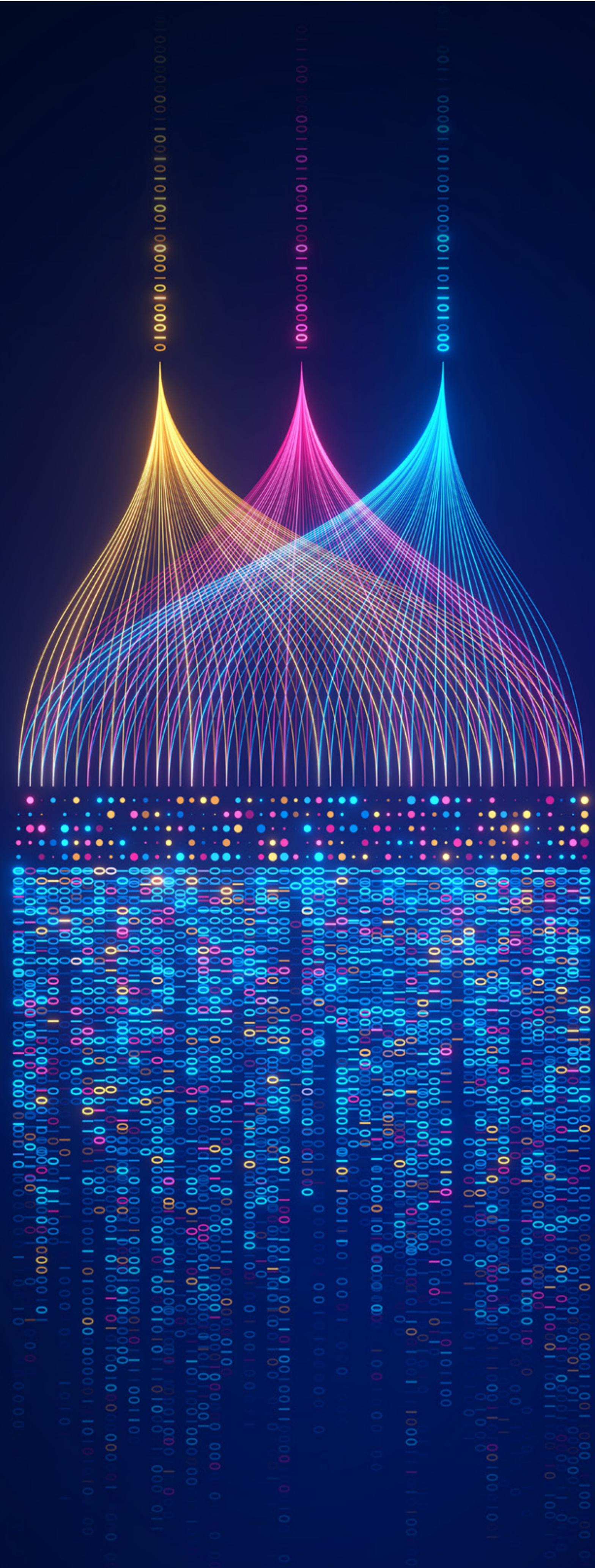

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Contents

Introduction to this Special Issue: “Continuously evolving to bridge significant gaps in our understanding of complexity”

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Although complexity plays a significant role in big history, substantial gaps persist in our comprehension. While the papers in this issue do not provide definitive answers to these gaps, they contribute to the ongoing discussion on how to address these issues and propose potential pathways for resolution. These gaps encompass measurement, focus, organization, relevance, consistency, and interpretation. While there may not be unanimous agreement on the specific direction to take, the academic discussions evident in these papers aim to elucidate the issues and foster understanding within the expansive and diverse scientific community.

The theme of this special edition is "*Evolving Continuously to Bridge Substantial Gaps in Our Understanding of Complexity*." Comprising 14 articles, including this Introduction, the issue is organized with a focus on complexity growth, evolution, and various aspects. The articles on growth explore methodologies for measuring, assessing, and examining the symmetry of singularity trends in complexity within the framework of Big History. Those addressing complexity and evolution delve into perspectives such as chaotic cascades, general evolution, selection, and chemical evolution. The aspects section encompasses discussions on integration with traditional academic disciplines, handling the multidirectional aspects of complexity, practical applications of complexity science, proposing an approach to interpreting the Big History journey, and comparing the process to cybernetic models.

The significance of the concept of complexity, along with its various facets, is not merely substantial; it forms the very structure of understanding. When contemplating the broadest concepts that can encompass the entirety of Big History or the field of evolutionary studies, only a handful stand out. These include notions tied to evolutionary dynamics, such as development, change, and progress, yet these concepts often spark debates. Central among them are energy and entropy, and to a lesser extent, self-organization—encompassing crucial aspects of energetic and structural ordering. Information is also a contender, though the period at which it becomes an independent aspect of evolution remains a subject of debate. However, we contend that one can fundamentally discuss information from the inception of Big History.

Arguably, few would dispute that complexity stands as one of the key concepts in Big History. Yet, given the substantial gaps in our understanding of the complexity concept, any novel ideas or hypotheses are warmly welcomed.

The complexity growth papers delve into fundamental questions of measurement, assessment, and symmetry of patterns. **Nick Nielsen** (“A Complexity Ladder for Big History”) suggests that big history could draw inspiration from astronomy, where a unifying ladder of distance measurement was constructed to handle diverse spatial and temporal scales. This ladder extended from the size and distances of the Earth-moon-sun system to other stars and galaxies, allowing telescopes across the electromagnetic spectrum to explore phenomena across different scales and times. **Robert Aunger** (“On Trends and Periods“) specifically examines diverse approaches to framing periodization within big history, having previously introduced the NESST (non-equilibrium thermodynamic steady-states) that has been referenced in big history papers.

Andrey Korotayev’s “Patterns of complexity growth in the Big History. A preliminary quantitative analysis” introduces a framework for examining the two singularity trends, one at the inception of the universe and the other during the current global transition on Earth. The singularity trend of cooling following the big bang has given rise to more intricate systems with greater potential for complexity. Steven Weinberg's 1979/1993 book, "The First Three Minutes," highlights that much of the complexity potential, including forces, particles, and interactions, was realized within the initial minutes of the universe. Interestingly, the somewhat evenly spaced physics energy scales (e.g., nuclear, atomic, molecular, solids) contribute to this singularity cooling trend, although the fundamental reason remains unknown.

Contrastingly, bio-social evolution on Earth originated from the bottom up as life emerged through a yet-to-be-understood process. Advances in complexity appear to have accelerated complexity rates, aligning with a process identified by Manfred Eigen in evolutionary systems, leading to trends suggestive of unlimited change within a finite time (singularity trends). While no actual singularity emerged due to system constraints, the population growth trend followed a similar pattern from ancient times until the early 1970s when limits became evident.

As criteria for evaluating patterns in big history are still under development, this theme of authors proposing "natural" divisions in big history persists in the works of Hoggard, Glötzl, and Grinchenko. **Nick Hoggard** (“From Big Bang to Chaotic Complexity: A Theory of Big Evolution”) proposes a sequence based on the Feigenbaum cascade to chaos, using a scaling factor of about 4.67. **Erhard Glötzl** ("The General Evolutionary Theory as Unification of Biological and Cultural Evolution: A Basis for a Natural Periodization") considers natural evolutionary transitions in information processing in an extended and integrated Darwinian evolution of genetic and cultural evolution. **Sergey Grinchenko** ("Big History in the Digital Perspective") employs critical levels of development phases derived from the work of Zhirmunsky to suggest a sequence centered around the identified critical number of e^e (about 15). The diversity of sequences with different factors suggests the need for a more precisely defined and assessed set of criteria. The prior special issue on periodization did propose such criteria and developed a framework aligning with traditional fields based on previous findings.

Borje Ekstig, known for developing relationships between evolution and development over evolutionary time, contributes to evolutionary thinking by offering a fresh perspective on natural selection (“Selection and Increasing Complexity in Evolution”). He emphasizes that natural selection, while contributing to changing system complexity, is not merely a reactionary phenomenon. Systems naturally selected in an environment often alter the environment through increased growth or efficiency, sometimes at the cost of resilience and robustness. This co-evolutionary dynamic between organisms and systems played a crucial role in the physical and social evolution of modern humans during the transition from predominantly genetic evolution to primarily cultural evolution.

Leonid Grinin’s “Chemical Evolution in Big History” adopts a broader outlook on the evolution of materials, spanning from the formation of matter shortly after the big bang (a process still not fully understood) to the contemporary utilization of materials in technology. The journey encompasses the creation and dissemination of elements from stellar interiors, the formation of planets, and the development of special molecules like water, oxygen, carbon dioxide, and silicates. The emergence of life from the chemical materials on early Earth remains a fervently pursued topic, with multiple avenues being explored to triangulate possible scenarios. The ongoing revelation of phenomena arising naturally or through engineering with relatively simple chemical elements continues to be surprising. This perspective on materials and how systems evolved to leverage these phenomena complements the traditional focus on complex systems. A similar viewpoint was previously emphasized in Jantsch's and Panov's timeline of evolving systems and environments (and tools), underscoring the importance of maintaining this perspective's freshness.

Within the papers addressing aspects, various issues are explored, including alignment with academia, practical application, pondering the big journey. Although complexity holds significant importance not only in big history but also in diverse fields such as economics, sociology, cognitive science, computer science, and physics (see LePoire et al. 2023)[1], its definition remains elusive, and ongoing

[1] LePoire D.J, Grinin L.E., Korotayev A.V. 2023 Evolution: Complexity in Nature, Society, and Cognition 2023 5–22 DOI: 10.30884/978-5-7057-6261-3_01

discussions surround its measurement. The complexity in big history presents an additional challenge due to the broad spectrum of phenomena it encompasses, ranging from the big bang to cosmic development, and the evolution of life, humans, and civilizations.)

Lowell Gustafson ("Emergent Complexity: A Rationale for the University") argues that while academia supports many aspects of big history, its integration still faces challenges related to disciplinary boundaries. He notes that big history often concentrates on the narrow path of increasing complexity, overlooking the fact that most systems either become extinct, get stuck in complexity, or revert to simpler states.

Ken Baskin's examination of systems analysis in big history highlights the potential application of various systems concepts, including punctuated equilibrium, scaling behavior, energy dissipation, information sensing, storage, processing, and learning ("The Practical Application of Complexity Science to Enhance Big History"). This becomes crucial as big history not only delves into the narrative from the big bang to the present but also broadens its scope to encompass more dynamics, addressing the 'how' and 'why' (as well as the 'how not' and 'why not') of systems evolution. This expanded perspective allows for the inclusion of systems that did not persevere along seemingly promising paths, the consideration of simplification as a potentially advantageous path for some systems, and an exploration of how internal growth dynamics, such as panarchy systems, might pose challenges as they expand, prompting a continual quest for more complex trajectories.

Marc Widdowson ("Last stop on the cosmic journey: An estimated time of arrival") adopts a distinct perspective by not focusing on the singularity inflection point, but rather on the time when society could potentially reach its peak measured by the optimal utilization of energy. He analyzes trends in energy consumption and assesses them on the Kardashev scale to investigate the potential timing of this technological utopia. The emphasis for the reader is not in the precise prediction date, but rather in appreciating the thought process concerning how technology and energy utilization might scale in the future.

This issue of JBH also features two non-papers, offering unique perspectives. **Gustavo Lau** "Perspectives: Sharing Inside Brains" provides insight into using analogies to examine the organization of books and collections. Not only does he delve into these topics, but he has also played a pivotal role in constructing a system with remote connections to students in Venezuela from his current residence in England. Lau's infectious enthusiasm for teaching and testing new ideas is evident as he explores abstract concepts, a big history book collection, and organizational thoughts inspired by Bill Gates.

Another contribution focuses on the development of a reference-citation database for big history by **David LePoire** "An Approach to Categorize Big History Papers". This database encompasses JBH papers, Russian Yearbooks papers, and listings of big history books, creating a searchable resource for efficiently using and managing references in papers. LePoire has implemented a categorization scheme based on ideas for periodization, incorporating three dimensions: the phase of big history evolution (cosmic, life, humans, civilization), the aspect of complexity (energy, information, organization, environment), and the type of research (framework, education, discipline, integration). This database is accessible online and shared for everyone to use.

Heartfelt thanks are extended to all the authors for their hard work and imaginative contributions to shaping these papers. The majority of these papers underwent peer review by the same group within the complexity project, which anticipates at least another JBH issue. One way to express gratitude is by engaging with the content—reading, contemplating, and initiating conversations with the authors. Whether you have questions, disagreements, or ideas for extending their work, reaching out to them or sending letters to the JBH editor for publication in future issues is encouraged. This collaborative approach allows us to continue learning from each other, fostering meaningful dialogue despite our diverse backgrounds and experiences.

We hope that this special issue will be useful both for those who study Big History and for specialists working in focused directions, as well as for those who are interested in evolutionary issues of Cosmology, Biology, Psychology and other areas of study. More than that, this edition will challenge and excite your vision of your own life and the new discoveries going on around us.

A Complexity Ladder for Big History

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Abstract: Complexity is a central problem for big history because big history has made complexity a central theme, constructing a cosmological periodization based on the sequential emergence of qualitatively distinct forms of complexity. How can the big historian differentiate distinct thresholds of emergent complexity while subordinating the entire sequence of thresholds to a single metric of complexity that demonstrates the increase of complexity over multiple scales of magnitude and across qualitatively distinct forms of complexity? The cosmologists' use of a cosmic distance ladder suggests an analogous construction for complexity: a complexity ladder for big history. While no complexity ladder is formulated in this paper, the program required for a complexity ladder is sketched.

Keywords: complexity, emergence, thresholds, big history, cosmological distance ladder, scientific measurement,

The Problem of Complexity: Definition and Distinction

Complexity is a central concept of big history, which makes use of thresholds of complexity to produce a periodization that holds from the most humble detail to the largest cosmological context. Unfortunately, there is no consensus in big history on a definition of complexity, nor on a metric for the measurement of complexity. This should not surprise us. The relative recentness of big history means that we cannot expect its fundamental concepts to be adequately defined as yet. Differences among big historians keep the nascent discipline percolating with ideas; big history is nowhere near a mature formulation such as we would expect from a well-established discipline. The absence of a clear definition and metric for complexity is a deficiency, but one that need not prevent field building in big history, but it is a deficiency of which we must be mindful, and which we should want to rectify at the earliest opportunity.

Furthermore, there is an implicit tension in big history between recognizing thresholds of emergent complexity, which implies distinct kinds of emergent complexity, and the attempt (or, if the attempt hasn't been made in any serious way, then the desire) to find a common measure for emergent complexity. If distinct emergent complexity regimes represent qualitatively different kinds of being (an ontological formulation of the problem), then these qualitatively difference kinds of being ought to be measured by qualitatively distinct metrics. However, were we to measure distinct forms of complexity by distinct measures of complexity, then the pretence of a periodization constructed on the basis of the increasing complexity of emergents falls apart. This, too, like the absence of a consensus definition of complexity, need not be a disaster: the claim that the universe manifests increasing complexity can be isolated from and developed independently of the claim that the history of the universe exhibits qualitatively distinct forms of complexity; both may be true, both may be false, or either may be true independently of the other.

Taking the Measure of Complexity

If the *differentia* of big history within the genus of history is periodization through thresholds of emergent complexity, then big history sets itself at odds with the entire tradition of reductivist scientific thought by seeking formulations in terms of greater comprehensivity, and placing as much weight upon the appearance of novelty as upon the persistence of consistent foundations. Ironically, however, there remains a reductivist imperative at the heart of emergentist thought by way of the very mechanism of periodization through emergent complexity: that we must unify emergent thresholds through a shared definition of complexity—whether by thermodynamic depth (Lloyd & Pagels 1988), energy flows

(Spier 2005), free energy rate density (Chaisson 2011), or some other means. Ultimately we cannot evade the scientific obligation to clarify the fundamental concepts we employ, though we can certainly delay the reckoning.

There is, however, more than one way to clarify fundamental concepts. Science offers us the opportunity, rather than attempting to *define* key theoretical terms by way of abstract concepts, of *measurement* based on empirical evidence. A metric of complexity may do as well as a definition of complexity, and in many contexts the metric is preferable, if only a sufficiently comprehensive metric can be found. This is a particular challenge for big history, as the complexities it considers range in space and time from the most minute fundamental particles to the extent of the universe itself, and from the briefest, most ephemeral processes to those that span eons and which are measured in units of Hubble time. How can these diverse phenomena be measured by a single scale?

The Cosmological Distance Ladder

There is a suggestive comparison that can be made between big history and cosmology. Astronomers today have many different methods for measuring the distance to astronomical objects. They have constructed what they call the *cosmological distance ladder* to build up a large-scale model of the universe. The astronomers are always measuring the same thing—distance—but they do so through different methods, which is analogous to the need in big history always to measure the same thing—complexity—by whatever method suggests itself, and perhaps, following the lead of cosmologists, through a variety of different methods that complement each other.

The movement of Earth around the Sun means that our observational position in the universe changes by two astronomical units when Earth passes through opposing points in its orbit around the sun. Our movement should make stars closer to us appear to move in relation to more distant stars, which apparent movement is called parallax. Astronomers realized this opportunity early in the scientific revolution, but it took time to produce instruments of sufficient precision even to be able to measure the parallax for relatively nearby stars in comparison to more distant stars. Eventually, however, it became possible to measure parallax, and this gave us our distances to the nearest stars.[1]

Harlow Shapley had been a pioneer of the use of Cepheid variables to map the structure of the Milky Way, first finding Cepheid variables close enough to obtain a distance by parallax, and then extending the first rungs of the cosmological distance ladder by finding Cepheid variables throughout the Milky Way. Shapley especially focused on finding Cepheid variables in the globular clusters that surround the Milky Way, and in so mapping the globular clusters found that they roughly defined a sphere, within which we were offset from the center. Shapley correctly made the intuitive leap that we are not at the center of the Milky Way, as roughly defined by the globular clusters surrounding it, but we are, rather, located some distance out from the center: another Copernican demotion from centrality.

Later, using the 100 inch Hooker telescope at the Mt. Wilson Observatory—again, a new scientific instrument incorporating more advanced technology—Edwin Hubble was able to resolve Cepheid variable stars in a nebula known as N.G.C. 6822 (Hubble 1925), as well as in the nebulae M31 (Hubble 1929) and M33 (Hubble 1926), that is to say, in the Andromeda and Triangulum galaxies. By applying Henrietta Swan Leavitt's period-luminosity relationship for Cepheid variables, Hubble estimated the distance to the nebula N.G.C. 6822 at about 700,000 light years, which implies that it is a system of stars entirely distinct from the Milky Way, because this distance is more than double the largest estimate for the size of the Milky Way, which was Shapley's figure of 300,000 light years across. Heber Curtis had estimated the diameter of the Milky Way to be an order of magnitude smaller, about 30,000 light years across.[2] By either measure, 700,000 light

[1] This story repeats itself throughout the history of modern science: the idea of a possible measurement that might be taken prompts the construction of increasingly precise scientific instruments intended to measure the postulated quantity. Attempts to measure gravity waves began with resonant mass antennas, cryogenic bar antennas, and spherical cryogenic antennas, but it was not until the laser interferometer LIGO was built that gravitational waves were first detected.

[2] Harlow Shapley and Heber Curtis were the participants in the Shapely-Curtis Debate of 26 April 1920, which took on these

years put N.G.C. 6822 well outside the Milky Way.[3]

These initial rungs on the cosmological distance ladder—stellar parallax and Cepheid variable stars—where joined soon after by the use of red shifts (Zwicky 1929) and, some time later, by Type Ia supernovae standard candles (Branch 1992), which pushed the cosmological distance ladder to the farthest reaches of the universe. As astrophysics and cosmology has flourished, a multiplicity of methods of determining astronomical distances have been added to the familiar rungs of the cosmological distance ladder, including, *inter alia*, planetary-nebula luminosity functions (PNLF) (Ciardullo 1993), Main sequence fitting, also known as cluster fitting (Turner 1994), surface-brightness fluctuations (SBF) (Blakeslee 1999), fundamental-plane relationships for elliptical galaxies (D_n - sigma) (Mobasher 1999), baryon acoustic oscillations (BAO) (Seo 2007), the eclipsing-binary method (Clausen 2004), H I-line-width relations (Tamburro 2009), globular-cluster luminosity functions (GCLF) (Rejkuba 2012), and now the possibility of a "standard shriek" of gravitational waves.

The cosmological distance ladder evolves through improvements and refinements to existing scientific instruments (for example, stellar parallax measurements have been greatly extended by the precision of the Hubble Space Telescope's Wide Field Camera 3), and to existing scientific techniques, as well as through the introduction of novel scientific technologies and techniques of measurement. The methods change, and how the distance is expressed—in light years, parsecs, galaxy diameters, etc.—changes, but throughout all it is distance that is measured, with an eye toward accurately reconstructing the shape and extent of the universe from our peculiar vantage point on Earth.

A Cosmological Complexity ladder

As astronomers seek always to measure distance but by different methods, might big historians seek to measure complexity, but by different methods, which can ultimately be expressed through the formulation of an emergent complexity ladder of overlapping techniques for measuring complexity across multiple scales of increasing complexity? This can be done if the complexity measured by a given metric extends beyond a single qualitative form of complexity, allowing the metric in question to overlap with the metrics of distinct forms of complexity. Given that later forms of complexity supervene upon early forms of complexity, and that the latter must continue to exist in order for the former to appear, and to be the basis for further metrics, the conditions for a cosmological complexity ladder appear to be met, although the devil will remain in the details.

The simplest procedure for reckoning a quantitative determination of complexity is by counting,[4] so let us begin a simple cosmological complexity ladder by counting the kinds of things there are at each threshold of emergent complexity. This procedure is not without ambiguity, as there are sometimes multiple taxonomies at any given level of complexity; carving nature at the joints, as contemporary metaphysics would put it, can be done in more than one way. However, in the context of a cosmological complexity ladder, this ambiguity works in our favor: each taxonomy may extend above or below its given level of complexity in a distinctive way, which creates an overlap among metrics that allows for the possibility of a complexity ladder.

It has been speculated that, in the immediate aftermath of the big bang, the fundamental forces of nature were unified in a single force. If we begin by counting fundamental forces, we begin with a single force (taking this physics speculation at

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questions of cosmology a few years before Hubble settled them by observation. (cf. Trimble 1995)

[3] Contemporary estimates for the distance to N.G.C. 6822 put it about 1.6 million light years away, or more than twice the distance estimated by Hubble. Proportional initial values were obtained for M31 and M33, with similar revisions made later with improved technologies and techniques. Current estimates place the diameter of the Milky Way at about 150,000 to 200,000 light years in diameter.

[4] This was recognized in the nineteenth century by Lord Kelvin: "I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of science, whatever the matter may be." (Kelvin 1883)

face value, and subject to change without notice), and complexification begins when the single fundamental force divides into the four fundamental forces between 10^{-50} and 10^{-10} seconds following the big bang. The particle zoo of the standard model begins to take shape as matter precipitates out of energy as the universe expands and cools. At present, there are 150 known particles in the particle zoo; once matter appears, we can begin to count these particles as they appear as a measure of the complexity of the early universe. As fundamental particles are assembled into matter, we can begin counting elements, beginning with hydrogen and helium. As stellar nucleosynthesis, and then supernovae[5], synthesize more complex forms of matter, we begin to fill out the periodic table of elements. The elements can also be expressed in terms of the fundamental particles that constitute them, so the quantification of fundamental particles and chemical elements can be reduced to their constituent parts, and this means that these measures overlap and can serve as a transitional stage in the complexity ladder.

At the same time as more complex forms of matter are appearing in the universe, more complex planets and planetary systems are forming.[6] Thus the growth in the complexity of matter overlaps with the growth in complexity of planets and planetary systems. We can count the growth of the complexity of planets[7] in terms of the number of mineral species present in the universe. The more complex planets become—the more forces at work on a given planet—the more mineral species form. Earth, as the most complex planet we know, has by far and away a greater number of mineral species than other astronomical bodies in the solar system. There are, for example, many mineral species that incorporate biological processes in their formation, and which are therefore mineral species that can only exist where biological processes supervene upon geological processes, so that the quantification of mineral species overlaps with quantifications of biological complexity. Greater mineralogical complexity supervenes on greater biological complexity, so that as the biosphere becomes more complex, the geosphere also becomes more complex; moreover, these measures of complexity systematically overlap.

There are other possibilities for counting the complexity at the level of planets and planetary systems that represent an ellipsis in our knowledge. We have no metric for assessing the complexity of planets or of planetary systems directly, without relying upon the proxy of mineral species, but it is conceivable that such a metric could be formulated, giving us another overlapping complexity count to span between anterior and subsequent forms of complexity. For example, the complexity of a planet might be quantified by the number of differentiated concentric layers of its internal structure, or by the number of geological, geomorphological, and geochemical processes that shape its crust. A planet might also be accounted more or less complex depending upon its particular situation within its planetary system: its number of

[5] More exotic events such as neutron star mergers are thought to produce heavier *r*-process elements not produced in stellar nucleosynthesis or by supernovae (Freiburghaus et al. 1999). That chemical elements are produced by distinctive cosmological processes suggests another overlapping complexity metric, which is the number of kinds of astronomical objects and processes there are. The universe cannot be populated with black holes until black holes form, and black holes cannot form until a stellar remnant that exceeds the Tolman–Oppenheimer–Volkoff limit forms, and such a stellar remnant cannot form until a star of sufficient mass completes its lifetime on the main sequence.

[6] We have little or no understanding at present of the planets that formed in the protoplanetary discs of population III stars of the early universe, but with the paucity of chemical elements available (i.e., low metallicity of the protoplanetary disk) we can infer the likelihood of the earliest planets being gas giants primarily composed of hydrogen and helium. Chemically these planets would have been relatively geophysically simple in comparison to the planets of population I or II stars, but they may have incorporated exotic states of matter such as metallic hydrogen, so it may be worth considering a quantification of the possible states of matter as another overlapping metric of complexity.

[7] "Planets" is here used loosely to mean any astronomical body in orbit in a planetary system. Given an adequate taxonomy of the kinds of planetary bodies—dust, asteroids, comets, dwarf planets, planets, etc.—we could also count these varieties of matter that clump into masses orbiting stars. The complexity of a planetary system, however, is intrinsically reducible to a star and its accompanying mass, though if a taxonomy of planetary system were formulated and the possible permutations extrapolated, we could count the number of taxa exemplified in actual planetary systems as an overall metric of the complexity of the universe at a given stage of its development.

moons, number of other planets, the degree of exchange of matter with other planets, the enrichment of its surface through asteroid and cometary impacts, etc.

There are a number of quantitative measures of life that could be employed. In the earliest history of life, when the biosphere was dominated by horizontal gene transfer and species were not as clearly defined as would be the case later, it would not be clear how to individuate organisms and thus to count them, but it would be possible to count the base pairs in DNA. Another metric could be based on the quantitative measure of biomass, and various divisions that can be made within the biomass of the early biosphere, e.g., marine and terrestrial biomass, autotroph and heterotroph biomass, etc. (Crockford 2023). Once distinct species emerge we can count species, but we can also count other clades. It is commonplace to express the loss of biodiversity from mass extinction events not only in terms of species loss, but also in terms of loss of genera, families, and so on up the Linnaean taxonomic hierarchy (cf., e.g., Elewa 2008).[8] In adaptive radiation, not only species, but also genera, families, and so on can expand in number. Note that we could continue to quantify the complexity of life in terms of the complexity of the underlying chemistry, or even the complexity of fundamental particles constituting living matter, which would be cumbersome, but, insofar as it is still possible, it demonstrates the possibility of overlapping complexity metrics from which a complexity metric can be constructed.

The appearance of central nervous systems, consciousness[9], and intelligence represent further stages in the complexification of biological organisms, each of which comes with its own quantification. The number of neurons in the average brain (or central nervous system) of a representative of a given species is a metric that will overlap for all animals with brains. Encephalization is another familiar metric (Jerison 1977). Behavioral complexity can be counted by the number of social institutions of these animals, and the behavioral complexity of other species overlaps with the behavioral complexity of human beings, who in turn introduce new metrics such as IQ.[10] In the case of human complexity, social institutions eventually include agriculture of increasing levels of sophistication, and eventually cities, and the metrics for social institutions will overlap with metrics for cities (e.g., number of cities in a given civilization, or the average or peak population of cities).

The future holds out the prospect of further novel metrics of complexity that will supervene upon, and therefore overlap with, existing complexity metrics, allowing us to extend the cosmological complexity ladder. A species that has transcended its homeworld can be measured by the number of off-world habitats it builds, or the number of *kinds* of off-world habitats it constructs, and, if that civilization eventually builds cities beyond its planet of origin, the continued count of cities will overlap with this newest metric of off-world habitats. A technologically sophisticated species that transcends its legacy biology could be measured by the number of technological modes of overcoming biology that it employs, or by extending existing metrics, or by both, which again would provide us with overlapping metrics and a more robust complexity ladder. For example, cognitive enhancement could be measured by IQ testing, while biological enhancement could be measured in terms of longevity or endurance, *inter alia*.

Just as in the cosmological distance ladder, no one method for the measurement of distance will work across all

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[8] Darwin already foreshadowed this metric for the biosphere in his *The Voyage of the Beagle* (written before he had formulated the idea of natural selection); he describes the novel ecosystems he explored not only in terms of the distinctive species, but also noting the genera and families present or absent.

[9] There are tantalizing possibilities for the quantitative measurement of consciousness. Analogously to intelligence testing, as mentioned below in note 9, consciousness studies of animals and human beings have not been formulated in a common framework, which limits their utility. As distinct from consciousness and intelligence, encephalization *has* been formulated as a common framework across species, and as such we have seen it employed extensively in the study of early hominids prior to anthropogenesis, wherever we happen to locate this juncture.

[10] Intelligence testing could itself be made a more comprehensive metric by developing methods that extend the human measurement of intelligence to other species. There is already considerable research into measuring animal intelligence, but animal and human intelligence measures have not been, for the most part, formulated in a common framework.

scales of measurement—Cepheid variables do not function as standard candles at the distances that Type 1a supernovae serve as standard candles—just so, no one complexity metric will be translatable to every level of complexity, but all the metrics taken together will overlap sufficiently to bind the whole structure of complexity together. Moreover, familiar scales of measurement themselves can be extended beyond their customary scope of application in order to ensure that these is a robust overlap of distinct metrics incorporated into the complexity ladder. The totality of assembled complexity metrics will interact to the ultimate benefit of complexity scale; the less well-defined metrics can be given greater clarity and precision by the metrics with which they overlap, just as carbon 14 dates have been calibrated by the precision of dendrochronological sequences, which, to the extent of their extrapolation, provide a year-by-year record of the past—a much finer granularity than carbon 14, or any of the other techniques such as the principle of faunal succession, employed before high technology methods such as radiometric dating.

Rationalizing the Complexity Ladder

Does the complexity ladder need the complexity equivalent of a calendar epoch, i.e., a point of origin, which would make the complexity ladder a ratio scale? At present, the recognized thresholds of emergent complexity constitute an ordinal scale, in which the order of thresholds is definitive, but the interval between the thresholds is not. There seems to be no reason to believe that there is an orderly and uniform interval between thresholds of complexity, so that it may not be possible to transform the ordinal scale of complexity into an interval scale of complexity. Wherever in the world we observe diverging forms of complexity, as soon as the lineages are distinct, their destinies different, with some evolving rapidly, some slowly, and some becoming virtually unchanged living fossils. However, it may be possible to define a purely conventional interval that can be placed over the surprising leaps of complexity with which the world presents us. An interval scale based on convention, and not upon those natural divisions that suggest themselves to us as thresholds, would not give us the satisfaction of "carving nature at the joints," but it would allow us to further rationalize the complexity ladder. And we may find, when immersing ourselves in the details of overlapping scales of complexity measures, that a conventional scale would provide a framework that none of the individual complexity measures provides.

Beyond the possibility of an interval scale for complexity lies the possibility of ratio scale, which would require an interval scale as well as establishing a zero point for the scale. To institute a zero point for the complexity ladder would embroil us in further difficulties. Zero complexity is pure nothingness, which is a philosophical rather than a scientific concept, so we will leave this aside for the moment. However, Willem De Sitter (De Sitter 1932) demonstrated that an empty universe (in which density is zero) is a better approximation to known cosmology than a static universe (in which density is stable and there is no expansion), and we could count an empty universe, even if it is only empty in a formal mathematical sense, as a zero point for cosmology, though De Sitter's empty universe is in no sense bereft of complexity. We can see that, while there are problems in fully rationalizing the complexity ladder, there are also opportunities, and more opportunities may suggest themselves in working through the details of a complexity ladder.

Permutations of Counting Complexity

This quantitative account of a complexity ladder makes it possible for us to overleap the qualitative gaps that emergent complexity threshold presents to us, and thus to assimilate all these various forms of complexity to a single, overall scale that is assembled from the many overlapping quantitative scales of measuring the complexity of matter, planetary systems, geology, life, social organization, intelligence, and so on. With such a quantitative scale we can remain agnostic on the qualitative nature of complexity, i.e., we can continue to study complexity without attempting to make any definitive claim about the nature of complexity, which we measure by quantifiable observations that serve as proxies for qualitative complexity. Indeed, the act of distancing ourselves from any claim regarding the ontology of complexity, and seeking to measure it only quantitatively, frees us both to extrapolate a complexity ladder even while continuing to explore the nature of complexity itself.

There is both a reductive and an emergentist interpretation of the numerical complexity ladder described herein. Reductively, each later form of emergent complexity counted can be reduced to the previous form (or to several previous forms) of emergent complexity counted. Such a reduction is a blunt instrument—information is lost in the reduction—but science flourishes to the extent that it can converge upon robust abstractions that allow for the explanation of many phenomena by one or a few mechanisms. In regard to emergentism, each new convention adopted for counting a beyond a new threshold of emergent complexity represents a qualitatively distinct metric, which therefore qualitatively expands the complexity ladder itself. This process is indefinitely iterable, so that there is no intrinsic limitation on the extrapolation of the complexity ladder. This, in turn, means that an extended complexity ladder will always place previous conceptions of complexity in a new light, by placing them in a larger (and systematic) context, which will mean newly emergent forms of understanding the universe so measured.

The potential iteration of the cosmological complexity ladder makes it pre-adapted to the unsuspected forms of complexity we may yet discover in the exploration of the universe. If alternative emergent complexities are to be found on other worlds,[11] the inherit flexibility of counting complexity (due to its ontological agnosticism) will not only allow this method to be employed in contexts of alternative emergent complexity, but it will also allow for the comparison of peer complexities, inconceivable to us at present, but perhaps only waiting to be found and described by future generations.

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Complexity growth patterns in the Big History. Preliminary results of a quantitative analysis

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Abstract: The paper presents preliminary results of a quantitative analysis of two patterns of complexity growth in the Big History – decelerating universal (cosmic) evolutionary development evidenced in the Universe for a few billions of years after the Big Bang (around 13.8 billion BP) and accelerating global (biosocial) evolutionary development observed for about 4 billion years on the planet Earth since the emergence of life on it and until the early 1970s. It is shown that the first pattern can be described with an astonishing accuracy (R^2 = 0.999996) by the following equation: $y = C_1/(t-t_1*)$, where y is the rate of the universal complexity growth (measured as a number of phase transitions [accompanied by the growth of complexity] per a unit of time), C_1 is a constant, and $t-t_1*$ is the time since the Big Bang Singularity (t_1*~13.8 billion years BP). In the meantime, it was earlier shown that the second pattern could be described with an almost as high accuracy (R^2 = 0.9989 to 0.9991) by the following equation: $y = C_2/(t_2*-t)$, where y is the rate of accelerating global (biosocial) evolutionary development, C_2 is another constant, and t_2*-t is the time till the 21st century Singularity (t_2*, estimated to be around 2027, or 2029 CE). Thus, the post-Big-Bang hyperbolic decrease of universal complexity growth rate and the hyperbolic increase of the growth rate of global complexity in the last 4 billion years proceeded following the same law. We are dealing here with a perfect symmetry: (1) the rate of the universal (cosmic) complexity growth decreases when we move from the Big Bang Singularity, whereas the rate of the global complexity growth increase when we approach the 21st century Singularity; (2) more specifically, as the time since the Big Bang Singularity increases n times, the universal (cosmic) complexity growth rate decreases the same n times, whereas when the time till the 21st century Singularity decreased n times, the global complexity growth rate increased the same n times. A somehow more complex symmetry is observed as regards the interaction between energy dynamics and complexity growth within both processes. The implications of the symmetry of both patterns are discussed.

1. Introduction

The point that within the Big History the decelerating growth of complexity in the Universe observed after the Big Bang can be contrasted with the accelerating growth of complexity traced on our planet for four billion years after the emergence of life on the Earth has been already noticed on quite a number of occasions (e.g., Panov, 2007, 2008; Tsirel 2009; LePoire, 2014, 2016, 2020b; Nazaretyan 2017b; Panov et al., 2020; Faixat, 2022).

However, till now nobody seems to have undertaken a detailed mathematical comparison of these patterns. In fact, by now a rather thorough mathematical analysis has been only performed as regards the global pattern of accelerating evolution.[1]

David LePoire appears to be the only person to have conducted some mathematical comparison of the two abovementioned patterns (LePoire, 2014, see Fig. 1). However, this has been only published as a presentation at the 2nd International Big History Association Conference at Dominican College in San Rafael, CA in August 2014 (LePoire, 2014) and it does not appear to have been noticed by big historians. In addition, in this presentation, his analysis of the post-Big Bang universal evolution deceleration pattern, while being basically correct, was rather brief and lacked much detail (unlike his later very thorough and detailed mathematical analysis of the

[1] See von Foerster et al., 1960; Hoerner, 1975; Taagepera, 1976, 1979; Jantsch, 1980; Kapitza, 1992, 1996a, 1996b, 1999, 2003, 2006, 2007, 2010; Kremer, 1993; Johansen & Sornette, 2001; Kurzweil, 2001, 2005; Modis, 2002, 2003, 2020; Tsirel, 2004; Korotayev, 2005, 2006a, 2006b, 2007, 2013, 2018, 2020a, 2020b; Panov, 2004, 2005, 2011, 2017, 2020; Grinchenko, 2006; Korotayev & Khaltourina, 2006; Korotayev et al., 2006a, 2006b, 2015, 2016; Grinin, 2006; Markov & Korotayev, 2007, 2008; Grinin & Korotayev, 2009, 2015; Grinchenko & Shchapova, 2010, 2020; Markov et al., 2010; Korotayev & S. Malkov, 2012; Grinin et al., 2013, 2014, 2015, 2020a, 2020b; Korotayev & Grinin, 2013; Korotayev & Markov, 2014, 2015; LePoire, 2014, 2015a, 2015b, 2016, 2020a, 2020b; Korotayev & A. Malkov, 2016; Korotayev & Zinkina, 2017; Podlazov, 2017; Dobrolyubov, 2020; Fomin, 2020; Malkov, 2020; Widdowson, 2020; Faixat, 2022).

accelerating growth of complexity traced on our planet for four billion years after the emergence of life on the Earth [LePoire, 2016, 2020a, 2020b]).

