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Insights from General Complexity Evolution for Our Current Situation

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Abstract

Will the pace of change in our global technological society continue to accelerate? Or will it follow the path of most previous technological waves, which slowed down as they matured? The purpose of this paper is to explore how historical general evolutionary processes involving increased energy flows and corresponding higher complexity levels might have contributed to the global problems we face today with regard to energy, environmental, inequality, and demographics. This situation will be compared with various integrated complexity evolutionary models of three major phases in evolution (life, humans, and civilization). While natural ecosystems seem to have both positive and negative feedback mechanisms to prevent the onset of senescence, the current economic system seems to have avoided constraints to enter a positive feedback loop that results in unsustainable resource use and pollution. There are still many contrasting interpretations of what this means for the near future, but integrating insights from these perspectives may help us better understand these processes.

Keywords: Energy, Complexity, Evolution

Evolving technology and social systems have led to a global system that is stressed to its limits (Grimes 1999; Brown 2004; LePoire 2004; Homer-Dixon 2006; Steffen, Crutzen, and McNeil 2007). There may not be any quick technological solution to large current challenges such as climate change, global infectious disease, resource scarcity, and pollution. These issues are exacerbated by the relatively slow social response in identifying and controlling negative aspects of the technology, leading to increasing inequalities, technological dependence of interconnected brittle systems, and uncertainties due to technological disruption (Linstone 1996).

These global problems also exacerbate the issue of an inter-core conflict as articulated by Grimes (1999). While the economic ties between leading countries offer mitigating forces, the current motivation to reduce these ties through self-sufficiency in manufacturing, such as microchips and advanced batteries, indicates concern about potential conflicts. Conflict might not be in a traditional war but instead in gathering power through resource, financial, and information leverage. The peripheral countries emphasize a fair resolution of climate mitigation and adaptation, since most have not contributed much to the greenhouse gases and are also being restricted from pursuing a relatively inexpensive fossil fuel development path that developed countries in the core have historically followed (Ciplet 2017; U.S. Global Leadership Coalition 2021; Klare 2022).

How did the increasing accelerating pace of technology come about? The rest of this section outlines the steps taken in this paper to explore this question. First, some of the current thinking on how complex adaptive systems (CAS) work and evolve are reviewed. This includes identifying major components of CAS, such as resources (e.g., energy extraction, information processing, organization, and interaction with the environment). This section expands some of the discussion of Grimes (1999) by taking a broader view of CAS he discussed, such as impacts of agricultural systems, fossil fuel dependence, environmental degradation, and global climate change. The further expansion of his points include discussions of uncertainty, a broader historical context, and an updated perspective on the current predicament and potential scenarios for resolution.

Before going further, the uncertainties and objectives must be discussed. A phenomenological model seems to have the best chance of generating the most understanding, compared to a full bottom-up detailed model or a regression-only model. The phenomenological model requires weighing evidence for it and against its alternatives. Such models are often based on a high conceptual level but supported by simplified dynamical models.

After this examination of uncertainties inherent in this approach, this CAS framework is coupled with one interpretation of the larger history on Earth. Supported by evidence in event rate and population trends, an accelerating model of complexity has been developed by many researchers, such as Modis (2002), Panov (2011), Korotayev (2006), and Kurzweil (2005). Essentially, it is an exponential model where the rate constant is also continually increasing. This cumulative growth model is consistent with these researchers' data sets. While the model trends toward a singularity in time, no real trend will be maintained to the singularity, as demonstrated by the population trend that diverged from the singularity trend in the early 1970s.

In addition to this primary singularity trend there seems to be additional substructure of the evolutionary stages of life, humans, and civilizations. Each of these three secondary stages (with different evolutionary mechanisms) are, in turn, formed by a tertiary structure of six nested steps.

Once the big history and CAS frameworks are connected, the analysis will shift to current implications and indications. These include predictions of a social-technological-environment model, the potential for negative marginal return on new complexity, and addressing whether the current situation indicates a global system senescence.

