex systems by taking small, incremental steps rather than extreme jumps or more distant possibilities. These smaller steps consume less energy and are therefore easier to happen.

Algorithm: An algorithm can be defined as a process that takes some set of inputs, manipulates those inputs in a sequence of steps based on a set of rules, and then produces a set of outputs. A baking recipe, for example, fits this definition (e.g., input flour, eggs, butter, sugar, baking powder, chocolate chips; stir well; bake at 175◦C for 30 minutes; allow to cool; then output some cookies). Dennett (1995) used the example of a tennis tournament where one inputs players, grinds them through a set of rules for advancing to quarterfinals, semifinals, etc, and then outputs a result: the winner.

Artificial system: A system designed and developed by people. Examples include software, hardware, the internet, societies, cities, the rule of law, artificial life, and so on.

Complex system: Fichter, Pyle, and Whitmeyer (2010b) described a "complex system as a group of "agents" existing far from equilibrium, interacting through positive and negative feedback, forming interdependent, dynamic, evolutionary networks, that are sensitive dependent, fractionally organized, and exhibit avalanche behavior (abrupt changes) that follow power-law distributions" (p. 65).

Complex adaptive system: The Santa Fe Institute (n.d.) defined a "complex or complex adaptive system as a system composed of many interacting components, without central control, whose emergent "global" behavior—described in terms of dynamics, information processing, and/or adaptation —is more complex than can be explained or predicted from understanding the sum of the behavior of the individual components. Complex systems are generally capable of adapting to changing inputs/environment and in such cases sometimes referred to as complex adaptive systems."

Evolutionary change: Fichter, Pyle, and Whitmeyer (2010a) defined evolutionary change as "any process that leads to increases in complexity, diversity, order, and/or interconnectedness then there are at least three distinct mechanisms, or theories of evolution: elaboration, self-organization, and fractionation" (p. 59).

Elaborating evolution: As Fichter, Pyle, and Whitmeyer (2010a) noted elaborating evolution "is characterized by experimentation—lots of experimentation; and failure— lots of failure. Indeed, failure is one of the key components of natural selection. But biology is not the only example of elaborating evolution. Businesses, for example, behave similarly to living systems as they diversify in an elaborating economy (Beinhocker, 2007), and on average 10% of businesses fail–go extinct–every year (Ormerod, 2007)" (p. 60).

Natural system: A non-biological system in the natural world, such as the earth system, atmospheric system, and star systems among many others.

Process: A process is a means of transforming a set of inputs to a set of outputs (examples) differentiation, selection, and amplification. In simple abstract mathematical terms, $y = f(x)$.

Self-organization: A process wherein global order arises from interactions between local parts.

Self-organizing evolution: Fichter, Pyle, and Whitmeyer (2010) defined a self-organization evolution as beginning "with an initial state of random agents that through the application of simple rules of interaction among the agents (e.g. an algorithm, or chemical/physical laws) evolves a system of ordered structures, patterns, and/or connections without control or guidance by an external agent or process" (p. 60). That is, global behavior is an outcome of local rules.

Social system: A system of connected individuals and/or organizations that meets at least the criteria noted by Meadows (2008).

System: Meadows (2008) provided a simple definition of a system as a set of interconnected elements that achieves its function or purpose.

System: Mobus and Kalton (2015) offered a more formal definition of a system as a 6-tuple, described by a set of subsystems, a network or networks, the set of nodes inside and outside the system, the boundary conditions, the interactions among the nodes, and the history of the system. While a variety of definitions of systems exist and there is no specific consensus on the definition of a system, an organization fits both Forester's (1971) and Mobus and Kalton's definition.