This paper aims at filling this gap by providing a more detailed quantitative analysis of the two abovementioned complexity growth patterns in the Big History. In addition, my comparative analysis is in no way a repetition of the one performed by David LePoire in 2014, as the comparative methodology I apply is quite different from LePoire's. Thus, my analysis does not contradict his, but rather complements it.

This article is structured as follows. In its first part, I present a summary of my previous systematic quantitative analysis of the accelerating global (biosocial) complexity growth observed for about 4 billion years on our planet. In the second part, I apply the same methodology that I have applied to analyze this accelerating pattern to the analysis of decelerating universal complexity growth evidenced in the Universe for a few billions of years since the Big Bang Singularity (around 13.8 billion years BP). Finally, the third part offers a systematic comparison of the both patterns.

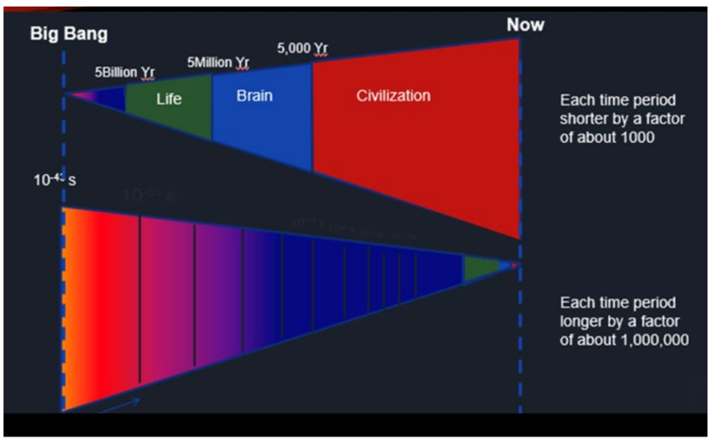

Fig. 1 Two Contrasting Views of Time Scales. *Source*: LePoire, 2014

2 Summary of Previous Results of the Accelerating Complexity Growth on Our Planet

Raymond Kurzweil was one of the first to arrange the major evolutionary shifts of a very significant part of the Big History along the hyperbolic curve that can be described by an equation with a mathematical singularity. For example, at page 18 of his bestseller *The Singularity is Near* (2006) the time sequence is shown[2]. However, rather surprisingly, Kurzweil does not appear to have recognized that the curve represented at this figure is hyperbolic, and that it is described by an equation possessing a true mathematical singularity (what is more the value of this singularity, 2029 is not so far from the one professed by Kurzweil himself [see Ranj 2016]).

A very important contribution to the quantitative analysis of the accelerating growth of complexity traced on our planet for four billion years was done in 2003 by a physicist from Lomonosov Moscow State University Alexander Panov[3]. Panov analyzed an essentially similar time series taken from entirely different sources but arrived at very similar conclusions, but in a much more advanced form. It is very important that he made a step (to which Kurzweil was very close but which he did not make actually) that allows to make the analysis of the time series in question much more transparent.

In his 2005 book Kurweil plotted at the Y-axis of his diagrams "time to next event", which hindered for him their interpretation in a rather significant way. In his 2001 essay at page 5 while analyzing a diagram with a similar time series (whose source, incidentally, was not indicated), Kurzweil began speaking about the acceleration of "paradigm shift rate" (Kurzweil 2001: 5), but almost immediately switched to another theme. However, what was necessary to make his diagrams much more intelligible was to plot at Y-axis not "Time to Next Event", but just "Paradigm Shift Rate" – precisely as was done by Panov. Indeed, to transform the time to next paradigm shift into paradigm shift rate one needed to do a rather simple thing – to take one year and to divide it by time to next paradigm shift; this will yield number of paradigm shifts per year, that is just a "Paradigm Shift Rate". As we have already said, this was not done by Kurzweil but was done by Panov who obtained the following graphs as a result (see Fig. 2):

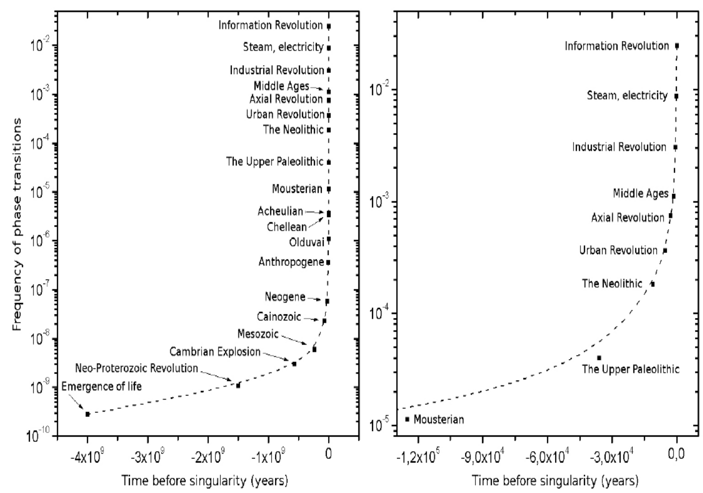

Fig. 2 Dynamics of the global complexity growth rate according to Panov. *Source* Nazaretyan 2018: 31, Fig. 3. The left-hand diagram depicts the acceleration of the global complexity growth rate starting from 4 billion years BP, whereas the right-hand diagram describes this for the human part of the Big History.

2 Actually, a prototype of this figure (but in a double logarithmic scale) was reproduced by Kurzweil already in 2001 in his essay "The Law of Accelerating Returns" at page 5.

3 His calculations described below were first presented in November 2003 at the Academic Seminar of the State Astronomic Institute in Moscow (Nazaretyan 2005: 69) and subsequently published in his articles (Panov 2004, 2005, 2011, 2017, 2020) and monograph (Panov 2008).

The mathematical interpretation of Panov's graph is much easier and more straightforward. Note that Panov himself denoted the variable plotted at Y-axis as "Frequency of the phase transitions per year". However, it is quite clear that Panov's "phase transition" is a synonym of Kurzweil's "paradigm shift", whereas "frequency of the phase transitions per year" describes just "paradigm shift rate", or global evolutionary macrodevelopment rate. This transformation makes it much easier to detect rigorously the pattern of acceleration of the global complexity growth rate.[4]

This was compared with the sequence presented in a paper by Theodore Modis "The Limits of Complexity and Change" (2003) prepared in its turn on the basis of his earlier article published in the *Technological Forecasting and Social Change* (2002) (note that in this article Modis denotes "phase transitions" as "complexity jumps"). Fortunately, Modis provided all the necessary dates in his articles, which made it perfectly possible to analyze this time series mathematically.

At the next step I let the X-axis represent the time before the singularity (whereas the Y-axis represented the macrodevelopment rate) – and calculated the singularity date by getting such a power-law curve that would describe our time series in the most accurate way. The results of this analysis are presented in Fig. 3 (note that our mathematical analysis identified the Singularity date for this time series as 2029 CE).

As we see, our power-law regression of the last "Countdown to Singularity" time series identifies the following best fit equation describing this time series in an almost ideally accurate ($R^2 = 0.999$) way:

$$y = \frac{2.054}{x^{1.003}}, \qquad (1)$$

where y is the global macrodevelopment rate, x is the time remaining till the singularity, and 2.054 and 1.003 are constants. Note that the denominator's exponent (1.003) turns out to be only negligibly different from 1 (well within the error margins); Of course, x (the time remaining till the singularity) at the moment of time t equals $t^* - t$, where t^* is the time of singularity. Finally, let us recollect that our power-law analysis of the transformed Modis – Kurzweil series has identified the singularity date as 2029 CE. Thus, Eq. (1) can be further re-written in the following way:

$$y_t = \frac{2.054}{2029 - t}. \qquad (2)$$

Now, let us apply a similar methodology to analyze mathematically the series of global macroevolutionary "phase transitions"/ "biospheric revolutions" compiled by Alexander Panov (2005; see also Panov 2008, 2011, 2017).

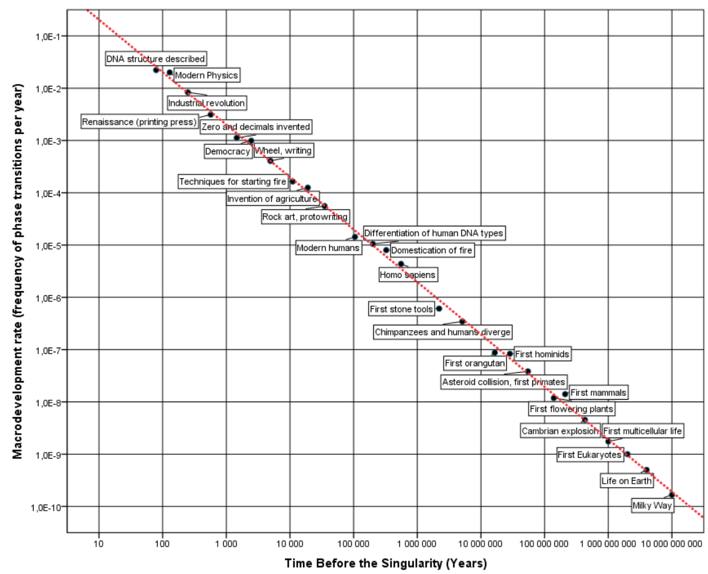

Fig. 3 Scatterplot of the phase transition points from the Modis – Kurzweil list with the fitted power-law regression line (double logarithmic scale) – for the Singularity date identified as 2029 CE with the least squares method

Note that Alexander Panov and Theodore Modis compiled their time series entirely independently of each other. As suggest my personal communications with both Panov and Modis, none of them knew that at almost the same time[5] in another part of Europe another person compiled a similar time series (Alexander Panov worked in Moscow, whereas Theodore Modis worked in Geneva). They relied on entirely different sources and the resultant time series turned out to be very far from being identical (see, e.g., Table 1).

As one can see for a major part of the planetary history (between the Cambrian explosion and the formation of *Homo sapiens sapiens*) the correlation between the two series is really weak; they look as really independent (and rather different) series.

It appears appropriate to recollect at this point that in their famous article published in the journal *Science* in 1960 von Foerster, Mora, and Amiot presented their results of the analysis of the world population growth pattern. They showed that between 1 and 1958 CE the world's population (N) dynamics can be described in an extremely accurate way with the following astonishingly simple equation:

$$N_t = \frac{C}{(t^* - t)^{0.99}}, \qquad (3)$$

where N_t is the world population at time t, and C and t^* are constants, with t^* corresponding to the so called "demographic

[4] Note, however, that most of the students of the global accelerating growth of complexity still prefer to deal with periods between phase transitions rather than phase transition rates (see, e.g., Panov, 2005, 2020; Grinchenko & Shchapova, 2010, 2020; LePoire, 2014, 2016, 2020a, 2020b; Dobrolyubov, 2020; Malkov, 2020; Faixat, 2022).

[5] Modis first presented his results in an article in *Technological Forecasting and Social Change* (that Panov only read in March 2018 after it was sent to him by me) in 2002, whereas Panov first presented his results next year at the Academic Seminar of the State Astronomic Institute in Moscow.

Modis – Kurzweil series	*Panov (2005) series*
(6) First mammals, first birds, first dinosaurs – *210 million years ago*. **(7) First flowering plants**, oldest angiosperm fossil – *139 million years ago*. **(8) First primates**/ asteroid collision/ mass extinction (including dinosaurs) – *54.6 million years ago*. **(9) First hominids**, first humanoids – *28.5 million years ago*. **(10) First orangutan**, origin of proconsul – *16.5 million years ago*. **(11) Chimpanzees and humans diverge**, earliest hominid bipedalism – *5.1 million years ago*. **(12) First stone tools**, first humans, *Homo erectus – 2.2 million years ago*. **(13) Emergence of *Homo sapiens*** – *555,000 years ago*. **(14) Domestication of fire** / *Homo heidelbergensis – 325,000 years ago*. **(15) Differentiation of human DNA types** – *200,000 years ago*.	**(3) Reptiles revolution** (The beginning of Mesozoic era) – *235 million years ago*. **(4) Mammalia revolution** (The beginning of the Cenozoic era). Dinosaurs died out. Mammalia animals became the leader of the evolution on the terra firma. – *66 million years ago*.· **(5) Hominoid revolution** (The beginning of the Neogene period). A big evolution explosion of Hominoidae (apes) – *22.5 million years ago*. **(6) The beginning of Quaternary period (Anthropogene) /** The first primitive Homo genus (hominidae) separated from hominoidae – *4.4 million years ago*. **(7) Palaeolithic revolution /** Homo habilis, the first stone implements – *1.8 million years ago*. **(8) The beginning of Chelles period** – *650,000 years ago*. Fire, Homo erectus. **(9) The beginning of Acheulean period**. Standardized symmetric stone implements.– *400,000 years ago*.

Table 1 Correlation between the phase transition lists of Modis and Panov for the period between 400 million years ago and 150,000 years ago

singularity". Parameter $t*$ was estimated by von Foerster and his colleagues as 2026.87, which corresponds to November 13, 2026; this made it possible for them to supply their article with a public-relations masterpiece title – "Doomsday: Friday, 13 November, A.D. 2026" (von Foerster, Mora, Amiot 1960). Note that von Foerster and his colleagues detected the hyperbolic pattern of world population growth for 1 CE –1958 CE; later it was shown that this pattern continued for a few years after 1958, and also that it can be traced for many millennia BCE (Kapitza 1996a, 1996b, 1999; Kremer 1993; Tsirel 2004; Podlazov 2000, 2001, 2002; Korotayev, Malkov, Khaltourina 2006a, 2006b). In fact, Kremer (1993) claims that this pattern is traced since 1 000 000 BP, whereas Kapitza (1996a, 1996b, 2003, 2006, 2010) even insists that it can be found since 4 000 000 BP.

It is difficult not to see that the world population growth acceleration pattern detected by von Foerster in the empirical data on the world population dynamics between 1 and 1958 turns out to be virtually identical with the one that has been detected above with respect to both Modis – Kurzweil and Panov series describing the planetary macroevolutionary development acceleration. Note that the power-law regression has yielded for all the three series the value of exponent β being extremely close to 1 (1.003 for the Modis – Kurzweil series, 1.01 for Panov, and 0.99 for von Foerster).

However, the resultant proximity of parameter $t*$ (that is just the singularity time point) estimates is also really impressive (the power-law regression suggests 2029 for the Modis – Kurzweil series, 2027 for Panov series, and just the same 2027 for von Foerster series[6]).

We have already mentioned that, as was the case with equations (1) and (2) above, in von Foerster's Eq. (3) the denominator's exponent (0.99) turns out to be only negligibly different from 1, and as was already suggested by von Hoerner (1975) and Kapitza (1992, 1999). As we see the resultant equation turns out to be entirely identical with Eq. (2) above that described so accurately the overall planetary macrodevelopment acceleration pattern since at list 4 billion years ago. Note that Eq. (3) has turned out to be as capable to describe in an extremely accurate way the world population dynamics (up to the early 1970s), as Eq. (2) is capable to describe the overall pattern of macredevopment acceleration (at least between 4 billion BCE and the present). We will show just an example of such a fit.

Let us take Eq. (3). Now replace $t*$ with 2027 (that is the result

[6] Note that the power-law regression that produced this value for the world populations series had been performed more than 50 years before a similar regression produced the same value of $t*$ for the Panov series (actually, the first regression was performed before the birth of the author of the present article). Still I would not take too seriously such astonishingly similar values of $t*$ parameter produced by different power-law regressions for very different time series in very different years; of course, there is a very high degree of coincidence here. In any case, as we will see below, there are no grounds at all to expect anything like Doomsday on Friday, November 13, A.D. 2026…

of just rounding of von Foester's number, 2026.87), and replace *C* with 215000.[7] This gives us a version of von Foerster – von Hoerner – Kapitza Eq. (4) with certain parameters:

$$N_t = \frac{215000}{2027 - t}. \quad (4)$$

The overall correlation between the curve generated by von Foerster's equation and the most detailed series of empirical estimates looks as follows (see Fig. 4):

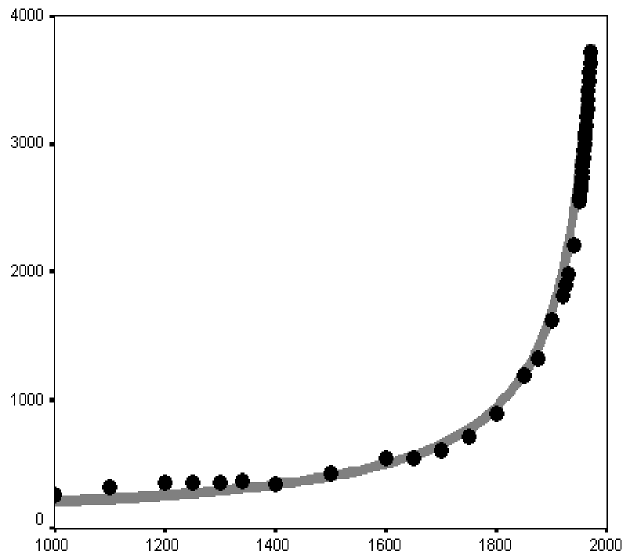

Fig. 4 Correlation between Empirical Estimates of World Population (in millions, 1000 – 1970) and the curve generated by von Foerster's Equation (3). *Note:* black markers correspond to empirical estimates of the world population by McEvedy and Jones (1978) for 1000–1950 and UN Population Division (2022) for 1950–1970. The grey curve has been generated by von Foerster's Eq. (10). $R^2 = 0.996$

As we see, indeed, Eq. (4) has turned out to be as capable to describe in an extremely accurate way the world population dynamics (up to the early 1970s), as Eq. (2) is capable to describe the overall pattern of global complexity growth rate acceleration.

We have shown that that the fact that, up to the beginning of the 1970s, the world population size (*N*) and the global complexity increase rate (*y*) in the Panov series grew following the same law ($x_t = C / 2027 - t$), is by no means a coincidence; it is rather a manifestation of a fairly deep pattern of the global evolution. Thus, at the social phase of universal and global history, the hyperbolic growth of the rate of increase in global complexity and the hyperbolic growth of the Earth's population are two closely related aspects of a single process. We have demonstrated that Eq. (4) can be derived from Eq. (2) and the other way around (e.g., Korotayev, 2020a, 2020b).

I must say that I had serious doubts when I first got across calculations of Panov and Modis (and I am not surprised that most historians get very similar doubts when they see their works). I had many complaints regarding the accuracy of many of their descriptions of their "canonical milestones", their selection, and their datings (see, e.g., Korotayev 2015). I have only started taking their calculations seriously, when I analyzed myself the two respective time series compiled (as we have seen above) entirely independently by two independently working scientists using entirely different sources with a mathematical model not applied to their analysis either by Modis or by Panov, and found out that they are described in an extremely accurate way by an almost identical mathematical hyperbolic function – suggesting the actual presence of a rather simple hyperbolic planetary macroevolution acceleration pattern observed on the Earth for the last 4 billion years. This impression became even stronger when the equation describing the planetary macroevolution acceleration pattern turned out to be identical with the equation that was found by Heinz von Foerster in 1960 to describe in an extremely accurate way the global population growth acceleration pattern between 1 and 1958 CE.

But how seriously should we take the prediction of "singularity" contained in such mathematical models? Should we really expect with Kurzweil that around 2029 we should deal with a few orders of magnitude acceleration of the technological growth (indeed, predicted by Eq. (2) if we take it literally[8])?

I do not think so. This is suggested, for example, by the empirical data on the world population dynamics. As we remember, the global population growth acceleration pattern discovered by Heinz von Foerster is identical with planetary macroevolutionary acceleration patterns of Modis – Kurzweil and Panov, and it is characterized by the singularity parameter (2027 CE) that is simply identical for Panov and has just 2 year difference with Modis – Kurzweil. However, what are the grounds to expect that by Friday, November 13, A.D. 2026 the world population growth rate will increase by a few orders of magnitude as is implied by von Foerster equation? The answer to this question is very clear. There are no grounds to expect this at all. Indeed, as we showed quite time ago, "von Foerster and his colleagues did not imply that the world population on [November 13, A.D. 2026] could actually become infinite. The real implication was that the world population growth pattern that was followed for many centuries prior to 1960 was about to come to an end and be transformed into a radically different pattern. Note that this prediction began to be fulfilled only in a few years after the "Doomsday" paper was published" (Korotayev 2007: 154).

Indeed, starting from the early 1970s the world population growth curve began to diverge more and more from the almost ideal hyperbolic shape it had before (see Fig. 4) (see, e.g., Kapitza, 2003, 2006, 2007, 2010; Livi-Bacci 2012; Korotayev, Malkov, Khaltourina 2006a, 2006b; Korotayev, Goldstone, Zinkina 2015; Grinin, Korotayev 2015; UN Population Division 2022), and in recent decades it has been taken more and more clearly logistic shape – the trend towards hyperbolic acceleration has been clearly

[7] Note that all the calculations below of the world population are conducted in millions. Note also that the value of parameter *C* used by us is a bit different from the one used by von Foerster.

[8] This is done, for example, by Nazaretyan (2017a, 2017b, 2018, 2020).

replaced with the logistic slow-down, with a clear perspective of transition to a negative population growth rate (see Fig. 5):

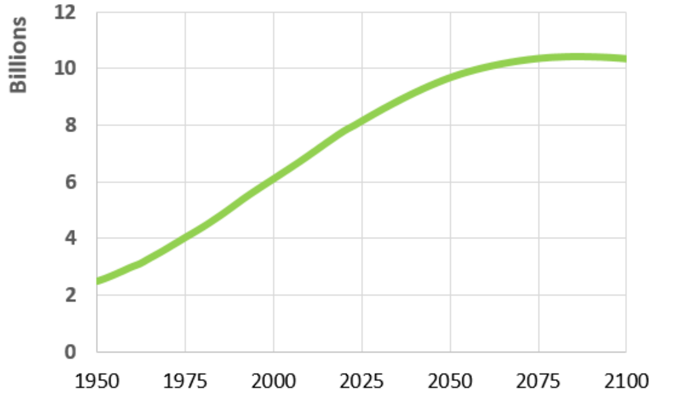

Fig. 5 World population dynamics (billions), empirical estimates of the UN Population Division for 1950–2015 with its middle forecast to 2100. *Data source*: UN Population Division 2022

In some respect, it may be said that von Foerster did discover the singularity of the human demographic history; it may be said that he detected that the human World System was approaching the singular period in its history when the hyperbolic accelerating trend that it had been following for a few millennia (and even a few millions of years according to some) would be replaced with an opposite decelerating trend. The process of this trend reversal has been studied very thoroughly by now (see, e.g., Vishnevsky 1976, 2005; Chesnais 1992; Caldwell et al. 2006; Khaltourina & Korotayev, 2007; Korotayev, Malkov, Khaltourina 2006a, 2006b; Korotayev 2009; Gould 2009; Dyson 2010; Reher 2011; Livi-Bacci, 2012; Choi, 2016; Podlazov, 2017) and is known as the "global demographic transition" (Kapitza 1999, 2003, 2006, 2010; Podlazov 2017). Note that in case of global demographic evolution the transition from the hyperbolic acceleration to logistic deceleration started a few decades before the singularity point mathematically detected by von Foerster.

There are all grounds to maintain that the deceleration of planetary macroevolutionary development has also already begun – and it started a few decades before the singularity time points detected both in Modis – Kurzweil and Panov. This is well supported by the growing body of evidence suggesting the start of the long term deceleration of the global techo-scientific and economic growth rates in the recent decades (see, e.g., Krylov 1999, 2002, 2007; Huebner 2005; Khaltourina & Korotayev, 2007; Maddison 2007; Korotayev and Bogevolnov 2010; Korotayev et al. 2010; Modis 2002, 2005, 2012, 2020; Akaev 2010; Gordon 2012; Teulings & Baldwin, 2014; Piketty 2014; LePoire 2005, 2009, 2013, 2015a, 2015b, 2020a, 2020b; Korotayev & Bilyuga 2016; Popović, 2018; LePoire & Chandrankunnel, 2020; LePoire & Devezas, 2020; Widdowson, 2020).

Now, let us sum up our quantitative analysis of the accelerating growth of complexity traced on our planet for four billion years since the emergence of life on the Earth.

It may be said that the general formula of the acceleration of the global complexity growth

$$y = \frac{C}{t^{*} - t} \quad (5)$$

can be described as follows:

- The rate of the global complexity growth increases when we approach the Singularity.
- As the time until the Singularity decreases *n* times, the global complexity growth rate increases the same *n* times.
- Thus, if the time until the Singularity lessens by a factor of 3, the speed of the global complexity growth rises 3 times; if the time till the Singularity diminishes 10 times, the global complexity growth rate escalates by a factor of 10, and so on.

Let us apply now the same methodology that we have applied earlier to analyze the abovementioned accelerating pattern to the analysis of decelerating universal (cosmic) evolutionary development evidenced in the Universe for a few billions of years since the Big Bang Singularity.

3 Decelerating Universal (Cosmic) Evolutionary Development After the Big Bang

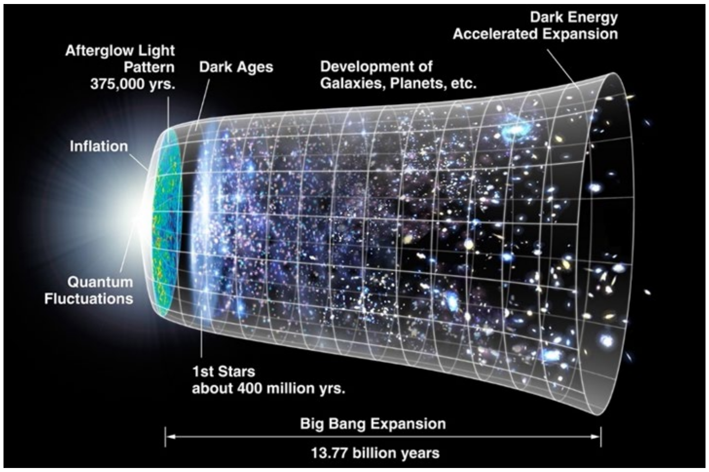

Fig. 6 Timeline of the universe. A representation of the evolution of the universe over 13.77 billion years. Source: https://en.wikipedia.org/wiki/Big_History#/media/File:CMB_Timeline300_no_WMAP.jpg

We have used the following time series for our analysis (shown in Table 2), taking into account the following phases of the universal complexity growth. The major phase transitions and phases of complexity growth in the Universe, as well as their dating in Notes. *Data sources for Tables 2*: Baumann, 2022; Chaisson, 2001; Coc, 2017; Coc et al., 2014; Gorbunov & Rubakov, 2018; Hawking, 2009; Karki, 2010; Loeb, 2006; May et al., 2008; Morison, 2015;

Mukhanov, 2005; Panov, 2008; Petter, 2013; Ryden, 2017; Spier, 2010; Sunayev & Chuba, 2009. Note that the list of phase transitions above does not include the transition from the radiation-dominated era to the matter-dominated one around 47 thousand years after the Singularity and the transition from the matter-dominated era to the dark-energy-dominated one [accompanied by the acceleration of the expansion of the Universe] around 9.8 billion years after the Singularity, as both of these important milestones of the cosmic history do not appear to have been accompanied by any clear increase in complexity. However, it is important to emphasize that our additional tests have indicated that their inclusion does not affect the results of our calculations in any significant way.

To identify an equation describing the post-Big-Bang decelerating growth of the complexity in the Universe we apply to the table above the same type of mathematical analysis that we applied earlier to the time series of Modis – Kurzweil and Panov. Thus, we correlate the frequency of phase transitions in the given Big History epoch with the time period separating this epoch from the Big Bang Singularity (see columns 3 and 5 in Table 2; the values used for calculations whose results are presented in Fig. 7 are highlighted with a bold font in columns 3 and 5 of Table 2).

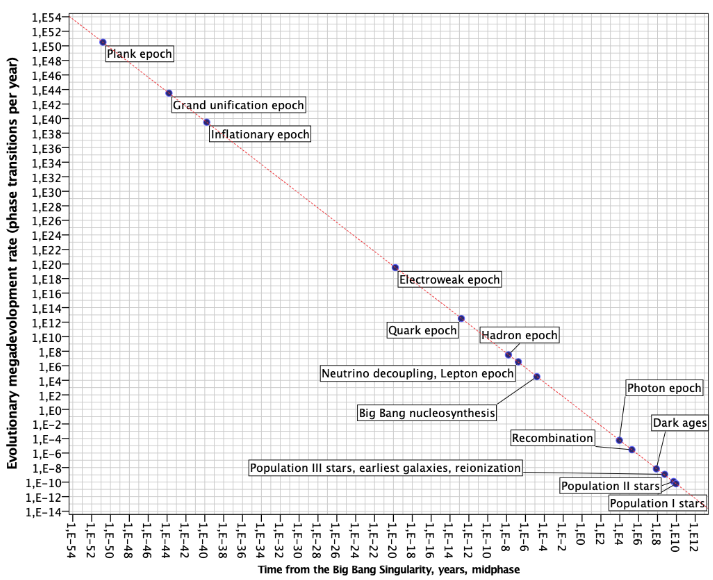

Fig. 7 Correlation between the time since the Big Bang Singularity and universal evolutionary megadevelopment rate (phase transitions per year). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line (log-log scale)

As we see, our power-law regression of the time series of phase transitions of the post-Bing-Bang-Singularity complexity growth in the Universe outlined in Table 2 has identified the following best fit equation describing this time series:

$$y = \frac{0.549}{x^{0.998}}, \qquad (6)$$

where y is the universal evolutionary megadevolopment rate (phase transitions per year), x is the time elapsed since the Big Bang Singularity, and 0.549 and 0.998 are constants. Note that the fit between the theoretical curve generated by simple power-law Eq. (13) and the empirical estimates of the complexity growth deceleration dynamics in the Universe spelled out in Table 2 (R^2 = 0.999996) has turned to be even higher than we observed above with respect to very similar power-law equations describing the global complexity growth acceleration pattern as regards Modis – Kurzweil series (Eq. (1); R^2 = 0.9989) and Panov series (Eq. (2); R^2 = 0.9991). Note that the difference of the denominator's exponent from 1 (0.998 – 1 = – 0.002) turns out to be as negligible as we could see it above with Eq. (1) describing the Modis – Kurzweil series (1.003 – 1 = 0.003) and Eq. (2) describing the Panov series (1.01 – 1 = 0.01). Hence, as we have seen this above as regards Eqs. (1) and (2), there are all grounds to use this equation in the following simplified form:

$$y = \frac{0.549}{x}, \qquad (7)$$

where y is the universal complexity growth rate (phase transitions per year), x is the time elapsed since the Big Bang Singularity, and 0.549 is a constant.

However, the correlation seems too good. In fact, this type of correlation follows from the type of data and the definition of the complexity rate. The data has large relative differences in time such that the difference between the time of an event and its predecessor, at a much earlier time, is just the time of the event. When complexity is defined as the reciprocal of this time difference, the curve is effectively being defined such that C(t)=A/t, independent of the data. So this does not seem to be a good test for a singularity trend.

A different formulation of a singularity is that equally weighted events would occur with a geometric sequence in time from (or toward) the singularity time. For the Panov and Modis sequences of the biosocial evolution on earth this factor is about a third. This would mean that the next event occurs at about 1/3 of the time before the singularity time. So, an event occurring at 1,500 years before the singularity time would be expected to be followed by an event at 500 years (1500/3) before the singularity time, followed by the next event at 167 years before the singularity time. With this fractal sequence there would be an infinite number of events before the project singularity time. Of course this would never happen in a real physical sequence. This can be analyzed by placing the events sequentially and using the event number to perform a correlation. A true geometric sequence of events would have the same factor of increased time until the next event. This plot is shown below (Fig. 8), where the 10 events give an R-Square

Phases of the universal complexity growth	*t – t** (**seconds** since the Big Bang Singularity)	*t – t** (**years** since the Big Bang Singularity)	*Time between phases (years)*	*Universal complexity growth rate (phase transitions per year)*	Radiation energy of the Universe, in electronvolts (eV)	Radiation energy (temperature) of the Universe, in Kelvins (K)
Planck epoch starts	10^{-47}	$3.17*10^{-55}$				
Planck epoch mid-phase	$5*10^{-44}$	**$1.58*10^{-51}$**	$3.17*10^{-51}$	**$3.16*10^{50}$**	**10^{28}**	$1.16*10^{32}$
Planck epoch > Grand unification epoch	10^{-43}	$3.17*10^{-51}$				
Grand unification epoch mid-phase	$5*10^{-37}$	**$1.58*10^{-44}$**	$3.17*10^{-44}$	**$3.16*10^{43}$**	**10^{25}**	$1.16*10^{29}$
Grand unification epoch > Inflationary epoch	10^{-36}	$3.17*10^{-44}$				
Inflationary epoch mid-phase	$5*10^{-33}$	**$1.58*10^{-40}$**	$3.17*10^{-40}$	**$3.16*10^{39}$**	**$5*10^{23}$**	$5.8*10^{27}$
Inflationary epoch > Electroweak epoch	10^{-32}	$3.17*10^{-40}$				
Electroweak epoch mid-phase	$5*10^{-13}$	**$1.58*10^{-20}$**	$3.17*10^{-20}$	**$3.16*10^{19}$**	**150 billion eV (150 GeV)**	$1.74*10^{15}$
Electroweak epoch > Quark epoch	10^{-12} (one trillionth of a second)	$3.17*10^{-20}$				
Quark epoch mid-phase	$5*10^{-06}$	**$1.58*10^{-13}$**	$3.17*10^{-13}$ of a year (~1 millionth of a second)	**$3.16*10^{12}$ (3.16 trillion phase transitions per year)**	**75.1 billion eV (75.1 GeV)**	$8.71*10^{14}$ (871 trillion K)
Quark epoch > Hadron epoch	10^{-05} (0.00001, 10 millionths of a second)	$3.17*10^{-13}$				
Hadron epoch mid-phase	0.500005	**$1.58*10^{-8}$**	$3.17*10^{-8}$ of a year (~1 second)	**$3.16*10^{7}$ (31.6 million phase transitions per year)**	**75.5 million eV (75.5 MeV)**	$8.76*10^{11}$ (876 billion K)
Hadron epoch > Lepton epoch	1 second since the Big Bang Singularity	$3.17*10^{-8}$				
Lepton epoch, Neutrino decoupling, mid-phase	5.5 seconds	**$1.74*10^{-7}$**	$2.87*10^{-7}$ of a year (~9 seconds)	**$3.51*10^{6}$ (3.51 million phase transitions per year)**	**550,000 (550 KeV)**	$6.38*10^{9}$ (6.38 billion K)
Lepton epoch > Big Bang nucleosynthesis	10 seconds	$3.17*10^{-7}$				
Big Bang nucleosynthesis mid-phase	505 seconds	**$1.60*10^{-5}$**	$3.14*10^{-5}$	**$3.19*10^{4}$ (31,900 phase transitions per year)**	**50,500 (50.5 KeV)**	$5.86*10^{8}$ (586 million K)
Big Bang nucleosynthesis > Photon epoch	1000 seconds	$3.17*10^{-5}$				

Phases of the universal complexity growth	*t – t** (**seconds** since the Big Bang Singularity)	*t – t** (**years** since the Big Bang Singularity)	*Time between phases (years)*	*Universal complexity growth rate (phase transitions per year)*	Radiation energy of the Universe, in electronvolts (eV)	Radiation energy (temperature) of the Universe, in Kelvins (K)
Photon epoch mid-phase	$2.84*10^{11}$	**$9.0*10^{3}$ (9 thousand years since the B. Bang Singularity)**	$1.8*10^{4}$ (18 thousand years)	**$5.56*10^{-5}$ (5.56 phase transitions per 100 thousand years)**	**500 eV**	$5.86*10^{6}$ (5.86 million K)
Photon epoch > Recombination	$5.68*10^{11}$	$1.8*10^{4}$ (18 thousand years)				
Recombination mid-phase	$6.12*10^{12}$	**194 thousand years AS**	$3.52*10^{5}$ (352 thousand years)	**$2.84*10^{-6}$ (2.28 phase transitions per 1 million years)**	**1 eV**	$1.16*10^{4}$ (11.6 thousand K)
Recombination > Dark ages	$1.17*10^{13}$	370 thousand years since the B. Bang Singularity				
Dark ages mid-phase	$2.37*10^{15}$	**75.2 million (13.7 billion years BP)**	$1.496*10^{8}$ (149.63 million years)	**$6.68*10^{-9}$ (6.68 phase transitions per 1 billion years)**	**0.203 eV**	2,350 K
Dark ages > Population III stars	$4.73*10^{15}$	150 million (13.625 billion years BP)				
Population III stars, earliest galaxies, reionization, mid-phase	$1.81*10^{16}$	**575 million (13.2 billion years BP)**	$8.5*10^{8}$ (850 million years)	**$1.18*10^{-9}$ (1.18 phase transitions per 1 billion years)**	**0.0034 eV**	39.5 K
Population III stars > 2nd generation of stars	$3.16*10^{16}$	1 billion (12 billion years BP)				
First 3rd generation stars appear against the background of predominance of the 2nd generation of stars, medium complexity galaxies, primitive planets, primitive chemical evolution, mid-phase	$1.61*10^{17}$	**5.1 billion (8,7 billion years BP)**	8.20E+09 $8.2*10^{9}$ (8.2 billion years)	**$1.22*10^{-10}$ (1.22 phase transitions per 10 billion years)**	**$1.89*10^{3}$ eV**	22 K
Predominance of the 2nd population of stars > predominance of the 3rd generation of stars	$2.90*10^{17}$	9.2 billion (4.6 billion years BP)				
Predominance of the 3rd generation of stars, complex galaxies, complex planets, complex chemical evolution	After $2.90*10^{17}$	After 9.2 billion years AS (after 4.6 billion years BP)	?	?	**$3.79*10^{-4}$ eV**	4.4 K

Table 2 Phase transitions and phases of the complexity growth in the Universe (advanced version)

of 0.97 (in log transformed data) with a best fit of 7.6 decades for the time scaling factor (i.e., 4×10^7).

