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Potential Nested Accelerating Returns Logistic Growth in Big History

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Abstract

The discussions about the trends in rates of change, especially in technology, have led to a range of interpretative models including accelerating rates of change and logistic progress. These models are reviewed and a new model is constructed that can be used to interpret Big History. This interpretation includes the increasing rates of the evolutionary events and phases of life, humans, and civilization. These three phases, previously identified by others, have different information processing mechanisms (genes, brains, and writing). The accelerating returns aspect of the new model replicates the exponential part of the progress as the transitions in these three phases started roughly 5 billion, 5 million, and 5,000 years ago. Each of these three phases might be composed of a further level of about six nested transitions with each transition proceeding faster by a factor of about three with corresponding changes in free energy flow and organization to handle the increased generation rate of entropy from the system. Nested logistic transitions have been observed before, for example in the ongoing exploration of fundamental physics, where the progress so far suggests that the complete transition will include about 7 nested transitions (sets of subfields). The reason for this number of nested transitions within a larger transition is not known, although it may be related to the initial step of understanding a fraction of the full problem. Too small of an initial fraction would lead to incomplete problem scope and definition. Too large of an initial step would lead to complications between the development of basic understanding and higher level derivations. An original step of one-seventh of the problem ends up within one standard deviation from the inflection point (mid-way through the transition).

Keywords: *Big History, logistical growth, complex adaptive systems.*

Current Technological Trends

The forecasts of the near future vary widely in scope and outlook, predicting from near utopia to near dystopia. The issues of great concern during this period include: (1) the energy transition problem of moving from an unsustainable fossil fuel-based economy to something else; (2) the widespread nature of the problems currently being discussed in terms of global warming, global trade, global terrorism, and global knowledge transfer; and (3) the possible opportunities and risks of new technologies such as genetics, nanotechnology, and artificially intelligent computers and robots (Bainbridge and Roco 2005). To gain a wider perspective on this transition, this paper further explores the transitions involving energy, environment, leadership and new technologies (Tainter 1988; Diamond 1997; Ponting 2007; LePoire 2010a) in time scales from the current era, modern history, extended past, and potential future.

Recently, various interpretations of trends in technological progress have led to widely differing predictions. Specifically, Ray Kurzweil (2005) hypothesized an ever-increasing rate of technological change, based on his analysis of over a century of progress in computation technologies. Theodore Modis (2002) hypothesized a very different future, one having a decreasing rate of technological change, based on the analyses of events from the 'Big Bang' to the present. Kurzweil investigated the more recent technological acceleration of computing performance. The inclusion of early electronic technologies, such as relays and vacuum tubes, led Kurzweil to propose that the rate of technological change is increasing with time, that is, Moore's Law of the doubling of electronic device densities every 18 months will be surmounted by new technologies that double in performance in less time. An ever increasing rate of technological change could soon lead to a technological 'singularity'. One attempt at a definition of the technological singularity is a 'future time when societal, scientific, and economic change is so fast we cannot even imagine what will happen from our present perspective, and when humanity will become posthumanity' (Vinge 1993).

Another model of technology progression and diffusion that has been studied is based on the logistic equation. This progression assumes that the rate of progress is proportional to both the current level of complexity and the fraction of complexity yet to be discovered. Logistic analysis has been found not only in market adoption and substitution of new products, but also in technology development and ideas (Marchetti 1986, 1980) such as democracy and energy. Theodore Modis (2002) suggests that the history of the Universe might also be considered as a logistic development of complexity. He arranged important events in the history of the Universe from a variety of sources, assumed that each event was equally important, and then made the assumption that the complexity of an event is its importance divided by the transition time to the next event. The dependence of the cumulative fraction of complexity on milestone number (not the event's time) could be interpreted either as (1) the first half of a logistic curve or (2) a sequence of events that will culminate in a singularity. Modis favored the logistic development interpretation.

These two scenarios can be related to different simple models: Kurzweil's singularity scenario, with continual increasing exponential progress, might derive from a simple complex model, whereas Modis's long-term logistic growth with a tipping point determined by limitations in the learning rate and energy extraction rate, might be related to the more complex but realistic model. If this latter transition is accurate, the rate of technological progress might peak and eventually slow with impacts for economics and leadership (LePoire 2008, 2014).

