I. COMPLEXITY IN EVOLUTION

1

Tickling the Dragon's Tail of Complexity: How Complexity Might Develop after an Inflection Point of a Singularity Trend

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Abstract

The rate of technological change seems to be continually accelerating. However, innovation in a limited specific area often seems to demonstrate similar acceleration before an inflection leads to a slower rate of change towards a technology maturation phase. Will the trend of the global technological society also follow this path to slowing down? If so, will the resulting societal organization simplify or continue to rise in complexity? In the past, rising energy flow seemed to be required to facilitate the increased complexity. Will this relationship continue? This paper explores historical analogues and context for indications of how a general inflection (slowing down) might occur along with its implications for energy usage, environment, inequality, and demographics. These analogues include previous, current, or potential technological development paths. One technique is to perform analysis of alternate histories where energy limits were realized at different times (e.g., if there was no oil to fuel the technology acceleration in the 19th and 20th centuries). One theme is that complexity is often concentrated in material and information processing, for example in components for transportation such as solar cells, battery storage, smart grids, and self-driving cars. However, simplification is most likely to be realized as reduced organizational and individual stress resulting from the slower rate of change. For example, large stresses occur due to technological changes contributing to indirect costs of obsolescence, short-term investment decisions, issues with inadequate testing before deployment, and requiring analysis of many optional uncertain technology paths to identify efficient long-term solutions.

Keywords: *complexity, technology, scenarios, inflection.*

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Introduction

Are we approaching a technological utopia or a collapse into chaos? Or will our path be different, for example, a continued growth but at a more relaxed rate of change? It may seem like we are continually applying new technologies to solve past problems, but these new technologies create problems with their unintended consequences (LePoire 2004). This seems to be similar to a runaway treadmill of increasing speed (Czech 2000). The rapid change of computer technology, which has so far followed Moore's Law (Chojecki 2021) for over three decades, saw computer power increase by about 50 million times in the last 50 years.

In the early days of computers, it was thought only a few computers would be needed. Then integrated circuits gave us pocket calculators, desktop computers, laptops, tablets and the ubiquitous smartphone. However, while the smartphone can address many previous issues such as finding the best route, connecting to anyone worldwide, allowing searches of all the scientific papers, it has introduced new problems that are not as simple to address, such as cybercrime, identity theft, social polarization, and digital inequalities. Much investment has gone into this industry while large long-term environmental problems seem to receive less attention. As Harold Linstone (1996) asked over 25 years ago: Is technological progress going too fast or the social response going too slow? That is, the technological change seems to be able to outpace the change for social responses to keep up, causing unresolved issues.

So will this lead to an eventual technological solution of general artificial intelligence to replace our social decisions leaving us in a technological utopia? The trend does not seem to be going that way. Or will the change continue to accelerate leaving us bewildered and in a state of chaos? For example, the push for just-in-time inventory and earning in business was becoming very optimal for the perceived business situation. However, this approach had not been tested over long-term surprise scenarios like the COVID pandemic (Grinin, Grinin, and Korotayev 2021), leaving business stressed and supply chains in chaos. Or can we find an alternate path to a balanced and controlled change rate such that decisions can be made appropriately without sacrificing our environment or reasoning?

While many transitions have been identified in Big History concerning development of life, humans, and civilizations, this current transition seems to be a bit different. In the long history of complexity development on Earth, the rate of change appears to grow hyperbolically with a trend to a singularity that is relatively soon (decades) (Korotayev and LePoire 2020). However, it is not believed this trend will continue, just as the global population trend did not continue its hyperbolic growth as observed in the mid-1960s. This transition is a bit different in that it is a set of global, integrated problems, which can drastically threaten our current way of life. And it seems like we are nearing or already have surpassed sustainable limits of the Earth.

While these are very practical questions used in constructing future scenarios and identifying potential solutions, the fate of society during this transition is also a fundamental question in the Big History of increasing complexity. We are nearing what seems to be the final step in the singularity trend before it breaks down. However, there could be imagined other scenarios where resources might have cut-short the last step, or alternatively, added another step before resources became limited. Resource availability might determine the fate of developing complex intelligent societies. For example, since the trend seems to be accelerating progress, if there are enough energy resources to support such acceleration, what would happen on a different planet or time with different energy resources available, for example, without oil formation, or easier solar energy extraction? Would those evolving systems follow the hyperbolic pattern to a lower (or higher) level before slowing down? What determines how close an evolving system gets to the singularity time before an inflection point is experienced?

However, complexity is not well defined or measured. There are various definitions in certain fields such as computation algorithms, data compression, and software but not a general one for interacting systems. Complexity seems to correlate with the rate of energy use within an evolving system (Chaisson 2004). Since an evolving complex system is out of equilibrium with its environment, it must use available energy to maintain its state and still grow. This seems to be the reason why systems that are more complex require greater energy flow for new organizations to emerge. This is complicated by the fact that this is a necessary condition but not sufficient, for example, just higher energy flow does not mean greater complexity. Also, it does not take energy efficiency into account. This points to the paradox that one of the most complex objects in our known universe is the human brain, which only takes about 20W of energy flow, five times lower than an old incandescent light.

So the question will be reframed as 'how will the rate of change continue after the inflection time of the singularity trend?' That is, progress can still happen after an inflection point, but the stresses (due to the rapid change) might be mitigated, leading to more sustainable solutions. But how would the world react if technology slows down?