A factor of about 6 decades in time would be expected if the energy scaled by 1,000 (due to the relationship of temperature and time after the big bang). A factor of 1000 in energy phenomena is seen in the middle range of physics phenomena from the proton mass 1,000 MeV, the electron pair production mass and typical nuclear excitation energy of 1 MeV, the ionization energy of elements at around 1 keV, a chemical binding energy around 1 eV, and intermolecular binding energies in the meV range (room temperature e = 25 meV). While this range of energy scales allows for separation of phenomena by temperature, it is not fundamentally known why it is that way.

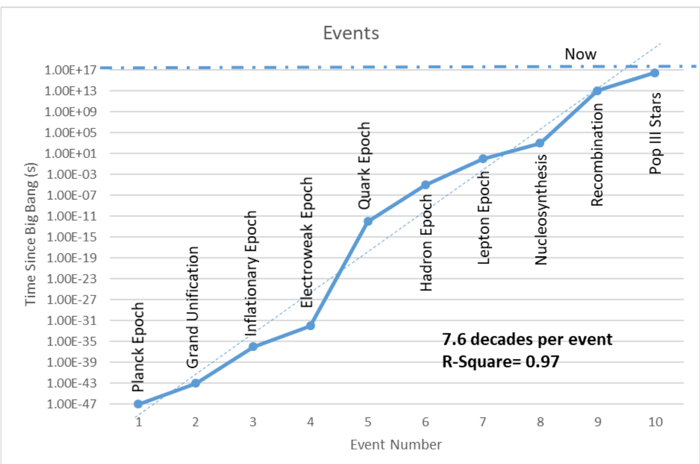

Fig. 8. Geometric sequence of post-Big-Singularity complexity jumps

Thus, our analysis has demonstrated that the decelerating universal (cosmic) evolutionary development evidenced in the Universe for a few billions of years since the Big Bang Singularity can be very accurately described by the following equation:

$$y_t = \frac{C_2}{t - t^*} \qquad (8)$$

where y_t is the rate of the universal complexity growth (complexity jumps per a unit of time) at time t; t^* is the time of the Bing Bang singularity, and C_2 is a constant.

Compare now this decelerating pattern of the universal (cosmic) evolutionary development evidenced in the Universe for a few billions of years since the Big Bang Singularity with the accelerating pattern of complexity growth traced on our planet for four billion years since the emergence of life on the Earth detected in the series of Modis – Kurzweil and Panov (see Fig. 3 and Table 1): This comparison may be also summarized in the following form (see Table 3).

It is difficult not to see here a striking symmetry – the basic regularities of the hyperbolic deceleration of the post-Big Bang universal increase in complexity turn out to be strikingly similar to the ones of the hyperbolic acceleration of the complexity growth observed on our planet for 4 billion years until the early 1970s.

<table>
<tr><th>Modis – Kurzweil global complexity growth acceleration pattern</th><th>Panov global complexity growth acceleration pattern</th></tr>
<tr><td>$y = 2.054 x^{-1.003}$ ($R^2 = 0.9989$), where y is the rate of the global (planetary) complexity growth; x is the time till the 21st century Singularity ($t^* = 2029$); $x = t^* - t$;
$y = \frac{2.054}{(t^* - t)^{1.003}}$;
$y = \frac{2.054}{t^* - t}$; $\boldsymbol{y} = \frac{C_1}{\boldsymbol{t^* - t}}$
$y = \frac{2.054}{2029 - t}$.</td><td>$y = 1.886 x^{-1.01}$ ($R^2 = 0.9991$), where y is the rate of the global (planetary) complexity growth; x is the time till the 21st century Singularity ($t^* = 2027$); $x = t^* - t$;
$y = \frac{1.886}{(t^* - t)^{1.01}}$;
$y = \frac{1.886}{t^* - t}$; $\boldsymbol{y} = \frac{C_1}{\boldsymbol{t^* - t}}$
$y = \frac{1.886}{2027 - t}$.</td></tr>
<tr><th colspan="2">Universal complexity growth deceleration pattern</th></tr>
<tr><td colspan="2">$y = 0.549 x^{-0.998}$ ($R^2 = 0.999996$),
where y is the rate of the universal complexity growth;
x is the time since the Big Bang Singularity ($t^* = 13.8$ biillion BP); $x = t - t^*$;
$y = \frac{0.549}{(t - t^*)^{0.998}}$;
$y = \frac{0.549}{t - t^*}$; $\boldsymbol{y} = \frac{C_2}{\boldsymbol{t - t^*}}$
$y = \frac{0.549}{t - 13.8 \cdot 10^9 \mathrm{BCE}}$.</td></tr>
</table>

Table 3. Comparison of the decelerating pattern of the universal (cosmic) evolutionary development evidenced in the Universe for a few billions of years since the Big Bang Singularity with the accelerating pattern of complexity growth traced on our planet detected in the series of Modis – Kurzweil and Panov

3.1 Relationship between the Cosmic Radiation Energy and Universal Complexity Growth Rate

Consider now the relationship between the radiation energy of the Universe and universal complexity growth rate = evolutionary megadevelopment rate (measured in phase transitions per year). We have used the following time series for our analysis, taking into account the following phases of the universal complexity growth and corresponding values of the radiation energy of the Universe (measured in eV).Below the same figure is presented with direct order of values along the x-axis (see Fig. 10).

$$\boldsymbol{y} = \mathbf{C_4} \boldsymbol{E}^{2}, \qquad (9)$$

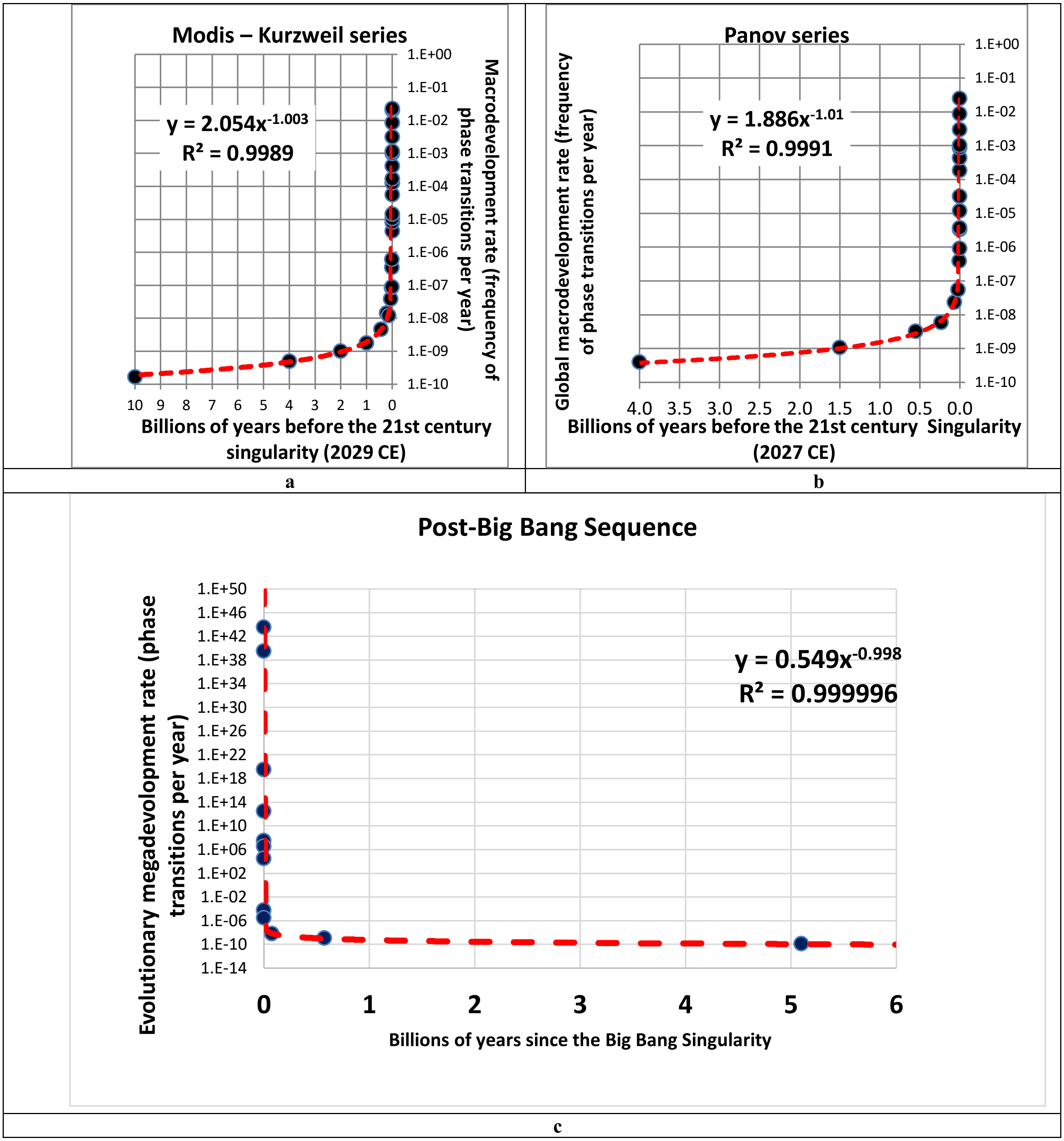

Fig. 9 Comparison of the decelerating pattern of the universal (cosmic) evolutionary development evidenced in the Universe for a few billions of years since the Big Bang Singularity (**c** above) with the accelerating pattern of complexity growth traced on our planet for four billion years since the emergence of life on the Earth detected in the series of Modis – Kurzweil (**a** above) and Panov (**b** above)

Decelerating universal (cosmic) evolutionary development	Accelerating global (biosocial) evolutionary development
$y = \frac{C_1}{t - t^*}$	$y = \frac{C_2}{t^* - t}$
Thus, the general formula of the deceleration of the universal (cosmic) complexity growth can be described as follows: • The rate of the universal (cosmic) complexity growth decreases when we move from the Singularity. • As the time since the Singularity increases *n* times, the universal (cosmic) complexity growth rate decreases the same *n* times. • Thus, if the time since the Singularity rises by a factor of 3, the speed of the universal (cosmic) complexity growth lessens 3 times; if the time since the Singularity increases 10 times, the universal (cosmic) complexity growth rate diminishes by a factor of 10, and so on.	Thus, the general formula of the acceleration of the global (biosocial) complexity growth can be described as follows: • The rate of the global complexity growth increases when we approach the Singularity. • As the time till the Singularity decreases *n* times, the global complexity growth rate increases the same *n* times. • Thus, if the time till the Singularity lessens by a factor of 3, the speed of the global complexity growth rises 3 times; if the time till the Singularity diminishes 10 times, the global complexity growth rate escalates by a factor of 10, and so on.

Table 4. Comparison of the decelerating pattern of the universal (cosmic) evolutionary development with the accelerating pattern of complexity growth (version 2)

3.2 Relationship between Cosmic Radiation Energy and Time Since the Big Bang Singularity

It can be easily shown analytically that if within the cosmic evolution the rate of the universal complexity growth *y* equals constant C_1 divided by the time since the Big Bang Singularity ($t - t^*$, or x)

$$y = \frac{C_1}{t - t^*} \tag{10}$$

and the rate of the universal complexity growth *y* is proportional to the radiation energy of the Universe *E* squared

$$y = C_4 * E^2 \tag{11}$$

then the radiation energy/temperature of the Universe *E* should be proportional to some constant C_3 (= C_1/C_4) divided by a square root of the time since the Big Bang Singularity ($t - t^*$, or x):

$$\boldsymbol{E} = \frac{C_3}{\sqrt{t - t^*}} = C_3 x^{-0.5} = C_3 x^{-\frac{1}{2}} \tag{12}$$

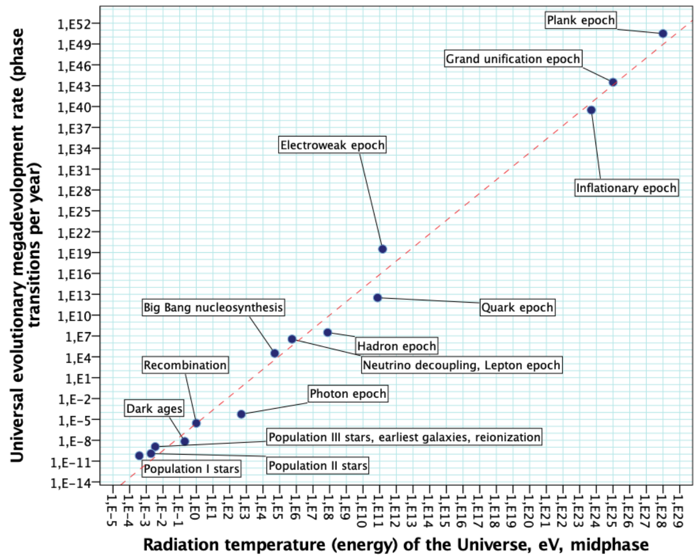

Fig. 10 Relationship between the radiation energy (temperature) of the Universe (eV) and universal evolutionary megadevelopment rate (phase transitions per year). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(log-log scale, with direct order of values along the x-axis)**

Indeed, if $y = \frac{C_1}{t - t^*}$ and $y = C_4 E^2$, then $C_4 E^2 = \frac{C_1}{t - t^*}$. Thus, $E^2 = \frac{C_1}{C_4} \frac{1}{t - t^*}$. Hence, $E^2 = \frac{C_3}{t - t^*}$, where $C_3 = \frac{C_1}{C_4}$. So, finally we arrive at $E = \frac{C_3}{\sqrt{t - t^*}} = C_3 x^{-0.5} = C_3 x^{-\frac{1}{2}}$, where *E* is the radiation energy (temperature) of the Universe (eV), $x = t - t^*$ is time since the Big Bang Singularity and C_3 is a constant.

The analysis of the data presented above in Table 2 suggests that this is indeed the case. Our analysis has demonstrated that the relationship between time since the Big Bang Singularity (years) and radiation energy of the Universe (eV) can be quite accurately described by the following equation:

$$\boldsymbol{E} = \frac{C_3}{\sqrt{t - t^*}} = C_3 x^{-0.5} = C_3 x^{-\frac{1}{2}}, \tag{13}$$

where *E* is the radiation energy of the Universe (eV); *x* (or $t - t^*$) is the time since the Big Bang Singularity, and C_3 is a constant (see Figs. 11 and 12).

In fact, this relationship is well known in cosmology and may be derived from original Friedman's equations (see, e.g., Mukhanov, 2005: 72)[9].

[9] In fact, Eq. (12) describes quite accurately the relationship between the time since the Big Bang Singularity and the radiation energy (temperature) of the Universe for the radiation-dominated era of its history only, whereas for the matter-

This suggests that the post-Big Bang hyperbolic deceleration of the universal complexity growth was directly connected with the post-Big Bang hyperbolic deceleration of the cooling of the Universe described by Eqs. (10) and (12).

In fact, this suggests that the above detected hyperbolic pattern of deceleration of the post-Big-Bang universal complexity growth rate is not just an artefact of some dubious numerological exercise, but rather reflects a well-established scientifically pattern of the hyperbolical slowdown of the speed of the cooling of the Universe.

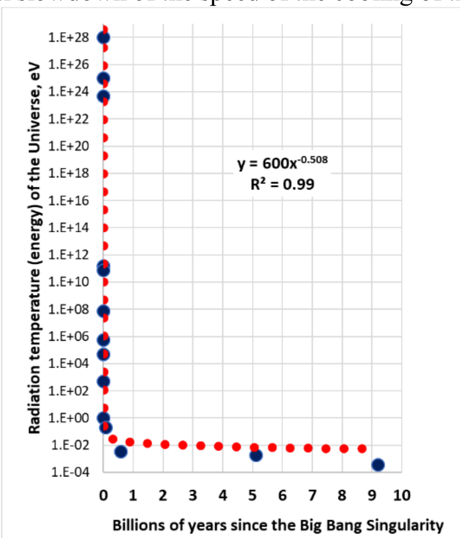

Fig. 11 Correlation between the time since the Big Bang Singularity (years) and radiation energy (temperature) of the Universe (eV). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(with a logarithmic scale for the Y-axis)**

After the Big Bang Singularity, the growth of complexity in the Universe was very tightly connected with its cooling. It was this cooling that allowed the formation in the Universe of more and more complex entities – quarks, then hadrons, then atomic nuclei, then atoms, then molecules (see, e.g., Baumann, 2022; Gorbunov & Rubakov, 2018; Grinin, 2013; Hawking, 2009; LePoire, 2016; Mukhanov, 2005; Ryden, 2017). At the very beginning the cooling of the Universe proceeded very fast, and the complexity in the Universe grew extremely fast (with a few phase transitions just within the first second after the Big Bang Singularity). Then the cooling of the Universe slowed down, which caused the slowing down of the growth of complexity in the Universe.

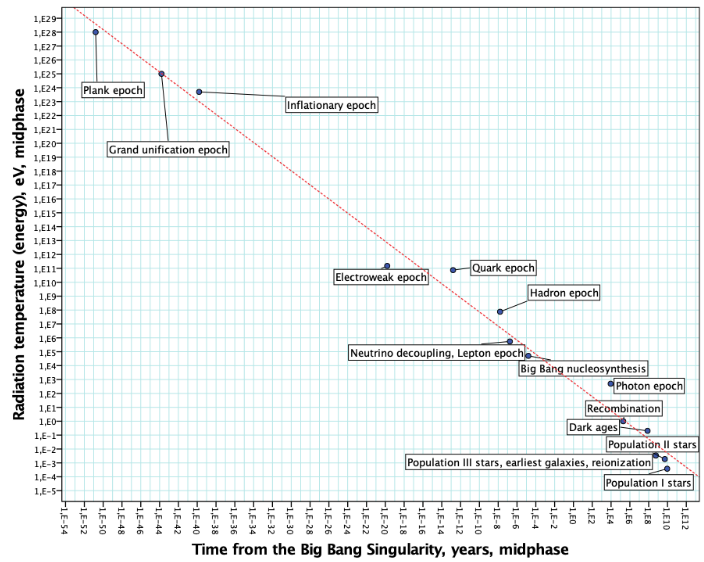

Fig. 12 Correlation between the time since the Big Bang Singularity (years) and radiation temperature (energy) of the Universe (eV). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(log-log scale)**

As we have seen, the slowing down of the cooling of the Universe followed a hyperbolic pattern, and it does not appear to be of any surprise that the hyperbolic slowdown of the cooling of the Universe after the Big Bang Singularity caused a hyperbolic slowdown of the universal complexity growth rate.[10]

4 Relationship between Energy and Complexity Growth Rate in Global Development

Consider now the relationship between time till the 21st century singularity (years) and world energy production (TWy) estimated by John Holdren (1991; see Fig. 13):

dominated era it is much better described by another equation (with -2/3 rather than -1/2 as the exponent):

$$E = C_3 x^{-\frac{2}{3}} \text{ (see, e.g., Mukhanov, 2005: 124).} \quad (14)$$

Note that this point explains why our mathematical analysis of the empirical estimates above (see Table 6 and Fig. 11) has produced a version of Eq. (14) with the exponent higher than 0.5. This is due to the fact that our analysis included a number of data points from the matter-dominated era. However, as the number of data points from the energy-dominated era exceeded the number of ones from the matter-dominated era, the value of the exponent turned out to be closer to 0.5 rather than 0.67.

[10] But it may well be said the other way around: at the beginning the concentration of the energy in the Universe was extremely high, which resulted in the extremely high rate of complexity growth, whereas the subsequent hyperbolic decline of the universal energy concentration resulted in the hyperbolic decrease of the rate of the growth of complexity in the post-Big-Bang Universe (e.g., LePoire, 2016: 229–230).

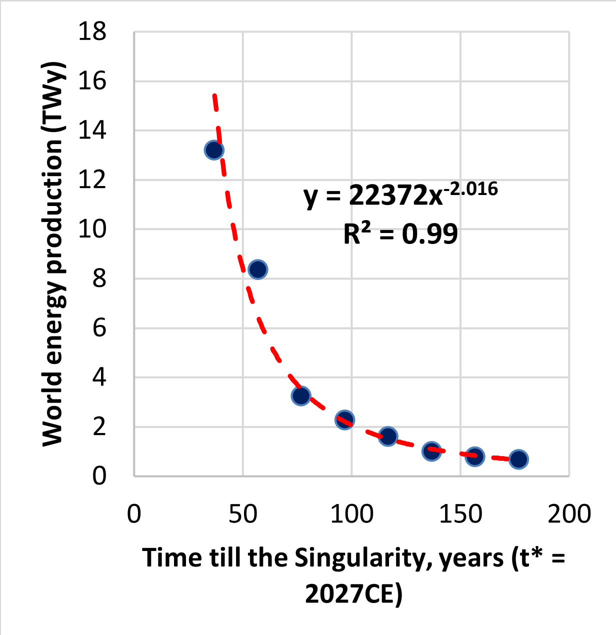

Fig. 13 Relationship between the time till the Singularity, years (t* = 2027CE) and the world energy production (TWy). *Data source*: Holdern, 1991: 245.

As we see, for the pattern of global hyperbolic acceleration we find a quadratic relationship between the energy production and the time till the singularity inversed to the one we saw with respect to the post-Big-Bang universal deceleration:

$$\boldsymbol{E} = \frac{C_6}{(t^*-t)^2}, \quad (15)$$

where E is the world energy production, $t^* - t$ is the time till the Singularity, and C_6 is a constant.

Correspondingly, the relationship between world energy production (E, TWy) and global complexity growth rate (y, phase transitions per year) is described by the following equation:

$$y = C_5\sqrt{E} \quad (16)$$

Thus, the growth of the world energy production 4 times only leads to a twofold increase in the global complexity growth rate; whereas in order for the global complexity growth to increase 4 times, the world energy production should grow by a factor of 16.

Note that this pattern is symmetrically opposite to the one we confronted above dealing with the post-Big-Bang deceleration of the universal complexity growth (see Eq. (12)), when the decrease of the universal radiation energy 4 times led to the decrease of universal complexity growth rate by a factor of 16.

Table 5 below summarizes the general mathematical description of decelerating universal (cosmic) evolutionary development:

Relationship between time since the Big Bang Singularity (***t-t****, years) and universal complexity growth rate (***y***, phase transitions per year)	$y = \frac{C_1}{t - t^*}$
Relationship between time since the Big Bang Singularity (***t-t****, years) and radiation energy (temperature) of the Universe (***E***, eV)	$E = \frac{C_3}{\sqrt{t - t^*}}$
Relationship between radiation energy (temperature) of the Universe (***E***, eV) and universal complexity growth rate (***y***, phase transitions per year)	$y = C_4 * E^2$

Table 5 Summary general mathematical description of decelerating universal (cosmic) complexity growth

5 Complexity Growth Comparison of Cosmic Deceleration and Global Acceleration

A general mathematical comparison between decelerating universal (cosmic) evolutionary development and accelerating global (biosocial) evolutionary development is presented below at Table 6.

As we see, the correlations between energy and decelerating growth of universal complexity display a striking inversed symmetry in comparison with accelerating global evolutionary development.

In the cosmic history, the rate of the universal complexity growth was proportional to the radiation energy of the Universe squared. In the global history, the rate of the global complexity growth was proportional to the square root of the world energy production (see Table 6, Row 2).

In the cosmic history, the moving from the Big Bang Singularity (Singularity_1) by n times was accompanied by the decrease of the radiation energy of the Universe by $\sqrt{n}$ times. Thus, the increase in the time since Singularity_1 by a factor of 4 was associated with the drop in the radiation energy of the Universe by a factor of 2. On the other hand, in the global history the moving toward the 21st century Singularity (Singularity_2) by n times was associated with growth of the world energy production by n^2 times. Thus, the decrease in the time till Singularity_2 by a factor of 4 was associated with the increase in the world energy production by a factor of 16 (see Table 6, Row 2).

Finally, Row 1 of Table 6 demonstrates a perfect symmetry already discussed above: (1) the rate of the universal (cosmic) complexity growth decreases when we move from Singularity_1, whereas the rate of the global complexity growth increases when we approach Singularity_2; (2) more specifically, as the time since Singularity_1 increases n times, the universal (cosmic) complexity growth rate decreases the same n times, whereas when the time till Singularity_2 decreases n times, the global complexity growth rate increases the same n times; (3) even more specifically, if the time since Singularity_1 rises by a factor of 3, the speed of the universal (cosmic) complexity growth lessens 3 times; if the time since

Singularity$_1$ increases 10 times, the universal (cosmic) complexity growth rate diminishes by a factor of 10, and so on. On the other hand, if the time till Singularity$_2$ lessens by a factor of 3, the speed of the global complexity growth rises 3 times; if the time till Singularity$_2$ diminishes 10 times, the global complexity growth rate escalates by a factor of 10, and so on.

Relationship #	**Accelerating global (biosocial) evolutionary development**	**Accelerating global (biosocial) evolutionary development**
1)	Relationship between time since the Big Bang Singularity (***t-t****, years) and universal complexity growth rate (***y***, phase transitions per year) $y = \frac{C_1}{t - t^*}$	Relationship between time till the 21st century singularity (***t*-t***, years) and global (biosocial) complexity growth rate (***y***, phase transitions per year) $y = \frac{C_2}{t^* - t}$
2)	Relationship between radiation energy (temperature) of the Universe (***E***, eV) and universal evolutionary megadevolopment rate (***y***, phase transitions per year) $y = C_4 * E^2$	Relationship between world energy production (***E***, TWy) and global (biosocial) evolutionary megadevelopment rate (***y***, phase transitions per year) $y = C_5\sqrt{E}$
3)	Relationship between time since the Big Bang Singularity (***t-t****, years) and radiation energy (temperature) of the Universe (***E***, eV) $E = \frac{C_3}{\sqrt{t - t^*}}$	Relationship between time till the 21st century singularity (***t*-t***, years) and world energy production (***E***, TWy) $E = \frac{C_6}{(t^* - t)^2}$

Table 6 General mathematical comparison between decelerating universal (cosmic) evolutionary development and accelerating global (biosocial) evolutionary development

6 Concluding remarks

Of course, this paper poses more questions than it answers. The most important of those questions seems to be – why do the basic regularities of the hyperbolic deceleration of the post-Big Bang universal increase in complexity turn out to be so strikingly similar to the ones of the global hyperbolic acceleration of the complexity growth when their mechanisms seem to be so different?

On the one hand, it has been shown that the global hyperbolic acceleration pattern of the last 4 billion years appears to have been produced endogenously by the second order positive feedback between the complexity of the global sociobiological system and the rate of its complexity growth: the more complex the global biosocial system, the less time it takes it to make the next complexity jump – thus, the more complex the global system was, the faster its complexity grew. It has been shown that when written mathematically, such a feedback produces precisely a hyperbolic acceleration effect (see, e.g., von Foerster et al., 1960; Taagepera, 1976, 1979; Kremer, 1993; Kurzweil, 2001; Tsirel, 2004; Korotayev, 2005, 2006a, 2006b, 2007, 2013, 2018, 2020b; Korotayev & Khaltourina, 2006; Korotayev et al., 2006a, 2006b, 2015, 2016; Markov & Korotayev, 2007, 2008; Korotayev & S. Malkov, 2012; Grinin et al., 2013; Korotayev & A. Malkov, 2016; Korotayev & Markov, 2014, 2015; LePoire, 2014, 2015a, 2015b, 2016, 2020a, 2020b).

On the other hand, as we have seen above, the hyperbolic deceleration of the post-Big-Bang universal complexity growth rate appears to have been produced exogenously by the post-Big-Bang hyperbolic deceleration of the cooling of the Universe: the slower this cooling proceeded, the slower the universal complexity grew – thus, the post-Big-Bang hyperbolic deceleration of the cooling of the Universe resulted in the hyperbolic deceleration of the post-Big-Bang universal complexity growth rate.

Yet, those apparently so different mechanisms appear to have produced such strikingly similar patterns of hyperbolic deceleration / acceleration.

Of course, this point needs further investigations.

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On Trends and Periods in Big History

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Abstract: Over nearly fifty years, Big History has evolved as an interdisciplinary approach, connecting cosmic, geological, biological, and cultural phenomena into a unified narrative of increasing complexity. This paper critically examines various theoretical frameworks within Big History, focusing on their scientific soundness. While progress has been made, challenges persist in establishing a theoretical core and achieving consensus. Commonalities exist, such as the recognition of a trend toward increasing complexity, the division into temporal eras and periods, and the acknowledgment of unique dynamics defining these phases. However, a consensus on the best foundational principles and canonical periods remains elusive. The paper suggests three strategies for theory development: employing cross-disciplinary theories, generalizing discipline-specific theories, or inventing novel theories. Each approach requires further refinement and empirical testing to contribute to consensus building. Big History is argued to have utility based on its ability to contextualize events within a broader framework, but more ambitious rationales and empirical work may be necessary for skeptical audiences. Despite ongoing theoretical debates, immediate progress can be achieved through empirical endeavors, contributing to the discipline's reputation.

1. Introduction

Several major philosophies of history can be identified in terms of the kinds of patterns of events they expect: a linear trend toward some objective (examples include St Augustine, Aquinas, Leibniz, Comte, Morgan), a series of repeating cycles (think of Thucydides, Ibn Khaldun, Vico, Spengler, Toynbee, Turchin), a 'dialectic' or repetition with progression (represented by Hegel, Marx), or random (i.e., just 'one damn thing after another'). Most Big Historians align with the 'dialectic' school – that there are features of history which repeat, but within an overall trend, typically seen as an increase in complexity.

In this view, the repetitive aspects of history allow one to break time into units, variously called 'eras', 'phases', 'periods' or similar. (I will prefer 'periods' going forward.) Big Historical periods have been identified using a variety of techniques, including leaps in the flow rates of free energy through relevant structures (Chaisson, 2001); changes in the way information can be stored and manipulated (DNA, brains, and artefacts (Sagan, 1977); or consistency with a mathematical temporal pattern (Panov, 2005). This paper seeks to find the strongest grounds for making such divisions for Big History as a whole (i.e., history since the Big Bang), together with the strongest theoretical foundation for describing the overall trend within which these divisions occur. The means used to find these theories will be to compare existing approaches using standard criteria of scientific strength. I will then suggest ways forward for the discipline consonant with an ambition to make it more scientific. First, a bit of background.

2. Background

2.1 Trend Theories

Why should there be a 'grand narrative' or overarching trend to history? What dynamic unifies the whole story? What makes history teleological – that is, in seeming quest of some objective? Most Big Historians see the grand historical trend as leading to phenomena of increasing complexity (however that is measured). This of course flies in the face of the thermodynamic imperative for the heat-death of the universe. We need an explanation for how Big History counteracts this cosmological principle, or adoption of another criterion besides complexity to define the Big Trend.

2.2 Periodization

It is philosophically possible to claim that all of history is just one long trend – for example, of increases in structures of maximal complexity – and that no clear breaks are real. It may be true that the processes working to produce these structures operate differently in the domains we call physics, biology and sociology, but these are ephemeral compared to the consistency with which events have unfolded since the beginning of time. However, it seems unfruitful to treat all of time and space as 'one big thing'. It has proven difficult to explain human social life using principles from physics, for example, which is why academic disciplines have split up their domains of explanation: one theory simply isn't big enough to encompass all phenomena from molecules to mankind. So it would seem periods are inevitable – especially for Big History.

A particular problem has been to rigorously identify the time-slots into which different periods of Big History fall, analogous to the periods into which historians have traditionally split up time since the invention of writing (the standard scope of history as an academic discipline) – that is, the equivalents of periods such as the Renaissance and Anthropocene. Hence, the search for the 'right' set of periods has become of central importance to Big History as an intellectual project. A rigorous periodization requires that causal mechanisms be found to explain how periods come about, and have the characteristics that they do (Aunger, 2007a). That is, we require an explanation of how periods arise.

A second question concerns when these periods occur. A common viewpoint is that periods recur with some pattern – often with accelerating regularity.[i] A second option is irregular periods. Christian, for example, chose a suite of events that occurred without apparent temporal regularity (Christian, 2008). In either case, understanding what circumstances precede the arrival of a new period needs investigation.

A third question concerns how many periods? Christian originally identified eight 'thresholds' (Christian, 2004). Others have suggested 12 periods (Hoggard, in press), 19 (Panov, 2005), 28 (Modis, 2002), etc. Is this just a question of how closely one is looking at history or a reflection of something more profound? Certainly the lack of consensus around this crucial issue (e.g., there is almost no overlap between the lists of Panov and Modis, despite both nominating many periods (Korotayev & Eurasian, 2018)) threatens the discipline's scientific credibility.

Finally, the why question. This is typically answered using the trend dynamic. But a number of Big History scholars also describe types of periods, some of which are more significant, 'major', or meaningful, than others (e.g., (Henriques & Volk, 2023; Grinin, in press). Obvious examples could be those periods that introduce new kinds of dynamics – such as the move from non-life to life, or individual life to social life – or differences in the scale of operation (e.g., from cosmological to earthly). For example, Henriques and Volk distinguish between 'level' and 'realm' transitions, where the former merely aggregates previously independent entities (e.g., atoms into complex molecules), whereas the latter bring about new kinds of dynamics (e.g., the origin of life) (Henriques & Volk, 2023).

2.3 Comparison criteria

We can compare approaches to these questions for their scientific value based on a number of well-recognized features of scientific theories.[ii] Such criteria of scientific 'strength' include:

- **Parsimony/Comprehensiveness**: Parsimony and comprehensiveness are related concepts – parsimony (also known as Occam's razor) being the quality of being able to explain a broad range of phenomena using relatively few principles and assumptions (compared to alternative explanations), and comprehensiveness in the present context implying that an approach is able to address the full range of phenomena included in Big History as a discipline (typically taken to start with the Big Bang and to end with contemporary human social history). As I will only be considering comprehensive approaches (see below), parsimony becomes the relevant criterion here.

- **Testability**: Theories from which empirically testable hypotheses can be derived are preferred. Particularly appreciated are those hypotheses which can, if proven, discriminate between competing approaches making somewhat different claims (Popper, 1962).

- **External validity**: External validity refers to the extent to which an approach's theoretical foundations are consilient with those of neighbouring sciences – that is, it relies on principles that do not clash in their implications with those processes at scales 'above' and 'below' those being explained (Feyerabend, 1975). I will consider the approaches covered here to have good external validity if they make reference to concepts or theories from disciplines of good standing.

- **Identification of Natural Kinds**: The concept of 'natural kinds' refers to categories of objects or phenomena that have an inherent nature or essence, leading to certain common properties or characteristics that distinguish them from other categories, and which define the fundamental units of some discipline (Quine, 1969; Griffiths, 1999; Griffiths, 1999). Examples include atoms (for physics), genes/species (for biology), and personalities (for psychology). A scientific discipline that successfully identifies a natural kind demonstrates a higher level of scientific rigor and tends to be more productive or progressive. For instance, in biology, the discovery of DNA led to the entirely new subfield of genetics being developed, leading to powerful new technologies.

3. The Approaches

I now move to comparing the candidate approaches. My analysis will exclude those approaches that do not seek to explain the distinguishing features of Big History: its historical scope and an attempt to provide a scientifically meaningful 'story' about that full scope. That is, I will exclude approaches that either deal with only a subset of eras covered by Big History (e.g., (Gehrels, 2017; Quaedackers, 2019; Torday, 2019)), or that don't make an explicit claim about long-term (inter-period) trend dynamics (e.g., (Delsemme, 1998)), or periodization (Constructal Theory (Bejan, 2016)), or both (e.g., the 'curve-fitting school' (Korotayev & Eurasian, 2018; Kurzweil, 2005; Modis, 2002; Panov, 2005), Hoggard, in press). [iii]

The candidate approaches having both an explanatory process underlying Big Historical periodization and a trend trajectory include (in historical order):

- the Self-organising Universe (Jantsch, 1980)
- the 'Grand Unified Narrative' (Christian, 1991; Christian, 2004)
- Cosmic Evolution (Chaisson, 2001; Chaisson, 2005)
- Perasmology (Aunger, 2007b; Aunger, 2007a)
- Extended evolution (LePoire, 2016)
- the 'Grand Sequence' (or 'Big History 2.0') (Volk, 2020; Henriques & Volk, 2023)
- Mega Evolution (Grinin, in press)

I will first describe each approach, briefly, in turn, and then move to the actual comparison. [iv]

3.1 Self-organising universe

Jantsch was an early advocate of the concept of 'cosmic evolution', which he saw as the history of events stemming from the dynamic processes initiated by the Big Bang, up to and including human civilization (Jantsch, 1980). While Jantsch didn't introduce novel mathematical models, he skillfully combined theories such as non-equilibrium thermodynamics, dissipative structures (a theory originally developed by Ilya Prigogine), and self-organisation to provide a framework for understanding the evolution of complex systems. He argued that once self-organization occurred at a certain level of complexity, it established relatively stable patterns of organization (which he called 'regimes') that persisted for some time. A regime involves a cycle of dynamics, driven by growth towards the limits of environmental capacity at a given level of complexity, followed potentially by collapse, reorganization, or the discovery of new resources. Complexity arises from energy gradients propelling non-equilibrium thermodynamic systems through processes of dissipative self-organization. He thought that energy, information, organization, and the environment all work in harmony to structure regimes, both during the physical development of the cosmos and in the evolution of life on planets like Earth.

One of the distinctive features of his approach was his idea of the concurrent co-evolution of both 'micro' and 'macro' structures. This means that self-organizing aggregations occur simultaneously at both small and large scales, brought about by various processes linking them. For example, gravitational forces simultaneously cause the clustering of atoms at micro-scale, but also into stars and planets at macro-scale, while life forms self-organize into ecosystems (micro-scale) and planetary Gaia (macro-scale).

3.2 Grand Unified Narrative

Christian's approach is to provide a 'grand unified narrative' that gets more deeply to human origins, to a complete explanation of where we come from (in causal terms). He outlines a broad periodization of 'Big History' with eight 'thresholds' or 'moments of change' that mark major shifts which have shaped the course of history and which provide a structured framework for dividing the history of the cosmos into meaningful stages (i.e., the Big Bang, star formation, complex chemicals, formation of planets, origin of life, culture, agriculture, modern life). These thresholds also mark significant shifts in the degree and forms of complexity at different scales that have occurred over billions of years.

As the framework which originally defined the field of Big History, it enjoys a special place in this field, and has been adopted by many as the proper approach to its content. Acolytes include Spier, who has very similar list of periods (cosmic, planetary, organic and human or cultural), but adds a 'Goldilocks Principle' (Spier, 2015). The Goldilocks Principle is that each threshold is preceded by a confluence of preconditions that establish a ready moment for the innovation to arise. What these conditions are depends on the level of complexity under consideration. Humans, for instance, cannot live below or above certain temperatures, and require sufficient air pressure, oxygen, food and water. Popularizations such as (Christian, 2018; Brown, 2012; Ferrone, 2021; Villmoare, 2023) have also appeared, indicating the high level of appeal of this approach.