History may well form a large complex adaptive system (Jantsch 1980; Marchetti 1980; Perry 1995; Spier 1996, 2010). As systems progress, new options that arise for the systems may spontaneously bifurcate into two potential discrete states (see Fig. 1). While the simplest model of complex systems can be driven into chaos, more realistic models with limitations suggest a possible reversal of increasing complexity (Stone 1993). The emergent properties of an evolving complex system might display simple patterns despite the complicated underlying processes (Cohen and Stewart 1994). Another approach is to take a longer view of historical trends and phases. Carl Sagan (1977) presented the stages of information processing, progressing exponentially from the early Universe to the present day. These stages were the development of life, brains, and technology, starting with life origins about 5 billion years ago. A geometrical progression rate would suggest transitions from life evolution to brain evolution around 5 million years ago and further transition to civilization and technological development about 5,000 years ago. The characteristic properties of complex adaptive systems include: (1) a resource which drives the level of complexity, such as energy use (Chaisson 2004); (2) new options at critical stages along development paths (Jantsch 1980); and (3) competition and learning as the options are explored (Dyke 1987).

Complex adaptive systems are found in a variety of fields and display a range of common emergent phenomena, such as bifurcations or transitions (Kauffman 1995). These transitions occur when an input to the system, such as energy flow, increases beyond critical levels. Studies of physical systems far from thermal equilibrium suggest that the energy flow is important in the development of more complex organization. Chaos and adaptation have been investigated in many natural developing systems such as biological evolution, ecosystems, and social systems. In such dissipative systems order can spontaneously form only when the system is maintained far from equilibrium, as measured by the usable energy that flows through a system.

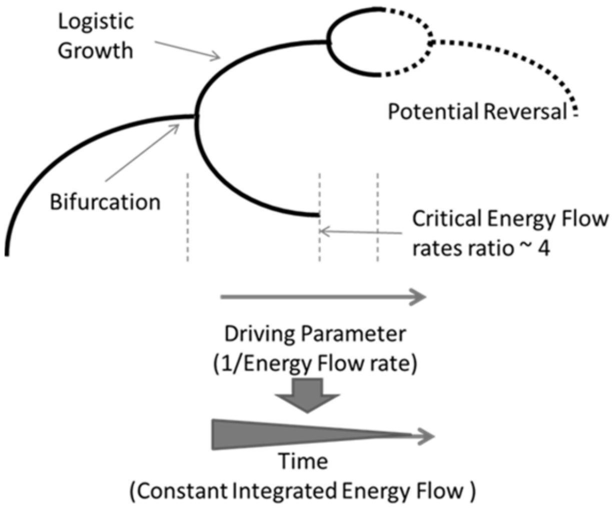

Fig. 1. Characteristics of an evolving Complex System. As the driving parameter (related to energy) increases over time, the organization of the system reaches a point where it is unstable but instead can grow in one of two ways. The growth between bifurcations is logistic

An approach to explore whether these processes are occurring (LePoire 2010b) include: (1) investigating the intensity and timing of energy flow organization; (2) investigating simple systems dynamics models; (3) rate of critical events in human historical transitions; (4) exploring the nested geometrical transition periods and energy uses in biological, mind and technology evolution; (5) exploring possible indications of a reversal in rate of change in fundamental physics and environmental issues; (6) examining the length scales of interacting systems and fundamental agents from the Big Bang to present.

A time contraction factor of about 3 is similar to time and energy contraction factors found by Snooks (2005) and Bejan and Zane (2012). This time contraction factor was used in describing the changes in energy intensity (Fox 1988; Morowitz 2002; Niele 2005; Chaisson 2004; Smil 1994; Bernstein 2004), as summarized in Table 1. Note that just one time contraction factor was realized from the Big Bang to the beginning of life on Earth. The remaining three large phases of life, human, and civilization evolution are separated by bold lines with different shadings. Each of these major phases has five or six subphases. Note that six subphases with a contraction factor of the square root of 10 (about 3) gives an overall contraction factor of 1,000 within each major phase.