Finally, potential options for an emerging complex adaptive system will be reviewed. There are many scenarios for the future path of aspects in energy, information, organization, and environmental interaction. It is unclear whether they will be developed and implemented in time, which requires integrated effective decision making and responsible scientific and technological investments.

Complex Adaptive Systems Aspects

Complex adaptive systems require first, an inflow of energy to combat disorder (entropy); second, some information processing to sense and act (both on the environment and its internal state) to identify needed resources while avoiding threats; third, an organization that maintains multiple interacting parts at various scales; and fourth, an interaction with the environment as a source of resources and a sink for wastes (Kauffman 1995; Perry 1995; Mitchell 2009). Often, researchers select one of these perspectives to guide further understandings of CAS. Some of these are briefly reviewed here.

The Information Perspective

The information perspective has undergone quite a transformation over the years. In *The Dragons of Eden* (Sagan 1977), Carl Sagan compared the estimates of information capacity for DNA and brains over the course of evolution. He then pointed out that later, external forms of storing information (e.g., books) enabled collaboration throughout the history. He suggested that life evolved mostly through DNA until brains offered a quicker way to gather, store, and transmit information. Another later transition occurred when the limited capacity of human minds was enhanced by writing. Further discussion generated a list of major events in information processing to find an acceleration in a singularity pattern (Coren 1998; Solis and LePoire 2020).

One of the main integrating theories of evolution is the Free-Energy Principle of Karl Friston (Ramstead et al. 2018). While this theory may sound like an energy perspective, its main focus is CAS internal models to predict outcomes (i.e., to prevent surprises). If a surprise occurs, this difference between the model and reality can be addressed in two ways: change the environment to better fit the model, or change the model to better fit the environment's reality. A CAS has some capabilities to change at least its local environment, such as repairing internal systems. The CAS model is flexible enough to learn from the environment passively and also actively though conducting "experiments."

Energy

The role of energy in biological human history and current economic systems has been well documented (Fox 1988; Neile 2005; Kummel 2010). Further relationships between energy and complexity, organism scaling laws, the temperature history of the Earth, and self-organization have been discovered as described below.

Eric Chaisson (2001) proposed the Free-Energy Rate Density (FERD), that is, the usable energy flowing through a unit of mass, to measure complexity of objects through big history. He applied it to galaxies, stars, earth's climosphere, plants, animals, humans, and various technological machines (Chaisson 2001). However, there are many issues being investigated. For example, the human brain works with only 20 watts, whereas computers require much more energy flow but are not as complex. Also, the boundaries of the CAS are not tightly determined in space and/or time. For example, the brain requires the rest of body to support it. It also has undergone a long integrated evolution along with humans and social groups. These system boundaries are crucial to the hypothesis since it determines the mass for flow density normalization. The FERD predicts that stars are more complex than galaxies, but the reality seems reversed, since stars are only one component in a galactic organization that might include dynamic feedback from the central massive black hole.

Instead of focusing on the energy rate density, another consideration is the energy flow through the full, evolving system instead of any one part of it. This would account both for the increased size of collaborating units and the additional energy to maintain their binding relationship. For example currently, the evolving system's energy would include the total consumed energy of the interconnected world system of economic, political, and cultural exchange. For the early Earth, the evolving system might only include a set of hydrothermal vents.

Other researchers have explored energy scaling laws due to biological and technological evolution. Georgiev (2019) pursued application of physics' least action principle to the evolution of integrated circuits. Bejan (2011) applied his constructal law to show size scaling in animals is related to the way energy flows through an organism (e.g., blood flow).

Deeper insights into energy flow were proposed for the role of entropy gradients and self-organization of dissipative systems (Schneider and Kay 1994). For example, energy conducts through a liquid slightly heated from below. However, for a sufficiently larger temperature, the liquid will self-organize in convection cells (Bénard cells) to increase the rate of entropy generation. That is, at least in this system, self-organization is not hindered by the second law of thermodynamics, but instead facilitates it.

