Interpreting “big history” as complex adaptive system dynamics with nested logistic transitions in energy flow and organization

March 31, 2015 · Academic

David LePoire[1]

1 Argonne National Laboratory

LePoire D. Interpreting “big history” as complex adaptive system dynamics with nested logistic transitions in energy flow and organization. Emergence: Complexity and Organization. 2015 Mar 31 [last modified: 2015 Mar 31]. Edition 1. doi: 10.emerg/10.17357.dbe7c8d6fae7f082c4f33c5b35df8287.

Abstract

Big History might be considered the study of an evolving, large, complex adaptive system with three very different phases progressing geometrically from the early universe to the present day. A geometrical progression rate would suggest transitions to life evolution beginning at about 5 billion years ago; to brain evolution around 5 million years ago; and further transition to technological civilization development about 5,000 years ago. Characteristic properties of complex adaptive systems include: (1) a resource which drives the level of complexity, such as energy flow; (2) new options at critical nonlinear decision points along development paths tied to levels of energy flow; and (3) continuous logistic learning as the options are explored; (4) scaling of other dimensions besides energy, such as length and time scales of important processes. This paper presents indications that these processes are occurring through historical trends in energy, environment, economics, and organization. The understanding of these phenomena could contribute to our ability to develop and anticipate potential future scenarios with more integrated, systemic, and effective approaches and expectations.

Approaches to complex adaptive systems

Complex adaptive systems [16,9,26,41] displaying a range of common emergent characteristics have been found in a variety of fields such as biological evolution [25], ecosystems [52] and social systems [46]. Some previous studies contribute to an interpretation that societies exhibit learning (of social organization, technologies, and energy use).

History may well form a large complex adaptive system[24,38,55,56]. As systems progress, new options that arise for the systems may spontaneously bifurcate into two potential discrete states. While the simplest model of complex systems can be driven into chaos, more realistic models with limitations suggest a possible reversal of increasing complexity[57]. Another approach is to take a longer view of historical trends and phases. Carl Sagan [51] presented 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.

Characteristic properties of complex adaptive systems include (1) a resource that drives the level of complexity, such as energy use [58,59,4,19,6,5] (2) new options at critical stages (bifurcations) along development paths; and (3) competition and learning as the options are explored (Figure 1). The difference in the dynamics of complex adaptive systems compared to a complex system is the adaptive or learning aspect. This changes the static diagram of complexity as a function of driving parameter in a complex system that might exist at one value of the parameter. The learning is logistic between bifurcations with increasing energy usage, which eventually leads to an environment that requires reorganization at a critical energy flow at the bifurcation points. Reorganization is required to control the increasing energy flow without crossing into chaos related to uncontrolled energy release such as fires, wars, and environmental degradation. The increasing energy flow drives environmental changes and challenges that might lead to a self-organized criticality at the bifurcation point. If the changes between bifurcation points are too large, the logistic learning phase might become nested (i.e., a single long logistic transition may be realized as several smaller logistic transitions). This has been observed in the development of fundamental physics discoveries that seem to be flowing within one large logistic growth pattern that could possibly be realized as seven sequential smaller logistic transitions[32]. The logarithmic time scale of Big History may be related to the substitution of the energy driving parameter with time, where each phase has a similar integrated energy flow. The energy flow rate ratio is about 4 times greater than in the previous phase. This ratio is similar to a reduction by considering energy flow in fractal systems by Bejan[1]. Korotayev [27] has articulated that an integrated large-scale world-systems model may be easier to understand and model similar to the way that aggregate macroscopic gas laws are simpler than the underlying microscopic molecular dynamics.

This evolution of increasing complexity goes against the natural flow toward randomness from the second law of thermodynamics. This is possible only because the Earth is not a closed system; it experiences a net flow of energy from the

Sun. The process of this more general evolution is not continuous; instead, it is separated into sequential phases of logistic adaptation followed by discrete bifurcations. This behavior has been seen in the development of leading capitalist countries[30]. In physics, one way to go against the flow is to use energy for controlled oscillations. For example, the natural tendency would be for a sailboat to go with the wind, just as the natural tendency for an inverted pendulum would be to fall under the force of gravity. In both cases, a strategy of oscillation—tacking for the sailboat and tip vibration for the inverted pendulum—can be used to stabilize the dynamic system out of equilibrium. In tacking, the boat alternates between traveling at angles to the left and right of the wind direction [36].