Table 1. Possible way to organize changes in energy flows through extended evolution covering life, human, and civilization development

Transition Start (Years ago)	Description	Energy Change
1	2	3
15 Billion	Gravitational	Gravitational energy causes clumping and nuclear energy causes energy to be release and element formation
5 Billion	Planet/Life	Life first gathers energy through chemicals or thermal gradients. Later the light from the sun is captured and turned into chemical energy
1.5 Billion	Complex Cells	Simple prokaryotes form symbiotic relationships to form a larger and more organized eukaryote cell
500 Million	Cambrian	Oxygen levels reach a concentration so that multicellular organisms can be supported. The many body types and survival strategies lead to rapid evolution
150 Million	Mammals	Animals move to land after plants. The larger temperature variations lead to a way to regulate temperature to ensure ability to be active throughout the day and seasons
50 Million	Primates	A generalist strategy using various food sources including fruits leads to greater energy to the brain
15 Million	Hominids	Further generalist strategies and social organization again leads to greater energy use by the brain
5 Million	Humans	Humans adapt to a changing climate by leaving the forest for the savannah along with the capability for walking to expand the range of natural resources
1.5 Million	Speech	Further social organization leads to an expanded food sources including scavenging
500,000	Fire	Fire improves the energy availability from food
150,000	Ecoadaptation	Humans move out into other ecosystems expanding the range of energy resources
50,000	Modern humans	The benefits of specialization and social organization are realized during the ice age

1	2	3
15,000	Agriculture	Domestication of plants and animals leads to a more intense and reliable use of the land
5,000	Civilization	Organization at a city level allows risk reduction and order with increasing population
1,500	Commercial Revolution	Financial and mechanical technological techniques are applied and improved in a sustaining growth organization
500	Scientific/Exploration	Exploration of lands and ideas leads to expanded energy resources
150	Industrial	Fossil fuel allows large amounts of resources to be used along with increasing specialization
50	Information	Control through systems and computers allows greater efficiency in the use of energy and handling of pollution

There are similarities and differences between this interpretation and previous papers in this series. Specific issues include: 1) the nature of the current inflection point (Panov 2011); 2) the emphasis on non-equilibrium dynamics including bifurcation or energy, technology and also social organization (Nazaretyan 2011); and 3) the organization of evolutionary trends into two or three phases (Grinin, Korotayev, and Markov 2011).

Alexander Panov (2011) also organized evolutionary history with 19 evolutionary crisis transitions with decreasing duration (by about a factor of 3). This is called the scaling law of evolution. If the trend continues, evolution would come to a very rapid rate of evolution at some point in time, the Singularity, which was predicted to occur somewhere within the past two decades. However, as he notes, the rate of evolution cannot approach this infinite rate but instead would be constrained by resources and the ability for evolutionary processes to work by testing various environmental fitness of technologies and cultures. This is similar to the law of Accelerating Returns by Ray Kurzweil. However, just as normal logistic transitions first start with exponential growth and later slow due to limitations to form the S-curve transition, the hyperbolic growth of evolution might also begin to slow. The combined law of accelerating returns and the logistic developed here is one way to model this important inflection point in evolution, the 'crisis of crises' as stated by Panov. Such an inflection would indicate the conflict between conventional economic and resource growth and constraints of global resources, pollution, population, and conflicts.

Panov (2011) continues to discuss the possible 'end' of science. The complexity of the increasingly intertwined processes of science, development, and production might be reflected in the limits of scientific growth within the constraints of society. An outgrowth of this entanglement might be seen in the recent organization of technological hubs which combine research into the scientific basis, product development, and production of new technologies. For example, the U.S. Department of Energy has formed many exploratory technological innovation hubs to pursue new energy technologies such as energy storage (batteries) for both transportation and electrical grid buffering.

This nested logistical pattern, interpreted as alternating evolution of smooth exploration followed by intense reorganizing transitions is compatible with the view of Akop Nazaretyan (2011). He emphasized the non-equilibrium aspects of the evolution and the role of mental capacities to form new organizations that would lead through the crises to a new sustainable growth. It is not just the energy flow that increases complexity, but the ability to control the environmental impacts of that flow. Control was important in many transitions including the use of fire, the use of engineered water projects, and the current issues with potential climate change. He identified the 21st 'bifurcation' century as a test where a major inflection in the complexity, suggested by Big History, might raise many issues concerning conflict, energy, and the environment.