This paper addresses this question by first taking a look at some of the challenges and costs of rapid change. Then some historical and current analogous systems are explored to determine how they responded to these challenges. After that, since an experiment cannot be done to test the questions, an approach of alternative histories is constructed. This means that it is assumed that history develops through certain stages but then some alternative situation is assumed. For example, here it will be that technology progresses through part of the Industrial Revolution, but that no fossil fuels are available. This could have easily happened if organic deposits had not been trapped and naturally processed for the last hundreds of millions of years. This alternate history is based on analyzing how the events in real history would not have been available due to lack of an inexpensive energy source, which seemed to accelerate the progress through the latter part of the 19th century and all of the 20th century. Then we return to our current history and project possible paths for new technologies in energy, communication, and transport.

The title is derived from experiments done in the early days of nuclear physics with two halves of weapon grade critical plutonium (Hill 2014). As long as the two halves were kept apart there was no problem but the closer they got, the more reactions would occur, leading to more information for the scientists to analyze. Some experimenters were tempted to make the halves as close as possible. However, two accidents occurred when a wedge (*e.g.*, screwdriver) slipped causing the halves to come together resulting in lethal radiation. This type of experiment was called ‘tickling the dragon's tail’, as they tried to get as close to the point of criticality (singularity of radiation). The analogy is made here that society might be doing an experiment of trying to get as close to the time of the singularity trend. However, how close we can get without causing chaos or irreversible damage is not clear. So, in a sense, we are tickling the dragon's tail of complexity.

Rapid Technology Change: Consequences and Costs

What is meant by complexity in a technological sense? In general a complex system has parts and processes on a wide range of spatial and temporal scales. The causal relationships can go from both top-down and down-up. Often complexity is eventually separated and chunked into a piece that can be substituted. For example, in the complex process of chip manufacturing, various tools perform multiple functions and can be bought and configured, instead of being built in a custom fashion.

The recent innovations in information technology contain many examples of issues and responses to increasing complexity (Chojecki 2021). Businesses often like certainty in order to forecast needs and plan accordingly. Rapid technological change causes greater uncertainty in future directions. The chip industry partially overcame this problem by almost self-fulfilling the goal of following Moore's law under which the density and cost of chips decreased by a factor of near two within 1.5 years. This allowed all competitors to plan accordingly. In the 1980s the cost of keeping up with this and the different approaches to national laws regarding sharing of information between companies, led to the formation of the Semiconductor Manufacturing Technology Research and Development Consortium (Sematech) in the U.S. to help distribute information in the semiconductor industry to offset the national policies in Japan. This organization eventually became international.

However, the number of chip manufacturers of the most intense chips dwindled as the complexity and cost rose. A decision by Intel led to their loss of a great amount of chip share to TMSC in the early 2000s. As companies depended on inexpensive chips to make just about everything 'smart', especially cars, the dependence on the supply chain was made clear during the COVID pandemic as chip manufacturers had to change their lines during the lockdown and were slow to restart the standard manufacturing. Then shipping became more difficult, which led to assembly lines to shut down. The locations of the innovation (SF) become much more difficult to live in as the economic index soars.

Another aspect of complexity in the current society is the widening income inequality both within developed nations and between nations. This is often modeled in world society technological-environmental models such as the Human and Nature Dynamics (HANDY) model (Motesharrei, Rivas, and Kalnay 2014). In this model, a certain fragment of society is protected by economic hegemony (elites) and the burden placed on those who produce. The recent dynamics of population growth and inequality were explored to identify a positive correlation (Korotayev, Goldstone, and Zinkina 2015).

Eventually new technology becomes ingrained and the economy is strongly dependent on it as the scale of applications grows. This was seen in the semiconductor industry as discussed earlier. A characteristic sign that complexity has gone too far is when marginal costs become negative (Tainter 1988). However, there is a delay in this cost due to the adaptation time and the unintended consequences. For example, the worker productivity gain from the introduction of PCs had about a ten-year delay and another period of low productivity growth is puzzling (Wolla 2017).

Besides this economic uncertainty of new technology, there are numerous potential risks. These risks include: 1) the loss of the skills and training for the previous technology through obsolescence; 2) inadequate testing at scale where new unintended consequences might be motivated (*e.g.*, ransomware); 3) inadequate measurement of 'progress' (Kubiszewski 2013) such as relying on the GDP compared to social indicators or including costs of resolving issues as part of the technology (*e.g.*, environmental cleanup, IT administrators); and 4) the inequality of initial benefits going to those who can first afford it.

While there have been papers advocating a general ethics on facilitating greater complexity (Delahaye and Vidal 2019), it is clear that complexity can eventually be detrimental to systems. The technology must be tested socially and economically, and environmentally, along with development of social responses to mitigate potential problems. System-wide flexibility facilitates mitigation of risks. Such flexibility includes consideration of active technology monitoring, collaborative response, and responsibility realignment among the system's organization at all levels from research, to manufacturing and use; from nations, to organizations, to individuals. An example of an issue with unresolved risks is the generation and dissemination of misinformation.

Approach

The approach is to extract insights from existing models and data.

● From the past there are a variety of natural systems that demonstrated evolution away from increased complexity in various ways. These include ecosystems that reached some environmental limit, models of collapsed complex societies, and recapitulation models that demonstrate how new evolutionary system innovations are incorporated into individual development.

● Next, recent and current processes are explored including the historical rates of discovery in fundamental physics and the current evolution of a recent collaborative complex system, software development.

● Then to find out how technological paths might have changed within various scenarios of limited resources, history is projected from the point of the differing assumption. In this case we will use fossil fuels as the resources since they fueled the extension of the population and technology growths. Two alternatives will be studied: 1) a world with no fossil fuels, and 2) a world with rapid nuclear energy to replace fossil fuels.

● This leads us then to consider the potential trajectories of current projection of technologies specifically for transportation, communication, and energy-major sectors in the economy and general life.