David Schwartman's (2002) tool offers a different approach to exploring the role energy played over evolution by comparing the estimated temperature of the cooling Earth with the emergent of major biological features. He suggests that the evolution of more complex systems from simple cells, to eukaryotes, to mammals forms as soon as the Earth has cooled enough to enable the higher energy flow in each system. He then suggests that replaying this evolutionary tape might give a similar evolutionary sequence because of this dependence on temperature.

Organization

Another aspect of evolving complex adaptive systems is the change in organization. Organization includes the structural and functional features (Heyleighen 1996) and the horizontal and vertical layers (McShea 2017). Despite a long history of attempts, defining a complexity measure based on these organizational aspects has not succeeded.

Volk (2017) focuses on the vertical aspects of organization through analyzing the many transitions that occurred when previously independent entities combined into a new level of organization. Volk's first five out of 12 combination steps occurred in the early universe as cooling from expansion led a sequence of bindings from more subtle forces (from nuclear to molecular). The next four steps occurred in biological evolution of simple prokaryote cells, eukaryote cells, multicellular organisms, and animal social groups. The last three steps concerned humans and their civilization in forming tribal groups, agro-villages, and geopolitical states. Again, the entities had to relinquish some of their independence for the emergent benefits of combining, that is, a social cooling where group disagreements diminished enough to facilitate sharing common goals, such as economy of scales, reduction of barriers, or defense.

The need for a critical size to support the next level of organizational complexity might be seen in the sequence of leading capitalist countries from the seventeenth century onward as the leadership shifted from the Dutch, to England (and the UK), to the United States (LePoire 2010). At each step the leadership moved to a country with twice the population as its predecessor, which suggests that the former country did not have sufficient population or resources to manage the required innovation for growth.

Environment/Limits

The evolving CAS produces organisms that can exploit new environmental niches. The growth in this environment then follows a logistic pattern: rapid exponential growth, inflection as environmental limits begin to affect the growth rate, and stasis as the carrying capacity is neared. This is similar to Coffman's (2022) sequence of immaturity, maturity, and senescence cycle as the relative ease of resource and energy extraction decreases and the amount of information required increases. Eventually, the information capacity is reached, leaving the system brittle with a lack of plasticity. Only discovery (or development) of a new environmental niche renews the cycle. The wider Panarchy model by Gunderson and Holling (2002) (which is similar to the model articulated by Ibn Khaldun in the fourteenth century [Anderson 2019]) includes these cycles at many levels of spatial and temporal scales.

Challenge

Each of these perspectives include some aspect required by CAS, that is, energy flow, information flow, organization, and relationship to the environment, to progress to another level of complexity along with associated emergent properties. Erich Jantsch (1980) explored this integration and suggested the three major stages of evolution on Earth distinguished by the primary mode of evolutionary information processing. The Earth has seen three top level evolutionary mechanisms from DNA in biological evolution, a combined behavior and biological phase when humans evolved (which Jantsch called epigenetics and has been recently explored by Corning [2022]), and a mostly cultural phase in civilization history. This corresponds to the three levels as noted by Sagan (1977).

While most organisms do not evolve with the risky strategy of becoming more complex, some organisms successfully navigate new environmental niches, often through greater specialization. A new complexity level is explored when the current system's growth pushes against the environmental limits. The CAS is then challenged to identify a new mode of organization before the old system collapses. This iterative process started slow; for example, prokaryotes were the leading complexity level for a large part of Earth's history. As evolutionary mechanism also evolved and the efficiency of resource extraction increased, this process accelerated towards higher levels of complexity.