3.3 Cosmic Evolution

Another of the most admired and widely used frameworks is that of 'Cosmic Evolution' (Chaisson, 2001), which makes use of the concept of energy flow through open, thermodynamic systems, including galaxies, stars, planets, life, and societies, to describe the subject matter of Big History. Chaisson uses increases in 'energy rate density' (the amount of free energy flowing per second through a gram of the most complex structure in existence at the time, measured in ergs (Chaisson, 2001)) as the metric of complexity. Transitions in the level of this value have produced, in turn, particles, galaxies, stars, planets, complex life, and human culture.

3.4 Perasmology

Perasmology, or the science of 'transitions', is the name given by Aunger to an approach based in non-equilibrium thermodynamics (like Jantsch) and Cosmic Evolution. Also featured is a generalization of the 'major transitions in evolution' (Maynard Smith & Szathmary, 1995), which covered biological and cultural processes, into what are called Non-Equilibrium Steady State Transitions, or NESSTs. NESSTs describe the internal dynamics of a transition to a new period, while the level of thermodynamic disequilibrium (measured via energy flow density) gauges a system's degree of complexity, as the theory of trend. NESSTs, as a more expansive use of the major transition idea, argue that there must first be an innovation in energy capture and flow, leading to the development of a novel kind of structure, which is then consolidated by novel control mechanisms arising in the new organisation to ensure its resilience and longevity. This sequence repeats to initiate a new period, with the consequence of a new kind of structure arising that has greater complexity than anything previously existing. Periods can be of varying length, with a trend toward an increase in the gap-time between periods during the cosmological era, but a decrease in gap-times during subsequent eras.

3.5 Extended evolution

LePoire has also argued that Big History takes place in two distinct phases: a cosmological phase, with a focus at the scale of the universe, during which transitions between periods occurred more slowly with time, followed by a second phase, with a focus only on earthly events, during which transitions occur with increasing frequency (LePoire, 2016). During the first phase, standard thermodynamical principles explain why transitions occur. But the second phase requires a different kind of explanation. LePoire argues that a good way to understand the mechanics of Big Historical dynamics in the second phase is via the use of complex adaptive systems models. Reorganizations arise to maintain a sudden increase in energy flows in these adaptive systems, leading to more complex organisations – a process he calls 'extended evolution'. LePoire more recently has argued that there are four necessary aspects to such a transition: use of a new energy source, an innovative information processing mechanism, (re)organization, and a new relationship to the environment (as a source of resources and a sink for wastes) (LePoire, 2023). Transitions arise when the existing complex adaptive system reaches an environmental capacity bound (LePoire, in press). LePoire argues that novel information storage and transmission systems occur first, enabling the subsequent development of new, more complex structures that can capture more energy (e.g., through photosynthesis) (LePoire, in press). A period of relative stability or smooth growth follows each transition.

He also distinguishes between eras (cosmic development, terrestrial life, complex ecologies, evolution of humans/intelligence and agriculture/civilization) and periods (not his terminology) (LePoire, in press). For example, periods within the most recent era include the invention of tools, plant domestication, evolution of chiefdoms, etc. Further, he notes that the duration of each of the nominated periods during this phase is roughly one third that of the previous period. A different but constant temporal relationship also exists between eras (each occurring 1,000,000 times slower or 1000 times faster over time, for cosmological or other eras, respectively), meaning that there should be roughly six periods per era.

3.6 Grand Sequence approach

Henriques and Volk also distinguish between periods (which they call 'levels'), and eras (called 'dynamical realms') (Volk, 2017; Henriques & Volk, 2023). A term of art associated with this approach, combogenesis, is an evolutionary step in which new organisations ('levels') are created, possessed of new relations among its elements achieved through combination and integration processes. Previously independent entities merge, with the structures of earlier transitions nested within them (Volk, 2017). Volk argues there have been twelve events of combogenesis in Big History, constituting a Grand Sequence: quanta, nucleons, atomic nuclei, atoms, molecules, prokaryotic cells, eukaryotic cells, multicellular organisms, social groups, tribes, agrovillages, and geopolitical states (Volk, 2017).

Within the Grand Sequence, four different eras can also be identified, each of which arise from a novel form of evolutionary dynamic (which they call a 'PVSR-dynamic', or form of Darwinian algorithm): Matter (physical laws), Life (biological evolution), Mind (psychological evolution) and Culture (cultural evolution). [v] They acknowledge that the initial, cosmological transitions didn't exhibit such evolutionary dynamics, which remains more applicable to those occurring since the rise of life. The jumps to new eras seem to these authors to be more dramatic and significant than the mere accumulation of through combogenesis, characteristic of jumps to new periods.

3.7 Mega Evolution

Leonid Grinin in recent work presents 'Mega Evolution' as an approach centred around ten 'phases' in Big History, five of which are major (Inflationary, Star-galaxy, Geological, Biological and Social), alternating with five 'transitional' (Pre-stellar, Planetary, Chemical, Biosocial and Anthropogenesis) phases; the latter are introduced to make it clearer how phenomena move from one level of organisation to the next higher level of complexity (Grinin, in press). Such increases are presumed to occur through an evolutionary process of search among alternative options. Some of these searches are successful, but do not lead to further complexification (e.g., the social insects are considered an early successful transition to social life, but a phylogenetic dead-end), while others become part of the main line of development of the Big History narrative, and become the building-blocks for later advances in complexity. Each transitional phase can be considered a precondition or pre-adaptation to the movement to the major phase. The existence of evolutionary dead-ends (in terms of further increases in complexity) shows that search and trial-and-error experimentation is required to reach a new major phase.

4. Comparing approaches

The approaches I have covered from the Big History literature are quite different in their theoretical claims, sets of periods, and other features. Nevertheless, they can be compared using the criteria outlined in the introduction to this paper (Table 1).

4.1 Self-organising Universe

Jantsch's approach was the first of several to rely on an 'extended' notion of evolution to cover the entire range of Big Historical phenomena. However, it is unique in its reliance on self-organisation as the primary mechanism inducing transitions to new periods. [vi] Jantsch's attempt to make specific links between macro- and micro-scale processes is also unique among Big History approaches. Jantsch was keen to combine a number of then-fashionable theories (self-organisation, non-equilibrium thermodynamics, dissipative structures), but this means that parsimony is low (although it does mean he brought in considerations of energy, structure and information, which would prove prescient). Because these theories are also non-disciplinary (i.e., applicable to a broad range of phenomena), they need specification to become empirically relevant, and don't make reference to the dominant theories in the disciplines allied to Big History, so external validity is also lower than it could be. The identification of periods as regimes can be considered a form of natural kind, however. It is interesting that none of the defining aspects of Jantsch's approach have been taken up by others in the intervening half-century, although his emphasis on evolution, energy, information and identification of transformative events remain central issues.

4.2 Grand Unified Narrative

The choice of Christian's thresholds seems to have been made primarily based on their educational, not scientific, value (Spier, 2022). Further, the causal model explaining how such negentropic events occur in the first place remains vague. Christian makes use of Spier's notion of 'Goldilocks conditions', or a 'just right' set of variables that allow a sudden increase in the complexity of material structures. For example, new technologies, increasing population pressure and warmer climates made Transition 7, to agriculture, possible. But why this particular confluence of factors is 'just right' to produce that threshold remains unclear, and different sets of factors are postulated to be responsible for other thresholds. This approach is thus quite weak on theoretical foundations (i.e., external validity) for both periodization and trend. (Though, to be fair, this approach is couched in a traditional history-as-one-of-the-humanities framework, not history-as-science paradigm, and therefore does not subject itself to the kind of criticism delivered here.) It also does not make a lot of claims about the causes of specific events which are different from those derived by the respective disciplines themselves, and so does not seem to be empirically productive (i.e., lead to novel testable propositions). It is more about the 'vision' provided from the large-scale viewpoint afforded by Big History.

4.3 Cosmic Evolution

The energy flow density metric has achieved near-universal adoption as a measure of complexity among Big Historical approaches. Parsimony and external validity are high, as Cosmic Evolution relies on a few principles from fundamental physics. Nomination of periods comes strictly from perception of a significant increase in energy flow density. So empirically, there must be a significant rise in this variable with each transition, a claim which has been contested by some ((LePoire, in press; Solis, 2023)). Nevertheless, this means testability is clear and straight-forward. These are all major advantages of this approach.

However, the approach is unusual in not postulating specific mechanisms of transition, nor any internal structure to transitions themselves. There is little in the way of description of the mechanisms leading up to, nor producing, a transition to a new period, and no identification of a natural kind unit. Instead, there is a continuously varying metric, the rate of energy flow density, at the foundation of this approach. Indeed, there are few other scientific claims associated with it.

4.4 Perasmology

The reliance on repeating NESSTs to define periods has a number of scientific advantages. First, it identifies a strong candidate for a natural kind: NESSTs themselves, which have specific characteristics. This should make Perasmology empirically productive, in the sense that the approach makes specific claims about what kinds of mechanisms operate within each transition, and the order in which they must take place (i.e., energy innovation before structure, and structure before information/control). This facilitates the development of testable predictions about the contextual and causal processes in operation during each transition. It can also be expected that there are distinct phases within each period – a beginning during which the transition occurs, followed by a period of relative stability until the next transition (thanks to the existence of new control mechanisms) – a prediction which can also be tested.

Chaisson convinced many early on that energy flow density was the go-to metric for defining progress in Big History. Others have suggested that information processing is also an important consideration (Hookes, 2011; Solis, 2018). As with several other contenders, but not Cosmic Evolution, Perasmology puts both energy and information (captured in the form of new structures and control mechanisms) together in its definition of Big Historical transitions. However, it is not as parsimonious as some other approaches, as it is based on one theory (non-equilibrium thermodynamics) to explain trend, and another (macro-evolution) to explain periods. These are, however, the dominant theories in their respective disciplines, so external validity can be considered strong.

4.5 Extended evolution

Breaking Big History into two very different phases, each of which follows different kinds of dynamics, but with a continuous underlying trend (in terms of energy flows), is distinctive. However, because this move requires making reference to two very different theoretical foundations, the approach is not as parsimonious as some others.

Further, complex adaptive systems, based in cybernetics, is a modelling approach that has been applied to phenomena from widely different disciplines, from physics to biology and sociology. This makes it powerful, but also generic. This is also unusual, because most other Big History approaches typically derive from discipline-specific theories. This reduces external validity in a standard sense as there is no clear external discipline to which the approach refers. On the other hand, the applicability of cybernetics to such a range of disciplines might suggest that it more easily covers a broad range of the phenomena included in Big History (although LePoire does not apply it to the cosmological or geological eras). The generality of complex adaptive systems models, and lack of any instructions for how they might be applied in Big History, leaves the idea of an 'evolutionary transition' as a quite weak natural kind for this approach.

The reasons why each period is only one third the duration of its predecessor (or why there is a 1000 fold reduction in intervals between earthly eras with time) are not made clear (except that these relationships have figured in the curve-fitting work of several previous scholars). Neither are we told why it is important that periodization display such a regularity. The commitment to these patterns seems to derive from an appreciation of this prior work, and an as-yet unfulfilled quest to explain such a regularity of periods.

4.6 Grand Sequence

Combogenesis is somewhat similar in nature to the structuration step in the major transitions of Perasmology, but does not include the energy-based stimulus nor information-based control steps. This leaves the concept lacking a causal engine producing new periods. The combogenesis concept also lacks reference to any particular discipline or theory, and so has low external validity. The reliance on the Darwinian algorithm (which Henriques and Volk call 'PVSR dynamics') also weakens external validity (see Discussion below). They also do not identify a process link between their periods and eras ('levels' and 'realms'). That is, how do new PVSR dynamics, when they arise, feed into the combogenesis meant to be responsible for each new period? This leaves the two kinds of processes unrelated, which reduces parsimony. There are, however, claims made about the nested nature of structures resulting from a given sequence of combogensis events which could be tested, as could whether the dynamics of any new realm fulfill the strictures of a PVSR process (i.e., show variation, diversity and inheritance).

4.7 Mega Evolution

Mega Evolution doesn't make reference to a clear theoretical foundation except 'evolution', which has been generalised in an indeterminate way to all Big Historical eras. This reduces external validity. Grinin marks periods by the emergence of new kinds of 'evolutionary dynamics'. However, the more precise nature of these is not elucidated – what kinds of specific mechanisms lead to successful transitions are not identified. For example, Grinin postulates the existence of a 'biosocial' transitional phase between his biological and social phases, but argues simply that the transition occurs because evolutionary processes introduce social relations among organisms. This is not an explanation but a description. Suggesting that successful transitions are preceded by 'pre-adaptations' (that is, they are successful as a transitional phase, and endure for some time in that form, but then also work as a first step to a new major phase) only indicates that, post-facto, it so happened that one development proved to be the grounds for another one. This lack of defined mechanisms underlying transitions weakens the approach, although the division of transitions into a two-level hierarchy is meant to facilitate the eventual identification of such mechanisms. There is a real lack of specifics about the processes underlying periodization, so that the nominal idea of an 'evolutionary transition' is a weak form of natural kind.

5. Discussion

The different approaches certainly exhibit a variety of strengths, although none seems to be strong across the board. Perhaps not unrelatedly, they also identify widely disparate events in the various Big Historical eras and different reasons for the historical momentum toward increasing complexity. This leaves us in the unenviable position of not being able to point to a 'winner' in the theoretical sweepstakes nor to identify an accepted sequence or periodization for the discipline. However, there is some agreement among the approaches as to the importance of a few periods or events, which appear on the lists of at least three of the candidates (shown in bold in Table 2): the appearance of atomic particles, stars, planets, complex chemicals, the origin of life, complex cells, multi-cellular organisms, social groups, language or human culture, agriculture and modern civilization. So it appears there *is* a degree of consensus around a 'minimal list' – one that is actually close to the original list put forward for the discipline (seven of Christian's eight thresholds make this minimal list of eleven periods). While interesting, this doesn't constitute a scientifically grounded way to consolidate opinion around which events are intrinsic to Big History.

Few of the candidate approaches are parsimonious in the sense of relying on a single theory – although given the scope of Big History, this may not be too surprising. One strategy to cover this range of phenomena has been to rely on generic theories, such as cybernetics or systems theory, but these tend to lack the specificity to allow empirical testing – at least at current levels of development – and to leave Big History without clear reference to, or embeddedness in, related fields. Some approaches also appear not to be 'complete' in the sense of providing explicit theories about both trend dynamics and periodization (e.g., just noting that the trend is toward increasing complexity).

Other aspects of the approaches need discussion. First, several scholars have argued that the tripartite principles underlying the 'Darwinian algorithm' – of variation, selection and inheritance – operate in all Big History eras

Table 1: Characteristics of the Alternative Perspectives on Big History

Quality	Self-Organising Universe	Grand Unified Narrative	Cosmic Evolution	Perasmology	Extended Evolution	Grand Sequence	Mega Evolution
Trend dynamic	Non-equilibrium thermo-dynamics	'Emergence'	Thermo-dynamics	Non-equilibrium thermo-dynamics	Thermo-dynamics/ 'Extended' evolution	Increasing complexity	Increasing complexity
Unique trend metric	Energy gradients	????	Free energy flow density	Free energy flow density	Energy flow	????	????
Period-inducing mechanisms	Self-organisation (non-equilibrium thermodynamics of dissipative structures)	'Goldilocks conditions'	????	Three-part transition involving energy innovation, novel organisation, and emerging control mechanism	New kinds of information processing and energy extraction	Combo-genesis; 'PVSR dynamics' (Darwinian processes of variation, selection and inheritance)	'Pre-adaptations'
Natural kind unit	Regime	Threshold/ Regime	????	NESST	Evolutionary transition	Level/ Realm	Evolutionary transition
Empirical testability	Medium	Low	High	High	Low	Medium	Medium
Degree of parsimony	Low	Low	High	Low	Low	Low	High
External validity	Medium	Low	High	Medium	Medium	Low	Low
Strengths	Addresses a wide range of elements (energy, information); Links micro- and macro-scale processes	Defined Big History as a discipline	Fundamental theoretical foundation, empirical metric	Unique process model encompassing information, energy, and structure	Synthesizes a number of prior approaches	Makes testable claims	Hierarchy of transitions potentially illuminates transition mechanisms
Weaknesses	No model of transition process	'Thresholds' chosen for pedagogic, not scientific value; Reliance on narrative characteristic of humanities; 'Goldilocks conditions' are specific to each Threshold	Lack of intrinsic transition dynamic; Theoretical foundation not specific to Big History	Not theoretically parsimonious	Lack of Big History-specific modelling	Use of Darwinian algorithm to describe transitions; Combogenesis remains abstract concept; Lack of trend-producing mechanism; No process link between levels and realms	Use of evolution concept not fully Darwinian; Transition mechanisms not identified
Reference discipline	Physics, Systems science	History, Cosmology	Physics	Physics, Biology	Physics, Cybernetics	Biology	Biology
Primary proponents	Jantsch 1980	Christian 2004; Spier 2015	Chaisson 2001/2005	Aunger 2007a,b	LePoire 2016	Henriques/ Volk 2023	Grinin in press

Table 2: Periods identified by the candidate approaches*

Period	Self-Organising Universe	Grand Unified Narrative	Cosmic Evolution	Perasmology	Complex adaptive systems	Grand Sequence	Mega Evolution
Cosmological era							
Big Bang/ Quanta		X				X	
Photons	X						
Leptons	X						
Baryons	X						
Nucleons	X					X	
Atomic nuclei	X					X	
Atoms/ Gravitational elements/ Particulate/ Inflationary	**X**		**X**	**X**	**X**	**X**	**X**
Molecules/ Pre-stellar	X					X	X
Stars	**X**	**X**	**X**	**X**			**X**
Stellar clusters	X						
Galaxies	X		X	X			
Galaxy clusters	X						
Superclusters	X						
Geological era							
Planets	**X**	**X**	**X**		**X**		**X**
Chemical/ Geological		**X**	**X**				**X**
Crystals	X						
Chemical abiogenic/ Rock formations	X						X
Gaia system	X						
Biological era							
Prokaryotic cells/ Origin of life	**X**	**X**		**X**		**X**	**X**
Eukaryotic cells	**X**			**X**	**X**	**X**	
Heterotrophic ecosystems	X						
Multicellular organisms/ Cambrian explosion	**X**			**X**	**X**	**X**	
Social groups/ Mammals	**X**			**X**	**X**	**X**	**X**
Primates					X		
Human era							
Hominids/ Anthropogenesis					X		X
Humans					X		
Division of labour	X						
Band/ (Human) Social				X			X
Tribe				X		X	
Human language/ Speech/ Culture	**X**	**X**	**X**		**X**		
Fire					X		
Eco-adaptation					X		
Modern humans					X		
Agrovillages		**X**			**X**	**X**	
Cultural era							
Civilization	X				X		
Chiefdom				X			
Geopolitical states				X		X	
Commercial revolution					X		
Scientific/ Exploration					X		
Industrial				X	X		
Information revolution/ Multi-national				X			
Globalization/ Modern life		**X**		**X**	**X**		
Primary proponents	Jantsch 1980	Christian 2008	Chaisson 2005 (Epic)	Aunger 2007a,b	LePoire 2106	Henriques/ Volk 2023	Grinin in press

* The set of entries in this table do not bear close resemblance to those in (Aunger, 2007b) for the same authors because that earlier compilation concerned events, not transitions, about which these authors have become more explicit (e.g., (Christian, 2008)) since that earlier publication.

(Baker, 2017; Grinin et al., 2011; Grinin, 2019; Volk, 2020; Henriques & Volk, 2023). This argument is often based on work by others suggesting the algorithm operates among multiple potential universes (Smolin, 1997; Harrison, 1995; Vidal, 2014), in the realm of minerals (to define planetary accretion and composition), among genes or individuals (as parts of biological populations) (Darwin, 1859), and between cultural variants (Dawkins, 1976). This algorithm is thus seen by them as the driver of increasing complexity across all eras of Big History, not just during the life and culture eras. As Henriques and Volk note, this is an empirical claim that can be investigated (Henriques & Volk, 2023)?

Unfortunately, the authors advocating the broad applicability of Darwin's insight about natural selection provide few examples of how to apply the Darwinian Algorithm to the central topics of these different eras in Big History. There appears to be little academic conversation around the proposition that there is variation and adjustment in the composition of individual planets due to selection, or among the bodies circling a star; in particular, how information inheritance might figure in these domains has not been explored to my knowledge. The multiverse concept remains highly contentious among cosmologists (Saunders et al., 2010; Kragh, 2009; Gordon, 2011); there is even debate that the Darwinian algorithm provides a good explanation for the mechanics of cultural evolution (via the meme analogy to genes) (Aunger, 2002; Chvaja, 2020; Kronfeldner, 2014). So while the notion of 'evolution' is regularly applied to aspects of change in the full range of Big Historical systems, the specific Darwinian algorithm most likely does not apply to domains outside of biology. [vii] (This is not so say that there aren't evolutionary processes operating outside of biology; for example, a plausible argument has been made that the number, types and complexity of minerals have increased over time on earth, due to a number of specific processes (Hazen et al., 2008).)

Later approaches do not seem to be scientifically stronger, nor always rely on advances made by previous approaches (excepting LePoire), indicating a lack of progressivism in Big History. Jantsch got to diagrammatic-level specificity already by 1980, although he did not engage in quantitative modelling, nor the dating of events. To be fair, most contemporary Big Historical approaches remain conceptual in nature rather than being couched as formal models (although one school is centrally concerned with event dating (Panov, 2005; Modis, 2002; Korotayev & Eurasian, 2018). This limits the degree to which the claims of such approaches can be empirically tested. Tests are still possible, however. For example, since Extended Evolutionary transitions begin with an information storage or transmission innovation, while Perasmological transitions start with an energy capture innovation, this represents a testable contradiction between these approaches. Similar kinds of tests should be identified and investigated.

6. Conclusion

There has now been nearly fifty years of theorising about Big History. What renders all Big History approaches similar is the basic proposition that phenomena arising at different spatial and temporal scales since the origin of the universe – cosmic, geological, biological and cultural – can be linked causally into a unified story about the increasing complexity of outcomes from similar, but distinct, processes. This philosophical choice of cycles-within-trend as the overall pattern of history gives Big History a particular flavour and meaningfulness: it has a grand scope and potential for an inspirational narrative (leading to a favoured outcome), while also encompassing sufficient content to find patterns capable of being empirically tested. However, identifying sound rationales for periodization and long-term trend dynamics continue to be central theoretical problems for Big History.

In this paper, I have therefore compared approaches that seek to explain history from the Big Bang to contemporary human society using particular theoretical frameworks. The comparison is based on various grounds linked to the scientific soundness of these frameworks. While several approaches cope fairly well with an analysis of their scientific merit, the primary conclusion from this comparison is that Big History has a way to go, both in terms of identifying a theoretical approach with strong foundations, and in achieving a consensus around this theoretical core. In one sense little progress has been made because Jantsch presented an approach in 1980 that is as sophisticated as contemporary offerings.

Progress is rather around a developing sense of consensus, not an actual approach. A number of things seem to be agreed upon (Aunger, 2007a; LePoire, 2016; LePoire, in press; Henriques & Volk, 2023; Grinin, in press):

- The Big Historical trend is about increasing maximal complexity over time
- This trend is broken up into temporal sections at multiple levels of importance (called here 'eras', and within eras, 'periods')
- A single theory encompassing the physical, chemical/geological, biological and cultural eras is possible
- Eras and periods are defined by unique dynamics
- Significant changes in some value (e.g., energy flow density, or reaching system capacity) create the conditions that initiate transitions to new periods and eras
- Transitions into new periods are themselves complex, involving changes in energy flow, information and structure.

But currently, there is little in the way of consensus about the best theory to explain these phenomena, nor around a set of canonical periods that define the Big History narrative – the central problems identified in our introduction. It is difficult to know how to get to a consensus on these issues as there is a tendency for each scholar to develop and prefer an independently created theoretical approach.

One way forward might be to determine the best strategy for theory development. The approaches covered here have each made one of the following choices to cover the broad range of phenomena that define Big History: use a cross-disciplinary theory (systems theory, self-organisation), generalize a discipline-specific theory ('evolution', the Darwinian algorithm, major evolutionary transition theory), or invent a novel theory (e.g., combogenesis). Each of these strategies has advantages, but all require further development to be brought to the point of broad testability. Some tests are currently possible, however. For example, some of the claims about the internal sequencing of transitional phases are different between approaches, and so can be investigated, to come down in favour of one or another of the theoretical approaches covered here, producing an evidentiary basis for preference that could lead to consensus.

As for utility claims, thus far the argument has largely been that simply placing events into a different, larger context (e.g., human history within the history of life on Earth), provides sufficient reason to engage in Big Historical narrative-building. However, for those not convinced by this argument, more ambitious rationales may be required. For such critics, it may also be necessary to produce a body of empirical work – for example, case studies or the 'little Big Histories' of Quaedackers (Quaedackers, 2019) – which demonstrates that novel findings about important historical processes and events can be discovered through use of Big Historical theory or perspectives. While theoretical issues will take time to settle down, empirical endeavours can proceed immediately and will likely contribute significantly to the reputation of Big History as a discipline.

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Endnotes

[i] There is also the problem that physical/cosmological periods become longer with the passage of time, while biological/social/technological ones become shorter (Korotayev & Eurasian, 2018; LePoire, in press). This too requires explanation.

[ii] LePoire has recently suggested a similar, but larger set of criteria on which to evaluate periodization frameworks, some of which are specific to Big History, unlike here (LePoire, in press).

[iii] A major sub-literature concerns efforts to identify dates for periods by fitting exponential curves to historical data (Panov, 2005; Modis, 2002; Korotayev & Eurasian, 2018). This requires setting a beginning date and acceleration or deceleration rate; the combination defines a curve on a graph of time since the present day against the time between significant events. This curve is then used to identify event times in Big History, for which evidence of emergent novelties occurring at those points in time are then sought (Panov, 2005; Snooks, 2005; Modis, 2002). Sometimes, the timing of the nominated events is chosen post-hoc, to better fit the estimated line. (Using time on both sides of the equation (Panov, 2005; Kurzweil, 2005) is also conceptually problematic.) Alternatively, some scholars start by arguing that 'learning' is the mechanism that causes geometric acceleration in the cycles with each repeat, using Christian's Grand Unified Narrative threshold set of events as a starting point against which to fit the acceleration factor. On such a graph, one can then place points that represent significant events in Big History. These points can be read as defining how fast major changes were occurring at various times in the past (e.g., around 2000 years ago, macroevolutionary shifts tended to happen at the rate of one per millennium) (Korotayev & Eurasian, 2018).

However, describing Big History via an exponential function (Panov, 2005; Modis, 2002; Kurzweil, 2005) only produces a line on which an arbitrary number of 'events' can be placed, as a line can be divided up in infinite ways. It therefore is not strictly determinative of what parts of that line count as a period – that is, it doesn't tell you which points on the curve count as inflection points in the underlying dynamic. All that has really been accomplished is a recognition that it is possible to describe some sets of events or periods with a simple two-variable equation involving time and a rate of acceleration. This work thus describes, but does not explain, historical trends, or events within them, especially when no rationale is given for the increasing momentum such lines describe. The generality of the approach (it also works to describe the increase in human population over time (Korotayev & Eurasian, 2018)) means it could simply be the consequence of some feature shared by many kinds of phenomena, and hence is not unique to Big History. From a theoretical point of view, this is unsatisfying, despite the mathematical neatness of the description.

[iv] I should note that I exclude from consideration a number of nineteenth-century predecessors such as (Chambers, 1844; von Humboldt, 1845; Fiske, 1874), all of whom used pre-Darwinian, and hence vague, notions of 'evolution' to cover material from the cosmological to the cultural in a single narrative. While laudable in the sense of adopting the same kind of perspective and ambition as contemporary Big Historians, and often covering the same eras, much less was known scientifically about all of these eras than in the 21st century, so there was neither the same kind of theorizing about trend nor periodization as became possible more recently.

[v] Henriques and Volk argue that non-human animal cognitive decision-making, which represents a new evolutionary dynamic based on within-individual Darwinian psychological mechanisms, is unique to their approach. This is true, within Big Historical accounts; however, this mechanism can be found in several prior works outside of Big History (Aunger, 2002; Fernando et al., 2012; Edelman, 1993).)

[vi] The complex adaptive systems modelling preferred by the Extended Evolutionary approach can also lead to self-organising or emergent outcomes in some cases, but is not the primary focus of such modelling.

[vii] Note that this is an argument against the operation of a *micro*-evolutionary mechanism across all Big History eras. It does not apply to macro-evolutionary mechanisms, such as major evolutionary transitions. Natural selection is a mechanism describing change between generations in biological populations, and so is couched at the wrong scale to explain the macro-scale events characteristic of Big History.

How Chaos Theory Brings Order to the Evolution of Intelligence

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Abstract: This study investigates links between human evolution, information transmission processes, and Chaos Theory, revealing a mathematical pattern underlying evolutionary milestones. By examining the timing of new methods of information transmission, the research confirms a suspected correlation with the Feigenbaum constant δ, a universal factor in Chaos Theory and also found in complex systems. This pattern is prominent in cultural evolution but also extends to biological evolution, as well as to the evolution of written language, suggesting a predictable framework for understanding the progression of complexity in life. The study incorporates findings from various disciplines, including cognitive science, archaeology, and nonlinear dynamics, providing evidence that our development, while it may be random in most aspects, is deterministic in the way complexity grows steadily and evolves information transmission of increasing sophistication. This multidisciplinary approach offers new insights into the links between chaos, complexity, and information, and their role in driving the evolution of intelligent life.

Key Words: Chaos Theory, Human evolution, Feigenbaum constant δ, Information, Accelerated evolution

1. Introduction

Big History and Evolution

Big History is the discipline of studying the past all the way back to the beginning of the universe from the human point of view to understand what happened. Ideally, we would like to have a single theory of evolution that covered the whole of Big History. The methodology used in most theories is to estimate the rate of increase of one or more evolutionary factors that have existed throughout big history, such as growth in energy, complexity, information, etc. Perhaps the work that has attracted most support is Eric Chaisson's proposal common measure of complexity, Free Energy Rate Density, or FERD (Chaisson, 2003). This is useful, because there is no generally agreed definition or measure of complexity and FERD can be calculated for astronomical objects as well as for objects on Earth. FERD has been praised as a metric, but Chaisson's writings about it have been criticized (Solis, Ken, 2023).

Many theories claim that evolution is accelerating. Some of them also include the idea of a technological singularity – defined as a point in time where technology is able to evolve itself faster than humans can develop it, and that the speed of evolution becomes very fast, very quickly (Kurzweil, 2014).

Chaos theory and Evolution

This paper proposes a theory based on information and complexity examined through the lens of Chaos Theory – also known as Non-linear Dynamics. Chaos Theory has a feature called Universality whereby various processes modelled by different mathematical functions can give the same results (Feigenbaum, 1983). In Linear Dynamics it is important that the correct mathematical functions are used. Not necessarily so in Non-linear Dynamics, where iteration of functions often obscures the differences between them and it can be enough to define relationships between variables as monotonic ("always increasing", or "always decreasing") and still get the same qualitative and quantitative result.

Chaos Theory Universality is potentially interesting for taking the different kinds of evolution– from the physical evolution of stars and planets, to the biological evolution of life, and cultural and technology development – and uniting them into a single theory where each kind of evolution behaves identically.

Unfortunately, history shows that that such a theory may not be taken seriously. When Chaos Theory was discovered in the first half of the twentieth century, "what made Universality useful also made it hard for physicists to believe. Universality meant that different systems would behave identically" (Gleick, 1987).

When Gleick wrote that in 1987, one may have thought that today, 35 years later, the mathematics of Non-linear Dynamics would be as widely used as Linear Dynamics was back then. Yet it seems that today there are still aspects of Non-Linear Dynamics that are not as well-known as they could be. It is widely thought that Chaos Theory “proves” that “sensitivity to initial conditions makes evolution completely unpredictable.”

In fact, Chaos theory also proves the very opposite – that given the right conditions, both chaotic and complex systems are completely *in*sensitive to initial conditions. This misunderstanding of Chaos Theory means that the prevailing view among evolutionary biologists is to be skeptical of theories that claim that evolution can be predicted in any way.

The unpredictable rate of evolution

As well as unpredictability about how organisms will evolve, Gould and Eldredge proposed that evolution is also unpredictable in speed, with their theory of punctuated equilibria. (Eldredge & Gould, 1997; Gould, 1990). However, more recent research challenges the paradigm, with evidence that evolution may be more predictable than currently thought (Kryazhimskiy et al., 2014)

Evolution as the accumulation of information

The events on which this paper is based concern the evolution of information. Big History theories often talk about the phases of evolution – especially Physical, Biological, and Cultural. Technological Evolution, starting with the evolution of Tools, is sometimes separated from Cultural Evolution, sometimes considered a part of Cultural Evolution. Carl Sagan wrote a book showing how that information was a common thread throughout evolution (Sagan, 1977). The information in question is information about how to survive and prosper. From an information perspective it can be useful to refer to Information Technology Evolution, which begins with Written Language. This means that Information was stored in a different way for each phase of evolution. This paper uses the following classifications of information:

- **Physical evolution** saw the evolution of the universe, stars and planets, eventually resulting in cell-like molecular structures. These structures "knew" how to survive, but there was no information other than the structure itself.
- **Biological evolution** saw the first living cells that could replicate themselves, or modified versions of themselves, from coded instructions (coded, for example, in DNA). From this point the prime mechanism of evolution was no longer direct change to the cell but change to the coded instructions in the cell’s DNA.
- **Cultural evolution** began when animals had sufficient awareness that they could recognize others of the same species and imitate and learn their behaviour and skills so that these useful skills can be passed on to future generations, thereby replicating the skills (Huber et al., 2009). Useful behaviour that results is stored in the phenotype (i.e. in the body – for example, in the brain) but not in the genotype (DNA). Learning led to teaching, which then co-evolved with tool development and language, all of which was a significant driver of biological evolution (Morgan et al., 2015).
- **Information Technology Evolution** began when information was stored "extrasomatically" ("outside the body") as written language.

(Note that this paper refers to evolution of Information Technology as separate phase after Cultural Evolution, and distinct from other kinds of technology such as Stone Tools, which evolved during Cultural Evolution together with communication and language.)

Also worth noting here:

- None of these phases of evolution have actually ended – all of them are still ongoing.
- Every stage has information replication, storage, and transmission, although with different formats and different information.

Looking at where humans are now, we can see that the accumulation of knowledge to survive and prosper is similar, if not identical, to the scientific search for knowledge in general as well as the knowledge to create useful things.

4.669...

Some authors have concluded that there is a characteristic rate of acceleration of evolution which can be expressed as events occurring at time intervals which become smaller. This paper also proposes an acceleration rate equal to 4.669. This number does not originate from an empirical study of history, but comes from the study of Non-linear Dynamics, also known as Chaos Theory. In particular it comes from a very common phenomenon known as a “Period-Doubling Cascade” or “Feigenbaum Cascade” (Cheung & Wong, 1987).

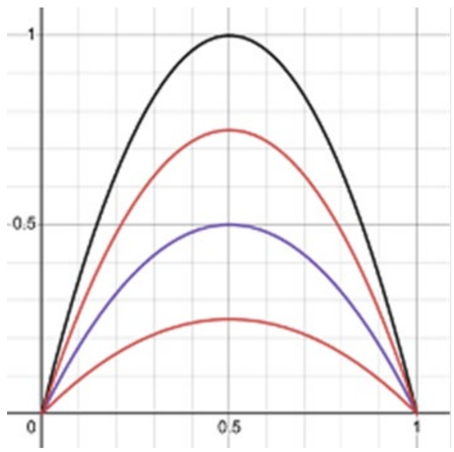

Figure 1: The logistic map (recurrence relation), $x \rightarrow r.x(1 - x/K)$, where r is population growth rate, x is population, K is carrying capacity of the ecosystem for the species. It is used to model systems with restricted resources. Shown for population growth rate, r = 1, 2, 3 and 4.

Feigenbaum Cascades are found in iterated nonlinear dynamic systems with limited resources. They are modelled using maps like the one in figure 1. (A map is a recurrence relation, which means that it is applied many times, with the output from each iteration fed back into the input.) At first the output increases as the input increases, but as the input increases to its maximum value, the output goes back down to zero and all the resources are consumed (Chen et al., 2021).

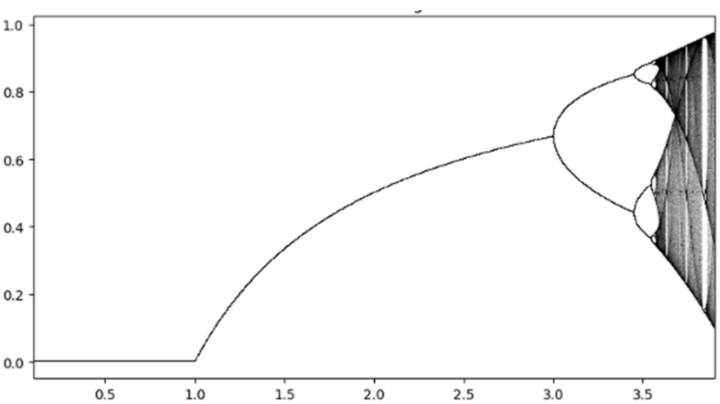

Figure 2: Feigenbaum Cascade. The simple logistic map, x → r.x(1 – x), where r is population growth rate, x is population (maximum is 1.0). When iterated, it displays chaotic behaviour, as shown. The ratio of intervals on the r axis between consecutive bifurcations converges to the Feigenbaum constant δ (4.669…). (The point where the population starts to rise above zero is called a transcritical bifurcation. The point where a line splits into two is called a flip bifurcation. Only the first three flip bifurcations can be seen on this diagram.) The bifurcations finish at the Accumulation Point (which, on this diagram, is approximately at r = 3.6) after which the chaotic region begins and cycles are non-periodic.

Figure 2 shows the "attractor" for a typical limited-resource map. The attractor shows the equilibrium value of x after many iterations as parameter r increases. At a certain value of r the output value x bifurcates into two values and oscillates (alternates) between the two values. Each bifurcation is usually accompanied by discontinuous changes in the process.

In a population model, the parameter r could be Population Growth Rate.

The relevance to evolution is that the Population Growth Rate could get higher as a species evolves, and there may be a link between Population Growth Rate and complexity.