These four methods are schematically shown in the figure below.

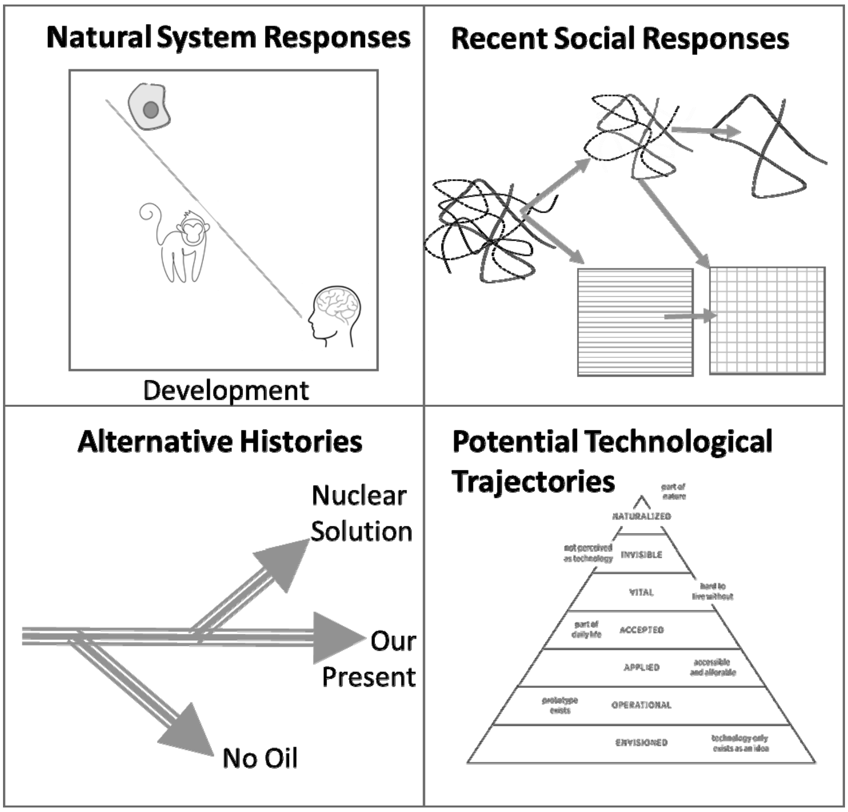

Fig. 1. Four methods to approach the question concerning potential responses to a slowing technological development rate

Natural Systems Responses to Complexity Change

Tainter (1988) identified that a main reason causing collapse of civilizations is that the marginal costs of additional complexities was greater than their benefits. So although we see increasing complexity in Big History leading to evolution of humans and civilizations, it does not mean that greater complexity is always better. It is important to consider the balance of risks and benefits of complexity within the situation of the evolving system. For example, developing agriculture while hunting and gathering resources were still quite abundant probably would not have survived, as the extra work involved in agriculture would have taxed their societies to a disadvantage. Only when the population density increased (through population growth or reduction of livable land) would the complexities of agriculture provide just a slight advantage to hunting and gathering.

In some ecological situations, a young ecosystem (such as regrowth after a fire) becomes more complex as it matures. However, eventually some resource limit is reached (*e.g.*, available water). Then the complexity does not continue, averting chaos, but instead reverses (Stone 1993). Resources in the system are reallocated at all levels to sustain growth within these limitations. A general description of such a complex system adaptation and evolution, panarchy, involves information and resources being exchanged both to lower and higher system scales of organization (Gunderson and Holling 2002). Each level of the system has a temporal pattern of growth, sustainment, collapse, and resource recovery. The multiple levels of the system interact to facilitate adaptation to the new environments and situations that may be either externally caused by some event (fire), or internally caused by, for example, nearing population limits. While most of the time the levels independently reorganize, there can be avalanches of change throughout the systems very similar to the sandpile model of Bak *et al.* (1987).

In social systems, some aspects of self-correcting systems have been found such as a market economy and checks and balances in governments, but their implementations often include inaccurate assumptions that must be fixed with regulations or controls, which complicate the earlier simple rules. The finding of a consistent set of relatively simple rules to encourage risks and innovations without recklessness, inefficiencies, or corruption is an ever-continuing difficult search. In these systems, information is consolidated and passed between various levels of organization for measurement, decisions, communication, and evaluations. For example, market economies use money as an information device, which reflects highly complicated processes of material gathering, human effort, capital investment, production, transportation, and marketing. But often this price does not include the costs that are realized after the product lifetime is over, such as costs of wastes that go into the environment.

In recapitulation models, the evolutionary pathway to the current complexity is somewhat replicated in individual development (Ekstig 1994). However, in order to maintain this relationship, new evolutionary innovations need to be quickly incorporated in earlier development. For example, new innovations in calculus started with only a few people in the 17th century but then they moved to academia, colleges, and high schools, as newer innovations took place at the leading edge of learning. This process involves taking a concept developed by a few people and organizing into more and more concise and understandable ways for earlier understanding, that is a reorganization of the material and teaching process.

Evolution of Recent Complex Social Processes

The global population had been following a trend towards a singularity (hyperbolic; 1/(ts-t)) for over 10,000 years (Korotayev 2020). The derivative of the population divided by population (*i.e.*, population growth rate) is also then a singularity trend. However, this trend in population growth rate stopped in the 1960s peaking at about 2.2 % per year (a rate to double every 32 years or about a generation). While the population has continued to rise, it is no longer following the previous trend. In some western countries, the internal population growth rate (not including immigration) has started to decrease. The current world population is projected to peak around the year 2100 at about 11 billion. Korotayev, Goldstone, and Zinkina (2015) showed a correlation between population growth rate and wealth inequality between countries. If this continues, one can expect the world to experience economic convergence along with population stabilization.