Goals Considering Uncertainty

When considering complex systems (e.g., organisms), should their encompassing environment (sustaining environment; development history; evolutionary history; potential for change) be included (Delahaye and Vidal 2019) in that consideration? How do we address uncertainty in the characteristics of evolutionary events and developments, which are often ill-defined, leave only a partial record subject to changing interpretation with new findings, and whose limited evidence supports a variety of hypotheses (e.g., origins of life, multicellular, language/speech, consciousness, agriculture, and technology)? Under such great uncertainty, is there any way to disprove a hypothesis? Alternatively, is the hypothesis just continually refined and compared against other interpretations until one seems to be most likely by a large factor (e.g., a Bayesian approach similar to how the IBM computer Watson played Jeopardy [Tessauro et al. 2013]).

These main questions lead to related issues such as: do we strive at first for proof of principle (i.e., a way to consistently interpret events without the proof or exclusion of other interpretations)? How do we organize events (hierarchical; nested; sequential; overlapping; just one thing after another)? Are multiple models/interpretations needed to address different questions? How appropriate are analogies? Under what criteria can we weigh the evidence in support of or against some interpretations? What role do future events have in helping determine the interpretation's validity?

These questions in approaching natural history are not new. For example, many of these questions are still be debated in the limited topic of biological evolution. Big history is another level of complexity since it deals with wider times scales, spatial scales, and a mixture of fields and units of study. Definitive answers are not expected, but at least some realistic expectations and bounds can be set for further discussion.

The abstraction level is a major concern with information interpretation. For example, DNA contains the information for all the proteins, cellular specialization, and organism development. However, while all the information is present in the linear sequence of nucleic acids, the abstract information about how the DNA sequence combines with the cellular "decoder" is not evident. Instead, there are various layers of abstraction such as the genetic network, the effect of epigenetics, and the specification of development processes instead of specific instructions.

Similarly, the extraction of abstract information and its semantic content from raw data, is not easy and is a major research field, for example, in artificial intelligence deep machine learning (Garcez et al. 2019). The result of training such a system may easily determine which result is best; that is, which letter does the scribbling best represent or which disease best fits the symptoms, but the reasoning behind the conclusion, the abstract level, is difficult to identify. This has led to a barrier in acceptance of such systems in medical applications where doctors want to feel comfortable with the diagnosis.

An engineering example might help clarify some differences in abstraction level (LePoire 1986). Consider the development of a new remote measurement tool. The interested group includes a physicist to understand the meaning of the measurement, an interpreter who could apply it to obtain valuable information, and a tool designer who wants to optimize the signal. Experiments might indicate a physical effect consistent with a detailed physics simulation. While the simulation could provide more information than the experiment, the full simulation might not indicate the underlying specific physical phenomena causing the effect. This simulation would be useful to the tool designer to optimize the tool for the realistic environment but not to the field interpreter nor the physicist because the meaning and value of the information would not be ascertained. Next, a correlation between measurements and aggregate characteristics might be performed to identify a structural characteristic as being the driver of the resultant measurement. This might help the field interpreter to know the type of measurement result; however, it would still not tell the physicist the underlying cause of the differences. Only when the physicist is able to identify a simple dynamic effective model (e.g., effective mass) would the underlying physical cause be identified. However, this would not be very helpful for the designer nor the interpreter, since it would be the least numerically accurate model. This shows that although full information might be accessible through detailed modeling, it can take great effort to construct meaningful and useful models. Each model of the information might be useful in different circumstances.

Big History Framework

A high-level summary of big history might go something like—"the integrated study of the history and emergence of the cosmos, life, humans, and civilization." This gives an overall hierarchy, which closely follows courses in high school or college such as astronomy (physics); evolution (biology); anthropology (psychology); and human history. This framing provides a way to construct a more detailed list of emerging phenomena instead of just listing all the events and then determining their relative importance. For each level of complexity there are many events associated with the new level (e.g., energy source, information mechanism, organization, relationship to environment) (Christian, Brown, and Benjamin 2014; Spier 2015).