Resource-Depletion Bifurcations occur in systems with limited resources, which is a substantial proportion of all systems. The bifurcations occur because a resource consumption threshold has been crossed, causing resources to be depleted to the level where starvation occurs, resulting in oscillations in the population level.

Very similar attractors can be found in, for example, 1) the pattern of drips from a dripping tap (where the parameter on the x-axis is water flow); 2) oscillations in neural networks; and 3) fluctuations of predator population in an ecosystem (where the parameter is population growth rate) (May, 1976). A remarkable feature of these bifurcations is that the ratio of distance between each resource-depletion bifurcation is always the same – namely 4.669, known as the Universal Feigenbaum constant δ. One always gets the same result from any "unimodal map" – that is, a map with a single "hump" – almost no matter what the exact function is.

The point here is that we could model say, a fish farm, using the simplest restricted-resource map – the Logistic map. Or we could study fish behaviour very closely, and make models – far more sophisticated than the Logistic Map – of how treatment with antibiotics increases the population growth rate in a fish farm. But the end result would still be a Feigenbaum Cascade with an acceleration that converges to 4.669.

Chaotic and Complex

The behaviours described here is not just applicable to simple Chaotic systems but also systems that are classed as Complex Systems, such as Life (Judd, 1990).

Teaching Methods according to Gärdenfors and Högberg

Gärdenfors and Högberg propose:

- That the most important forms of Information Transmission during Cultural Evolution – at least among human ancestors – were all forms of Intentional Teaching of offspring by parents. This was because Intentional Teaching provided the necessary fidelity for the acquired skills to be accurately passed on for an indefinite number of generations.
- That each new Teaching Method was added to the toolbox of methods and did not replace any earlier Teaching Methods, all of which remain active to this day.
- That there were six of these well-defined teaching innovation events during Cultural Evolution.

The intervals between the events in this sequence of events that appear to be close to the interval ratio 4.669. However, the question of dates is not simple.

Teaching techniques do not usually leave archaeological remains that can be dated. Gärdenfors and Högberg state that two of the teaching methods ("Demonstration" and "Communicating Concepts") enabled two important advances in toolmaking techniques ("Oldowan" and "Late Acheulean") to be taught. This implies that the teaching methods may have appeared some time before and applied to the tools later.

Relationship between teaching methods and tool innovations. I suggest an alternative scenario. It is reasonable to make the assumption that the tool innovations and the corresponding teaching method appeared simultaneously, as they are mutually dependent.

A likely scenario that one or both lay dormant until conditions reached a tipping point where they both became active – for example, when the net energy produced crosses the threshold from negative to positive). A stable equilibrium becomes unstable, which is what causes a bifurcation. It is the date of the tipping point, when the processes become active, that is the date of interest. Even if one event triggered the other (that is to say, a Teaching Method enabled a Tool Innovation, or vice versa), they can still be essentially simultaneous if one follows immediately from the other.

(Of course, seeing the tool innovation and the teaching method as two separate things is a human way of understanding them. Evolution, which produced them, does not "think" about them at all. In reality there are lots of parts and nothing works until the last piece is in place and the conditions are right.)

Assuming the Teaching Method and Innovation become active simultaneously, then if we can ascertain which teaching method belongs with which new skill, then if we know the (easy-to-find) date of the Tool Innovation, then we know the (hard-to-find) date of the Teaching Method.

Original work in this paper

Because Feigenbaum Cascades are so common, there is the possibility of finding them in Evolution, which seems to fulfil the relevant requirements of being an iterated non-linear dynamic process. The goal of this paper is to investigate whether Feigenbaum cascade has occurred during evolution resulting in its characteristic signature, the Feigenbaum constant δ, equal to 4.669201609102990671853203820466… to give the first 30 of an infinite number of decimal places, shortened, for readability, to 4.669.

The investigation begins with set of 6 methods of Intentional Teaching proposed by cognitive scientists for Information Transmission during Cultural Evolution (Gärdenfors, 2021; Gärdenfors & Högberg, 2017). These methods appear to follow a pattern similar to that of a Feigenbaum Cascade. Each new teaching method corresponds to new capabilities for the species in question. And each teaching method in Cultural Evolution transmits different information at a higher cognitive level and in a different form. Teaching methods seem to be the same across species. For example, great apes teach their young how to make tools, and so do some corvids (a group of birds including crows and birds related to crows).

Question 1. The first question asked is, does the interval between new teaching methods form a Feigenbaum Cascade? If so, the idea that evolution is completely unpredictable is disproved.

Question 2. The second question asked is, does this pattern extend into in the other phases of evolution – Physical, Biological, and Technological. If so, then we may be able to unite the different phases into one theory. In fact, we already know of two information transmission methods in Biological Evolution – cell division and sexual reproduction. So we shall be seeing whether these fit the pattern.

Information Channels. These other forms of evolution do not transmit information by teaching. The two biological methods transmit information via DNA. We can say that each new method transmits through a different Information Channel. The concept of an Information Channel works for all 4 different kinds of evolution.

Evolution Processes. Just as Information Channel is a generalization of Teaching method, we need another generalized term for Tool Innovation. I use the terms Evolution Process and Evolution Space. The Evolution Spaces are classes of phenotype traits or behaviours or extrasomatic artefacts that are adaptive (i.e. can change to give an advantage).

Just as certain tool innovations require a new teaching method, an innovation is not a new Evolution Space unless it needs a new Information Channel. Each stage of evolution has a new Evolution Process with its own Evolution Space. The new Evolution Process explores the new Evolution Space. The new Evolution Process adapts more quickly and so takes over from the previous Evolution Process and takes evolution in a new direction. Table 1 shows examples of Evolution Space / Information Channel pairs.

Are Eukaryotes an Evolution Space? Eukaryotes "invented" sexual reproduction, so are they an Evolution Space? No, because there are single-celled Eukaryotes. It is multicellularity, and the possibilities it gives, that drives evolution.

Evolution Space	Information Channel
Single-celled Organisms	Copying DNA during cell division
Complex Multicellularity	Combining DNA in sexual reproduction
Using Tools	Tool Transfer (parent gives tool to young)
Making Tools	Drawing Attention to an Object (parent signals to young to pay attention prior to a tool-making lesson)

Table 1: Examples of Evolution Space / Information Channel pairs

2. Methods

Aim of study
We suspect that intervals between dates of new Intentional Teaching Methods during Cultural Evolution to be shrinking by a constant factor equal to 4.669. So we would like to fit the curve to historical data, which should make it clear if such a pattern exists.

If the pattern is confirmed, we also want to see if we can find more events by calculating when they should happen using the Feigenbaum Constant δ = 4.669.

Different kinds of dates
In this study, the events cover the whole of time up till now and can be very different in character, from single cells to human-made objects. The data is in the form of dates, with the following variations:

- Dates of Biological and Cultural Evolution, as revealed by fossils and artefacts, dated by using various techniques of different accuracies.
- Dates of more recent Cultural or Information Technology Evolution recorded in documents.
- Dates arrived at by considering many factors (e.g. Big Bang)
- The date of the Most Recent Common Ancestor may be used if a number of related species share a trait we are interested in.
-

First occurrence
In this study we are looking for the earliest confirmed date for all the events we are looking for.

Dating errors
There are different kinds of dating errors that can be made:

- A correctly identified fossil or artefact may give the wrong result from the dating technique used.
- An archaeological artefact may be identified correctly with the correct date. It may still be the wrong answer if one is looking for the earliest or the latest occurrence because there may be other artefacts that are earlier or later but have not been found.

Confidence levels
We are interested in the date of the earliest example of each object. Each date is really two dates representing an interval of 95% confidence. That means that there is a 95% probability that the actual date of the object is between the two dates. 95% is assumed unless explicitly stated, and all dates here are 95%. Some dates are known very accurately (small interval) and many less accurately (larger interval).

Presenting the data
The data is one-dimensional, consisting only of dates on a timeline, and the event associated with each date.

Scaling the data. The Feigenbaum Cascade is a geometric progression, which can be matched by a geometric series or a continuous exponential curve. The interval decreases geometrically in 10 steps from 13.8 billion years to a few thousand years, which is a difference of about 10 million in interval size. If we are to show the largest interval by a line that will fit on a sheet of paper, say about 20 cm, then the 6th interval will be 0.025 mm, and the following intervals will be too small to distinguish from one another.

We can solve this by using a logarithmic scale for the time axis (Lewis, 1960). This will make every interval appear the same size. This means we can see, for example, the difference between the theoretical and the actual intervals for all known events on the same diagram.

Methods Part 1: Confirming the Feigenbaum Cascade in Cultural Evolution

Least Squares Regression is a suitable method for fitting a theoretical timeline to a set of data points here. *Weighted* Least Squares Regression is better because some dates are more accurately measured, but was not possible in the time available for this study.

Methods Part 2: Extending the Feigenbaum Cascade: looking outside of Cultural Evolution

The second part concerns how the time-pattern is extrapolated forwards and backwards in time to see if the pattern indicates any more similar events before or after Cultural Evolution.

Extrapolation Method. If we have the dates of the seven Teaching Methods of Cultural Evolution and have confirmed that they are part of a Feigenbaum Cascade, we can extrapolate the sequence backwards and forwards in time to find new dates where we would expect to see more Information Channels created. The method for doing this is as follows:

1. Begin with the dates of the Cultural Teaching Methods
2. Create a best-fit timeline for the data points.
3. With the Timeline, we can extrapolate in two directions. Extend the Timeline at each end by one event, using the Feigenbaum constant δ = 4.669 to scale the interval:
   - multiply the time interval by 4.669 when going back in time, and
   - divide by 4.669 when moving into the future.
4. Look at the predicted dates and see if either of them corresponds to an existing Information Channel at that date.

5. (Optional:) If a suitable event is found at the given date, but no event found to follow, try including new dates in the data set and work out a new best-fit timeline. Repeat as needed.

3. Results

Results Part 1: Confirming the Cascade. Looking for evidence of the Feigenbaum Cascade in Cultural Evolution

Ratio of which intervals?	Ratio of intervals	Error compared to 4.669
1 and 2	24.5	+412%
2 and 3	4.72	+1%
3 and 4	5.69	+22%
4 and 5	4.49	-4%

Table 2a. First attempt to find a Feigenbaum cascade with ratios near 4.669. The table shows ratios of intervals between teaching methods, using data from archaeological and palaeontological sites. The expected ratio around 4.669.) The size of the ratio between intervals 1 and 2 has a large error (412% more than 4.669), which suggests a missing event. (There are 6 dates, so 5 intervals and 4 ratios between them.) Total error is +51%.

Ratio of which intervals?	Ratio of intervals	Error compared to 4.669
1 and 2	5.85	+25%
2 and 3	3.58	-23%
3 and 4	4.72	+1%
4 and 5	5.69	+22%
5 and 6	4.49	-4%

Table 2b. Second attempt to find a Feigenbaum cascade with ratios near 4.669, after Tool Transfer has been added between the first two events. The table shows ratios of intervals between teaching methods, using data from archaeological and palaeontological sites. (7 dates, so 6 intervals and 5 ratios between intervals.) The ratios are between 3.58 and 5.85. Total error is +2%

False start. The initial attempt to match Gärdenfors and Högberg's Teaching Methods to a Feigenbaum Cascade failed because one of the intervals was too large, by a factor roughly equal to δ + 1 (4.669 + 1 = 5.669). This gap indicated that there may be a Teaching Method missing from G&H's list (table 2a).

Saved by Tool Transfer. This gap in the sequence is after the first teaching technique, Parental Approval or Disapproval. This technique is applicable to both behaviour without tools and behaviour with tools. The next teaching method, Drawing Attention (to an object), is used to indicate to the student that they are about to be shown something important about the object, namely, how to make a tool. In retrospect it seems obvious that the missing behaviour should be to do with learning how to use a found tool, because Tool Use is a higher cognitive threshold than behaviours without tools, and lower than Making Tools.

However, the behaviour in question (Tool Transfer, which is when the parent gives a tool to their young) does not involve teaching in the way we think of it. But Tool Transfer nevertheless fulfills the definition of a teaching method — that the student learns, that the teacher is present, and that the process involves a cost for the teacher (in this case the time and energy to acquire the tool) (Hunt & Gray, 2007). Tool Transfer is necessary for learning Tool Use because the student needs to practice with a suitable tool before they can learn the next part of Using Tools, which is to find a suitable tool.

Tool transfer was not recognized as a Teaching Method among chimpanzees until Musgrave reported it in a paper published October 2016 (Musgrave et al., 2016). Gärdenfors and Högberg's paper was published February 2017 on researchgate.org and contains no references after 2015.

The probable reason it was not known as a teaching method among chimpanzees until 2016 is that Tool Transfer is not observed in all groups of chimpanzees, possibly because of Genetic Assimilation of Behaviour, whereby acquired behaviours can become instinctive after many generations and therefore no longer need to be taught (Tierney, 1986) (see below).

Tool Transfer is still necessary for every tool that is taught, even today. All the other methods are still in use too, although perhaps updated.

As well as fitting the cognitive gap in the series of Teaching Methods, Tool Transfer also fits the mathematical sequence using the Feigenbaum constant δ (table 2b).

Cherry-picking avoided. The problem with the missing event indicates that events have not been cherry-picked to fit the interval ratio 4.669. Indeed, the authors do not mention any mathematical rule for the events. And there is nothing in any literature about the Feigenbaum constant δ in evolution at the time their paper was published. It follows that the authors were unaware of any mathematical relationship between the dates of each event and were not cherry-picking events to match a mathematical relationship.

Genetic Assimilation of Learned Behaviour. Genetic Assimilation of learned behaviour is a process by which learned behaviour may gradually become instinctive and no longer need to be passed on by teaching because it is passed on by DNA instead. This is thought by some to happen when the behaviour is established as part of the cumulative culture. Any genetic changes that aid this behaviour may be selected. Indeed, the whole behaviour may eventually become instinctive. New Caledonian

Crows brought up in isolation from other crows make tools, but their tools are not as sophisticated as the tools of the crows that learned the behaviour from other crows (Hunt & Gray, 2007). This may be an example of genetic assimilation of behaviour. Genetic assimilation may be a reason why teaching steps might not be observed in some populations of some species.

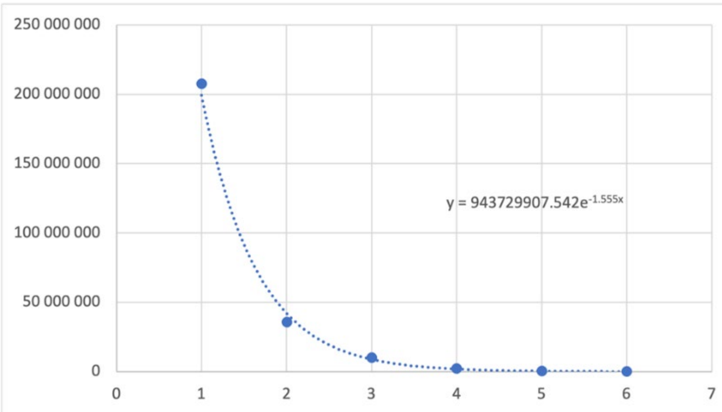

Figure 3. Event intervals and an exponential curve match to it (Microsoft Excel).

Figure 3 shows the intervals between successive events on a linear scale. Using commercial software (Microsoft Excel) an exponential curve has been fitted to the data. The formula calculated from the data by the software is

$$y = 943{,}729{,}907.542\ e^{-1.555x}$$

where x is the number of intervals. The result is averaged over all data points. If we want the average for one interval, then $x = 1$, and $e^{-1.555x}$ is 0.2112.

We want the reciprocal because the intervals are shrinking, not growing, which is 4.735.

This differs from the Feigenbaum Constant 4.669 by 1.4%. This is less than the combined error margins of the date measurements used, so we cannot expect a more accurate answer than this. A cascade of decreasing intervals with a ratio within 1.4% of 4.669 is very strong evidence of a Feigenbaum Cascade.

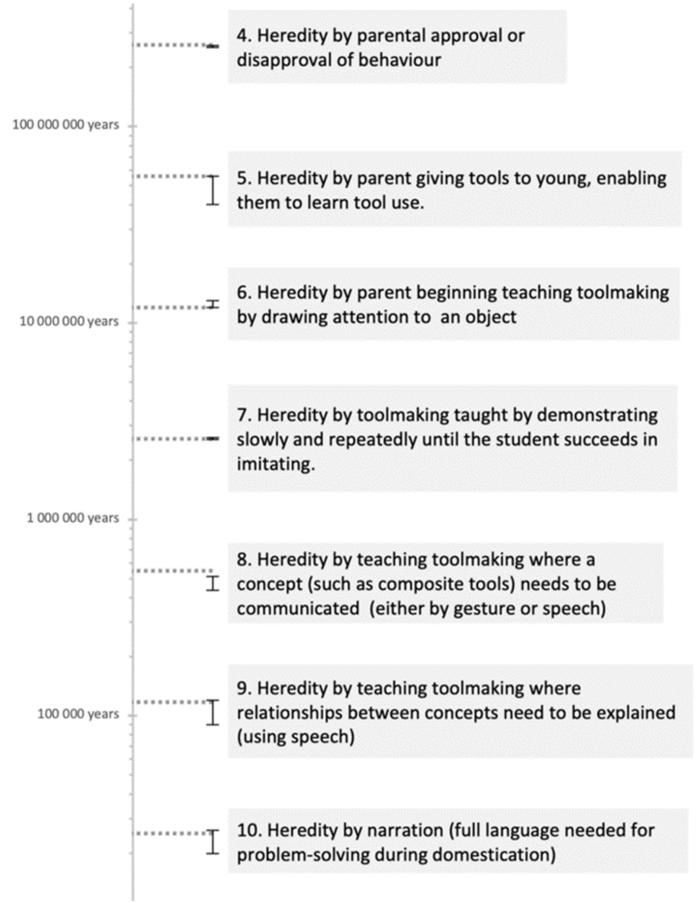

Figure 4. Timeline showing creation dates of the seven teaching methods (here called "heredity") that arose during Cultural Evolution. The error bars of each event are shown. They match the pattern of a Feigenbaum Cascade which is marked by the dotted lines. The timeline is scaled so that events appear equidistant. In linear time the interval between events decreases at each event by the factor 4.669 as predicted by Chaos Theory.

Figure 4 shows the Cultural Evolution events on a timeline. The actual date of the events are shown. The graph is scaled logarithmically as described in the methods section, so that successive intervals with the ratio 4.669 appear the same length on the graph. The dates match the pattern of a Feigenbaum Cascade (dotted lines), where successive intervals are shorter than the previous interval by the factor 4.669.

The Seven Information Channels of Cultural Evolution. The appendix shows the events of cultural evolution together. Each teaching method is an Information Channel. They are examined in

No	PREDICTED DATE years before 2000 CE	ACTUAL DATE years before 2000 CE	Actual vs predicted	INFORMATION CHANNEL	EVOLUTION SPACE
				CULTURAL EVOLUTION:	
4	252 million	259 to 252 million	0%	Parental Approval and Disapproval	Sociality and Parental Care skills
5	53 million	56 to 40 million	0%	Tool transfer.	Tool Use
6	11 million	16 to12 million	-10%	Drawing attention to an object (aka Referential gestures).	Making Tools
7	2.57 million	2.60 to 2.55 million	0%	Showing by Demonstration - Performing tasks slowly and with repetition	Making Tools with Tools
8	502 thousand	550 to 450 thousand	0%	Communicating concepts.	New Concepts in Toolmaking (e.g. Composite tools)
9	106 thousand	120 to 90 thousand	0%	Explaining relationships between concepts	Tools with new functions
10	25 thousand	26 to 20 thousand	0%	Narrating (Complete language)	Domestication

Table 3. The seven Intentional Teaching Methods (Information Channels) of Cultural Evolution. Predicted dates that are within the error span of the measured dates are marked as 0% error.

No	PREDICTED DATE years before 2000 CE	ACTUAL DATE years before 2000 CE	Actual vs predicted	INFORMATION CHANNEL	EVOLUTION SPACE
				PHYSICAL EVOLUTION	
1	26.8 billion	13.82 to 13.78 billion	-51%	Persistence of matter	Dissipative Systems
				BIOLOGICAL EVOLUTION	
2	5.67 billion	4.28 to 3.77 billion	-25%	DNA copying during cell division	Single Cell Organisms
3	1.22 billion	1.22 to 1.17 billion	0%	Sexual Reproduction and gene recombination	Multicellularity (differentiated cells)

Table 4. Extrapolation of dates backwards from Cultural Evolution

more detail in table 3, together with descriptions of the Evolution Processes and an explanation of why the Information Channel and the Evolution Process are associated with each other. We start the numbering of the Information Channels with number 4, because we will see later that there are 3 Information Channels before Cultural Evolution.

Results Part 2a: Before Cultural Evolution.

Using the equation from the curve-fitting, and going backwards in time from the first Cultural Evolution event, gives the following results in table 4.

Date results

1. Date 1 is twice the currently accepted age of the universe.
2. Date 2, which we expected to match Single-celled Life, is off by a large margin. For it to be correct, Single-celled

Organisms would have had to evolve in space before the Earth was formed. This is not an impossible scenario, but beyond our current knowledge.

3. Date 3 is a match for Complex Multicellularity. Clearly, the date of Multicellular life is part of the same Feigenbaum Cascade as the Teaching Methods in Cultural Evolution. It has a unique Information Channel (DNA Recombination) and Evolution Process (Complex Multicellularity).

The two dates that are not close (Big Bang and Multicellular life) are not a problem for the Feigenbaum Cascade, because the first couple of numbers in a Feigenbaum Cascade often differ considerably from the ratio 4.669, depending on the non-linear map used. The important point is that the intervals converge to 4.669, and the dates above converge by event 3. Finding a non-linear map that fits the first two events in evolution is a suggestion for future research.

In summary, although the dates were not as expected, the errors can be reasonably accounted for and the data for the date nearest to the Feigenbaum Cascade in Cultural evolution strongly supports that idea that the cascade extends to the beginning of life and perhaps to the beginning of the universe.

Information Channels 1 to 3 are detailed in the appendix.

No	PREDICTED DATE years before 2000 CE	ACTUAL DATE years before 2000 CE	Actual vs pre dicted	INFORMATION CHANNEL	EVOLUTION SPACE
				IT EVOLUTION	
11	4,734	4,600 to 4,500	2.9%	Teaching to Read and Write	Written Language

Table 5. Extrapolation of dates forwards from Cultural Evolution

Results Part 2b: After Cultural Evolution.

Using the equation from the curve-fitting and going forwards in time from the *last* Cultural Evolution event, gives the result in table 5.

Extrapolation into the future is difficult because of the wide confidence interval of the last event in Gärdenfors and Högberg's list, Narration/Domestication. The regression curve from Excel was used, without any calculation of errors.

The first of the dates found – Written Language – is the most reliable of the forecasts, being closest in time to previous events. Written Language is the first example of Information Technology and shows that the Feigenbaum cascade extends into the age of Information Technology Evolution.

Dates following Written Language are still under investigation.

Is this the end of evolution? Not according to the bifurcation diagram, the upper edge of which represents the maximum population, which continues to grow for a few billion years after the transition to chaotic behaviour. This is, of course, when simulating evolution with the Logistic Map. Further research may give more information about the characteristics of the actual map that fully matches evolution.

Information Channel 11 is detailed in the appendix.

Figure 5 shows the known Information Channels. Seven of them ("Parental Approval" to "Narration") are the Teaching Methods from Cognitive Science research, and the remaining ones are extrapolations of that sequence using the Feigenbaum constant δ, 4.669. It can be seen that the first two events do not match the Feigenbaum dates, but the events converge to the Feigenbaum dates by the third event "Sexual Reproduction". The initial error and rapid convergence are normal for Feigenbaum Cascades. The confidence intervals for each stage are shown. The horizontal lines represent the Feigenbaum ratio, 4.669. The scale is adjusted to a logarithmic scale (older dates are squeezed together) so that the Feigenbaum lines appear to be equidistant even though they get closer together as time passes. The results are also summarized in Table 6.

4. Discussion

Results from Part 1

We looked at the evolution of new teaching methods in Cultural Evolution. In order to date teaching methods, we made the (reasonable) assumption that new teaching methods arise simultaneously with milestones in tool technology, because they are mutually dependent. This apparently worked, because we got a positive answer to our first question, – Yes, there is a Feigenbaum Cascade in Cultural Evolution. The results clearly show the pattern of a Feigenbaum Cascade in the series of Intentional Teaching Methods during Cultural Evolution, where the difference between 4.669 and the average (mean) interval between Teaching Methods according to the fossil and archaeological record is 1.4%.

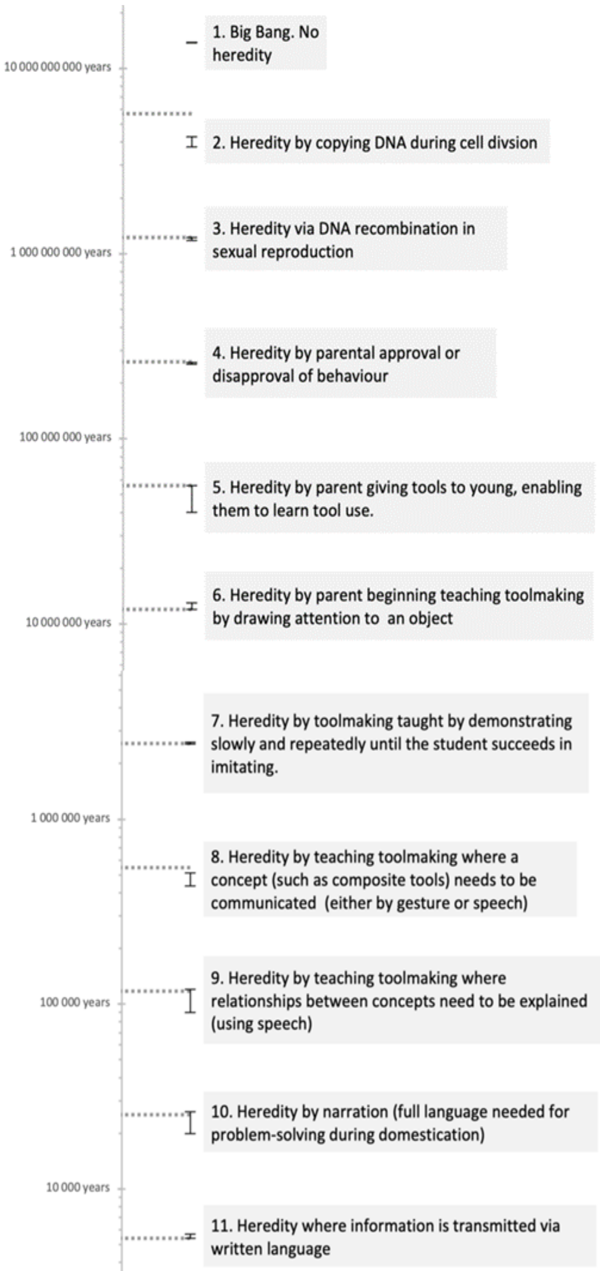

Figure 5. Timeline showing creation dates of the first eleven Information Channels (here called "heredity") that arose during Physical, Biological, Cultural and Information Technology Evolution. The error bars of each event are shown. They match the pattern of a Feigenbaum Cascade which is marked by the dotted lines, except events 1 and 2. The timeline is scaled so that events appear equidistant. In linear time the interval between events decreases at each event by the factor 4.669 as predicted by Chaos Theory.

Results from Part 2

We also generalized teaching methods to Information Channels and related innovations to Evolution Processes in order to find similar events in Physical, Biological and Information Technology Evolution.

This also apparently worked because we got the answer to the second question– Yes, this cascade extends into Physical, Biological and Information Technology Evolution.

Non-random Evolution

We can also state that evolution is not completely random, at least when it comes to the rate of decreasing intervals in Information Transmission.

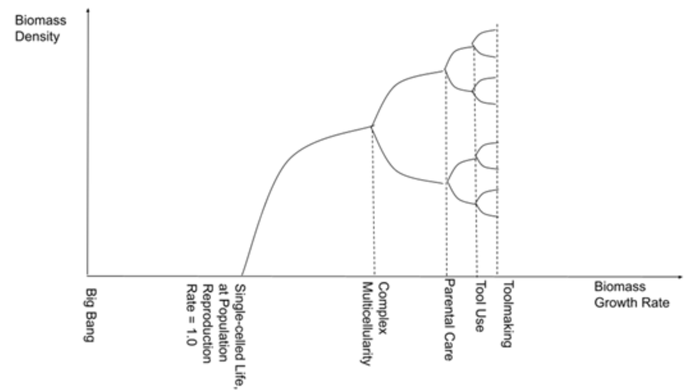

Figure 6. The first six stages of evolution of humans

The bifurcation diagram for Evolution

Figure 6 shows the beginning of a bifurcation diagram for the evolution of humans. Bifurcation diagrams are often used to show how population of a species varies as population growth rate (or birth rate) changes. Normally one would draw a diagram for a single species, with the horizontal axis being birth rate and the vertical axis is population. For a given birth rate the map is iterated until the population settles down to an equilibrium value. It is the equilibrium value for each birth rate that is shown on the diagram. With no essential change in meaning of the axes, a bifurcation diagram can be used to represent evolution:

1. The diagram usually represents one species, but we shall be looking at a diagram for all human ancestors back as far as the beginning of prebiotic evolution.
2. The vertical axis is normally population, but as species change during evolution and individuals change in size – especially in the transition from unicellular to multicellular organisms – it is more useful to measure the biomass density (biomass per unit area).
3. The horizontal axis commonly shows birth rate for a population. In an evolutionary context, the equivalent

measure is Population Growth Rate, which is a measure of Darwinian fitness. Again, to allow for size of individuals we shall use Biomass Growth Rate. But we shall make 2 assumptions –

- The biomass growth rate increases with complexity
- Complexity increases with time.

No	PREDICTED DATE years before 2000 CE	ACTUAL DATE years before 2000 CE	Actual vs pre- dicted	INFORMATION CHANNEL	EVOLUTION SPACE
				PHYSICAL EVOLUTION	
1	26.8 billion	13.82 to 13.78 billion	-51%	Persistence of matter	Dissipative Systems
				BIOLOGICAL EVOLUTION	
2	5.67 billion	4.28 to 3.77 billion	-25%	DNA copying during cell division	Single Cell Organisms
3	1.22 billion	1.22 to 1.17 billion	0%	Sexual Reproduction and gene recombination	Multicellularity (differentiated cells)
				CULTURAL EVOLUTION:	
4	252 million	259 to 252 million	0%	Parental Approval and Disapproval	Sociality and Parental Care skills
5	53 million	56 to 40 million	0%	Tool transfer.	Tool Use
6	11 million	16 to12 million	-10%	Drawing attention to an object (aka Referential gestures).	Making Tools
7	2.57 million	2.60 to 2.55 million	0%	Showing by Demonstration - Performing tasks slowly and with repetition	Making Tools with Tools
8	502 thousand	550 to 450 thousand	0%	Communicating concepts.	New Concepts in Toolmaking (e.g. Composite tools)
9	106 thousand	120 to 90 thousand	0%	Explaining relationships between concepts	Tools with new functions
10	25 thousand	26 to 20 thousand	0%	Narrating (Complete language)	Domestication
				IT EVOLUTION	
11	4,734	4,600 to 4,500	2.9%	Teaching to Read and Write	Written Language

Table 6. Actual and predicted dates for all stages of evolution

The diagram starts with the Big Bang at the origin. Physical and pre-biotic evolution take place, the Earth is formed, and at some moment in time on Earth, the population of the first living cells begins to rise above zero at the first complexity threshold, when complexity is high enough for proto-cells to become sustainable living cells, in other words, when their Growth Rate is greater than 1.0.

In Population Dynamics, bifurcations are caused by overconsumption due to delayed negative feedback increasing above a threshold, which can be caused by various reasons, such as the weather. Overconsumption causes disturbs population, causing it to oscillate. The oscillation appears as a bifurcation in the diagram. The population oscillates or alternates between two values instead of settling on one value. It is a cycle of feast and famine, of starvation and population recovery.

Step Change in Adaptation Speed

I propose that overconsumption and population oscillation is also happening in evolution, but that the cause is step changes in adaptation speed at each bifurcation (for example, at multicellularity, Parental Care, Tool Use, etc). This agrees with what is seen in bifurcation diagrams – at a bifurcation, the population starts increasing at a sudden higher rate, which can be explained by a sudden increase in adaptability causing a greater increase in population. Increase in population requires more food, but because food is limited, there will a shortage of food the next year because the food source it is not able to replenish itself in time. This is delayed negative feedback, causing starvation.

Paradoxically, the oscillations punish the increased adaptability. But this does not necessarily matter because there may be other advantages that do not show up in a bifurcation diagram, such as the ability to adapt to other habitats. It is important to note that any such oscillations would not affect the complexity, and the complexity would not oscillate. The causation would be in one direction.

Cause of Step Change in Adaptation Speed

What causes the step change in adaptation rate and why does it behave as a Feigenbaum Cascade? Feigenbaum Cascades are an indicator of limited resources, which express themselves (in life, at least) as patterns of starvation and population recovery. What is the limited resource in evolution? Food is a limited resource, but not a diminishing one on an evolutionary timescale. Any shortage is essentially temporary.

Another possibility is the amount of free energy from the sun. But this is only limited by our ability to use it, and there is far more than we can use for a long time.

Cost of Complexity

A more likely possibility is complexity. There is something called the Cost of Complexity which says that as the complexity of an organism increases, it gives diminishing returns because beneficial changes become less and less likely (Allen Orr, 2000). This means diminishing returns on an evolutionary timescale. Looking at the Bifurcation Diagram for Evolution, this explains the reason why all curves at every bifurcation start out steep and become less steep as time moves on and complexity increases.

New evolution processes at complexity thresholds

This would also explain the opportunity for new Evolution Processes. Due to the cost of complexity, an Evolution Process inevitably exhausts the possibilities for adaptation that exist in its Evolution Space, and slows down, giving a chance for another Evolution Process to take over. Because although complexity has caused the slowdown, complexity is increasing elsewhere, creating a new evolution process ready to take over at the next threshold when its contribution to population growth exceeds 1.0 (echoing the first appearance of life, and perhaps the Big Bang was a similar threshold). A new Evolution Process takes hold of evolution at a bifurcation and takes it in a completely new direction which is outside the box of the previous Evolution Process, and explores a different Evolution Space, where things are simple again and innovations come thick and fast.

Complex and Simple at the same time – Encapsulation of Complexity

Things that are complex in one Evolution Space can be simple in other Evolution Space. For example, single cells are complex inside, but for the Evolution Process that drives multicellularity, all of that complexity is hidden inside the cell. Multicellular complexity is about how cells work together, in which the function provided by cells is important, but not how that function is achieved. In a sense, the cells provide various services to the body, and the body does not have to know about the inner workings, just how to control them by sending signals. The knowledge in the cells is encapsulated.

This is probably true of the relationship between every level. For example, the evolution of Tool Use involves changes to adjust the body schema (a hypothetical map of the body) to make Tool Use easier. Higher levels of evolution can make use of the body schema without having to know details of its implementation.

Levels of Information

Each stage of evolution has a new Evolution Process, new Evolution Space, and a new Information Channel. The new

Information Channel stores a new kind of data compared with the previous stage. Just as each new stage uses the products of the previous stage as if they were service-providing opaque boxes with hidden complexity, so the information for each stage is also limited to a single level, so that every level has its own unique level of information, and which may be stored in a completely different way on, or in, entirely different media.

Levels of Cognition may match Information Levels

It would make sense if the subjective interpretation of information, and the ability to understand it, are divided into the very same levels. G&H associate each Teaching Method (i.e. Information Channels 4 to 10) with a new cognitive level, requiring an increasing level of mind reading, cognition and communication. This raises the question of whether the other stages can be considered to have increasing level of these attributes, or whether equivalent attributes can be defined. Single cells are considered to have cognition (Shapiro, 2021). And Written Language is considered to have impacted human cognition (Pegado, 2022). This supports the idea that the stages of evolution are also stages of cognition.

The old Evolution Processes continue

When an Evolution Process hands on the baton of evolution to another Evolution Process, it does not stop operating. It continues in co-evolution with the new Evolution Process. The new Evolution Process determines the direction of evolution, and the old Evolution Processes continue to generate variation, albeit at a slower rate than the current Evolution Process, and variations that help the current Evolution Process will tend to be selected. For example, biological changes in early humans to improve communication by speech. The very same changes would not have given any advantage before speech began to be used and would not have been selected.

Period-doubling absence

Period-doubling population bifurcations have not been found in real ecosystems. They are considered sensitive to external perturbations (in the forms of noise or immigration) (Rohani & Miramontes, 1996). This need not be a concern. The cause of bifurcations is increased complexity, which may create adaptations anyway, no matter what. In any case, it seems that if period-doubling is too sensitive to exist in real ecosystems, it is often replaced by quasiperiodic bifurcations instead and they can also follow the Feigenbaum constant 4.669 (Van Veen, 2005).

Recursion

Each new Evolution Process uses some capabilities that are the products of the previous Evolution Process. In this sense, evolution is recursive. A product of evolution becomes part of the process of making more products of evolution.

Linearity

It is in the nature of the bifurcation diagram that the exact relationship between variables such as time, complexity, population/biomass density growth rate, etc., do not have to be linear – it is enough that they are monotonic (roughly, that they increase together). The decreasing intervals have the effect of sampling a shorter and shorter part of any curve, so that they become more and more linear.

The stages shown in the diagram are stages 1 to 5 in evolution. There are an infinite number of bifurcations in theory (in reality there will be a minimum size limit below which there will no more bifurcations) which finish at the Accumulation Point. After that, the biomass density is non-periodic (that is, non-repeating, or in other words, with an infinite period).

More on Bifurcations

It may seem strange to equate the evolution of intelligent life with a dripping tap. It can be done because Chaos Theory takes control of certain kinds of process and imposes a Feigenbaum Cascade onto the process. This a consequence of applying *iterations* to the process.

At every bifurcation, the process that has been taken over repeats the thing it started with, but with increasing complexity.

For example:

- In a dripping water tap, every bifurcation changes the pattern of water drops.
- Treating a fish farm population with antibiotics can cause bifurcations that change the number of fish that die of starvation.
- In evolution, each bifurcation marks the creation of a new Evolution Process and a new Information Channel. The first single-celled life created an Evolution Process and an Information Channel, and every subsequent bifurcation does the same.

Within a particular process, each bifurcation will be of the same type, but also different in some respects to the previous bifurcation. This applies whether the Bifurcation Parameter is time, amount of antibiotics, or water flow rate.