Another analogy might be found in the history of the discoveries in fundamental physics (LePoire 2005). It was shown that starting with the scientific revolution in the late 16th century; the discoveries can be grouped into topics, which progress with logistic growth patterns. However, the full series of topics also shows logistic growth, with the early period of Galileo and Newton in gravitation, mechanics, and waves being the slowest developing topics, whereas the fastest developments were in the early to mid-20th century in relativity, quantum mechanics, and nuclear physics. This dramatic change in physics upturned many previous assumptions, including the projection for the end of new physics discoveries.

Currently much of physics has now been unified, which has led to a simplification of its description (while the research into new areas become more difficult and expensive). Yet, this unification has not yet been extended between gravity and quantum mechanics, nor are 95 % of the mass-energy of the universe identified, nor has the existence of matter been explained (as the matter and anti-matter would have annihilated in the early stages of the Universe). However, explanations of origins of fundamental forces are now quite simple. For example, Peter Atkins' (2018) book *The Conjuring of the Universe* covers many important aspects of these discoveries under the assumption that 'nothing much happened' with the Big Bang. The 'bootstrap' approach to physics has explained many aspects of the forces through consideration of fundamental assumptions along with the possible intrinsic spins of particles (Wolchover 2019).

The process of applying physics has been facilitated by multi-process physics simulations that has rekindled interest in fusion energy again (*e.g.*, Creely *et al.* 2020). Therefore, although the research has become more complex due to the need to process huge data streams to discover infrequent events, the explanation and application has been simplified. The complexity has been removed by discovery and advanced computation.

Software is a very difficult and complex process (Carey 2021). It requires capturing the wishes of many others to do something for them with limited language skills and common sense about inputs. It must be implemented to run in the current volatile computer environments. However, over the years there has been a stack (or levels) developed to separate the details of the electronic bits and gates from the high-level application goals.

The various layers or levels of abstraction evolved from linear structured instructions into conceptualizations of identifiable objects with attributes and behaviors. Exceptions could be addressed with overriding behaviors in special circumstances. The relationships of general and specific types of objects (*e.g.*, 'my car is a Toyota') can be handled by inheritance. This led to flexible, but often frustrating, software development as the relationship between the objects in the artificial object model needed to be understood in detail.

However, now some software development is being simplified as the rate of change increases. For example, user interfaces are simpler in smartphones, data access is simplified in cloud-based computing, and some development environments are trending towards the original simplified run-time environment (*e.g.*, Google's Collaboratory) (Yalçin 2020). However, some practices and organizational policies (*e.g.*, quality assurance systems) might become quickly antiquated due to changing technology, leading to potentially adverse incentives.

Software problems often follow the same 'U' curve of mechanical equipment with high rates of problems in new products and then again as the products age. Issues arise early in both mechanical equipment and software as they are being made or first tested as a complete system. This is usually followed by a period of smooth operation assuming some minimal maintenance is done. However, later mechanical systems start to wear out and fractures build up, sometimes causing cascading system failures. For example, oil might be changed periodically, but the gaskets wear down, causing oil leaks and burning. It is not repaired at the source, the lack of proper oil cooling could lead to greater mechanical and thermal stress on other parts eventually causing a major malfunction. In software, the process is similar but different in some aspects. The lines of code never wear out. Instead, new requirements are added or new functions are extended, or underlying libraries or operating systems are changed. These may be patched to solve the immediate problem but eventually the patches leave enough residual issues to cause the software to not properly operate. In these cases the whole software needs a major overhaul through refactoring or rewriting. This includes the aspects of the software including components, interaction with lower levels, testing environments, and data structures.

The history of software development may offer an analogy of a system that starts out simple, begins to become more complex, and then is refactored into a simpler but more powerful system. Software development evolved from linear instructions on punch cards to much more complex processes with changing requirements of objects, web integration, and collaborative workflows with non-compatible proprietary tools and components. However, the open source movement greatly simplified the process with languages like Python, extensive powerful libraries like NumPy, and an integrated development platform like Jupyter. However, the management of change was difficult. While each component had version control, the overall integration did not, which meant it was difficult to share an integrated code and ensure that it worked on a different computer. This integration was finally tackled by Google's Collaboratory allowing consistent access to updated environments, with little thought given to compatibility.

Alternative Industrial Revolutions

In our current situation, fossil fuels have helped maintain acceleration through the 20th century at a hyperbolic rate (LePoire and Chandrankunnel 2020). However, these fuels had drawbacks – mostly environmental climate change issues but also global imbalances and the finite limit of availability. Population had undergone demographic transitions from early technology to medical and agricultural innovations such as artificial fertilizers, which required energy. Research was facilitated by increased communication and larger markets for new innovations. Computers played a large part in the advancing technologies in the latter part of the 20th century. This technology was originally expected to have a small market. However, military needs for small electronics for control of missiles subsidized the research that led to the rapid development of the technology following Moore's law.

Two alternative history scenarios are considered: how would the technology trend change if there were more or if there were less available energy? For example, what if there were no fossil fuels available to sustain the technology progress of the 20th century? On the other hand, what would the trend have been if there had been an early substitute for fossil fuels, that is, early adoption of advanced nuclear energy? The expectations from the hyperbolic growth model would suggest that the hyperbolic trend continues until the growth can no longer be sustained due to some limit (LePoire and Devezas 2020). However, if the energy use can still continue to grow (although not at the hyperbolic rates) then the trend will undergo an inflection into a slower growth rate much like the second part of a logistic transition. In the case where there is more clean energy available, the current transition due to climate change might not be experienced, instead many problems such as availability of sufficient clean water could be solved with inexpensive energy. In this case, the hyperbolic energy trend might continue to another level before approaching a different limit.