As Grimes (2017) related in Chapter Three, the physical universe can be considered to be a developing dissipative system, although calling it "evolution" requires a broadened definition (Chaisson 2001). However, much of the laws of physics as we understand them along with most of the matter that we interact with were established in the first three minutes after the Big Bang (Weinberg 1977; Atkins 2018). This phase saw rapid cooling from temperatures that are orders of magnitude hotter than we can achieve today. The universe continued expanding and therefore cooling, allowing more subtle forces to participate in forming structures. Grimes correctly identifies the strange property of gravity with its effective negative heat capacity, as the reason why the matter needed to first cool enough to eventually heat up. Within a gravitational cloud, such as the one that collapsed to form our sun and solar system, the more energy radiating away from the gas, the hotter it gets. There is no magic energy creation here, it is just that the gas "falls" (into the gravitational potential), and about half of that fall is irradiated away while the other half is converted into the increased temperature.

Complexity increased at an accelerating rate on Earth through evolution of life, humans, and civilizations (Morowitz 2002). Each of these three major phases has a unique way to store and transmit information (through DNA; the human mind and language; writing and artifacts). The capacity and speed of each information mechanism has been increasing with subsequent phases, transitioning when the previous seems to reach its capacity. These new information mechanisms enabled the development of new emergent complex structures and organization to capture more energy (e.g., through photosynthesis).

However, increased complexity requires greater energy flow to counteract the natural disordering tendencies (entropy). Balancing the increased energy flow and its wastes (e.g., heat) becomes more difficult. In return, new ways to address the wastes result from new information and organization. This continues the evolutionary process to the next growth phase.

One interpretation of Big History is that the three major terrestrial evolutionary stages—life, humans, and civilization—form the first half of a modified logistic transition (LePoire 2015). However, this learning (or growth) pattern is different as it is formed from nested smaller transitions and it also changes (learns) at an accelerating rate as it approaches our current time. These three major stages started at about five billion, five million, and five thousand years ago. This acceleration is a factor of 1,000 from the one stage to the next. While more precise times are known for the beginning of the universe at 13.8 billion years ago, and the formation of the Earth at 4.54 billion years ago, approximation on a logarithmic scale is used here.

A further tertiary structure (after the primary singularity trend and secondary information stages) might nest six steps within each evolutionary stage (with an acceleration factor of three). Furthermore, the duration of the universe from the Big Bang to the present is approximately one step factor (three) larger than the history of the Earth. However, this step is qualitatively different in that the evolution takes place through cooling and gravitational attraction rather than through natural selection evolution.

To gain a perspective on these factors, if the time values of the three major stages are plotted on a line (i.e., five billion, five million, and five thousand) with the line being one kilometer long, which represents the age of Earth, then the development of humans would start at one meter from the end. All of written civilization history would occur in the last one millimeter. If the time between the Big Bang and Earth formation were added, the line would stretch to three kilometers. A human generation scale of 50 years would be 10 micrometers; less than the width of a hair.

Singularity trends in evolving systems have been identified and studied for over 60 years. Singularity trends in population growth were identified in 1960 (von Foerster, Mora, and Amiot 1960) with the singularity estimated for November 2026. In 1971, Nobel Prize winner Manfred Eigen identified singularities in evolving autocatalytic cycles that may have contributed to the early formation of life on Earth (Eigen 1971). Panov (2011) and Snooks (2005) identified the factor of three in general evolutionary trends. The population trend was further analyzed (Kremer 1993; Korotayev 2006). Others (Modis 2002; Kurzweil 2005; Aunger 2007) provided additional perspectives. The development of physics understanding was shown to grow in a nested logistic pattern (LePoire 2005). Seven nested subphases of physics were predicted based on the five historical phases. The discrete steps taken in a logistic pattern might be due to the need to take separate steps to define, explore, standardize, unify, and identify gaps for the next phase.

Further hypothesis have been explored with this framework include developing, first, a heat extraction model showing similar characteristics based on Bejan's constructal model (Bejan 2011, LePoire 2020); two, estimating the number of steps to the singularity time based on the comparison of a human lifetime and the universe's age; and three, extending the early singularity trend into a more complete mathematical model with inflection and post-inflection development consistent with the early trend (LePoire 2022).