Self-replication involves all the stages of evolution in the same sequence

Self-replication of an organism goes through all of the stages that arose during evolution. Single-celled organisms simply divide into two independent daughter cells, copying the DNA in the process.

Complex multicellular organisms have another Information Channel in Sexual Reproduction, where DNA

from two parents is combined. Once the DNA has been combined in a single cell, the Information Channel for single-celled organisms takes over. Using the Information Channel for single celled organisms, the single cell divides into two daughter cells, copying the DNA for several kinds of cell, plus instructions for development from single cell to mature organism. But as cell division continues, the cells stay together and differentiate, as the cells begin to follow new instructions on how to grow from one cell to maturity.
Replication of organisms at higher states of evolution involves not just biological replication, but also teaching (or "transmission of cultural information through the Information Channels that evolved during Cultural Evolution"). Replication of an organism is only complete when transmission on all Information Channels is complete (aka "upbringing").

Bifurcations of permanent advantage
I have claimed that mismatch in adaptation rate causes a permanent alternating population bifurcation among the species involved. This is partly corroborated by Adams & Matsuda who find that differential Evolution Process rates cause permanent population oscillations, even when different parameters would result in a steady state (Abrams,Peter & Matsuda,Hiroyuki, 1997). That these are period-doubling bifurcations is not confirmed.

Simple life is also needed
Humans need the ecosystems of the Earth. We do not photosynthesize and are not primary producers. It follows that not all forms of life on Earth can evolve in the same direction as humans, or to high complexity in any direction. Single-celled organisms are still well-represented in the total biomass of the Earth. This does not mean they have a different Feigenbaum Constant. Their evolution has stopped perhaps because they have no need to evolve, just a need to adapt to change. Or perhaps there is no route for them out of the ecological niche they find themselves in.

The route to intelligence may be the same for all
Some animals have been evolving in the same direction as humans have done, and the stages towards intelligence seem to be universal, at least on Earth. The Great Apes and some Corvids (New Caledonian crows, ravens) have climbed the same event ladder, past Tool Use, and have reached the stage of Toolmaking.

Does this hypothesis mean that evolution is predictable?
This paper is about the increase in complexity with time and how thresholds of complexity predicted by the Feigenbaum Constant 4.669 give rise to new Information Channels and Evolution Processes, and an increase in adaptation rate. It does not predict what animals may evolve, only the capabilities of the most advanced species. Only the complexity of life follows a regular predictable pattern. All other aspects of evolution may still be completely random.

Heredity vs Communication
During Cultural Evolution, information begins to be transmitted horizontally – that is, within the same generation – and not just strictly from parent to offspring.

How did this pattern not show signs of shocks by meteorites, epidemics, climate change, etc?
Random external mass-extinction events, such as the extinction of dinosaurs by meteorite, is an oft-quoted reason for unpredictability. However, Natural Selection is constantly removing species, usually those species that are at the bottom of the scale of adaptability, allowing the more adaptable species at the top of the scale to live on. Whether circumstances and conditions remove 1% or 99% of species, the most adaptable and most evolved species are more likely to survive.

The theory presented is largely about organisms that are the most advanced and most adaptable, those at the cutting edge of evolutionary complexity and have advanced furthest along the proposed stages.

Also, the theory is about stages of evolution, not population levels, so evidence of low population level does count as disruption unless it led to delays.

There is every reason to believe that it is possible for even the most resilient species to be disrupted, there was no obvious evidence to that effect.

Evidence for a Fiegenbaum Cascade.

- Cherry-picking has been ruled out.
- Evolution is an iterative, nonlinear, dynamic process.
- The dates match a Feigenbaum Cascade
    - Decreasing interval between events.
    - Interval ratio converges rapidly to 4.669.
    - Bifurcations signify a physical change that is similar but different to the previous one.
- All selected events are of the same type:
    - Information is new
    - Information is of one level of evolution.
    - Format of information may be new
    - Means of transmitting information may be new
    - Means of storing information may be new
- Evolution stages can be explained by Chaos-Theory Universality (different processes, same qualitative and quantitative result).
- The bifurcation tree (Feigenbaum Cascade) can be explained as follows:
    - horizontal axis matches

        - biomass density (population) growth rate,
        - which increases monotonically with complexity,
        - which in turn increases monotonically with time
    - vertical axis matches Biomass density (biomass per unit area) (population)
- There are diminishing resources over the course of evolution, causing the population instabilities. (The diminishing resource is possibly "beneficial changes", due to increasing complexity)
- There is evidence that the Feigenbaum Cascade is also found in complex systems (Judd, 1990).

Summary of argument.

- As evidence that the cherry-picking of events to match dates has not occurred, the original series of teaching events is based on a paper on cognitive archaeology research which does not mention dates or Feigenbaum cascades.
- As further evidence that the events where not cherry-picked, the original series did not conform to the Feigenbaum cascade because one of the events (Tool Transfer) was missing. The series, once corrected for reasons of cognitive archaeology, also now fulfilled the chaos theory conditions for a Feigenbaum cascade.
- Extrapolation, using the equation of the regression curve of the series, finds:
    - 2 events at the beginning of evolution that show expected rapid convergence to the cascade interval ratio. (Physically, the difference for the first two events may be due to the fact that the first event and possibly the second event, did not occur on Earth because they occurred before the Earth was formed.)
    - The date of Written Language very close to the cascade interval ratio.
- All of the known events are of the same kind and represent distinct stages of type and format of information during evolution.

Limitations of the study

- Lack of specification of Evolution Process in G&H's paper.
- Lack of associations between Teaching Methods and Evolution Process in G&H's paper.
- The following assumptions have been made:
    - That new Evolution Process and Information Channels become active at the same time
    - That sex and multicellularity are mutually dependent
    - That the worked stones found at Lomekwi 3 are not tools, but were used as a mineral diet supplement as modern capuchin monkeys do.
    - That Full Modern Language and domestication are mutually dependent.
- The theory rests rather heavily on Gärdenfors and Högberg's articles.
- The processing of numerical results could be improved.

Conclusions

Information and Evolution

This study began as an investigation into whether it was significant that the sequence of new information transmission (inheritance) processes (which during Cultural Evolution took the form of new methods of Intentional Teaching, proposed by Gärdenfors and Högberg) seemed to follow the same pattern found in many chaotic processes.

The result is a hypothesis that proposes that the entire history of evolution is a Feigenbaum Cascade of new Information Transmission processes (Information Channels), each of which was needed for passing on innovations in the way organisms adapt and evolve.

Evolution has followed a mathematical series, which suggests that the milestones of evolution – such as tool-use or language – are generated by the evolution of life, not by external events. It follows that evolution is a result of the increasing complexity of life. As each stage slows, it supports, and is revitalized by, newer stages. These new stages are the result of new Evolution Processes at complexity thresholds. These Evolution Processes produce innovations that lie within the Evolution Space of the Evolution process. Successful innovations are passed on by new transmission methods (Information Channels).

Knowledge is Power

The hypothesis follows Carl Sagan's insight that information unites the different phases of evolution. It supports the idea that the evolution of life, once started, is compelled to evolve intelligent life. Cells began by exploring which random sequence of instructions in DNA survive best. Each subsequent stage of evolution accumulates more information for the same reason.

It should not be surprising that information is at the heart of evolution. From the beginning of life, the amount of resources – such as energy and food – that could be captured and consumed by a cell depended on the information in the DNA. Information becomes active when it is converted into physical complexity and into behaviour. And the importance of replication and transmission of information to the next generation is underlined by the fact that it is a distinct set of processes within the replication of the species.

Universality

While not being a proof, the universality found in Chaos Theory explains how it is possible that each stage of evolution can fit into a Feigenbaum Cascade, despite the fact that the evolution process changes at every stage. The first two dates have the biggest deviation from the logistic map, but we don't know whether the logistic map is the best model for Physical evolution and single-cell evolution. Neither do we know how much of the first two stages took place on Earth, which may have different rate of evolution. However, the remaining stages (Stage 3 onwards) fit the Fiegenbaum Cascade reasonably well.

Significance.

If the hypothesis is proved correct, it could potentially have a wide impact because it covers a wide span of subjects from physics to behaviour. It is likely to also influence the debate about humankind and our place within the universe. And it offers a simple yet rigorous theoretical framework for understanding Big History.

Directions for further research

- Find more events that may have occurred since the invention of Written Language.
- Develop a reliable and clear definition of important events that fits only the events within the cascade and excludes all other events.
- Find quantitative predictions or metrics that can be verified. For example, the speed of the Evolution Processes, or the effect on speciation at each level.
- Create a theory from first principles that explains the entire evolution sequence in detail.
- Find a non-linear map that fits the Big Bang and Single-celled Organisms.

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Appendix

Information Channel 1

Information Channel: Limited Heredity
Evolution Process: Dissipative Systems

Description: The Big Bang is thought to be the beginning of the universe and is used here as a reference point. There is no life, self-replication, heredity, or modification. But there is Physical Evolution which will eventually produce these things(Lazcano, 2018).

Why did they appear together? Dissipative Systems, far-from-equilibrium systems that create order at the cost of increasing entropy, are considered to be a possible route to the evolution of Life. Dissipative Systems have a form of heredity that is limited, and not sufficient for life.

Earliest known date? 13.82 to 13.77 billion years before 2000 CE (Planck Collaboration et al., 2020) (-50% compared to predicted interval)

Information Channel 2

Information Channel: DNA copying
Evolution Process: Single-celled life

Description: Information Channel: DNA copying during cell division (Lemmens & Lindqvist, 2019). Evolution Process: Single-celled life (Brunet & King, 2020).

(Variation: Mutation(Griffiths,Anthony, 2023).)

Why did they appear together? They both appeared at the same time in the first living cells.

Earliest known date? 4.28 to 3.77 billion years before 2000 CE (Dodd et al., 2017) (-25% compared to predicted interval).

Information Channel 3

Information Channel: Sexual Reproduction
Evolution Process: Multicellularity

Description: Heredity: Sexual Reproduction (Butterfield, 2000). Evolution Process: Multicellularity (Butterfield, 2000).

(Variation: Recombination of gene alleles (Britannica editors, 2023).)

Why did they appear together? It is suggested that Sexual Reproduction arose first and solved the problems that made Complex Multicellularity unviable, and that Multicellularity began immediately afterwards (Butterfield, 2000).

Earliest known date? 1.22 to 1.17 billion years before 2000 CE (Butterfield, 2000).

Information Channel 4

Information Channel: Parental Approval
Evolution Process: Parental Care

Description: Parental approval or disapproval is when a parent signals to their offspring that their behaviour is correct or incorrect. Intentional teaching can be a simple “grunt of disapproval”. It improves the fidelity of their learning so that it is sufficient to be passed on indefinitely (Gärdenfors & Högberg, 2017). Teaching requires learning of course. The theory of Social Learning in humans concerns how humans learn from each other. Social Learning is thought to occur by observation and imitation. Imitation requires the evolution of vision. Parental Care is adaptive as it can increase offspring fitness.

Why did they appear together? Parental Care is needed for teaching by Parental Approval/Disapproval. The earliest teaching among animals is not known, but from an energetic point of view it is reasonable to assume that would have arisen at the same time as parental care, because looking after offspring must in the long term take more energy than teaching them to look after themselves (Gärdenfors & Högberg, 2017).

Earliest known date? There are two possible fossil candidates:

- One candidate is fossils of a group of Cynodonts (precursors to mammals) of adult and juvenile age, known to live underground in burrows, and therefore probably social by necessity and have the opportunity for Parental Care, 259.1 to 251.9 million years before 2000 CE (Damiani et al., 2003).
- There is another candidate, although only one adult and one juvenile reptile together, under a tree. It is a less clear case that the Cynodonts. The reptiles may not have been related, and could simply have been sheltering from a storm under the same tree. This fossil is dated 309 to 306 million years before 2000 CE (Maddin et al., 2019).

Given the relative uncertainty of the reptile case and the more relatively clear reptile Cynodonts, it seems admissible to exercise some discretion and choose the event that best suits the theory.

Cynodonts, 259.1 to 251.9 million years before 2000 CE, or
Reptiles, 309 to 306 million years before 2000 CE

The result is that the Cynodont case fits the Feigenbaum Cascade much better than the reptile case.

Information Channel 5

Information Channel: Tool Transfer
Evolution Process: Using Tools

Description: Use of tools refers to Found Tools, objects found and used as tools. But a tool is not just an object that is found or made by an animal. A tool is an extension to the body that is used to manipulate the environment, although there are alternative definitions (Cabrera-Álvarez & Clayton, 2020). Many animals are thought to have a Body Schema which tracks the body and limbs in 3D space. Tool-users are thought to have a flexible Body Schema that can incorporate tools and, for example, track the working tip of the tool in three-dimensional space. Using tools is a Evolution Process without DNA changes. Tools can be added and discarded at will and in real time. Tools do not work with the Parental Approval Information Channel, because offspring need to be given an appropriate tool for the task being taught. The giving of the tool is called Tool Transfer. Only after mastering the tool can the student find their own tools.

Why did they appear together? Tool Transfer is the most basic of the tool actions and naturally belongs with the first use of tools (Musgrave et al., 2016)

Earliest known date? The use, as tools, of rocks and twigs found lying on the ground, has left no trace in the archaeological record. We don't know the exact date of first tool use, but we can narrow down the range by estimating both the earliest and latest likely dates of the first tool use. The earliest date of first tool use is most likely when the first primates appeared 56 million years before 2000 CE, because many, though not all, primates use tools today and it is likely that they were the first tool users (Steiper & Seiffert, 2012). Because they live in trees, their front legs and feet have evolved into arms and hands with opposable thumbs for grasping branches and holding onto fruit while they eat.

We don't know if the earliest primates used tools. Not all primates today use tools. But if we assume that all the descendants of first tool-using primate also use tools, then that primate is likely to be the Most Recent Common Ancestor of all the primates that use tools today. These include tool-using new world capuchins (Judd, 1990) and old world tool-using primates (humans, gorillas, chimpanzees, orangutans, and macaques). The Most Recent Common Ancestor of these was around 40 million years before 2000 CE, which we can use as the last likely date of first tool use.

Likely least recent date of first tool use = 56 million years before 2000 CE.

Likely most recent date of first tool use = 40 million years before 2000 CE.

*Most Recent Common Ancestor (or Last Common Ancestor) method. If two species share a rare trait and share ancestors, then there is a high likelihood that both inherited the trait from their Most Recent Common Ancestor (Haslam, 2014). The date of the Most Recent Common Ancestor gives the most recent date by which the trait had appeared. (Not to be confused with LUCA, the Last Universal Common Ancestor of all life on Earth).

Information Channel 6

Information Channel: Drawing Attention, aka Referential Gestures
Evolution Process: Making tools

Description: Young are naturally curious when they see their parents using tools to get food, and naturally try to join in. Seeing the parent making a tool does not elicit the same interest. The parent must draw their attention, indicating that they should watch how to make a tool (Locke et al., 2011). The Evolution Process is the making of, and improvement of, tools.

Why did they appear together? Both are concerned with the simplest means of making tools. Teaching how to make tools belongs naturally with Making Tools (Gärdenfors & Högberg, 2017).

Earliest known date? 16-12 million years before 2000 CE. Last Common Ancestor of toolmakers orangutans (Laumer et al., 2018) and humans (Locke et al., 2011).

Information Channel 7

Information Channel: Demonstration
Evolution Process: Making Tools with Tools

Description: Hands can strip leaves from a twig, but they cannot make a sharp stone knife. Another tool is needed that is harder than the tool that is being made. Also, a tool is made at the same time as a tool used These tools need to be taught by demonstration. In other words, the teacher slows down and repeats actions, for example (Gärdenfors & Högberg, 2017).

Why did they appear together? Teaching how to use a tool to make a tool using Oldowan stone technology requires careful instruction (Gärdenfors & Högberg, 2017).

Earliest known date? 2.60 to 2.55 million years before 2000 CE.

Notes. A site in Africa known as Lomekwi 3 apparently has tools with conchoidal flakes that are as old as 3 million years (Harmand et al., 2015). If true, that will be a problem for this paper. But this interpretation of the findings at the site has been questioned. Capuchin monkeys in Brazil have been filmed producing conchoidal flakes accidentally while breaking rocks to obtain quartz to supplement their diet(Proffitt et al., 2016). "The accumulation and the stones, if discovered in a three-million-year-old context in Africa, might be taken as evidence of an early stone tool culture." Also, the Lomekwi 3 "tools" are not considered to require the same level of cognition as the Oldowan tools (Gärdenfors & Högberg, 2017).

Information Channel 8

Information Channel: Communication of Concepts
Evolution Process: Tools with Concepts

Description: The use of tools that have a concept that needs explaining may give a competitive advantage (Gärdenfors & Högberg, 2017). Having tools made up of different materials is also a concept, and timewise, the first composite tools (wood spears with a stone head) also appeared at this time (Wilkins et al., 2012).

Why did they appear together? According to G&H, late Acheulean tools incorporated concepts that needed communication, either by gesture or by speech. One concept that originates from this event is Composite tools. The oldest composite tool artefact is a spearhead from South Africa. When dated with optically stimulated luminescence (OSL), a sample taken from sediments in direct association with the lithic artifact gives an age estimate of 511 to 417 thousand years, and an Equus capensis tooth recovered adjacent to the OSL sample gives a U-series/ESR age of 582 to 435 thousand years before 2000 CE, which is similar to and overlaps the other date (Wilkins et al., 2012). Assuming there is no reason to think that one method is more accurate than the other in this case, the simplest way to combine these is to simply take the interval of the overlap. This gives an interval of 513 to 435 thousand years before 2000 CE.

Earliest known date? Composite tool, 513,000 to 435,000 years before 2000 CE (Wilkins et al., 2012).

Information Channel 9

Information Channel: Explaining Relationships between
Evolution Process: Tools with new functions

Description: Information Channels 6, 7, and 8 improved on the original Found Tools, but this event saw the beginning of "Complex Culture and Cognition" and tools that had new functions (Hallett et al., 2021). The first definite example was a tool for making clothes, although no clothes survive from this time. The harpoon – a spear with barbs for catching fish – appeared thereafter, followed by more and more inventions. This stage may have required speech to explain the usage of the tools (Gärdenfors & Högberg, 2017).

Why did they appear together? New inventions required more explanation than improvements on existing tools (Gärdenfors & Högberg, 2017).

Earliest known date? Tools for making clothes. 120,000 to 90,000 years before 2000 CE (Hallett et al., 2021)

Information Channel 10

Information Channel: Narration (Complete Language)
Evolution Process: Domestication (New Livelihoods)

Description: The creation of new livelihoods is the new Evolution Process , beginning with the domestication of animals and plants. And the first of these was the domestication of the dog (Perri et al., 2021). Narration is the last stage of language development in Gärdenfors' hypothesis (Gärdenfors & Högberg, 2017).

Why did they appear together? The challenges of a change of lifestyle from the instinctive hunter-gatherer lifestyle require a complete language to enable logical thought in order to solve problems (Gärdenfors & Högberg, 2017).

Earliest known date? Domestication (of the dog) 25,950 to 19,650 years before 2000 CE (Perri et al., 2021).

Information Channel 11

Information Channel: Teaching Reading and Writing
Evolution Process: Written Language

Description: Heredity: transmission of information is by visual symbols. Information is stored "extrasomatically" (outside the body) on clay tablets or paper, which means the human memory capacity no longer restricts the amount of knowledge that can be accumulated.
The first Written Language developed out of Cuneiform, which had been used for bookkeeping for hundreds of years before it expanded to become a "true" Writing System, i.e. a system that can express everything that a spoken language can. Many texts have been found, but writing was not "coherent" until 4600 to 4500 years before 2000 CE.

Why did they appear together? They are both aspects of the same innovation.

Earliest known date? 4600 to 4500 years before 2000 CE (Cooper, 1999)

The General Evolutionary Theory as Unification of Biological and Cultural Evolution and as Basis for a Natural Periodization

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Abstract: The general evolutionary theory can be seen as a comprehensive generalization and extension of Darwin's theory. The basic idea is to consider not only the evolution of genetic information - as Darwin did - but also the evolution of very general information. It shows that evolution is characterized by the fact that new types of information have developed in leaps and bounds, each with new storage technologies, new duplication technologies and new processing technologies. This unified concept of evolution makes it possible, among other things, to 1) achieve a unified view of biological and cultural evolution; 2) find a natural periodization of the evolution from the formation of the earth until today; and 3) understand the exponential acceleration of evolution through the emergence of targeted variation mechanisms.

1. So why is the world the way it is?

The central aim of Big History (Christian, 2004; Spier, 1996) is to understand the essential mechanisms of evolution that have led to the world being the way it is. The general theory of evolution attempts to provide an answer for the period from the formation of the earth to the present and future. It was first published by E. Glötzl (2023b, 2023a). The present work is a slightly adapted, summarized version. A more extended summary can be found in (Glötzl, 2024). Charles Darwin (Darwin, 1859) has already explained much of this: namely the biological evolution, i. e. how and why the different species have evolved from single-celled organisms to animals and finally to humans, but he was not able to explain everything. In particular, he did not provide answers to cultural evolution, such as the following questions:

- Why, for example, did hearing, speaking, writing, printing and computer technology develop in this order?
- Why did the economy evolve from a barter economy to an economy based on the division of labor and further on to a market economy with money and investment?
- Why has money evolved from commodity money to coin money to paper money and to electronic money?
- Why can animals imitate and humans learn and teach?
- Why and when did the different cooperation mechanisms develop (group coop., direct coop., debt coop., indirect coop., cooperation via norms?
- Why did everything develop in exactly this order?

But more importantly,

- Why is everything evolving faster and faster?
- Where is the journey of evolution heading in the future**?**
- Are we heading for a singular point?

All these and many other questions are questions of cultural evolution (Boyd & Richerson, 2005). The most prominent discussions explaining cultural evolution relate to universal Darwinism (Campbell, 1965; Cziko, 1997), dual inheritance theory (E. O. Wilson, 1999), and memetics (Blackmore, 1999; Dawkins, 1989). There is much debate about the extent to which there are parallels between biological and cultural evolution (Grinin et al., 2013), and how unification can be achieved (Mesoudi et al., 2006).

Coren (2003) as many others already pointed out the growth of information and the escalation of logistic behavior as a characteristic element of evolution. Other ideas for general principles to understand evolution and a periodization of the timeline are:

- self-organization (Jantsch, 1980),
- non-equilibrium steady-state transitions (NESST) (Aunger, 2007a),
- energy-flow (Chaisson, 2002; D. J. LePoire, 2015; D. J. LePoire & Chandrankunnel, 2020; Schneider & Kay, 1994),

However, some proposals for the periodization of evolution (Kurzweil, 2005; Modis, 2002; Panov, 2005) are not based on objective principles, but merely on a subjective perception of evolutionary milestones.

In contrast to other disciplines such as geology, there are still no generally accepted principles for the periodization of big history. However, there is an ongoing debate about how best to periodize the evolutionary timeline (D. LePoire, 2023; Solis & LePoire, 2023). Periodization raises three questions, among others: What general principle should periodization be based on, why is evolution evolving faster and faster, and will there be a singular point (A. V. Korotayev & LePoire, 2020) in the near future where the further development of evolution changes qualitatively?

Comparing the methodology of the general theory of evolution with the methodology of other authors (see Chap. 0), we argue that the general theory of evolution may indeed be a favorite for a unified view of biological and cultural evolution and its periodization because it develops the idea of information as an essential element for understanding evolution and its periodization in a stringent and comprehensive way.

The basic idea (see Chap. 2) is to consider not only the evolution of genetic information - as Darwin did - but the evolution of very general information, which of course includes the evolution of genetic and cultural information. It can be seen that evolution is characterized by the fact that new types of information have developed in leaps and bounds. Each type has subsequently developed in 3 successive stages: new storage technology, new duplication technology and new processing technology. This uniform concept of evolution makes it possible, among other things, to:

- achieve a unified view of biological and cultural evolution
- find a common natural periodization of the evolution (see Chap. 3 and Chap. 0) for
    - Living being forms (see Chap. 4)
    - Evolutionary systems and cooperation mechanisms (see Chap. 4)
    - Variation mechanisms (see Chap. 4)
    - Debt creation (see Chap. 5)
    - Driving forces (see Chap. 6)
- understand the exponential acceleration of evolution through the emergence of targeted variation mechanisms (see Chap. 7).

2. Basic ideas and terms of the general evolutionary theory

The basic concern of the general evolutionary theory is to understand the biological, technological, social and economic structures of evolution from the origin of life to the present and into the future from a unified perspective and structure.

The general evolutionary theory can be seen as a comprehensive generalization and extension of Darwin's theory of evolution. The general theory is neither about modifications of Darwin's theory in the sense of the synthetic theory of evolution (see e.g.(Lange, 2020)) nor about the expansion of the concept of selection to include multilevel selection (D. S. Wilson & Sober, 1994) nor about new findings from evolutionary developmental biology (Evo-Devo) (Müller & Newman, 2003) nor epigenetics research. The general evolutionary theory goes far beyond this. It extends the terms "biological species", "genotype", "phenotype", "mutation" and "selection" corresponding to the Darwinian theory and replaces them with much more general terms: (see *Table 1*).

Darwinian evolutionary theory →	**General evolutionary theory**
Biological species →	Species (in a broader sense)
Genetic information →	General information
Phenotype →	Form
Mutation mechanism →	Variation mechanism
Selection system →	Evolutionary system

Table 1: Terms of the general evolutionary theory

These conceptual extensions allow evolutionary developments in quite different fields to be described from a unified point of view and within a unified time frame. See examples in *Table 2*.

Just as a biological species is characterized by its genetic information (genotype) and the biological traits of the corresponding organism (phenotype), a "species in a broader sense" is characterized by a certain general information and the traits of the resulting form.

Just as a selection system describes the survival of the best adapted phenotype resp. biological species and their genetic information, evolutionary systems describe the dynamics of the frequencies of the best adapted forms, resp. species in a broader sense and the underlying general information. Typically, dynamics of evolutionary systems and as special case selection systems are formally described by differential equation systems.

$$\frac{dn_i}{dt} = f(n,p) \qquad n = (n_1, n_2, \ldots) \quad \textit{frequencies of species}$$
$$p = (p_1, p_2, \ldots) \quad \textit{parameters}$$

.

Biology	Hominins → homo → homo sapiens
Data types	RNA → DNA → electrochemical potential
Targeted variation mechanisms	Imitation → learning → teaching
Technologies	Writing → letterpress → computing
Monetary systems	Commodity money → coin money → paper money → electronic money
Economic systems	Barter → division of labor → investment
Economic regimes	Market economy → capitalist market economy → global capitalist market economy
Cooperation	Group coop. → direct coop. → debt coop. → indirect coop. → norms coop.
Driving forces	Gradient of concentration → gradient of electrochemical potential → gradient of utility

Table 2: Examples of evolutionary developments in quite different fields

Just as mutation mechanisms lead to mutations (i.e. changes in the genetic information of the genotype and traits of the phenotype), variation mechanisms lead to variations of the parameters p to p' (i.e. lead to changes in the general information and traits of the form). These terms are explained in more detail using 3 examples:

Example 1 from Darwin's theory of evolution:

DNA is a technology for storing genetic information. The DNA leads to a biological trait of a phenotype A. This genetic information can be changed into new genetic information by a mutation mechanism (chance, chemical substances, radiation, etc.). This new genetic information is called a mutation. It leads to an organism B with a changed biological trait. The development over time of the frequencies of A and B are described by a differential equation system which is called selection system. If the reproduction rate of B is greater than the reproduction rate of A, the offspring of B will reproduce faster than the offspring of A and the relative frequency of B increases over time and that of A decreases ("survival of the fittest").

Example 2 from the general evolutionary theory:

Each biological species of mammals is characterized by its specific genetic information (genotype), from which the specific organism with its traits (phenotype) arises. Analogously, a market economy occurs in different species (in a broader sense). Each particular type of market economy is shaped by a variety of different general information, such as technological knowledge, governmental norms of behavior, education of people, etc. This specific general information gives rise to a particular form of economic activity with all its traits, e.g. the capitalist market economy or one of its special forms.

Example 3 from the general evolutionary theory:

The neural network in the human cerebrum is a technology for storing general information, such as complex causal relationships, e.g: "If you look for wild grain, you will find food". This general information leads to a certain behaviour. It can be changed into a new causal relationship through the variation mechanism "learning", e.g: "If you don't eat all the cereal grains, but sow some of the cereal grains, you will no longer need to search for cereal grains, but can harvest more cereal grains". This new causal relationship stored in the cerebrum (grow grain → eat more) is therefore a variation of the old causal relationship (look for grain → eat). The old causal relationship leads to an evolutionary system that describes the temporal development of the gatherer's frequencies. The new one leads to a new evolutionary system that describes the temporal development of the frequencies of the sower and its food.

There are some specific important evolutionary systems:

- Selection systems: The frequency of one individual increases, while that of others decreases.
- Win-win systems: The frequency of two, resp. all, individuals involved increase.
- Prisoner's dilemma systems: These evolutionary systems are called prisoner's dilemmas, because they lead to a case that appears paradoxical at first glance. Although the fitness (reproductive rate) of the pure species of cooperators is greater than the fitness (reproductive rate) of the pure species of defectors an arbitrarily small set of defectors will finally displace all cooperators.
- Cooperation systems: The overcoming of prisoner's dilemmas is a very important achievement of evolution. Variation mechanisms that enable prisoner's dilemmas to be overcome are called cooperation mechanisms and the resulting systems are called cooperation systems.

3. From Darwin's theory of evolution to the general evolutionary theory in 3 steps

The basic idea is, not only to consider - as Darwin did - the evolution of genetic information, but instead to consider the evolution of very general information. It shows that evolution is characterized by the fact, that new types of information have developed in leaps and bounds, with new storage technologies, new duplication technologies and new processing technologies. Furthermore, it shows that each new information technology has led to increasingly well-targeted variation mechanisms, that have exponentially accelerated evolution.

Darwinian theory:

Let's start with the basic concept of Darwinian theory: A selection system (usually a differential equation system) describes the dynamics of the frequencies of genotypes. A mutation mechanism leads to a new genotype and thus to a new phenotype with a new trait. This leads to a new selection system with changed parameters and the Darwinian cycle starts all over again (see *Figure 1 top left*).

First step:

In a 1st step of extension, we extend Darwinian terms:

- Instead of genetic information, we consider general information, e.g., content of consciousness, cultural behavior or constitutional laws.
- Instead of phenotypes, we consider forms, e.g. agriculture or livestock breeding.
- Instead of mutation mechanisms for genetic information, we consider variation mechanisms for general information, e.g. imitation, learning, teaching, logical reasoning.
- Instead of simple selection systems, we consider general evolutionary systems, e.g. the prisoner's dilemma or, e.g., the evolutionary systems resulting from the different cooperation mechanisms.

This results in the Darwinian cycle for the extended terms (*Figure 1 top right*)

- selection system is replaced by evolution system,
- genetic information by general information
- mutation mechanism by variation mechanism
- and the term phenotype is replaced by the term form

Second step:

If the Darwinian cycle has been run through many times, a qualitative leap in biological traits can occur. The general theory in a 2nd step (*Figure 1 middle*) assumes that the evolutionary leaps fundamental to evolution, lead to the appearance of new information technologies. First, for each new type of information a storage technology emerges, resulting in a qualitatively new evolutionary system. Subsequently, the Darwinian cycle is run again, until there is another leap, which results in a new duplication technology and a qualitatively new evolutionary system. After further runs, a new processing technology and finally a new type of information occurs and the process of the emergence of new technologies and qualitatively new evolutionary systems starts all over again.

Third step:

In a 3rd essential step of extension (*Figure 1 bottom*), one can show that each new information technology leads to a new variation mechanism, in particular to targeted variation mechanisms. The higher the information technology is developed, the more the new variation mechanisms are targeted.

Examples of targeted variation mechanisms are: horizontal gene transfer, imitation, learning, teaching, logical reasoning, utility optimization, investment, or genetic manipulation. Targeted variation mechanisms do not change information in a completely random way, but change information with information that has already proven to be advantageous in a previous evolutionary system. Targeted variation mechanisms have a particularly high influence on the speed of evolution, because, to a certain extent, they shorten evolutionary detours and avoid erroneous developments. They are therefore a very significant cause of the fact, that evolution is proceeding faster and faster. For further details, see Chap. 8.

4. Natural periodization of evolution (evolutionary theory of information)

One of the important results of the general theory is that it leads to a common natural periodization of evolution based on the emerging new information technologies. Therefore, we call this periodization also the evolutionary theory of information. If we compare the methodology of the general theory with other methodologies (see Chapter 9), we consider it justified to call the classification and periodization

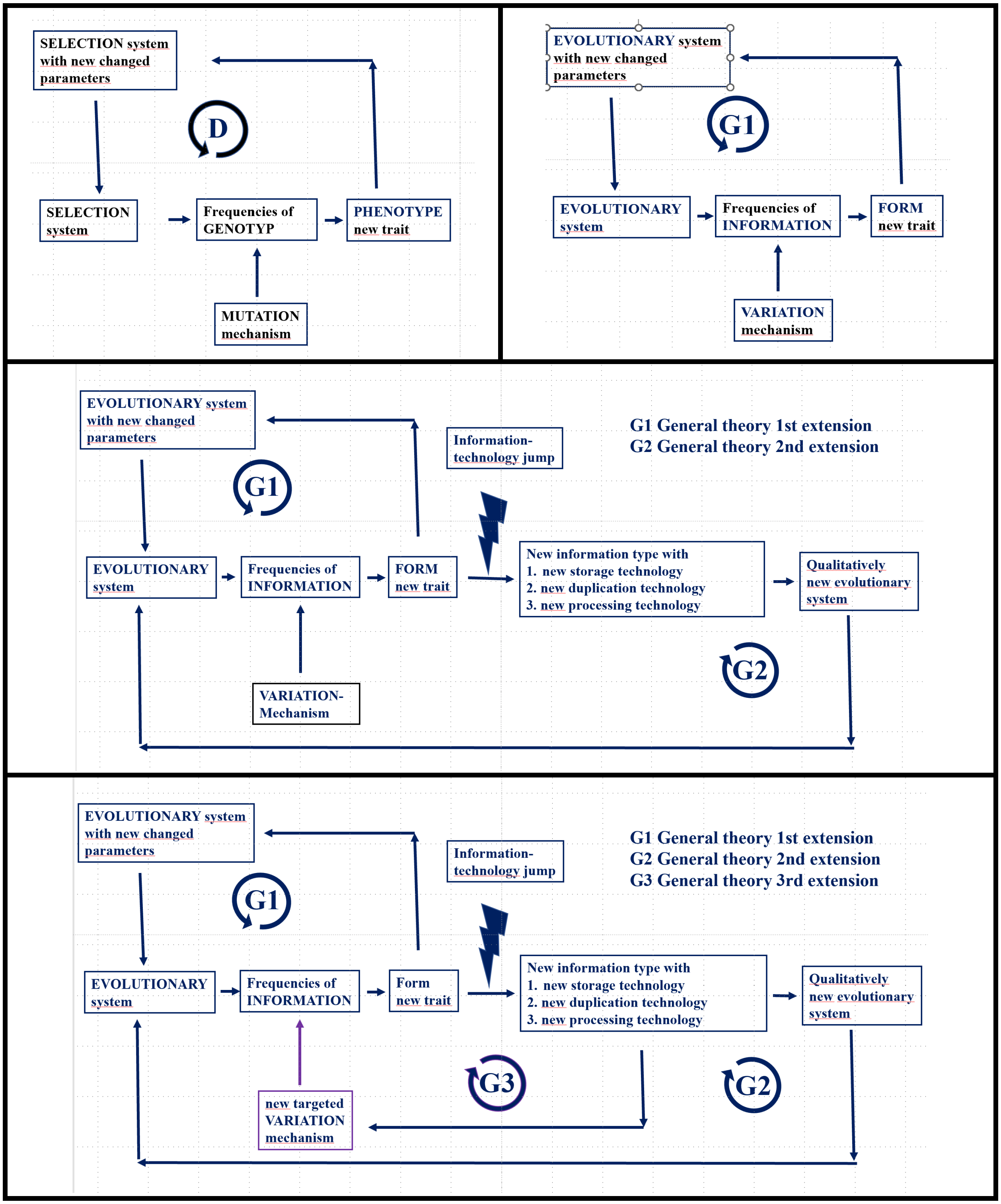

Figure 1: Darwinian theory (top left);
Extensions 1 (top right), 2 (middle), 3 (bottom)

Age	Start years ago	Information type (Storage medium) Information technology
[0]	4.6×10^9	Crystal
[0]	$4{,}6\ 10^9$	Self-organization of inorganic matter
[1]	4.4×10^9	RNA
[1.1]	$4{,}4\ 10^9$	Self-organization of organic matter
[1.2]	$4{,}0\ 10^9$	Autocatalysis (Stone, 2013)
[2]	3.7×10^9	DNA
[2.1]	$3{,}7 . 10^9$	Genetic code, phenotype formation (Dodd et al., 2017)
[2.2]	$2{,}1 . 10^9$	Cell division, cell association (Sánchez-Baracaldo et al., 2017; Veyrieras, 2019)
[2.3]	$1{,}0 . 10^9$	Sexual reproduction (Droser, 2008)
[3]	630 000 000	Nervous system
[3.1]	630 000 000	Nerve cells/monosynaptic reflex arc (Podbregar, 2019; Rigos, 2008)
[3.2]	550 000 000	Brainstem/polysynaptic reflex arc
[3.3]	66 000 000	Limbic system
[4]	6 000 000	Cerebrum
[4.1]	6 000 000	Neural network / storage of causal relations
[4.2]	900 000	Simple language / duplication of experience
[4.3]	60 000	Cognitive revolution / logical reasoning
[5]	5 000	External local digital data
[5.1]	5 000	Writing/ external storage of digital data
[5.2]	500	Letterpress/ External duplication of digital data
[5.3]	50	EDP/ external processing of digital data
[6]	10	Cloud (external dislocated networked data)
[6.1]	10	Internet/networked storage/duplication networked data
[6.2]	Present	Storage/ duplication/ processing of big data, AI 1.0
[7]	Future	Analog data in quantum computer / AI 2.0

Table 3: Ages and sub-ages of the natural periodization

within the framework of the general evolutionary theory the "natural" periodization of evolution on Earth, since it is based on a simple logical and easily understandable common principle for all evolution. Overall, the entire development on earth from the beginnings to the present can be divided into 8 ages, which correspond to the times when the 8 types of information first appeared. (It should be noted that in the following, when we speak of a point in time when a technology "first appeared", we actually mean more precisely, firstly, that this technology has established itself in an efficient form and secondly, that it has led to far-reaching changes)

These ages correspond to the following 8 information types resp. storage technologies: Crystal, RNA, DNA, nervous system. cerebrum, external local data, the cloud as external dislocated networked data and a future information type which is based on quantum computers. Each of these ages can generally be divided into three successive subages, in each of which a new storage, duplication or processing technology develops (*Table 3*).