Image not readable or empty
https://journal.emergentpublications.com/wp-content/uploads/2015/11/c7021bd0-340b-d9ca-cfe9-f4927713d879.png

Fig 1. Characteristics of a complex adaptive system

This paper reviews previous studies that indicate elements of the above system. These studies include recent and longer-term energy flow rates, logistic trends of major historical events, nested logistic transitions in physics, and trends in important length scales. This complex adaptive system hypothesis of Big History is compared with two recent hypotheses concerning the rate of technological change of Kurzweil [28] and Modis [40]. Possible implications are then explored, including a possible slowing-down in progress due to going beyond the inflection point of the overall logistic curve; interpreting the Big History logistic curve as a spiral along a double cone; and possible connection with a self-consistent interpretation in quantum mechanics.

Historical energy flows

How have energy flows changed in the past? [53,43] Since the hunting-gathering stage, human societies have undergone transitions toward more complex forms (e.g., from agricultural villages to civilized states, to trading networks, to industrialization, to the current evolution of a services- and knowledge-based economy). Human beings have used various sources to derive energy to support various levels of societies. These energy sources include our own muscle and that of animals, as well as wood, wind, water, coal, oil, and nuclear power. The increase in energy usage over this period is illuminating: a human’s intake of 2,500 calories per day corresponds or averages to about 100 watts (W) (i.e., about as much energy as a large incandescent light bulb uses). The average current per capita rate of energy use in the United States stands at 15 kilowatts (kW) of energy (including commercial, industrial, and residential use), or about 150 times a person’s food energy intake/use per day. This measure corresponds to about 3.5 factors of Feigenbaum’s number and suggests there might be three or more transitions, or bifurcations, where the energy flow increases by a factor of about 5 (assuming that the ordering parameter is inversely related to the energy flow). Additional transitions might be the result of a concentration of energy use by parts of a civilization. For example, the agricultural transition from hunting/gathering occurred over a long period but saw a concentration of effort (as measured by time spent on food production). In addition, the development of civilizations then organized rural work efforts to support urban development and classes. The details of specific developments or energy sources and uses have been studied; [53] however, to test the relationship between leadership and an aggregate measure such as energy consumption it is necessary to estimate the energy use quantitatively for various leading societies in human history.

Image not readable or empty
https://journal.emergentpublications.com/wp-content/uploads/2015/11/b5f23eff-8a4f-7bf2-60ee-ec7d2c367eb5.png

Fig 2. Temporal relationship of the energy fuel source, energy intensity, and leadership. The energy fuel source and leadership exhibit pulses. The ratio of the energy intensity (energy per person in the leading nation) between pulses is about four [35].

Once freed from depending on slave labor as in the ancient civilizations, there was more motivation to explore mechanical and energy extraction to help reduce physical efforts, leading the West to utilize water, wind, and wood along with mechanical machines. Artifacts such as cathedrals, ships, and castles attest to their ability to apply these technologies and energies in creative ways. This activity led to a shortage of wood in Western Europe (especially in England and the Netherlands) after the recovery from the Black Plague, which created the need to import vast amounts of wood and timber from further north and east as was traded by the Hanseatic traders [3]. An estimate of annual wood use in the middle of the Northern Renaissance (in 1670) is 4 cubic meters (m3) per person. Water, wind, and animal-derived power were also utilized. The sum of the usage conversion rates of these energy sources suggests that there could have been approximately 500 W of energy consumed per person in the late Renaissance, or about a factor of 5 times greater than the 100-W consumption rate of one person.

The energy use per person then increased again as fossil fuels became extensively used[42,47]. The use of coal enabled the Industrial Revolution. By 1860, energy use in the United States was up to about 3.5 kW per capita. Over the course of the 20th century, oil and natural gas, along with nuclear power and hydroelectricity, were added to use. The oil crises in the 1970s prompted a more efficient use of energy resources, with the result that the productivity of energy resources increased by about a factor of 1.6 [12]. This increase in raw energy resources use, combined with more efficient use, led to an increase of a factor of about 5 in energy use per person in the United States (Figure 2).

Energy changes in extended evolution suggest a geometrically decreasing timescale for subsequent transition periods, along with increasing energy flows. If evolution occurs in three phases[8], there are 3 factors of approximately 1,000 in this timescale from the beginning of life approximately 5 billion years ago, to the beginning of human brain development 5 million years ago, to the beginning of Ancient civilizations 5,000 years ago.

Within each of the three phases, the evolution might also occur in a geometric pattern. If the shortest duration of the most current sub-phase is 50 years, chosen because it is similar to the current Kondratiev period[13] and similar to a generational time, then there were 20 of these periods during the civilization phase. Spread out over 6 sub-phases would give the geometric factor in time of 20 to the 1/6 power which is a factor of just greater than 3. This time contraction factor was used in describing the changes in energy intensity [18,11,43] 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. This factor is also similar to time and energy contraction factors found by Snooks [54] and Bejan [1].

Table 1. Changes in energy flows through extended evolution

Transition (years ago)	Description	Energy Change
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
15,000		