Current Issues

The CAS and Big History frameworks can provide insights into our current situation with global issues of environment, inequality, and limited resources. This is similar to the approach articulated by Peter Grimes (1999, 2017). A few approaches provide perspectives. First, as the long-term trend of accelerating evolution continues, uncertainty grows with difficulty, predicting the trajectory of the social and economic trends. For example, the nature of jobs, services, and products rapidly changes through technological "creative destruction." Another approach concerns simple conceptual models of relationships between social, economic, and environment. For example, the Human And Nature Dynamics (HANDY) model (Motesharrei, Rivas, and Kalnay 2014) includes aspects of pollution degrading natural resources, inequality, and demand for continued growth. Its consideration of a buffer effect of wealth inequality seems to be a major factor in determining whether the system survives or collapses (Servigne and Stevens 2020). Still another approach considers alternate histories after a major historical decision point; for example, the critical transition in the early 1980s, when a path towards more equality and more humble lifestyles was considered after the energy price shocks of the 1970s. Instead, the economy went forward based on fossil fuels, shifting efficiency gains towards investors, and maintaining organizations to defend the lifestyle.

James Coffman (2022), a developmental biologist, sees the previous rapid rise in technology, fueled by fossil fuels, to be an autocatalytic reductionist cycle; that is, reductionist methods are required to resolution specific problems, but also generate options that cause additional unanticipated consequences. This reductionist approach has led to information overload, inefficient energy use, and senescence. Instead the problems currently being experienced involve systems which require a more holistic approach. Or in his words: “The reductionist mindset of STEM discourses has played a central role in the development of or current global industrialized and capitalized civilization to the precarious state in which it now exists” (Coffman 2022). He claims that the current world capitalist system is overdetermined in being too specialized in occupations, leaving little room for wider integrated approaches. In the information area, there are diminishing returns on information processing since there are large uncertainties due to a deluge of raw data being processed with obsolete models. This leads to problem situations where the data processing and interpretation is too inadequate to act effectively. Instead, information becomes increasingly distorted. He suggests that much of the current energy flow is used to maintain our lifestyle with very little excess capacity to invest in solutions to the larger problems.

As Coffman mentioned, it is unclear if the marginal returns of innovations are beneficial (Coffman and Mikulecky 2012) which is a major factor in complexity transitions (Tainter 1996). Often this uncertainty is replaced by reliance on measures (e.g., Peter Drucker’s saying “If you can't measure it, you can't manage it.” [Patrinos 2014]) such as the GDP. Very early on this measure was seen as flawed by Keynes and Robert Kennedy (Kapoor and Debroy 2019), since it counted cleanup after accidents as positive economic activity but did not include beneficial but unpaid activities such as raising children. However, new measurements are difficult to construct and agree on. One such proposed index was the Genuine Progress indicator which seemed to have peaked in the mid 1970s, while the GDP continued its rapid rise (Talberth, Cobb, and Slattery 2007; Kubiszewski et al. 2013;).

One attempt to generate an ethics for approaches to the future is Partridge’s extension of John Rawls’ (1971) “veil of ignorance.” Partridge (1976) asked how would someone design the system if they did not know when they would be born (just as Rawls asked how the location and circumstances differed). However, this conceptual ethical approach again runs into problems with dealing with uncertainty. Many who want continuous economic growth argue that future generations are helped by the “progress” of previous generations. While that might have been true in the past, it is not clear that assumption is still valid.

Projected Options for the New Complex Adaptive System

There are options already identified and being pursued that might contribute to a new way that our complex system might transition into. These include the aspects of energy, interaction with the environment, organization, and information. Often the transition starts with multiple potential options being tested. The current transition needs to occur quickly however, since the periods have been decreasing geometrically in time down to the order of a human adult lifetime (e.g., about 50 years).

Energy

While there are quite a few energy sources being pursued, none have demonstrated the economic viability and the capacity to resolve the issues as fossil fuels are being replaced (Smil 2010). Hydropower is the traditional renewable energy resource, which is economically viable but geographically limited in capacity. While generating much power since the early- to mid-twentieth century, they are not without environmental impact as the rivers are unnaturally affected.