5. Natural periodization of living being forms, evolutionary systems, cooperation mechanisms and targeted variation mechanisms

It turns out that there is a very close relationship between the periodization of evolution based on new information technologies (evolutionary information theory), which we presented in Chap. 3, and the evolution of biological, technological and social structures. Evolutionary information theory is thus the theoretical key to understanding evolution in a very general sense.

The respective information technologies can be understood as characteristic biological-technological traits of the species of the respective age. They typically also represent the preconditions for the development of the evolutionary systems and variation mechanisms characteristic of the species of the respective age. The periodization of species in a broader sense (living beings and forms), evolutionary systems and variation mechanisms thus results directly from the periodization of information technologies, as described in Chap. 3. The resulting periodization is described in detail in *Table 4*.

For a comparative overview of the different cooperation systems see Chap. 5 and for a comparative overview of the different targeted variation mechanisms see Chap. 7.

6. The evolution of debt documentation and the importance of debts for cooperation mechanisms

Martin Nowak classifies the cooperation mechanisms into five mechanisms (Nowak, 2006): *Network selection, group selection, direct selection, indirect selection, kin selection.* (We prefer to use "cooperation" instead of "selection"). In 2010, however, there was a heated debate on kin selection and inclusive fitness theory as to whether kinship can lead to cooperation. We share the view of Nowak and Wilson that this is not the case (Nowak, Tarnita and Wilson 2010). In the following, we show that the concept of debt allows for a much broader classification of cooperation mechanisms.

A key characteristic of the biological traits of the ages [3.1] - [3.3] was that an event often triggered an immediate, temporally instantaneous response to that event:

- Age [3.1]: information about environment → immediate monosynaptic reflex
- Age [3.2]: information about environment (or other body parts) → immediate polysynaptic reflex (e.g. fight, imitation)
- Age [3.3]: information about complex process in the environment → processing and categorization in the limbic system → immediate complex process (emotion, tit for tat)

An essential characteristic of the following ages, on the other hand, is the possibility that an event does not have to lead to an immediate reaction, but that the reaction to this event can also occur with a significant time delay. An important example for this are debts. Debts arise from services that are initially not matched by any direct compensation. Debt formation triggers debt repayment much later. This is why the documentation of debt is so important for debts to work.

The fundamental importance of debt is that the possibility of debt formation greatly facilitates the formation of cooperation, which is a major survival advantage and a win-win mechanism for all individuals. Debts therefore are the core element for the formation and cohesion of social communities. The reason why debts facilitate the formation of cooperation is explained in detail in (Glötzl 2023b, Chap. 5.10.2.1.). The idea behind it can be explained by the following simple example.

Age	Living being, Form	Evolutionary system, Cooperation system	Variation mechanism
[0]	Inanimate matter	Crystallization	Temperature, Pressure
[1.1]	RNA molecules	Creation-destruction	Environmental change
[1.2]	Ribocytes (Altman, 1989) (Eigen & Schuster, 1979)	Genotype selection (survival of the fittest genotype)	Mutation, Constraints
[2.1]	Single-celled	Phenotype selection (survival of the fittest phenotype)	Epigenetic variations
[2.2]	„Simple“ multicellular	Network-win-win systems	Horizontal gene transfer
[2.3]	„Higher“ multicellular	Sexual win-win	Sexual reproduction
[3.1]	Monosynaptic animals („first eating“ animals)	Predator-prey, Prisoner's dilemma, Network cooperation	Network formation, Swarm formation
[3.2]	Polysynaptic animals (apterygota, insects, fish, amphibians, reptiles, early birds, early mammals)	Group cooperation	Group formation, Learning of statistical relationships
[3.3]	Limbic animals (higher birds, higher mammals)	Direct cooperation	Emotion formation, Imitation, Learning of near-time causal relationships
[4.1]	Hominins	2-sided debt cooperation	Testing of time-delayed causal relationships
[4.2]	Homo	Indirect coop. (social debt), Barter	Teaching
[4.3]	Homo sapiens (Wiese, 2004b, 2004a)	Norms cooperation, Division of labor, Commodity money	Logical reasoning, Individual utility optimization
[5.1]	Market economy (Brodbeck, 2009)	Religious norm systems, Individual contracts, Regional trade (coin money)	Quantitative individual economic utility optimization, Animal and plant breeding
[5.2]	Capitalist market economy	National systems of norms, National trade (paper money)	Investment in real capital
[5.3]	Global capitalist market economy	International norms, World Trade (fiat money)	Investment in human capital
[6.1]	Internet society	Global sanctions, Internet trade (electronic money)	Investment in data capital
[6.2]	AI society	Stabilization based on automatic global sanctions, Blockchain money	Investment in stability and resilience, Gene manipulation
[7]	Cyborg	Human-machine symbiosis Completely new form of social organization	Overall utility maximization

Table 4: The periodization of species in a broader sense (living beings and forms), variation mechanisms and evolutionary systems

If a tailor makes shirts and a farmer makes potatoes, then it is obviously a win-win situation for both to exchange them. But what if the tailor is hungry today and needs a month to make a shirt? Why should the farmer give him potatoes without (immediate) compensation? It helps to document the tailor's debt to the farmer with the help of a debt bill, which the tailor hands over to the farmer and which he gets back when he hands over the shirt.

The precondition for the possibility of documenting debt relationships is the existence of a storage technology for information (see *Table 5*). Therefore, the evolution of win-win mechanisms is closely related to the evolutionary theory of information.

For the formation of direct cooperation through the behavior of direct reciprocity (tit for tat, “you me so me you”) in the age [3.3], documentation of the debt relationships over a longer period of time was not yet necessary, since the reactions usually took place in immediate temporal proximity.

Long-term debt relationships were only possible with a powerful cerebrum in age [4.1], which had the ability to store complex information. Therefore, the first debt relationships did not exist before age [4.1]. In this age they were typically characterized by 2-sides (bilateral) debt relationships ("I helped you") and led to what we call debt cooperation.

The emergence of cooperation through the mechanism of indirect reciprocity in age [4.2] is based on the formation of a high reputation for cooperators. The reputation of a cooperator can be seen as documentation of his services to many other people without direct reciprocation. Reputation is therefore, so to speak, the documentation of a social debt liability that the general public has towards a cooperator. The emergence of a high reputation of an individual requires not only the ability to store complex information, but also the ability to communicate in the form of a simple language in order to spread the knowledge of the cooperator's reputation in the community (Nowak, 2006). Indirect reciprocity therefore only became possible in the course of evolution with the development of a simple language in the age [4.2] of homo.

The next evolutionary step in the formation of debt relations was the possibility of forming commodity debts in the age [4.3] of homo sapiens. As a special form of the formation of debt relations can be considered the tradition of providing gifts, which contributed to the stabilization of human societies by consciously producing debt relations through gifts.

The next major breakthrough in the age [5.1] was the ability and method to describe or value different debts with a single symbol. This one symbol is called money. Money has subsequently itself been subject to major technological change that has had far-reaching effects on the development of mankind. The technology of money and with it the documentation of debt relationships became more and more efficient: From coin money in age [5.1], to paper money [5.2], fiat money [5.3], electronic money [6.1], to blockchain technology [6.2]. Money is the underlying cause of the enormous extent of win-win mechanisms in humans. This enormous extent of win-win mechanisms can only be found in humans and nowhere else in nature (Nowak & Highfield, 2012). Money as an efficient documentation mechanism for debt relationships is therefore the actual cause of human dominance on earth.

7. Evolution of driving forces

The dynamics of all physical and chemical processes in nature is determined by so-called driving forces. All these forces are determined by the change of the free enthalpy. The change in free enthalpy is equal to the change of enthalpy minus temperature times the change in entropy, which is called the Gibbs-Helmholtz equation. For example, for the motion of a ball in a bowl, the free enthalpy is given by the height of the bowl wall, and no entropic forces exist. The dynamics of the ball is determined by the slope of the wall, which is exactly equal to the gradient.

Interestingly, the driving forces that have emerged over the course of time can also be placed in the periodization of evolution and understood with the help of the general evolutionary theory.

We confine ourselves to describing the natural chronology of the development of the driving forces resulting from the general theory of evolution in *Table 6*.

8. The importance of targeted variation mechanisms for the rate of evolution

Overview and characteristics of targeted variation mechanisms

First let us clarify the difference between untargeted and targeted variation mechanisms. In the case of an untargeted variation, the change of information is completely random and it only becomes apparent in retrospect whether this change of information represents a fitness advantage. In the case of a

Age	Living being, Form	Technology for Win-win/ Cooperation	Debt and dept documentation	Win-win system, Cooperation system
[2.1]	Single-celled	No	No	No win-win
[2.2]	„Simple“ multicellular	Cell association	No	Network win-win
[2.3]	„Higher“ multicellular	Sexual reproduction	No	Sexual win-win
[3.1]	Monosynaptic animals	Simple sensors for recognition of neighbours	No	Network cooperation
[3.2]	Polysynaptic animals	Complex sensors for recognition of group traits	No	Group cooperation
[3.3]	Limbic animals	Processing of complex information	No	Direct cooperation
[4.1]	Hominins	Storing of conscious content (brain)	2-sided debt relations	2-sided debt cooperation
[4.2]	Homo	Duplicating of conscious content (simple language)	Social debt (reputation)	Indirect cooperation
[4.3]	Homo sapiens	Counting (abstract language)	Commodity debt	Division of labor
[5.1]	Market economy	Writing	Coin money	Regional trade
[5.2]	Capitalist market economy	Printing	Paper money	National trade
[5.3]	Global capitalist market econ.	EDP	Fiat money	World Trade
[6.1]	Internet society	Internet	Electronic money	Internet trade
[6.2]	AI society	AI	Blockchain money	Stabilization from global sanctions
[7]	Cyborg	Human-machine symbiosis	No	Human-machine symbiosis

Table 5: The evolution of debts

targeted variation some part of the information is changed by information that has already proven to be advantageous in another evolutionary system. In this way, targeted variation mechanisms shorten evolutionary detours and avoid erroneous developments. They are therefore a very significant cause of the fact that evolution is proceeding faster and faster. Now let us give an overview about the different targeted variation mechanisms and their properties (*Table 7*).

The increasing rate of evolution is the reason why we head for a singularity

Obviously, in the course of evolution, the variation mechanisms become more and more targeted. This leads to an increasing rate of evolution because they shorten evolutionary detours and avoid erroneous developments. Each beginning of a new age or subage respectively can be regarded as a milestone in evolution. If *n* denotes the consecutive number of a milestone and t_n the corresponding beginning, then $(t_n - t_{n+1})$ describes the duration of the respective age and $1/(t_n - t_{n+1})$ therefore describes the rate at which a new milestone occurs. *Diagram 1* shows that the logarithm of the evolutionary rate remains more or less constant until the Cambrian (age [3.2], n = 8), but then increases largely linearly until today (age [6.1], n = 16).

This means a more or less constant evolutionary rate before the Cambrian and an exponential increase in the evolutionary rate from the Cambrian to the present day. Since exponential or similar growth cannot take place permanently in a finite world, there must be a singular point, a point at which the dynamics of the system change qualitatively.

Modis (2002), Panov (2005), Kurzweil (2005) and others arrive at very similar diagrams and statements. For a discussion of these results, see (A. Korotayev, 2018; A. V. Korotayev & LePoire, 2020; Solis & LePoire, 2023). However, the derivation of "canonical milestones" in general evolutionary theory that we present in this paper differs in principle from all these aforementioned papers. They are not based on a general concept of how a milestone should be defined. Therefore, there is a certain subjective arbitrariness about what should be considered a milestone. As a result, in these papers different events are often regarded as milestones. However, in this subjective way, milestones can always be defined or found to correspond exactly to the desired curve. One of the targets of the general evolutionary theory is to eliminate this subjectivity and give milestones an objective basis. A milestone of evolution in the sense of the general evolutionary theory is always exactly the appearance of a new information technology.

A central question is what happens at and after the singular point. In principle, it is not possible to answer this question based on the systems behaviour in the past. But typical behaviour near such a singular point can be (see *Diagram 2*): overshoot and collapse, overshoot and stabilization at a lower level, or stabilization at a higher level. Predicting what will actually happen at a singular point is usually quite impossible.

9. Discussion and comparison with other periodization models

What is the methodological key difference between the periodization model of the general evolutionary theory and other models?

Methodology of most models:

1. Due to the feeling that evolution is developing faster and faster, it is assumed that the date of occurrence of evolutionary milestones or the duration of the periods defined by the milestones increases exponentially when looking into the past, see for example (Coren, 2001, 2003). This leads to linear diagrams in a log-linear coordinate system.

2. Some authors are looking for possible causes for these exponential developments:
- self-organization (Jantsch, 1980),
- escalation of logistic behavior (Coren, 2001, 2003)
- non-equilibrium steady-state transitions (NESST), *"All historical transitions between non-equilibrium steady-states follow the same pattern: an energy innovation first, structural adjustment second, and new control mechanisms third"* (Aunger, 2007),
- energy-flow (Chaisson 2001, D. J. LePoire, 2015; D. J. LePoire & Chandrankunnel, 2020; Schneider & Kay, 1994)

But even if the causes for the exponential developments were correct, periodizations cannot be stringently derived from them.

3. Rather, an attempt is made to find evolutionary milestones from other scientific disciplines such as geology, biology, anthropology, sociology or technology that fit the assumption of exponentiality or the linear diagrams. At first glance, this appears to be an objective procedure, but since the selection is subjective and not based on objective criteria, in

Age	Start years ago	Storage medium	Driving force
[0]	4.6×10^9	Crystal	Self-organisation of inorganic materials along the gradient of enthalpy
[1]	4.4×10^9	RNA	Self-organisation of RNA molecules along the gradient of enthalpy
[2]	3.7×10^9	DNA	Minimization of free enthalpy along the gradient of concentration
[3]	630 000 000	Nervous system	Minimization of free enthalpy along the gradient of electrochemical potentials
[4]	6 000 000	Cerebrum	Minimization of free enthalpy along the resultants of the gradients of networked electrochemical potentials in the cerebrum by non-linear processes far away from equilibrium
[5]	5 000	External local storage	Individual monetary economic utility optimization along the resultants of individual utility gradients
[6]	10	Cloud	Attempt to achieve global overall utility maximization through individual utility optimization along the resultants of individual utility gradients with internationally sanctioned norms as constraints
[7]	future	Quantum computer	Overall utility maximization along an overall utility gradient

Table 6: Periodization of driving forces

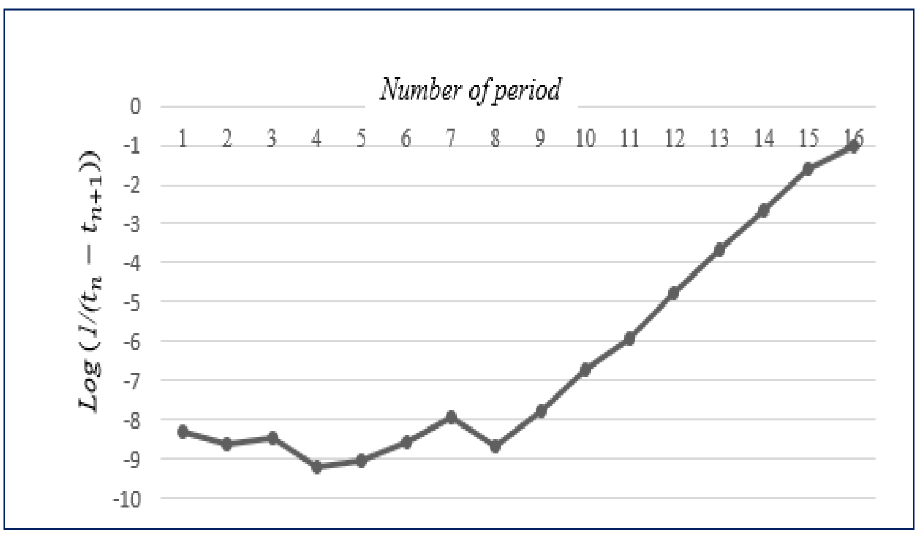

Diagram 1: Logarithm of the evolution rate

principle a different selection could fit completely different diagrams.

Methodology of Aunger

In a largely stringent manner, Aunger (2007b) identifies a common cause for the occurrence of successive major milestones from the Big Bang to the present based on "NESSTs" (non-equilibrium steady states). He identifies 17 non-equilibrium steady states (Aunger, 2007b, Table 2). His thesis is: "All historical transitions between non-equilibrium states follow the same pattern: first an energetic innovation, then a structural adjustment and finally new control mechanisms"

Methodology of the general evolutionary theory:

1. The general theory of evolution is limited to evolutionary processes in the narrower sense, i.e. processes that are characterized by inheritance, variation and selection. This means that in these processes "something" is inherited that can change in its traits and thus in its occurring frequencies. But the processes from the Big Bang to the formation of the Earth are not characterized by this type of evolution, but by symmetry breaking due to the decreasing temperature caused by the expansion of the universe (Jantsch, 1980, p.77). The general theory is therefore essentially limited to the period from the origin of life to the present. The "something" that is inherited, varies and whose frequencies change is obviously information in its most general form.

2. The different types of information that are relevant for evolution are characterized by different storage technologies. They are subject to a logical hierarchy: Crystal, RNA, DNA, electrochemical information in nerve cells, complex contents of consciousness in the cerebrum, local external digital information (writing), delocalized external digital information (cloud), external analog information in quantum computers. The hierarchy results from the fact that the existence of the previous type of information is the prerequisite for the emergence of the subsequent type of information.

3. There are 3 basic information technologies for each type of information, which are subject to a logical hierarchy: storage technology, duplication technology, processing technology. The hierarchy in turn results from the fact that the existence of the preceding technology is the prerequisite for the emergence of the subsequent technology.

4. The times at which these technologies first appeared can be determined relatively precisely. It turns out that the timing of the technological leaps at the beginning is not subject to any simple law (see *Diagram 1*). Only from about the Cambrian Revolution onwards are these points in time subject to exponential development, because only at this point were the mechanisms of directional variation developed to such an extent that the speed of evolution was largely determined by them alone. In a sense, the mechanism of each targeted variation reduces the space of all possible variations to a smaller space of more probable variations, each with a higher evolutionary fitness. Of course, since each specific variation is stochastic, each evolutionary path can lead to different outcomes. Since the specific targeted variation mechanisms arise from the information technologies, the periodization is the same as for the information technologies.

5. The periodization by the general evolutionary theory is based on a simple logical and easily understandable common principle for all evolution. It leads not only to a periodization of living beings and forms, but also to a consistent periodization of cooperation mechanisms, debt formation and driving forces. Therefore, compared to other methods, we consider it justified to call the classification and periodization within the general evolutionary theory the "natural" periodization of evolution on Earth. Furthermore, we hypothesize that evolution on other planets is characterized by the same principles, even if these can of course lead to very different concrete results in individual cases.

Similarities and differences in different periodization models

Why crystals in the Periodisation table:

If we restrict the term evolution to processes that lead to new structures through inheritance, variation and changes in frequency, then evolution on earth only begins at the age [1.2], the age of the ribocytes. The formation of structures in the period from the Big Bang to the beginning of evolution on Earth, on the other hand, is determined by a qualitatively completely different principle. Without going into detail, these structures are created by the expansion of the universe, which leads to falling temperatures, which in turn leads to symmetry breaking and thus to new structures (Jantsch, 1980 p. 77).

We begin with the age of crystals [0] because this age lies at the boundary between these two principles. Crystals (age [0]) and RNA molecules (age [1.2]) were the last ages to emerge as a result of decreasing temperature. Put simply, crystals were probably necessary as a catalyst for the formation of RNA molecules and RNA molecules were in turn

n	Age	Start years ago	Targeted variation mechanisms
1	[0]	4.6×10^9	---
2	[1.1]	4.4×10^9	---
3	[1.2]	4.0×10^9	---
4	[2.1]	3.7×10^9	Epigenetic variations
5	[2.2]	2.1×10^9	Horizontal gene transfer
6	[2.3]	1.0×10^9	Sexual reproduction
7	[3.1]	630 000 000	Interaction, Swarm formation
8	[3.2]	550 000 000	Learning of statistical relations
9	[3.3]	66 000 000	Imitation, Learning of near-time causal relationships
10	[4.1]	6 000 000	Learning of time-delayed causal relationships
11	[4.2]	900 000	Teaching
12	[4.3]	60 000	Logical reasoning, Individual utility optimization
13	[5.1]	5 000	Quantitative individual economic utility optimization, Animal and plant breeding
14	[5.2]	500	Investment in real capital
15	[5.3]	50	Investment in human capital
16	[6.1]	10	Investment in data capital
17	[6.2]	Present	Investment in stability and resilience, Gene manipulation
18	[7]	Future	Overall utility maximization

Table 7: Overview about targeted variation mechanisms

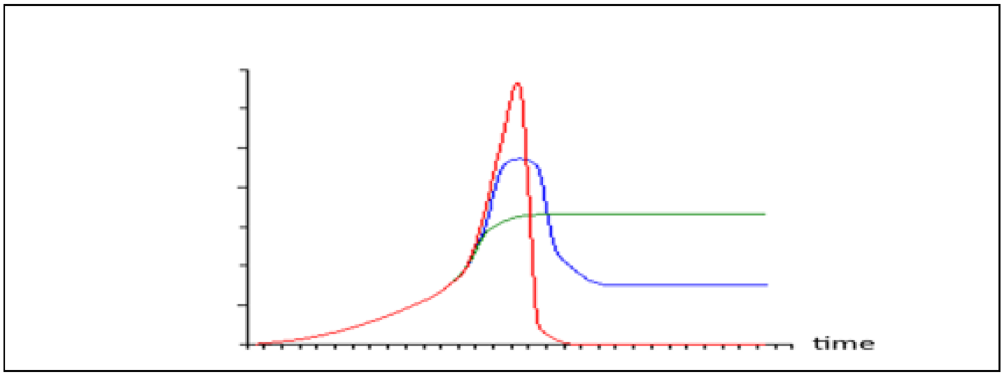

Diagram 2: Exponential growth in a finite system and its consequences at a "singular point".

the prerequisite for the autocatalytic formation of the first life-like structures in the form of ribocytes (Altman, 1990). This autocatalytic process is described by the theory of hypercycles (Eigen & Schuster, 1979). It represents the beginning of evolution on Earth.

Why we distinct between RNA and DNA:

From the perspective of information theory, RNA and DNA are fundamentally different: not only is the storage technology different (single strand versus double strand), but also the replication process. The main difference, however, is that DNA, together with the genetic code, creates the possibility of forming phenotypes. Selection no longer takes place at the genotype level as with RNA, but at the phenotype level.

Singular point:

One of our main goals in starting to analyze evolution was to understand the past in order to find answers for the future. But the analysis of the past has shown that we are heading towards a singular point in the near future (see chap. 0), which has also been suggested by others (A. Korotayev, 2018; Kurzweil, 2005). At a singular point, however, the structure of a dynamic system changes in unpredictable ways. Therefore, the only statement we can make with great certainty about the future on Earth is that there will occur far-reaching qualitative changes in the near future. Anything is conceivable, from the collapse of human society to a completely new organization of society in the form of a cyborg.

10. Conclusion

The general evolutionary theory can be seen as a comprehensive generalization and extension of Darwin's theory. It may actually be a favorite for a unified view of biological and cultural evolution and its periodization. The basic idea (see Chap. 2) is to consider not only the evolution of genetic information - as Darwin did - but the evolution of very general information, which of course includes the evolution of genetic and cultural information. It shows that evolution is characterized by the fact that new types of information have developed in leaps and bounds, each with new storage technologies, new duplication technologies and new processing technologies. This unified concept of evolution makes it possible, among other things, to

- achieve a unified view of biological and cultural evolution
- find a common natural periodization of the evolution (see Chap. 3) for
    - Living being forms (see Chap. 4)
    - Evolutionary systems and cooperation mechanisms (see Chap. 4)
    - Variation mechanisms (see Chap. 4)
    - Debt creation (see Chap. 5)
    - Driving forces (see Chap. 6)
- understand the exponential acceleration of evolution through the emergence of targeted variation mechanisms (see Chap. 7).

The general evolutionary theory develops the idea of information as an essential element for understanding evolution and its periodization in a stringent and comprehensive way. From the perspective of the general evolutionary theory, the following megatrends of evolution arise:

1. The periodization of evolution is characterized by the regular succession of new information types with the respective new storage technologies, duplication technologies and processing technologies.
2. At the beginning of evolution random variations have determined the development of evolution. However, as evolution has progressed, targeted variation mechanisms have become increasingly important. Targeted variation mechanisms are a major reason why evolution is developing faster and faster.
3. Evolution produces more and more efficient cooperation and win-win mechanisms.
4. Values and norms are a result of evolution.
5. The interplay between individual utility optimization (competition) and general utility maximization (cooperation) is of fundamental importance for the understanding of evolution.
6. We hypothesize that the evolution also on other planets basically follows the same sequence of information technologies as in the general evolutionary theory.

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Selection and Increasing Complexity in Evolution

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Abstract: This paper explores the concept of complexity in the evolution of life and human culture, proposing that the overarching increase in complexity is driven by the fundamental mechanism of selection. From the origin of life to contemporary human culture, selection plays a pivotal role in favoring complexity in reproductive processes and cultural expressions. The paper distinguishes two main phases of life on Earth: the emergence and evolution of life and animals, and the subsequent emergence of the human species with its complex cultural expressions. Despite apparent differences, both phases are argued to be guided by the same fundamental mechanism—selection, taking various forms such as adaptive natural selection, non-adaptive selection, sexual selection, and memetic selection. The paper identifies the acquisition of language as a crucial development, influenced by imitation and sexual selection, and suggests that the strong selective pressure for language has driven the rapid growth of the human brain and intelligence. This enhanced intelligence, in turn, has played a pivotal role in cultural, scientific, and technological achievements marked by unprecedented levels of complexity. The role of memetic selection is explored in the dissemination of religion across human societies, and the unintended consequences of Martin Luther's introduction of literacy and schooling for Western culture are examined. By integrating evolutionary principles with cultural and linguistic insights, this paper offers a comprehensive perspective on the unifying force of selection in the evolution of complexity in life and human culture.

1. Introduction

At her speech at the banquet for Nobel laureates in December 2018 in Stockholm, Frances Arnold gave her vision of a biologist's explanation of gravity: Once upon a time, apples used to move in different directions. Some fell to the ground, thus giving rise to new apple trees with the inherited feature of their apples to fall to the ground. Therefore nowadays, all apples are falling to the ground.

To me, this fairy-tale illustrates that such a central physical phenomenon as gravity cannot be explained by any biological principle. It is equally clear that significant biological phenomena cannot be explained by physical laws.

In his classical book *What is Life?* the physicist Erwin Schrödinger (1944) speculates how it is possible that life can proceed by increasing its complexity—a fact that he, like many other authors, seems to take for granted. Increasing complexity for a physicist, however, means a violation of the Second Law of Thermodynamics, thus implying a bothering enigma to him.

An attempt to solve the riddle of the increasing complexity of evolution has been proposed by Ilya Prigogine (2017) in inferring a process that he calls self-organization. This idea is expanded by Erich Jantsch (1980).

2. Selection, complexity and the origin of life

In this paper, I suggest the mechanism of selection to be an alternative to the notion of self-organization. I maintain that the mechanism of selection can give a sufficient explanation of increasing complexity in its various forms in organic life and human culture. Let me try to show how the mechanism of selection might be able to accomplish all this.

Nobody knows how life started on our planet. There are no traces to be found from these early days of the evolutionary history that could give some hints about the crucial beginning of life and the evolutionary process. Yet, in order to challenge the widespread notion of a divine intervention, I think we should at least present a possible and plausible scientific explanation of the very beginning of life.

Such an attempt was suggested by the Russian biologist Alexander Oparin who in 1936 proposed a process of chemical evolution of gradually increasing levels of organization implying a continuity between inanimate matter and the first living organisms. During the 1950s, Stanley Miller conducted his famous experiments through which Oparin's theory was verified. Especially interesting is that from merely inorganic substances amino acids were shaped. A recent review of the research about the origin of life is given by Sara I. Walker et al. (2017) providing a detailed analysis of the chemical substances being involved in the first stages of biological evolution.

I adhere to the widely spread notion that, as soon as the temperature of our planet was low enough to allow for *liquid water* to condense, small shallow ponds were formed. In these ponds a great variety of chemical substances was accumulating. Because of the great diversity of these elements, rich possibilities to form larger molecules were opened, notably by means of the dynamic features of carbon. Of special interest, *amino acids* were spontaneously formed by combinations of these substances, and subsequently, *protein* molecules could be shaped. Next step could be that such molecules were attached to each other into even greater conglomerates.

I now suggest the occurrence of a crucial incidence. I think it is reasonable to suppose that once a large conglomerate of several amino acid molecules, and maybe protein molecules as well, had been formed, it could break up into two or more pieces. This process was endorsed if the conglomerates had a chain form that chiefly was growing at its open ends. Such a chain form is indicated by Walker et al. I find it possible and even probable that this chain construction easily could be broken up into shorter parts, as for instance when the water waves were breaking against the rocks. Each of these parts, I suggest, possessed the essential features of its original as well as the ability to grow by attaching additional molecules to its ends. In this way, a kind of *copying process* had come into being.

Most of these constructions were certainly built at random thus resulting in a totally *chaotic* form. Then of course the broken parts got this chaotic characteristic as well and the growth of them didn't result in any less chaotic constructions. Incidentally, the remnants exhibited quite different properties compared to each other.

However, some of these chains, certainly quite few and in spite of extreme low probability, accidently may have got a more *well-ordered form*. Such an order might for instance have included a sequence of the same molecules or shorter sequences of different molecules that were repeated in longer arrays. Actually, for the present purpose it is sufficient to think that merely one such ordered chain was shaped. When such a well-ordered chain in turn grew and decayed, the pond was gradually permeated with its 'offspring' because they were similar, not to say identical, to each other. This is so because of the well-ordered form of the original chain. After some 'generations' of this process a kind of a 'population' of well-ordered entities was created in the pond. It seems reasonable to assume that this population consisted of rather few members as compared to the much greater number of chaotic elements. The important thing is that their number increased successively.

We must now consider the possibility that the pond in which these processes were occurring was located in a tropical environment in which the evaporation of water from the surface was balancing the inflow of water from the surroundings. Actually, such a process is self-regulating inasmuch as the surface of the pond will expand or shrink corresponding to the inflow of water. In this way, the closed pond came successively to contain higher concentrations of abiotic elements; it became what has been called a primordial soup. The resulting chains of molecules were preserved in the pond and the intimated processes could continuously be going on for a long period of time.

Due to random variations, the chains achieved insensibly small changes of their features. If such a change implied a decrease of their level of order, their chance of forming a unitary population was reduced. Therefore, only an unchanged or increasing order was promoted over time. I suggest that the indicated process can be characterized by the mechanism of *selection*. The most well-ordered entities were systematically selected in the process of reproduction.

The entities in the pond can thus be characterized by the properties of variation, copying ability, and selection; in other words, they owned the essential characteristics of living substances. Life had arisen. A Darwinian principle of evolution was set in motion. Indeed, I maintain that the principle of selection is the essential clue to the process by which inanimate physical substances were transformed into living organisms with the ability of evolutionary progression.

As we just have concluded, entities with the highest measure of order were systematically promoted in the Darwinian process. When this process was going on over periods of millions of years, we may conjecture that RNA-molecules, vesicles, cells, and real living creatures was gradually shaped. The very evolution of life was ignited.

As we have assumed, the most well-ordered entities were promoted and furthered in the suggested selection process. The central feature of these substances can be characterized by the concept of *complexity.* Therefore, we may conclude that complexity benefits reproduction in that the most complex entities are systematically selected in an enduring Darwinian process.

Charles Lineweaver and coauthors (Lineweaver et al. 2013) have in their book *Complexity and the Arrow of Time* brought together a number of scientists exploring the concept of complexity. They find the lack of definition frustrating, but as they ask, even without a definition or a way to measure it, isn't it qualitatively obvious that biological complexity has increased? Do we really need to wait for a precise definition to think about complexity? I strongly adhere to this view.

Like these authors, and like most people's intuitive notion as well, I maintain that the evolutionary process can be characterized by steadily increasing complexity. One may say that increasing complexity makes evolution progressive, a notion analyzed in depth by Michael Ruse (1996).

This conclusion has been disputed because of the fact that the concept of complexity neither is defined nor measurable. Still, I think it is the main concept that can give a sensible basis for the main characteristic of evolution of life on Earth. Many authors seem to take increasing complexity as a central feature of evolution for granted.

It should also be mentioned that an obstacle to this view has been put forward in that most species do not seem to increase their complexity once they had emerged. However, I have (Ekstig 2019) suggested increasing complexity mainly is occurring at the emergence of new species which then in their continued existence don't change much. This notion gives the evolutionary process a staircase form of increasing complexity with the human species occupying the highest level as I will discuss in the forthcoming text.

This primary evolutionary process had to wait for the next step in more than two billion years, indicating that a new step must have been quite difficult to achieve. Nevertheless, at the beginning of the Cambrian Period about 540 million years ago, *multicellular organisms* emerged. This crucial event gave rise to the appearance of many of the major phyla now making up the great diversity of life.

I maintain that selection can be seen as the outermost explanation of the origin of life and I suggest that it may explain the emergence of all organisms and animals up to the spectacular evolution of the human species and our culture with all its multifaceted expressions of unparalleled complexity.

3. The Tree of Life

Our model of biological evolution must of course include its fundamental features. First, life on our planet at present comprises the simultaneous existence of species of highly different levels of complexity; from the simplest bacteria to chimpanzees and man and the later in history they have appeared the higher their complexity. This view is expressed by Edward O. Wilson in pointing out that "biological diversity embraces a vast number of conditions that range from the simple to the complex, with the simple appearing first in evolution and the more complex later." (Wilson 1992 p. 175).

Another fact to be included in our model is that most species do not show any great change after their appearance. Wilson clearly express this feature: "Species emerge quickly and fully formed after a rapid burst of evolution, then persist almost unchanged for millions of years." (Wilson 1992 p. 80, 81)

My ambition is to suggest a model that, in applying the concept of complexity, gives answers to some challenging questions: Why haven't all species increased their complexity to the same level as man. Why is there such a great diversity in nature that we now can see around us? And, if a Darwinian principle is responsible for the increasing complexity as I have assumed, then why haven't those having been subject to this principle for the longest time attained the highest level? In reality, the opposite is the case. I have discussed these questions in my previous work (Ekstig 2019) but due to the focus on complexity in the present work, I think it is motivated to repeat the main arguments.

Let me take a point of departure in a highly schematic picture.

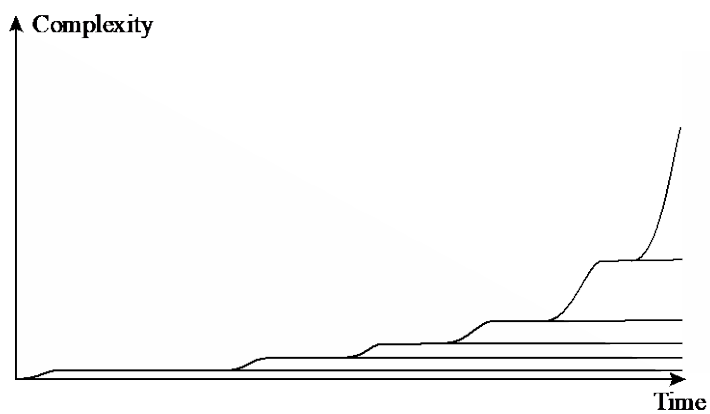

Figure 1 *The Tree of Life.*

The lines in this diagram depict the complexity of species all over the history of life. The lines may be interpreted as species as well. The horizontal lines illustrate species adhering to stabilizing evolution and the steps in the step-shaped line elucidate the emergence of new species. Let us discuss an example.

Imagine that the third horizontal line illustrates a fish species. At some occurrence, some fishes became trapped in a shallow pond, the amount of water of which was varying with the tides. Those surviving periods of drought for the longest time were selected according to the Darwinian principle. In this way, we may speculate, the ability to breath with lungs was developed and a new species was formed, let us think it was frogs. The new species is illustrated by the fourth horizontal line. The majority of fishes, unaffected by this occurrence, continued their own way of life in the sea as is illustrated by the continuity of the third line.

Let us now imagine that at a later point of time another group of fishes were trapped in a similar pond rendering them the same chance to develop to frogs. But now the conditions are changed. While struggling for their lives in the dried-up pond, they became easy prey to terrestrial predators already adapted to the terrestrial habitat thus being much superior creatures.

The consequence of this reasoning is that, in general, only species of the highest level of complexity get the possibility to change to a habitat of a still higher level of complexity because, for those starting from lower level complexity, the habitats of higher levels are already occupied by superior species that exposes them to strong competition. This conjecture is supported by Daniel Dennett (1995, p. 89) in stating that the odds are heavily against any mutation being more viable than the theme on which it is a variation. **T**he conclusion is that the emergence of a new species occurs only once.

According to this model, complexity increases cumulatively over time. The latest appearing species therefore has the highest level of complexity. At present, this species is the human species. The step-shaped line illustrates the common ancestry of the human species. This reasoning, I conclude, explains why not all species have increased their complexity to the same level as man and why there is such a great diversity of living creatures living simultaneous. It also explains the contra-intuitive fact that animals being exposed to Darwinian evolution for the longest time display the lowest degree of complexity whereas those exposed to this principle for the shortest time show the highest degree of complexity. The diagram illustrates these conditions and I suggest it to be called *The Tree of Life*.

The suggested form of The Tree of Life illustrates the commonly anticipated notion of a general and accelerating increase of complexity of life. This picture of the evolutionary trajectory is similar to that suggested by Kurzweil (2005) in pointing out how an ongoing exponential trend can be composed of a cascade of S-curves.

The suggested model implies that species form a hierarchical order. There is an apprehension that if one admits a hierarchy of species, one must be prepared to accept a hierarchy in human ethnic groups as well. Regarding this highly contentious issue, I would like to refer to Jared Diamond (1997) who asserts that the gaps in power and technology between human societies do not reflect racial differences but rather originate in random initial environmental conditions.

Let us compare this picture of The Tree of Life with the diagrams constructed by Richard Dawkins in his book *The Ancestors' Tale* (Dawkins 2004).