There is also the question of whether the evolutionary process occurred in three major phases discussed here – biological, human, and civilization, or two – biological and social phases as discussed by Grinin, Korotayev, and Markov (2011). The reason the phases were split into three in this paper is because of the three information storage and passing mechanisms identified (Sagan 1977), that is, DNA, the human mind, and writing/artifacts. It is true that genetic changes were key in the development of humans but much of the learning was passed through social signals leading to the new tool of spoken language, while also beginning to control aspects of nature such as fire, dogs, and plants. Grinin *et. al.* (2011) mention this aspect in the afterward of their paper by discussing intermediate subphases such as the biological-social type which would be similar to the human mind phase discussed here. Then the civilization, or pure social phase, is distinct because of the hierarchy of the social groups in combination with written records supporting the new organization.

Growth Pattern Characteristics

The first topic concerns the combination of accelerating returns model and the logistic model. The accelerating rate of return can be written $y' = ky^2$. This tends to grow faster than an exponential with a singularity at some point in time. The logistic equation can be written $y'=ky(1-y)$, which has an inflection point but more linear progression of time scales. The super-exponential early growth can be combined with the logistic equation by combining the features of each $y'=k[y(1-y)]^2$. This is shown in Fig. 2 in linear and log form. This is appropriate for a long-term development discovery system, whereas the simple logistic equation is more appropriate for diffusion of information. More insight can be gained by noting the exponential growth rate, y'/y, which is proportional to $1-y$ for a traditional logistic growth, y for an accelerating returns growth, and $y(1-y)^2$ for the combination.

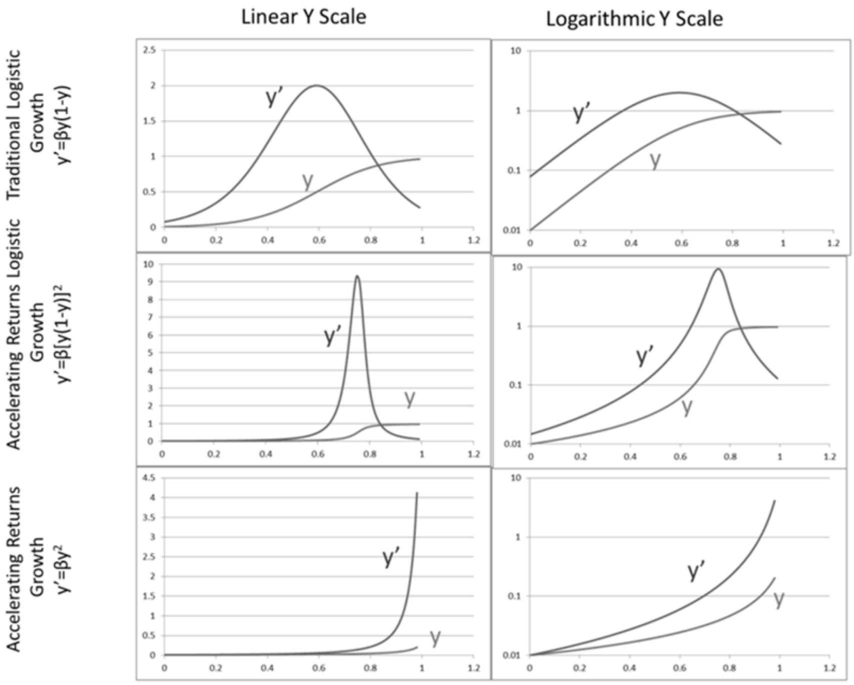

Fig. 2. Patterns of growth- Logistic (top), accelerating returns logistic growth (middle), and accelerating returns (bottom)

The second characteristic is the nested logistic growth pattern in the both overall information mechanism transition, and in energy flow. The historical complexity and energy use growth seems to have about 3 development phases with different information systems until the inflection point leading to a rate of 6 per full transition. Each of the three phases seem to be formed by 6 or 7 subphases where the information mechanism is the same (*i.e.*, DNA, brain, writing) but the energy flow is continually increasing.