Beyond this traditional renewable resource, wind and solar energies are currently being rapidly developed. However, the full life cycle costs still need to be determined since the current technology has not had enough time to degrade and be replaced (Wang et al. 2021). However, great progress has been made in price reduction through learning through the production scaling (a typical learning curve where the cost of production is reduce by a factor for each doubling of the cumulated production). Besides the direct energy conversion technology, a large amount of infrastructure for electricity transmission and storage must be developed since this renewable energy generation is often remote and variable. Depending on the variability, a standby fossil-fuel electrical generation station may be needed.

Various nuclear technologies seem to be gathering venture capitalist interest, which indicates interest beyond government research support (Bordoff 2022). These nuclear options include various forms of nuclear fusion (thermonuclear and inertial) along with advances in nuclear fission (molten salt reactors, traveling wave reactors, small modular nuclear reactors). A combination of new materials, advanced modeling, and advanced control using artificial intelligence have regenerated interest and demonstrated progress in this large suite of technologies.

Besides traditional solar energy generated from either photovoltaic or thermal techniques, NASA and other countries are continually revising estimates and designs for potential space-based solar power to be collected without interference of clouds to be beamed back to earth (Jones 2022). Space technologies have recently seen great strides in reducing the costs of getting material into space which is a major cost. Robotic construction and repair would be a key to making these technologies viable.

Information

Information technology previously spawned many disruptive innovations and continues to do so with explorations of artificial intelligence (e.g., language interpretation; self-driving vehicles), multiscale models, and quantum computing. However, many problems also arose with these advances such as cyber security, the propagation of misinformation, the invasion of digital privacy, and the dependency on immature technology. The projected future implications vary from the emergence of a global consciousness (Halal 2021) to a path leading to potential large-scale distrust and dissolution of large-scale community (Haque 2022). Either way the impact of this new and emerging set of technologies offers many options.

Much progress has been made in the last decade concerning artificial intelligence with deep learning through artificial neural networks. While the base technique existed for decades, there were numerical difficulties in implementing the ideas. These problems included the inability for the network to converge and the lack of computer capacity to optimize the thousands to millions of parameters.

While quantum computing was identified as a possible way to circumvent the limits of some classical computing in the early 1980s, it was only later that both some algorithms and physical instantiations were developed. It seems like every new finding in quantum physics is suggested as a potential contributor to quantum computing. This is often because nobody really knows the best path to a functioning quantum computer. So all technology pathways are open, including superconducting junctions, atoms in diamond, laser-trapped atoms, and even topological materials that don't yet exist. The quantum computing process is very sensitive to environmental noise, which requires an estimated hundreds of real but noisy qubits necessary to support one effectively noise free qubit. However new techniques are being explored and discovered that might mitigate this noise, for example, maintaining the qubits topographically separated in time rather than in space (Bauer et al. 2022).

Models have been continuing to improve by handling multiple spatial and/or temporal scales, such as considering all processes lasting seconds to years. Artificial intelligence is one tool to facilitate simplified but accurate ways of combining scales when nonlinear processes mix the effects of large and small scales, such as climate modeling.

Besides the technical aspects of information technology, a major hurdle is connecting humans into a collaborative decision process. Reasoning, articulation, explanation, visuals, dynamic portals, and argument tracking are all parts of communicating and establishing understanding and trust with humans. While these goals receive attention, the progress is often much slower as would be expected since human to human communication still has many similar problems.

While some believe the dawn of conscious information technology will be realized in decades, there seems to be wide gaps. Even the great progress in deep learning in areas such as self-driving cars and language communication, the actual understanding within the model does not seem to be close. In fact, the hyped learning algorithms seem to be very inefficient compared to the human mind in terms of required data, processing, and energy. The current level of understanding is revealed in a recent DARPA call for proposals to emulate a two-year-old human (Corrigan 2019). This is clearly not at the stage of AI participating in the great discussion of the day, but is one major step, since the learning rate of a two-year-old is near the peak with the capability to test and refine models of world as they explore it and develop common sense.