How would this difference in energy availability in the past affect the development of technology and science? Answering this type of question offers a way to do a thought experiment concerning the important aspects and how they are connected (Cowley 1999). However, the results might only be insightful but not definitive because any real experiment can never be done. Potential ‘What If’ topics might consider access to energy resources from a slight change in physics or biology; a slightly different earth; and specific 20th-century events during the rapid progress of technological applications (Swain 2017).

Fossil fuels played a unique role in rapid change in the 20th century; hopefully facilitating technology advances that help us replace fossil fuels with sustainable energy sources. But what if no oil had formed during Earth's history? Perhaps, the Industrial Revolution, which was fed by fossil fuels such as coal, oil, and natural gas, would have been delayed or never happened. There might have been insufficient energy concentration to generate the scientific breakthroughs necessary to create the new level of sustainable society based on renewables and nuclear energy. The Industrial Revolution might have stalled with no great improvements in transportation, communication, computing, and scientific progress. Cities would not have become so large and complex (Balland *et al.* 2020) if the diminished sources of energy limited growth.

Alternatively, increased energy availability to continue hyperbolic growth closer to the time of the singularity is a bit risky. It is a bit like the before mentioned early experiments in nuclear engineering – two halves of a sphere of plutonium could be brought together slowly – tickling the dragon's tail. This is somewhat similar to approaching the time of singularity, that is, getting closer allows more technology change but at some point the social system cannot adopt the technology fast enough and the rapid change results in chaos instead of progress.

No Fossil Fuels

How might oil not have formed? It does take special conditions to form oil and other fossil fuels such as the ability for plant and plankton material to be relatively stable against decomposition before it is buried and stored (Schobert 2013). The evolution of plant structures during the Carboniferous period led the evolution organisms to decompose it. However, during this evolution much more material that is organic survived until it had been buried, as others have called it the Earth's indigestion period. The oxygen level in the atmosphere increased due to the burying the carbon without oxidizing it (which leads to coal formation). According to the theory of a self-regulating Earth based on changes in the atmosphere to keep certain properties like surface temperature constant despite the increasing energy output of the Sun. About 400 million years ago carbon was removed from the atmosphere to cool Earth since the Sun had become hotter.

On Earth, nature captured the carbon debris but it still had to be converted into an energy dense material easy to transport (oil). This work of nature over millions of years made oil much more convenient compared to extracting the similar energy from current crops. An example of the early energy revolution towards fossil fuels in England was the need to get fire hot enough to process iron. Burning wood would not generate the high temperature directly but it first could be processed by burning without oxygen to form charcoal. Charcoal burning does sustain a high temperature for ironwork, but great amounts of wood are needed in its manufacture. As the wood supply from forests in England diminished to support this activity, coal became a substitute that continued the Industrial Revolution with the positive feedback among coalmines, ironworking, and iron steam engines to pump water from mines (Ayres 1990).

What might have happened if there were no coal and oil during the early Industrial Revolution? Most of the early steam engines were fueled with wood. Coal would not contribute as much energy as wood until the later part of the 19th century. So history might not have been greatly impacted until that time, meaning that railroads would have been explored (as they were used in the U.S. Civil War but not the Napoleonic Wars earlier in the century), electricity and magnetism would have been discovered and consolidated since Faraday's experiments and Maxwell's theory were completed by then (Smil 2008). With electricity, the early electrical generation was from hydropower such as Niagara Falls hydropower. What would impact history would be the growing scarcity of wood with no inexpensive coal substitute to continue the economic growth into the 20th century.

The search for greater energy resources might have led to large deforestation outside of Europe, such as North America and Siberia. Windmills, which had helped the Dutch in their economic Golden Age in the 17th century, might be converted and upgraded to make electricity instead of raising water or grinding grains. However, hydropower dams would generate most early electricity. The cities would be supplied first. Radio would probably develop but the infrastructure for the development and operation of television probably would not come as early as it did. Since the development of rocket and nuclear technology motivated the early research and development of microelectronics, the computer revolution might have been much delayed without this incentive. Rockets might be developed later with the use of hydrogen and oxygen as fuels, but planes which are quite dependent on fossil fuels would probably be delayed along with the extended use of zeppelins instead.

Coal was adopted earlier for other uses. For example, naval ships depended on the use of coal at various stations around the world. Steel and cement manufacturing shifted from using charcoal, a high carbon fuel made from wood, to using coal. It is not sure how this would have affected the development of rails. However, there would be no fight between Carnegie and Rockefeller over being the richest man in the world in the late 19th century on the basis of the use of oil and steel.

Without the use of fossil fuels for fertilizer, the population growth rate would have been limited earlier. Solar power might be developed through concentration by mirrors to drive steam generators as they are now, but probably not by photovoltaic cells since that is connected to the semiconductor revolution of microelectronics. Transportation and communication would be slower, although radio would replace the telegraph of the 19th century. The suburbs would not develop as fast, so the urban population would be more concentrated and dependent on public transit such as the limited rails and subways.

Under these circumstances, World War II might not have happened because there was no competition for the oil fields. However, there would always be resources like river hydropower and forests to fuel disagreements. In our current situation, the remoteness from much of the fighting in World War II left the U.S. relatively intact to lead in technology and science. The U.S. gained much advantage from the ability to attract top students from around the world to work and study. Without a technologically enabled World War, Europe might have had a better chance to maintain its lead in these areas. Economically there would be less trade due to the higher costs of shipping, meaning that manufacturing would stay local instead of developing as a global supply chain.