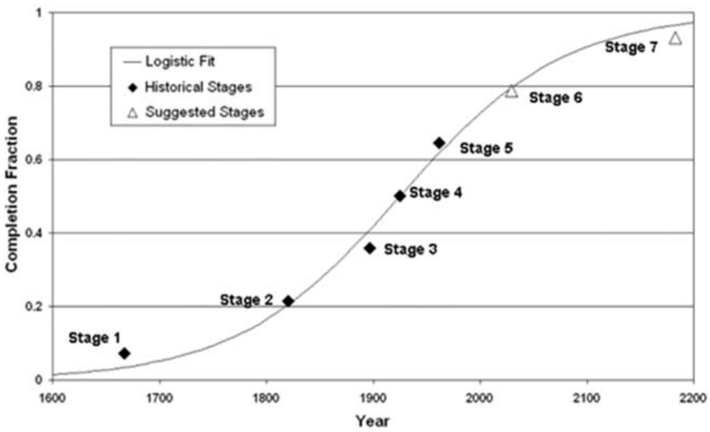

Fig. 3. Nested logistic growth in the area of fundamental physics. Each stage represents a logistic growth in at least one field of fundamental physics starting with gravitation and classical mechanics. Stage 4 occurred with the fastest pace as general relativity, quantum mechanics, and nuclear physics were being developed

This nested pattern of logistic growth with about 7 subphases was observed in the development of fundamental physics (see Fig. 3) (LePoire 2005). This analysis considered the rate of discoveries in various physics subfields. The subfields showed logistic growth patterns with initial slow progress followed by a period of steady progress, ending with another slow rate of progress as the subfield was fully integrated in a consistent manner. Within this one field of science, the nature of logistic development is seen in both the subfields and the complete field. If the logistic interpretation is correct and is followed, the data suggest that string physics is likely to be 50 per cent complete in 2030 and 80 per cent complete in 2090. However, if the development curve is logistic, then the development curve would be symmetric around the midpoint, identified as the 'Golden Age' of physics in 1920s with the simultaneous developments in general relativity, quantum mechanics, and nuclear physics. This would imply that there should be symmetric stages that correspond to each other, that is, if three stages are identified before the midpoint, then there should be three after the midpoint. String physics is only the second identified stage, leading to the suggestion that another stage in the development of fundamental physics might come after string physics. If symmetry holds, the last stage's 20 per cent, 50 per cent, and 80 per cent completion times would be 2100, 2180, and 2260.

Why would a logistic transition be broken into 7 substeps? In the process of exploring a new field, one of the more difficult steps is the first in defining the subject, the scope, and process. While there were many discoveries in physics before Galileo, the sustained nature of scientific progress afterwards points to this difficulty. Some difficult concepts to frame were inertia – bodies tend to keep on moving, the relationship between force and acceleration (versus the force in the static mechanics). This led Galileo to the experiment with simple toy-like apparatus' like rolling balls down inclined planes and measuring objects at the end of strings. If the first step was in the wrong direction, too small or too large, the progress could be halted. Some of the Greek philosophers tried to solve everything in one hypothesis but were not able to defend it with measurements. If Galileo had observed the moons of Jupiter and then asserted the laws of the heavens had inertia but that did not apply on Earth, the rolling balls down incline planes would not have generalized the concept, that is, it would have been too small. Instead the first phase of fundamental physics was the idea of laws of motion that applied on Earth and in the sky was set out by Galileo and took about 150 years through the great mathematics of the 18th century to develop the tools such as calculus, variational calculus, wave theory, and generalized laws of motion such as the Lagrangian. These tools that were developed in the first phase would become instrumental in further developments, for example*,* the Lagrangian formulation was instrumental in quantum mechanics whereas Newton's laws were found only applicable in classical mechanics.