Interactions with the Environment

Clearly, the interaction with the environment is a large current issue. Climate change is one of many environmental issues to be resolved at a global level. Rockstrom (2009) identified nine planetary boundaries of environmental concern that were being threatened. These included the oceans, fresh water availability, soil health, disease spread, pollutants such as plastics, and chemicals (pesticides; fertilizers). While energy substitution for fossil fuels is a large part of the climate change mitigation, energy could also be a factor in many of these issues since with clean inexpensive energy ocean water can be desalinated, waste can be more easily recycled, and pollutants more readily treated (Smalley 2003). However, the incentives to transition towards a green or circular economy need to be explored and refined based on emerging technologies and environmental findings.

Such solutions include new packaging materials such as more environmentally friendly plastics (non-toxic, biodegradable, recyclable, mushroom based substitutes). The European Union is exploring the option of the producers paying upfront for the waste generated by their products and packaging. Designing plastics that are simpler with lego-like monomers would facilitate the recycling of plastics, compared to the current system where only downgraded plastic result from the limited recycling.

Organization

It is difficult to organize the incentives to drive the market economy towards a solution that benefits all participants. Businesses and consumers are often reluctant to change, especially when higher costs are involved. Designing incentives with reliable information is difficult. However, it is a larger challenge with the many uncertainties in environmental impacts, technological options, and social acceptance. A free-market economy is able to quickly respond to new demands, but it often outpaces the social system's response to mitigate unintended consequences. The Technology Forecasting and Social Change editor, Hal Linstone (1996), articulated this succinctly in his question of whether the technological change will slow down or speed up the social response. This is a challenge for the slower, more deliberative democratic process to address negative technological consequences, although potential mitigating methods have been discussed (Feurth and Faber 2012).

Various forms of a networked virtual organization have been proposed and are being explored such as the World Social Forum (Álvarez and Chase-Dunn 2019) for political action at all levels and the Millennium Project (Glenn 2017) for characterizing global challenges and developing potential scenarios for their resolution through collaborating global nodes.

Public acceptance is a major factor in the transition to an emergent sustainable way of handling energy, environment, information, and organization. Often it takes a calamitous situation to move people to new views. In the past this has often been through wars. Hopefully, this can be avoided and instead focus on how to stop our "war" on the environment. As in any war, there will be enough causes, blame, and contributions to discuss and debate.

A metaphor might convey the urgency and excitement of this transition. One such metaphor is society as a rocket that has been launched to achieve an orbit (LePoire 2018). The rocket starts with a limited amount of fossil-based fuel that must propel it with enough speed to reach a self-sustaining equilibrium orbit. Halal (2021) makes the case that these challenges are really a part of the maturing process of a global system. These challenges offer great risk but also the possibility of great opportunities. Technological civilization grew tremendously over the last century, being supported by Mother Earth's supply of fossil fuels. Now as Stewart Brand (1968) said over 50 years ago in the Whole Earth Catalog: "We are as gods and might as well get good at it."

Conclusion

This paper has presented evidence that Grimes' perspective (1999, 2017) of seeing evolution being an integrated process of a continuing dissipative complex adaptive system seems to have much support. There are many different approaches to looking at these complex systems by focusing on aspects of energy, organization, information processing, and interaction with the environment. Coupled with a simple big history framework and evidence based on population growth and event rates, this continuing evolution of complexity on Earth (through stages of life, humans, and civilizations) can be understood with a simple model of exponential growth where the rate constant also increases in time. However, a singularity will not be realized; instead, a transition similar to a large inflection seems to be occurring. This recent change in technological options have enabled rapid consumption of resources and increase in both overall population and quality of life. This is our current challenge and opportunity. Some possible paths towards a sustainable scenario exist, but it is still unclear if these will be realized.

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