Perhaps, an all-electric economy could have formed but the fraction of global electrical energy that can be extracted from dams is currently at about 17 %. For transportation, batteries would have to be developed early instead of the internal combustion engine. In fact, some early cars did run on batteries, but the infrastructure and storage were not capable of competing against oil.

Could wind have supplied more power like the one we see today? Wind had been used by windmills for mechanical purposes such as grinding grain and pumping water. Other uses of wind included the use in transportation especially by ship. Could the transition be made from the early windmill technology of the Turks, Dutch and Cistercians into the more modern technology that we see today for electricity generation?

The end result is that it would be more difficult to transition from one sustainable energy technology to another more advanced set of technologies without the use of fossil fuel in between while the advanced renewable technologies are developed.

Abundant Non-Fossil Fuel Energy

What if the world took a slightly different path after World War II? At that time, it was known that energy stored in uranium could be released with either destructive or beneficial purposes. Some predicted that the energy from nuclear power in the future would be 'too cheap to measure'. US President Eisenhower called for 'Atoms to Peace', the United Nations formed the International Atomic Energy Agency (IAEA), and later a Global Nuclear Energy Partnership was proposed. If these efforts had led to greater acceptance of nuclear energy (as it was done in France) then one possible scenario is that nuclear power might have replaced some of the demand for fossil fuels. This might have mitigated the trend toward climate change.

One technology that might have enabled this nuclear power growth is the molten salt reactor (Waldrop 2019) which is safer, with less proliferation potential, and better nuclear waste management. It seems like the growth of commercial light water reactors (LWR) was somewhat incidental, being chosen over advanced realtor designs of the time based on the investment in LWR by the military for submarine propulsion.

The impacts of this hypothetical energy source would be great. Energy prices would come down without dependence on international oil supply. Climate change gas emissions would be reduced. The fossil fuel substitutes would still be valuable for industrial production of plastics and chemicals. All the benefits of inexpensive energy that Richard Smalley (2003) listed in the 21st century such as clean water supply would be available.

However, would there have been a downside if this energy source had been realized? This question asks whether a slowdown in technology development is due to either: 1) the lack of energy or 2) the inadequacy of social responses to integrate the new technology. If the latter, then the slowdown would proceed as it is, however, with less stress because of the better environmental conditions and greater equality with access to relatively inexpensive energy.

Instead, if it is the increased energy availability that enables more technology exploration, it could be imagined that more countries than the Asian Tigers would have been able to develop quicker. This would lead to greater economic equality, but the increased demands and higher global labor costs would have caused higher prices even if the energy prices stayed low. However, it would also result in the diffusion and growth of research and development around the globe, leaving the U.S. with diminished opportunities to recruit outside scientists and engineers that had fueled its growth in the real post-World War II era. The technology of robotics probably would have received much more emphasis along with exploration and extraction of materials such as metals. This probably would still cause environmental issues such as loss of biodiversity and toxic substances in the environment, although not carbon dioxide.

While the amount of uranium is limited, the early nuclear power scientists knew this and had designed reactors that could produce fuel from ores that are currently not being used. The pressure for renewable technologies such as solar and wind is unclear. Commercial shipping could have been powered by reactors just as aircraft carriers and ice cutters are now. The most difficult part to substitute fossil fuel energy is air travel. There might be a few options such as limited use of fossil fuels, generation of biofuels as is now occurring, or using electricity to generate chemical fuels with high enough energy densities to enable economical flight.

Of course, there could be some dark sides to this scenario. While the reactors might have been safer, there is a chance that the widespread use of nuclear power might have been subverted for weapons production. However, the hot spot of the Middle East would no longer have the pressures of being a major energy supplier.

Potential Trajectories of Emerging Technologies

Processes similar to the movement of complexity in the software development process may also contribute to perceived simplification of some technologies such as transportation, communication, and energy (BBC 2021).

Transportation

The current automotive transportation requires a set of complex processes to enable transportation. The cars are mostly internal combustion engines, which have been honed for over 100 years to highly efficient machines that use a very high density energy storage fuel – gasoline. They require extensive interaction with the driver in order to operate safely, but even then, there is a high risk for human and car damage covered by the insurance industry.

Some of these components: car, fuel, operation, insurance, might be replaced over time by systems that seem simplified. For example, an electric car has fewer parts and a lower maintenance costs, the electricity can be obtained off the local grid and does require the extensive oil exploration, extraction, transportation, refining, and special distribution through gas stations. The operation is beginning to be more automated with safety features, which operate well in appreciated conditions. If the operation is sufficiently automated, the accident rates and liability might decrease, which leaves insurance simplified (as well as fewer deaths and injuries). Furthermore, the car might be rented such as an extension of Uber, so that the transportation service means that distributed storage of cars (garages) might not be necessary. The automation of the operation might allow smart driving to reduce road congestion.

Part of the complexity has been moved to the material research for batteries meeting the criteria, the processing and communication for smart driving, and the liability that the manufacturer and service extends to the passenger. In this scenario the GDP in the automobile industry might go down due to safer, more energy-and time-efficient, and more maintainable technologies. But it is similar to the GDP drop from the early PCs to the currently available computers that have much more capabilities.

Communication

The Internet has provided many opportunities for communication and has also replaced transport in remote work, virtual presence and virtual reality. The complexity has been mostly captured by the layers of infrastructure and standards that enable cell phones, and Wi-Fi. This has influenced the one-way communication so that broadcast has been replaced by on-demand services for entertainment. Further extensions might be continuing in virtual reality of travel, and virtual presence. One issue is to ensure security and scalability of the infrastructure to the higher demands.