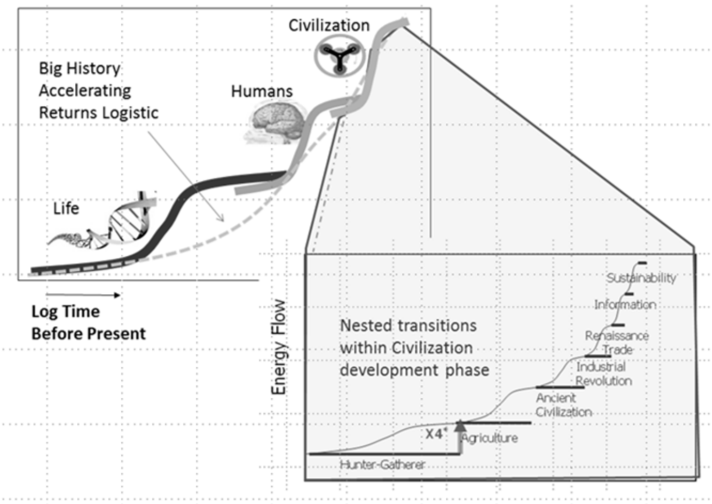

Fig. 4. Example how the major three phases of extended evolution might be considered to be each formed by a nested set of sub-phases (civilization sub-phases shown here)

An appropriate first step in a nested transition might be big enough to tackle fundamental issues. For example, in the physics case above, the fundamental laws of physics were developed and the common force of gravity was explained. However, the first step cannot be too big, due to the dependency of the steps. For example, again in the physics case above, the theory and experimental techniques developed in the first phase were a necessary prerequisite for the second step (electromagnetism) to be explored. An appropriate step size might be less than half of the transition. A simple measure of the width of the transition is its standard deviation, *i.e.*, a characteristic duration of the full transition. So the first step size of 16 per cent of the full transition means that the second step would start one standard deviation from the inflection (mid-point) of the transition (Fig. 5). If equal fractions of the problem (*e.g.*, 16 per cent as in the first step) are later tackled, it would take about 6 steps to complete the logistic transition.

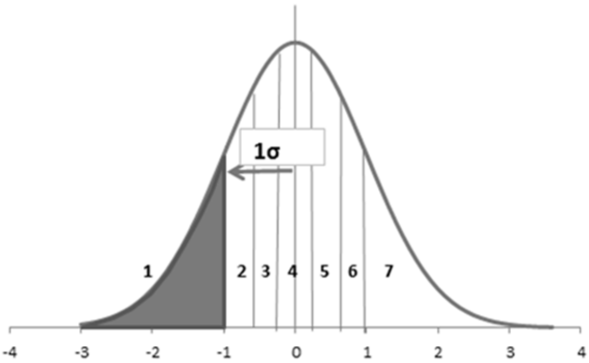

Fig. 5. Nested steps in approaching a normal distribution. If the full exploration of a phase is the whole normal distribution, one possible strategy to initiate the process is to break the problem into subphases, starting with a fraction that is neither too small nor too large. Here it shows that if the whole is divided into seven (or six) equal area sections, then the first section would represent exploring up to one standard deviation from the inflection point (middle of the normal distribution)

Possible Pattern Extensions

One way to project what a logistic world would look like after the inflection point would be to mirror past rates of change. For example, if 2000 was the inflection point, meaning that technological change continues for a while at the same rapid progress but does not accelerate, then the 20th century might be a good indication of some of the changes we might see in the 21st. In the 20th century there was such growth in population and resource use to move the world beyond sustainability. The major energy supply was from non-renewable fossil fuels. The expansion was driven by relatively inexpensive energy, new insights from physics leading to electrical, aerodynamic and material technology. These innovations led to creative destruction in capital formation and development as exemplified by the semiconductor industry which followed Moore's Law. The technology also caused problems such as arms races, environmental impacts, and expensive medical options. The 21st century might adjust by slowing to a more sustainable society with more efficient energy use, a stable or declining population, reduction in the gap between incomes, and exploration of ways to mitigate global environmental impacts while maintaining robust fair trade.

While there are possible indications that a large transition such as a general technological slowdown is underway (LePoire 2014) there are reasons why we might be experiencing a transition inflection point in general evolution from a bootstrap natural evolution type system to a technologically design driven evolution which might show initial speed in development and then slow as leadership is assumed.