Energy

The growth of the energy flow through the evolving global system will probably continue but not as fast as they have been. It can already be seen that economic contentment is not proportional to energy flow, that is, it saturates with more energy. This is in part due to higher efficiencies in energy use and conversion along with trends to dematerialization, for example, use of information technology such as web conferences to replace real travel. Currently, to have the world using the same energy intensity (energy/person) then the global energy supply would need to be about a factor of 4 higher than today. It is expected that renewables of solar and wind will play a large role in the energy increase. However, new nuclear fission, fusion along with solar power satellites are being considered and explored. This increase in energy flow usually involves a new layer of reorganization, probably some type of international cooperation such as the IAEA or GNEP proposal.

Discussion

From these four perspectives, both hypotheses and scenarios could be constructed and analyzed. Various scenarios have already been suggested such as the dystopia, realistic, and utopian (Haque 2021; Grinin and Grinin 2016; Vidal 2008; Smart 2019; Kurzweil 2005). It is clear that the future is not determined but there are various paths that could be taken. The obvious one is the collapse of civilization, as we know it, but there are other potential paths that lead to better outcomes, in which the complexity costs are controlled through decoupling (much like the open-source software development) so that the stress of quick change is mitigated. As in panarchy (Gunderson and Holling 2002), this would mean redistribution of resources, values, and responsibilities among the various levels of many organizations. This process is clearly not simple and straightforward.

This process of decoupling leads to greater phase space to solve problems instead of the rat-race treadmill process of quickly applying new technologies to solve the previous problems. This greater room in phase space allows the problems to be addressed and communicated in a linear way instead of the complicated mess of the nonlinear options when limits are approached. In this way complexity may still increase but diffused, resolved, and contained at appropriate levels.

This situation might have resulted from quick technological progress that generated many unresolved risks and social problems at many levels. This can be compared to heating the system up with the temperature being similar to the change rate (Karasik 2014; Johnson 2019). Once the limit has been reached, the system cools down (lower rates of change). In a metal, this is called annealing, giving time for atoms to find the lowest energy state for a given temperature. This removes many of the defects as the system cools into a refined metal. The metaphor of annealing has also been applied to the brain (Johnson 2019) where it incorporates the elements of free energy landscapes, Bayesian modeling, and panarchy models.

Summary

- The singularity trend of Big History seems to be approaching to an inflection point. Some ways this trend might continue are towards utopia, chaos, slowing down, or collapse.
- This inflection is near the point when many global issues such as energy supply, environmental damage, agricultural productivity (water, soil), biodiversity, infectious diseases seem to require international collaboration.
- Systems in population, physics, evolution/development, ecosystems, and historical civilizations have shown various responses which reached various limits and subsequently slow down or collapse.
- Since energy is important in enabling new complexity levels to emerge, alternative histories of cases with less and more energy than in our situation were considered.
- In the case with no fossil fuels, the change rate would probably have slowed down before reaching technological levels we experience today.
- In the case with more energy, technological development might have continued accelerating with fewer environmental and geopolitical issues. However, the need to slow down might be dependent on the social response capabilities.
- A slowing rate of change would by definition reduce the complexity of life by relieving the costs of obsolescence, uncertainty, and inequality.
- Annealing of metals as they cool might be used as an analogy of a slowing-down society. Once technological society has reached a global scale, it can focus on unresolved risk issues at all scales.

References

Atkins P. 2018. *Conjuring the Universe: The Origins of the Laws of Nature.* Oxford University Press.

Ayres R. U. 1990. Technological Transformations and Long Waves. *Technological Forecasting and Social Change* 37: 1–37. URL: http://pure.iiasa.ac.at/id/eprint/3225/1/RR-89-001.pdf.

Bak P., Tang C., and Wiesenfeld K. 1987. Self-organized Criticality: An Explanation of the 1/F Noise. *Physical Review Letters* 59(4): 381–384.

Balland P. A., Jara-Figueroa C., Petralia S. G. *et al.* 2020. Complex Economic Activities Concentrate in Large Cities. *Nature Human Behavior* 4: 248–254.

BBC 2021. Future Technology: 22 Ideas about to Change Our World. *Science Focus.* URL: https://www.sciencefocus.com/future-technology/future-technology-22-ideas-about-to-change-our-world/.

Carey S. 2021. Complexity is Killing Software Developers. *InfoWorld.* November, 1. URL: https://www.infoworld.com/article/3639050/complexity-is-killing-softwaredevelopers.html.

Chaisson E. J. 2004. Complexity: An Energetics Agenda; Energy as the Motor of Evolution. *Complexity* 9(3): 14–21.

Chojecki P. 2021. Moore's Law Is Dead. Now What? *Builtin.* November, 12. URL: https://builtin.com/hardware/moores-law.

Cowley R. 1999. *What If?: The World's Foremost Military Historians Imagine What Might Have Been.* Putnam, NY.

Creely A., Greenwald M., Ballinger S., Brunner D., Canik J., Doody J., Zhu J. *et al.* 2020. Overview of the SPARC Tokamak. *Journal of Plasma Physics* 86(5).

Czech B. 2000. *Shoveling Fuel for a Runaway Train.* Berkeley: University of California Press.

Delahaye J.-P., and Vidal C. 2019. Universal Ethics: Organized Complexity as an Intrinsic Value. *Evolution, Development and Complexity: Multiscale Evolutionary Models of Complex Adaptive Systems /* Ed. by G. Georgiev, C. L. F. Martinez, M. E. Price, and J. M. Smart, pp. 135–154. Springer.

Ekstig B. 1994. Condensation of Developmental Stages and Evolution. *BioScience* 44(3): 158–164.

Grinin L., and Grinin A. 2016. *The Cybernetic Revolution and the Forthcoming Epoch of Self-Regulating Systems.* Moscow: Uchitel.

Grinin L., Grinin A., and Korotayev A. 2021. COVID-19 Pandemic as a Trigger for the Acceleration of the Cybernetic Revolution, Transition from E-Government to E-State, and Change in Social Relations. *Technological Forecasting and Social Change* 175: 121348.

Gunderson L. H., and Holling C. S. 2002. *Panarchy: Understanding Transformations in Human and Natural Systems.* Washington D.C.: Island Press.

Haque U. 2021. 2021Was the Beginning of the Age of Collapse. *Eudaimonia*. December, 29. URL: https://eand.co/2021-was-the-beginning-of-the-age-of-collapse-97bb39544268.

Hill K. 2014. Tickling the Dragon's Tail: The Story of the 'Demon Core'. *Nerdist*. December, 11. URL: https://archive.nerdist.com/tickling-the-dragons-tail-the-story-of-the-demon-core/.

Johnson M. E. 2019. Neural Annealing: Toward a Neural Theory of Everything. *Opentheory.net*. November, 27. URL: opentheory.net/2019/11/neural-annealing-toward-a-neural-theory-of-everything/.

Karasik M. S. 2014. Forecasting the Evolution of Cultural Collisions Using Annealing-Nucleation Models. *Predicting the Future in Science, Economics, and Politics* / Ed. by F. W. Wayman, P. R. Williamson, B. Bueno de Mesquita, and S. Polachek, pp. 261–298. Edward Elgar Publishing.

Korotayev A., Goldstone J. A., and Zinkina J. 2015. Phases of Global Demographic Transition Correlate with Phases of the Great Divergence and Great Convergence. *Technological Forecasting & Social Change* 95: 163–169.

Korotayev A. 2020. The Twenty-First Century Singularity in the Big History Perspective – A Re-analysis. *The 21st Century Singularity and Global Futures. A Big History Perspective* / Ed. by A. Korotayev, and D. LePoire, pp. 19–76. Springer.

Korotayev A., and LePoire D. 2020. *The 21st Century Singularity and Global Futures. A Big History Perspective.* Springer, Cham.

Kubiszewski I., Costanza R., Franco C., Lawn P., Talberth J., Jackson T., and Aylmer C. 2013. Beyond GDP: Measuring and Achieving Global Genuine Progress. *African Journal of Food, Agriculture, Nutrition and Development* 13(5): 1–12.

Kurzweil R. 2005. *The Singularity is Near : When Humans Transcend Biology*. New York: Viking.

LePoire D. J. 2004. A 'Perfect Storm' of Social and Technological Transitions? *Futures Research Quarterly* 20(3).

LePoire D. J. 2005. Application of Logistic Analysis to the History of Physics. *Technological Forecasting and Social Change* 72: 471–79.

LePoire D. J., and Chandrankunnel M. 2020. Energy Flow Trends in Big History. *The 21st Century Singularity and Global Futures. A Big History Perspective* / Ed. by A. Korotayev, and D. LePoire, pp. 185–200. Springer, Cham.

LePoire D. J., and Devezas T. 2020. Near-Term Indications and Models of a Singularity in Big History. *The 21st Century Singularity and Global Futures. A Big History Perspective* / Ed. by A. Korotayev, and D. LePoire, pp. 213–224. Springer, Cham.

Linstone H. A. 1996. Technological Slowdown or Societal Speedup – the Price of System Complexity. *Technological Forecasting and Social Change* 51: 195–205.

Motesharrei S., Rivas J., and Kalnay E. 2014. Human and Nature Dynamics (HANDY): Modeling Inequality and Use of Resources in the Collapse or Sustainability of Societies. *Ecological Economics* 101: 90–102.

Schobert H. H. 2013. *Chemistry of Fossil Fuels and Biofuels*. Cambridge: Cambridge University Press.

Smart J. M. 2019. Evolutionary Development: A Universal Perspective. *Evolution, Development and Complexity: Multiscale Evolutionary Models of Complex Adaptive Systems* / Ed. by G. Georgiev, C. L. F. Martinez, M. E. Price, and J. M. Smart. Springer.

Smalley R. 2003. *Our Energy Challenge*. Houston, TX: Rice University. URL: http://video.google.com/videoplay?docid=-4626573768558163231#.

Smil V. 2008. *Energy in Nature and Society: General Energetics of Complex Systems.* MIT Press.

Stone L. 1993. Period-Doubling Reversals and Chaos in Simple Ecological Models. *Nature Cell Biology* 365: 617–620.

Swain F. 2017. *The Universe Next Door: A Journey Through 55 Parallel Worlds and Possible Futures.* London: John Murray Publishers.

Tainter J. A. 1988. *The Collapse of Complex Societies*. Cambridge.

Vidal C. 2008. A Cosmic Evolutionary Worldview: Short Responses to the Big Questions. *Foundations of Science*. Special Issue of the Conference on the Evolution and Development of the Universe. URL: https://evodevouniverse.com/wiki.

Waldrop M. M. 2019. Nuclear Technology Abandoned Decades Ago Might Give Us Safer, Smaller Reactors. *Discover Magazine*. February, 26.

Wolchover N. 2019. Why the Laws of Physics Are Inevitable. *Quanta Magazine*. December, 19.

Wolla S. A. 2017. The Productivity Puzzle. *Page One Economics Newsletter*. March.

Yalçın O. G. 2020. 4 Reasons Why You Should Use Google Colab for Your Next Project. *Towards Data Science*. November, 23. URL: https://towardsdatascience.com/4-reasons-why-you-should-use-google-colab-for-your-next-project-b0c4aaad39ed.