The problems with a bootstrap natural selection is that it has a difficult beginning and is stuck in historically determined structures, for example, the long period (billions of years) between the development of simple life and earth and multicellular life during the Cambrian explosion. The energy mechanisms, information storage and expression of biological systems were determined and mostly stable throughout further development. The systems also have difficulty scaling due to individual perspectives and limited information resources for collective action but instead are good at individual exploration, competition, and growth. The techniques for dealing with uncertainty are intuitive and based on evolutionary trajectories, for example, a simple intuitive fight or flight mechanism.

The assumption in the technological singularity is that technology will be able to quickly resolve human and biological constraints and continue an exponential growth path. However, this is unlikely as many constraints are tied to human systems and are also filled with uncertainty which might be better handled but will not be eliminated.

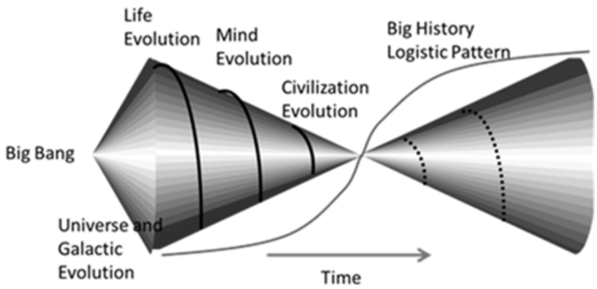

Fig. 6. Hypothesis of the Big History logistic growth pattern. The left hand side is what has been discussed in this paper. The trend towards shorter duration phases cannot continue. One way to extend the pattern is using an all-encompassing Big History logistic pattern which shows an inflection point where the rate of change is the largest

If the natural evolution is viewed as an ever quickening set of phases from molecular evolutions, cellular evolution, multicellular, primate, human civilization and technological stages then it might be expected that the technological evolution might show similar phases. Since the design of the technology is driven by humans there is a period where the two are tightly coupled. For example, the development of fundamental components similar to the molecular evolution for energy, information, and movement structures in organelles would be compared to the development of the understanding of theoretical logic, mechanical relays, electromechanical relays, transistor tubes, and isolated semiconductor transistors along with the resistors, capacitors, and inductors necessary for electronic designs. The next phase of integration, which might be compared with cellular evolution, was done at first in large computer rooms such as ENIAC, then IBMs with semiconductor transistors, but a major breakthrough in integration came with Texas Instrument's integrated chip technology which formed the ability for scalable integration and functionality. The network enabled quick growth of shared information and applications through the Internet, wireless and cellular networks might be compared to evolution of multicellular organisms. However, the Internet resulted in unintended consequences of malware, high dependence requiring high reliability, and ID theft. Concern over integrating with grids, decision support, and automated robotic support are leading to cautious rates of applications. It will be interesting if the artificial intelligence evolves at an accelerating rate or moves more cautiously as this artificial intelligence and robotics start complementing the intelligence that took billions of years to develop on Earth.

On a much longer time-scale the reflection of the rate of change would look something similar to Fig. 6. This paper focused on the left cone which includes the three phases (shown on a log time scale) of life evolution, human evolution, and civilization. If this follows the large logistic trends identified, the pattern in the future would look something like the cone on the right, again three phases with the characteristic slowing-down. However, it is not clear how and whether the logistic development pattern will continue

Conclusion

The three major phases after cosmological development (*i.e.*, life, human, and civilization) had durations of about 1,000th that of the previous. Each might have six subtransitions with durations being reduced by a factor of 3. Energy and organization might qualitatively change between the transitions to handle the additional entropy flow through the systems. These characteristics seem to be consistent with the interpretation of a complex adaptive system with evolution through a sequence of bifurcations and logistic learning. A logistic accelerating rate of return logistic pattern, formed by combining the accelerating rate of return growth and the traditional logistic growth pattern shows similar exponentially shorter transitions. The pattern eventually reverses as has been observed in ecological systems. The decomposition of each phase into six transitions is motivated by the reorganization to maintain increasing energy flows. This nested logistic transition has been observed in the history of the discoveries in fundamental physics. While it is not known why a nested logistic transition would decompose into this number of subtransitions, it was observed that with seven subtransitions, the first step explores up to one standard deviation of the inflection point. Future inflection, symmetrical from boot-strapped to engineered system may gain more control over energy and physical systems.

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