In his pictures, Dawkins follows the human lineage backwards. This line of the human lineage is by Dawkins called "already joined" and corresponds to the step-shaped line in Figure 1. The incidents of appearance of new species are called "rendezvous". Dawkins draws many diagrams with successively more compressed time scales. Actually, Dawkins' diagrams have the same topological form as that of Figure 1.

I conclude that my diagram exhibits great principal similarities to Dawkins' although those of Dawkins are much more detailed in that he specifies the species involved and give rough dates of their appearance. A significant difference, however, is that my diagram displays complexity.

The diagram of Figure 1 can be seen as an illustration of human cultural evolution as well. I suggest that there are cultural, scientific and technological breakthroughs that can be seen as corresponding to the steps in the step-shaped line. Examples are given by the Copernican revolution and Darwin's discovery of natural selection. Such breakthroughs imply increases in mankind's total content of complexity.

Thomas Kuhn (1962) comments on the analogy that relates the evolution of science to the evolution of organisms though reminds us that it can easily be carried too far. But with respect to his idea of paradigms it is, as he states, nearly perfect. In the present context, I think one can interpret paradigm shifts as corresponding to the stepwise elevations of complexity in biological evolution.

The very mechanism behind the discussed process of increasing complexity is natural selection.

4. Natural selection

The principle of selection was discovered by Charles Darwin (1859) in observing that the finches of the Galapagos Islands displayed beaks with somewhat differing forms that matched the types of nuts that they exploited as their main source of food. This observation led him to the conviction that adaptation was not to be seen as an indication of the widespread notion of purpose and final cause so widely embraced in the Christian faith but rather a naturally emerging phenomenon. He realized that adaptation was a result of a process of selection according to which beaks that were best adapted to the environment were systematically chosen. He called this principle natural selection.

To be complete, it should be mentioned that the discovery of natural selection should be ascribed to Alfred Russel Wallace as well, though the honor is mainly given to Darwin because of his much more elaborated analysis.

Darwin realized that this principle had a far-reaching general application which could explain much of the very evolutionary process. But he also realized that it should evoke strong reactions because it implied such a terrific conflict with common religious faith.

This first discovery of the principle of selection was thus coupled to the mechanism of adaptation. It had such an overwhelming explanatory power that the very principle of natural selection ever since has been intimately associated to adaptation. But as I will argue, this interpretation is unnecessarily restricted. In the forthcoming sections, I will suggest several forms of selection that are not adaptive; they work independently of the external environment. I call this form of selection non-adaptive selection.

All forms of life on earth exhibit a remarkable characteristic in that individual creatures repeatedly reconstruct themselves through a developmental process starting with the zygote and ending in adult creatures which eventually die. This developmental process is governed by genes that propagate inherited instructions for the individual's growth process. Therefore, genes have impact on evolution only indirectly through their control of development. Natural selection is thus a process mainly working during the developmental growth of individual creatures in a population.

Let me express my conviction that Darwin's discovery of selection is the single greatest breakthrough in the history of science. His idea implied a denial of the common sense notion of purpose and final causes of nature. He had to break the spell of religious faith that he himself initially as well as most people were trapped into. He had to find empirically supported evidence for his theory that could be sufficiently convincing for his brave idea. He had to take the risk of being socially reproached by his friends. Yet, he presented a scientific theory of unprecedented explanatory power.

5. Complexity

As I have already suggested, complexity benefits reproduction. Therefore, the most complex entities in the evolution of life at any point of time are systematically selected so that increasing complexity has come to be a ubiquitous feature of the evolution of life. Such an increasing complexity makes evolution progressive, let alone the interpretation of this concept has turned out to be highly controversial (Ruse 1996).

5.1 Arms Race and competition

Let me give an example of arms race. Hares are exposed to a selection pressure from foxes (their environment) that accomplishes, amongst other things, an increasing efficiency of their hearts. A corresponding effect can be envisaged in foxes. There is thus a mutual increase of the efficiency and complexity of the heart accomplished by this special kind of mutual selection. This process is progressive, a statement emphasized by Dawkins (2004 p. 496) in pointing out that arms races are deeply and inescapably progressive in a way that, for example, evolutionary accommodation to weather is not.

To speak in more general terms, competition is always present in any habitat that regularly tends to be crowded up to its maximum capacity. This competition accomplishes a selection pressure on the creatures to steadily increase their complexity because it is by means of increased complexity that they can achieve a reproductive advantage in the competition of others. This competition occurs between members of the same species as well as in the relation to members of other species.

5.2 Selection for efficiency

As pointed out by Stephen Stearns (1992), the growing creatures are during their developmental course vulnerable to the hazardous conditions of the environment including predators. Therefore, it is advantageous to pass this risky period as quickly as possible.

There is actually another advantage of a shortening of generation time. To reach maturation in a shorter time means more frequent occasions of reproduction over time. This circumstance adds to the selection pressure for the speeding up of the development process.

This means that there is a general selection pressure to speed up the development process of every organ and of the body as a whole. I have by means of a mathematical analysis of population growth confirmed the existence of such a selection pressure (Ekstig 2019 ch. 4).

The selection for a speeding up of the development process has implied a very early development of many organs of present creatures during their ontogeny. Thus, the heart and the kidneys of mammals have reached their complete construction already after only a few fetal weeks.

In order to perform a particular task in a shorter time, one has, so to speak, to work more efficiently. I propose that this concept be applied to the process of evolution. The selection pressure for shortening of generation time can thus be seen as causing an enhancement of the efficiency of the growth of organs during the developmental process without change of their function.

Because of the addition of new traits to the growing creature, its developmental growth may be prolonged. The two mechanisms—addition of new traits and the fine-tuning of existing traits—are acting independently of each other and it may very well be that the total change of development over time implies its prolongation. It is however difficult to separate the respective influences of the two mechanisms.

A mere variation of efficiency of the growth of an organ or an organism without change of its function gives natural selection no alternative which could fit better to any environmental characteristic. Therefore, regardless of the environment, efficiency is always promoted. The selection for efficiency is therefore to be seen as a non-adaptive kind of selection. Examples can be found in the development of the eye, the heart and the kidneys.

The Eye: Ryan Gregory (2008) has given a detailed analysis of the evolution of the eye. He describes how the eye has evolved from a first flat layer of photo-sensitive cells on the skin, then to a cup-formed construction and finally to the vertebrate eye with pupil, lens and retina. All these steps have continually been developed towards ever-higher efficiency of the organism's capacity of sight, obviously driven by their promotion of survival of the organism. This process is not coupled to the external environment because good sight is equally important in any environment. Such an increase of efficiency is strongly contributing to the increase of complexity of the organism.

The Heart: During the course of evolution of vertebrates, the heart has evolved from a two-chamber construction in fishes, to three-chambers in frogs and finally to a four-chamber heart in birds and mammals. These adjustments of the heart construction are driven by the advantage of an increased efficiency of blood circulation. However, the selection for these evolutionary changes is accomplished independently of the external environment because a good blood circulation is advantageous in any environment. Such an increase of efficiency of the heart has strongly contributed to the increase of complexity of the organism.

The Kidneys: The same conclusion can be inferred regarding the development of many other organs as well, as for instance the kidneys. The function of the kidneys is to extract waste from blood. There are three stages of their evolution; pronephros, mesonephros and metanephros, all of which are results of a selection for increased efficiency because of the survival value of this capability.

This selection pressure is independent of the prevailing environment because regardless of the environmental conditions, selection always benefits efficiency. Such an increase of efficiency of the kidneys has strongly contributed to the increase of complexity of the organism.

The Brain: Actually, nowadays there are few new impressive changes of the evolutionary course of animals. It seems that most species now have reached what is called stabilizing selection. And if there are changes, these are very small as compared to changes associated to the emergence of novel species. However, evolution has entered a new avenue practiced by one species only, implying an unprecedented rise of complexity. That is the evolution of the brain and intelligence in the human species. This part of the evolutionary process is accomplished by non-adaptive selection because high intelligence is beneficial in all kinds of environments but also to a great deal by means of an additional kind of selection, sexual selection.

6. Sexual selection

The peacock's tail implied a challenging problem for Charles Darwin because, according to his theory of natural selection, all organs and features of organisms have evolved because they have promoted survival and reproduction. But the peacock's tail seemed rather to be an impediment. It is costly to bring forth, it implies a burden to carry around and it is a conspicuous signal for predators. These circumstances impose a contradiction of natural selection, an enigma Darwin was very frustrated about. After years of contemplating, he solved the challenging problem by introducing the process of sexual selection.

Sexual selection is an extremely complicated evolutionary mechanism as reviewed by Kuijper et al. (2012). There are mainly two variants of sexual election. The first is the struggle between males for access to females. This selection has led to large body size and diverse kinds of weapons like horns. The second variant is that females choose their mate according to arbitrary features, ornaments, for which they have got inherited preference. This mechanism has resulted in a mutually runaway reinforcement of the ornaments as well as of the taste for them (Dawkins (1988, p. 203).

Adaptive natural selection mainly benefits survival and reproductive success whereas sexual selection exclusively benefits reproduction. Indeed, sexual selection often occurs in spite of a disadvantage for survival, as is the cases of the peacock's tail and the impressive antlers of the deer. Other cases of its manifestations are less costly as can be seen in the color decorations of birds and fishes. The birds' songs offer another testimony of sexual ornaments. Sexual selection sooner or later leads to an equilibrium between the reproductive advantage of the sexual ornaments and their disadvantage for survival.

Sexual selection accomplishes a variation in the characteristics and behaviors especially of birds, mammals and human beings that significantly adds to the complexity that has been achieved by natural selection. Therefore, I conclude that sexual selection is a mechanism of evolution that has driven complexity in evolution to reach much higher levels than otherwise could have been achieved.

6.1 Sexual selection in the human species

Of special interest is of course to what extent sexual selection has formed the bodies, behaviors, and cultural characteristics of our own species. In the majority of cases, sexual selection in animals involves a selective act by females and an exhibition of ornaments by males. As pointed out by Prum (2018 p. 252), the human species demonstrates a remarkable exception to this principle in that also women exhibit traits that indubitably are formed by men's preferences. Sexual selection has significantly increased the complexity of human bodies and behaviors.

I will start by discussing one case of female choice of male features. One such feature is men's talent to seduce women. These men, just think of Don Juan or James Bond, are not seldom preferentially chosen by women. The female behavior is understood because they will achieve a reproductive advantage in mixing their genes with those of such he-men. Their sons will inherit this talent and their daughters will inherit their mothers' preferences. This mode of women's partner choice has continued and been reinforced up to the present day.

6.2 Men's choice of women's features

As I already have emphasized, men's choice of women's features is a human-specific feature, the corresponding process of which is rarely, not to say never, practiced among other species. As Prum (2018 p. 254) states: "Rare among primates, male preferences for female sexual ornaments have clearly evolved on the uniquely human branch of the Tree of Life". This indicates that the evolution of the human species has been directed by additional processes compared to all other animals.

Women's bodily qualities are of course connected to their task of giving birth to as many healthy babies as possible. From the man's point of view, it is advantageous for his envisioned mate to be young in order to encompass as long a fertile period as possible. Therefore, the man has to estimate the age of his prospected mate and therefore women have advanced methods to give an impression of a young age. In our modern time, women's endeavors for this striving involves the wide-spread use of cosmetics to reinforce the impression of youth. Likewise, the use of bust bodices is now commonly utilized to give the bust a young form. Indeed, modern females even use surgical means to improve this feature.

Subcutaneous fat is richer in women than in men. I think this is a result of men's sexual choice because it enhances the pleasure of direct bodily contact and caressing. The fact that it is more pronounced in women than in men and that it has no obvious adaptive value supports the conclusion that it is a sexual ornament in women.

Why, then, is the male choice of female features exclusively restricted to the human species?

I suggest this evolutionary feature to be due to the fact that other animal males have no reason to bother about any choice. They copulate indiscriminately with any available female, a habit that renders them highest possible reproductive success, as it seems, without any expressions of pleasure. In contrast, I think that our highly developed intellectual and emotional faculties have rendered us the capability of pleasure connected to the sexual act, a feature that according to Prum (2018 chapter 9) is unique for the human species. This pursuit of pleasure has brought about the conscious choice of a partner that seems to be able to offer the highest pleasure, a pursuit that essentially has contributed to the sexual ornaments of both sexes.

The modern science of biochemistry has revealed that pleasure is connected to the production of endorphins which increase feelings of wellbeing. Sexual pleasure is thus not merely a good-feeling experience but endowed with a material substrate giving the discussed pursuit for sexual pleasure a concrete underpinning.

7. The emergence of the human species

In the context of big history, I would like to express my view that, on our planet, two really significant breakthroughs have arisen. The first is the emergence of life, the second is the emergence of the human species. Actually, according to the traditional Christian view, humans have an exclusive position in the envisioned creation. The Christian church had in fact forbidden the dissection of human bodies, as I believe, in their attempt to keep this view unchallenged.

However, the French philosopher René Descartes (1596–1650) defied the decree against dissections and performed extensive comparative studies of the anatomies of animals and human bodies. He then discovered that there were great similarities between the anatomical structure of animal bodies and the human body as testified in the following quotation:

> *There is no one who does not already have some knowledge of the various parts of the human body, that is to say, who does not know that it is composed of a very large number of bones, muscles, nerves, veins, arteries, together with a heart, a brain, a liver, lungs, a stomach; and even who has not sometimes seen various animals opened up, on which occasions they have been able to observe the shapes and positions of their internal parts, which are approximately the same in them as in us (Descartes, 1647).*

Unfortunately, as convincingly disentangled by the German philosopher Theodor Ebert (2009), Descartes in 1650 was by means of arsenic murdered by a catholic priest. I suggest that this evil deed can be seen as a consequence of the competition of rival memes that I will discuss later.

Two hundred years later, the continuity between animals and man was scientifically settled by Charles Darwin, a notion rising fierce protests. People couldn't accept that we were, as it was expressed, descended from the apes.

However, with regard to the tremendous difference in complexity, I think that, without diminishing Darwin's discovery, we may regard the emergence of the human species as an extraordinary accomplishment in the history of the evolution of life on earth.

It has been somewhat surprising that modern genetic science has revealed such a minimal genetic difference between humans and chimpanzees. Therefore, of course, it should be no surprise that our human morphological and anatomic features are very similar to those of apes. But in considering the breadth and depth of all human cultural manifestations, especially the ability of language, I find humans far more complex than anything apes exhibit.

In his ambition to strengthen the preeminence of the human species, American philosopher George Kateb (2011 p.17) passionately articulates the supremacy of mankind amongst all species:

> *We human beings belong to a species that is what no other species is; it is the highest species on earth—so far. /…/ All other species are more alike than humanity is like any of them; a chimpanzee is more like an earthworm than a human being, despite the close biological relation of chimpanzees to human beings.*

I think Kateb expresses many people's intuitive notions.

We may find a supporting expression of the supremacy of mankind in the last sentence of Dawkins's book *The Selfish Gene*:

> We, alone on earth, can rebel against the tyranny of the selfish replicators. (Dawkins 1976).

If we now accept the description of the human species as an extraordinary accomplishment, the question is to what extent the mechanisms that have been in action in the evolution of life, primarily selection, can be applied for the analysis and explication of human culture. The answer is, as I will argue, that the mechanism of selection can be applied in the analysis of human evolution as well. First, however, we will make a short resume of the evolution of mankind.

The human species separated from a common ancestor with chimpanzees some five or six million years ago. After this separation, the size of the human brain has successively increased all the way up to now, whereas the chimpanzees show no such development. This observation indicates where to find the crucial cause of the difference between these two species. But the mere size of our brain just gives a crude hint.

The size of the populations of pre-human species was quite small, a circumstance that facilitated the rapid implementation of genetic and behavioral changes. From remnants of pottery and stone tools we can see a slow but continuous development of such artefacts which indicates a rise of the level of technological abilities.

Unfortunately, there are no fossil traces of the important human-specific capability of language. But this capability must have necessitated a big brain, the size of which may be used as a crude indicator of the development of language.

Agriculture emerged about 12,000 years ago, transforming the human society from small nomadic groups to settlements with hierarchies of governance. Agriculture could feed more people and gave rise to faster population growth in spite of the fact that crowded living facilitated the spread of diseases, and that a more limited diet might have caused nutritional deficiencies.

So far, the intimated reasoning has been restricted to the material manifestations of the evolutionary process. However, with the evolutionary changes of the nervous system, a systematically more complex behavior evolved because complex behavior has been beneficial for survival and reproductive success. With the appearance of the human species, evolution has employed a still more dramatic and significant avenue. Selection has gradually started to work on immaterial features of the nervous system, generally recognized as intelligence. The target of selection is now what Dawkins (1976) has suggested to be what he called *memes*. Because survival and reproductive success is favored by high intelligence, this process has led to a systematic increase of intelligence having its foremost expression in the human ability to understand and use symbols, especially manifested in language and mathematics. But this is not the whole story. Nowadays, intelligent persons do not necessarily have higher relative survival and reproductive success. Therefore, one may conclude that intelligence has promoted its own evolution.

The study of the coupling between biological and cultural evolution got a breakthrough by Edward O. Wilson through his book *Sociobiology* (Wilson 1980). In this provocative work Wilson claims that gene-culture coevolution is a special extension of the more general process of evolution by natural selection. Wilson's ideas have been sustained by the concept of memes, forming a corresponding kind of hereditary unit in the human cultural evolution as that of genes in biological evolution. Daniel Dennett (1995) has extended Dawkins's ideas, suggesting that the Darwinian process, involving variation, selection and heredity, may be seen as a substrate-neutral evolutionary algorithm that could be applied to the social sciences by applying memes as the bearer of heredity.

I find it interesting to note that Wilson builds his analysis on natural selection. But as I will argue in the following text, natural selection and especially adaptive natural selection, plays a subordinate role in the evolution of the most significant components of human culture—language and technology.

8. Verbal language

In the previous section we discussed the evolution of our big brain. This attribute is of course coupled to our high intelligence, which directly is seen in our superior ability to understand and use symbols as emphasized by Terence Deacon (1997). The most important manifestation of this ability is our talent to talk, which is the preeminent expression of intelligence. Indeed, I claim that the proficiency of language is the essential clue to the process by which man achieved his transformation from the animal to the human kingdom.

Language is a truly advanced mental ability that requires a great brain capacity. I maintain that selection of language has driven the growth of the capacity of the human brain. Of course, language has not appeared instantaneously; rather it has evolved continuously in insensibly small steps all the way after our separation from the chimpanzees. We can get a presentiment of the first steps of this process in the simple grunts and gestures found in chimpanzees. Significant for the development of language is that it is not just a process in individual brains but a collective process. First and foremost, language stands for an interaction between brains of separate individuals, a feature of great significance for the evolution of human culture.

It is interesting to observe the development of the verbal language in children. I think it follows the main course as that of the human evolutionary history. It can thus be seen as a nice example of recapitulation as I previously have suggested (Ekstig 2019).

Verbal activities need a lot of brain capacity. These verbal activities certainly had a high survival value not least in the days when all kinds of hazards constantly threatened the survival of the small groups. But the human brain is costly; it needs a lot of high-quality nutrition for its growth as well as for its maintenance and it makes the birth of a child with its big brain a hazardous event. Its growth during mankind's first evolutionary steps must therefore have been the result of a strong selective pressure. What then are the mechanisms of the acquisition and evolution of language?

8.1 Mechanisms of language acquisition

Language was an all-purpose innovation that was beneficial across various environments. One may therefore conclude that, both on the individual and population level, language in a broad perspective can be seen as an outcome of natural selection. Seen in more detail, one can identify two specific mechanisms for its development, imitation and sexual selection.

Imitation: In her book *The Meme Machine*, Susan Blackmore (1999) suggests that people preferentially copy people with the best language. These people then pass on genetically whatever it was about their brains that made them good at copying these particularly successful sounds. In this way, the brains and the organs of speech gradually become better to form and make use of just these sounds. This aptitude for imitation seems to have become deeply incorporated in our genetic set up. Actually, we can see it in babies' early ability to imitate adults' facial expressions. Blackmore emphasizes that selection favored those who could make the most intelligent choices on what to imitate.

Parents with high verbal talent will have a positive influence on the language acquisition of their children, who, when grown up and producing children of their own, will have a similar positive impact on the next generation children— a coupling indicating a positive feedback process. Children in the small tribes certainly also took part in common activities as for instance by sitting around the campfire listening to storytelling adults. In these situations, the most verbally talented adult person certainly dominated the talk, and in this way, children benefited from adults with the highest language ability.

In her studies of babies' language acquisition, Patricia Kuhl in her 2015 *Scientific American* article discusses how mothers across all cultures are stimulated by their babies to use "baby talk"; a form of simplified talk characterized by high pitch, slow tempo and exaggerated intonation, a practice called *motherese*. Babies obviously convey a reaction in their mothers to use a simplified way of talking which facilitates their imitation of their mothers. This gives another example of a self-reinforcing feedback process.

The earlier a child's acquisition of speech is achieved during its childhood, the more time will it have during the rest of its growth for additional finetuning of its verbal talent and the greater will its communicative faculty be as an adult. This implies a selection pressure for a speeding up of children's acquisition of language. We may thus conclude that this process is analogous to the selection pressure for the speeding up of the biological development process that we discuss in the above section *selection for efficiency.*

Sexual selection: Blackmore, in addition to imitation, remarks that verbal ability makes the brain visible for sexual selection because, as she points out, being highly articulate makes you sexually attractive.

As she notes, the history of love poems and love songs suggests as much, as does the sexual behavior of politicians, writers and television stars. She emphasizes that people preferentially mate with people with the best language. I suggest that not only a good language ability makes a person sexual attractive, but the very preference for this talent in the mating choice situation is a trait that will be inherited by the resulting children who thus not only will inherit the higher linguistic talent but the preference for it as well. As we may recognize, this process is analogous to the process of sexual selection that we discussed in connection with the development of organic traits. I conclude that we may regard language as a sexual ornament in both sexes in the human species.

9. Cultural endeavors

In addition to language, more recent expressions of human intelligence are to be found in art, literature, and music as well as in religion, mathematics, science and technology. These activities require an extremely high level of complexity of our nervous system. I discuss some of these expressions.

9.1 Arts, music, and literature

The early manifestations of arts, music, and literature seems to originate from a deep human need of creative activity. Music and dance may in addition have contributed to the coordination of group emotions and actions which might have had a survival value of the tribe.

The endowments for arts, music, and literature can in many respects be seen as analogous to the talent of language. Thus, it is observed that successful artists in many cases are notably sexually active. Sexual selection is therefore certainly an important driving force in these endeavors. In analogy with my discussion of the evolution of language, the very preference for artistic endowments in the mating choice situation implies that the resulting children will inherit the higher artistic talent as well as the preference for it. This mechanism enhances the evolution of the manifestations of arts, music, and literature permeating all human societies, ancient as well as current.

9.2 Memetic selection and religion

Our propensity to understand causes of natural phenomena, evolved due to its survival value, became gradually extended to envisage causes of imagined nature, first and foremost of a creator of everything, the foundation of all religions. Furthermore, human consciousness has instigated us to envisage a life after death—a notion that has become deeply incorporated in all religious thinking.

In his introduction of the concept of memes, Dawkins (1976) suggests the occurrence of religions as a typical example. As to the memes of religion, there has been a selection process in action according to which memes that had the best ability to replicate and spread to other human brains also successively became more frequently represented in the meme-pool. This ability can be associated to missionary activity implying that religions with the most effective mission became most effectively spread. This means a selection for improving missionary techniques. The memes will thus affect their host, the human being, to act to their own advantage and reproduction. Dawkins accentuates that this kind of selection is not good for anything else but for the spreading of the meme itself.

An efficient method in establishing a meme in other persons is by indoctrination of children whose brains are particularly susceptible for such influence because they have developed the vital aptitude to trust their parents and other adults. Once indoctrinated in childhood, a person may have difficulties to make himself free from the acquired notions. Therefore, indoctrination was subjected to a memetic selection pressure for further refinement. An example of this mechanism is found the establishment of school systems, the initial purpose of which was to indoctrinate children in the current religion.

An important feature of the selection process on memes is that they, in their fighting against rival memes, cause a pervading influence on human behavior. I can see several expressions of this phenomenon of which one is the frequent occurrence of wars of religion, as for instance the Thirty Years War. Another expression is to be found in the oppression of heresy that resulted in the establishment of The Inquisition Court, a Catholic special court that was given the task of tracking down and punishing anyone nurturing views contrary to church dogma. A well-known case is the dreadful execution of the scientist Giordano Bruno in 1600 and the trial of Galileo. As I see it, the Inquisition is a dreadful expression of the fighting of memes against their rivals.

Still another example is given by the awful prevalence of witchcraft during the Middle Ages. As seen from a meme´s eye view, the dominant meme for the notion of witches reinforced its control over rival memes and the most efficient and cruel methods became successive selected in spite of the erroneous, not to say quite stupid, logics of the arguments in the trials and the suffering it caused. Fortunately, these devastating expressions of memetic rivalry are now wiped out.

Fortunately, this terrible period of western history came to an end at the Reformation. As Joseph Henrich (2021 p. 9) emphasizes, “Luther not only created a German translation of the Bible, which rapidly came into broad use, but he began to preach about the importance of literacy and schooling”. In this way he initiated a public-school system in Germany which successively became spread over other parts of Europe. I believe Luther’s introduction of literacy and schooling brought about an unintended but crucial opening for freedom of thought and a democratic, varied, and complex societal development as expressed during the period of the Enlightenment—the intellectual and cultural movement in the eighteenth century that emphasized reason over superstition and science over blind faith. This period released the advancement of mathematics, science, and technology.

9.3 Mathematics

The ability to count is certainly as old as the human species itself. Already during nomad living, people had a need to keep track of how many animals they had seen, to tell how many children they had and so on. With the entrance of agriculture, they needed to measure their cultivated land and to keep track of how many cattle they had. The ability to count certainly increased their chances to survive and can therefore be seen as an expression of a selection for survival.

In 1937 archeologists in the region of what now is Czech Republic uncovered a nice wolf thighbone which was found to be 30 000 years old. The remarkable thing was that there were scratches carved on it. Every fifth scratch was somewhat longer than the others which is interpreted as a means of counting something. This is one of the oldest known artefacts with mathematical significance; to use a symbol to represent a real object. This symbol is a number which has a general application. The number 3 may denote the number of children, apples or celestial bodies. Like the use of language, counting means a requirement of the ability to use and interpret symbols.

In this context we must remember Euclid, who about 300 B.C. developed geometry in his work *Elements,* which, up until our own time, has been of profound significance for the teaching of mathematics. The development of mathematics has successively led to higher levels of abstraction and complexity and in many countries, it has been included as a central element in school curricula.

To solve a mathematical problem means an intellectual effort and to find its solution means a kind of satisfaction that may release endorphins. Besides of its practical use, this release of endorphins, I suggest, is the basis of motivation for people to make so great efforts in the development of mathematics.

9.4 Science

I suggest three processes that have initiated and reinforced the evolution of science.

First, the aptitude of curiosity which, I think, has been developed by its survival value and thus there has been a selection pressure for the enhancement of science.

Second, the disclosure of an explanation of a dazzling phenomenon may release endorphins which may boost continued efforts to find further explanations. A nice example can be found in the myth of Archimedes.

King Heron had given Archimedes the task to examine if his crown was made of homogenous gold. When Archimedes took a bath, he came across the solution which now is known as Archimedes' principle. He then became so euphoric that he, according to Vitruvius, ran out into the street shouting "eureka" without even remembering to put on his clothes. Certainly, I think, Archimedes must have got a great portion of endorphins. Even if the myth isn't true, people obviously find it trustworthy thus supporting the general notion that endorphins may be released by science problems solving.

The third instance that has reinforced the evolution of science is sexual selection. I think that the aptitude of understanding difficult problems and of finding solutions to them gives a person high status and thus makes him/her sexually attractive. In this way, the person is encouraged to make further efforts along the same line.

Science is contra-intuitive. A typical example is found in Copernicus' suggestion of a heliocentric worldview. Actually, everyone has the immediate experience that the earth stands still and that the sun is moving. To defy this intuitive notion therefore requires a highly developed ability of abstract reasoning. Another example is found in Newton's theory of gravitation. Everyone has the intuitive experience that in order to bring a force to an object one has to apply a direct material contact. Therefore, Newton's conjecture that the Earth could affect the Moon with a force over the great distance was a highly contra-intuitive notion that initially caused a lot of hesitation to the very notion of gravity. As we know, Newton's theories gradually became accepted thus laying the ground for the all-encompassing scientific development of our culture. It must be observed, however, that neither Copernicus nor Newton scarcely were compelled by sexual drives.

Science, though it deals with reality, is a highly abstract enterprise. It can be traced back to ancient Greek culture and has after Copernicus' breakthrough been developed to unprecedented extension and complexity. The complexity of this evolutionary process has been enhanced by the use of mathematics, instruments, computers and other contraptions of high complexity.

<u>9.5 Technology</u>

The evolution of technology can be said to have been developed by the same mechanisms that we have discussed above in connection with the scientific evolution. Let us discuss an imagined situation in the dawn of technological evolution.

As studied by John Shea (2017), archeological findings of stone tools exhibit a continuous increase of complexity and efficiency. It seems plausible that the ability of the construction of stone tools already from its very emergence has been beneficial for survival of the individual as well as of his tribe. In this way there has been a selection pressure for enhanced efficiency of the shaping of stone tools.

However, I think that sexual selection has been in action as well. As Susan Blackmore (1999, Chapter 8) emphasizes, imitation and sexual selection are significant human features in the evolutionary process. Regarding the ability to construct stone tools, I think that a man who could make the best stone axes became the best hunter and the best warrior in the tribe. These features made this man sexually attractive. Young men understood this coupling and therefore tried to imitate and even improve the methods for stone axe construction that seemed to bring about such a success amongst women. Thus, I conclude that the evolution of stone tools to a significant degree has been accomplished by the aptitude of imitation and sexual selection and I think this conclusion can be generalized to many other innovative abilities during the evolution of our technological progress.

Technological achievements often happen in an outstretched progress. An illuminating example is found in the development of the car engine. We start by going back to the ancient Greek culture where Empedocles made experiment with water and air from which he concluded that vacuum cannot exist. This idea was challenged by Evangelista Torricelli who in 1643 preformed experiments with mercury that led him to the insight that nature's avoidance of vacuum is limited. This inspired Thomas Newcomen and James Watt during the latter part of the 1800th century to construct the first steam engines that came to initiate the Industrial Revolution. The next step was taken by Nicolaus Otto in eliminating the steam boiler by, so to speak, placing the fireplace inside the cylinder. In this way he constructed the first combustion engine which he in 1878 installed in a car. Since then, this motor has undergone continuous refinements while its main operating parts have remained the same.

All these steps of engine constructions are illustrations of a progressive development with successively increasing levels of complexity. This type of technological development is now further enhanced by information and digital technologies, the level of complexity of which far exceeds that achieved by mechanical designs. The unprecedented level of complexity of this development can now be seen as extended in extra-human devises in what is called Artificial Intelligence. Such contrivances contribute additional complexity to what already has been achieved by the human brain and by the mechanical and digital achievements.

10. Summary

The literature of complexity seems mostly to be focused on the task to find support of the very presence of complexity in the evolution of life and human culture. In the present paper I have suggested that the evolution of organic life as well as of human culture in their chief outlines can be characterized as a process of increasing complexity explained as a result of the mechanism of selection, which has been in action from the very the origin of life to the latest expressions of human culture. I have suggested that the mechanism of selection explains the ubiquitous increase of complexity because complexity is favored by selection in the reproductive processes of life and at the spreading of the multifarious human cultural manifestations.

I have argued that life on Earth is manifested in two main parts; the first of which is the emergence and evolution of life and animals; the second of which is the emergence of the human species including our cultural expressions. The reason why humanity occupies this exclusive position is that we have achieved a superior level of complexity in comparison with all other animals, first and foremost as a result of our ability of language.

However, in spite of the highly different characteristics of these two manifestations of evolution, I have argued that they are driven by one and the same chief mechanism, i.e. selection, of which I have discussed several different forms. Among these are adaptive natural selection, non-adaptive selection, sexual selection, and memetic selection.

In the human species, sexual selection has accomplished sexual ornaments, not only in the male but in both sexes, which is unique amongst all animals. Human sexuality has contributed to the superior level of complexity of our species.

As to the uniqueness of mankind, I have as a pivotal occurrence suggested our acquisition of language that to a large extent is instigated by our ability of imitation as well as by sexual selection. The strong selective pressure for language has, I propose, caused the exceptionally rapid growth of our brain and our high intelligence. The growth of our intelligence has in turn brought about many of our cultural, scientific and technological achievements all of which convey unprecedented levels of complexity.

I have referred to the selection mechanism of the meme as providing an important clue to the pervading spreading of religion over most human societies and the unintended result of Martin Luther´s introduction of literacy and schooling for the democratic development of Western culture.

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Chemical Evolution in Big History

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Abstract: Unfortunately, there is insufficient research on the course of chemical evolution within the framework of the study of both Big History and evolution. The lack of attention to chemical evolution is all the more disappointing since it is a very important part of megaevolution and Big History, which at some of its stages even act as the leading line (in particular, in the formation of pre-life on the Earth five billion years ago). The paper presents a brief history of chemical evolution: from the formation of the first atoms in the Universe to abiogenesis on the Earth, that is, the stage of pre-life and the formation of prerequisites for the emergence of the first living organisms. The history of chemical evolution before life's origin can be divided into three stages: the formation of atoms (pre-evolution); history before the start of the abiogenic phase on the Earth; and abiogenic chemical evolution. However, the author aims to elaborate a more detailed periodization of chemical evolution before life's origin. One should also pay attention to the important feature of chemical evolution which distinguishes it from other lines of evolution, namely, its co-evolutionary nature. The author demonstrates that chemical evolution at all its stages acted as a part of a co-evolutionary tandem: first, as a part of cosmic and stellar-galactic evolution, then as a part of planetary evolution since it is on planets (where temperature parameters are much more comfortable for chemical reactions) that a new qualitative stage in the development of chemical evolution begins. Finally, on the Earth, it developed first as a part of geochemical evolution, and then as a part of bio-chemical evolution, and this development continues until now.

Keywords: chemical evolution, megaevolution, Big History, cosmochemical evolution, co-evolution, bio-chemical evolution, geochemical evolution, star-galaxy era.

Introductory Notes

It is strange, but there is little, if any, research on chemical evolution in the framework of the study of Big History. Why? This is a difficult question. Perhaps, no one knows the answer. I do not know it either but I have an idea, which will be presented below. One way or another, considering the chemical line of Big History can significantly enrich our ideas and understanding about the general course of Big History and about the path to increasing complexity. Moreover, without understanding the history of chemical evolution, one can hardly grasp either the mystery of the origin of life and development of life in the early periods.[*]

However, the question of the formation of the chemical elements has always been among the most important questions and remains so today. Among seminal works is the 'The Origin of Chemical Elements' by R. A. Alpher, H. Bethe, and G. Gamow (1948). The Alpher–Bethe–Gamow theory explained correctly the relative abundances of the isotopes of hydrogen and helium. The mistake was in the idea, that all atomic nuclei are produced by the successive capture of neutrons, one mass unit at a time. Later it was recognized that most of the origin of heavy elements was the result of stellar nucleosynthesis in stars. The stellar nucleosynthesis theory supported it with astronomical and laboratory data first suggested by E. M. Burbidge *et al.* (1957). The authors identified nucleosynthesis processes that are responsible for producing the elements heavier than iron. The paper became highly influential in both astronomy and nuclear physics.

The process of formation of elements up to and including iron took place mainly in the cores of stars. But the cosmic origin of elements heavier than iron has long been uncertain (Kasen *et al.,* 2017). At present this process has become clearer. Two types of processes are distinguished: s-

[*] See Bernal, 1969; Betekhtin, 2007; Galimov, 2008; Glyantsev, 2019; Guotmi & Cunningham, 1960; Degens & Reuter, 1967; Dickerson, 1981; Dobretsov, 2005; Zavarzin, 2003; Zaguskin, 2014; Calvin, 1971; Kamshilov, 1970, 1979; Lima de Faria, 1991; Rudenko, 1969; Spiridonov, 2019; Haldane, 1949; Lyons *et al,*. 2014; Grinin, 2013, 2017, 2018, 2020; Grinin & Grinin, 2019.

process (the slow neutron-capture process) and r-process (the rapid neutron-capture process).

S-process. Previously it was known that processes that create elements heavier than iron occur as a result of supernovae explosions, when some stars become supernovae at their demise and spew those s-process isotopes into interstellar gas. And both explosions and results of s-process were observed due to astronomical observations. They believe that the s-process is responsible for the creation (nucleosynthesis) of approximately half the atomic nuclei heavier than iron. However, it was unclear how very heavy elements were formed.

R-proccess. Another – rapid – process for the formation of elements heavier than iron (the r-process) has also been described theoretically. In fact, to create elements heavier than iron, such as strontium, an even hotter environment with a large number of free neutrons is required. Rapid neutron capture occurs in nature only under extreme conditions and environments, where atoms are bombarded by huge numbers of neutrons. This is observed in very rare cases. When two neutron stars merge, an explosion occurs. This event is called kilonova. As a result, conditions are created for the synthesis of a large number of elements heavier than iron. This event was observed in 2017, resulting in the identification of strontium in the spectral analysis. In addition, during the observations, a large amount of new data was collected. In particular, it has been recorded that heavy elements, such as gold, platinum and uranium are formed during neutron star mergers. The observational results and theoretical conclusions have been published in *Nature* (Kasen *et al,.* 2017; see also Yamazaki *et al.,* 2022; Arcones & Thielemann, 2022; Curtis, 2023).

Thus, about half of the abundance of elements heavier than iron originates in some of the most violent explosions in the cosmos (Curtis, 2023). Note that the very important rule of evolution – the Rule of coincidence of unique conditions for the emergence of qualitatively new phenomena – is clearly manifested here (for more details see Grinin, 2017). Supernova is a rare event. But kilonova is an exceptionally rare event, where the colossal energy is concentrated, and only this amount of energy can produce such a result.

So the formation of hydrogen, helium and a small amount of lithium atoms (Johnson, 2019: 474) in the first period after the Big Bang, and the accumulation of heavy element atoms as a result of the star collapses were the most important events in chemical evolution. However, the formation of atoms cannot be yet considered as a chemical evolution in the full sense of the word. Chemical evolution is *the emergence and development of different and more complex types of molecules and substances.* One should realize that such evolution could hardly begin in a very hot universe, nor could it take place in the depths of stars.

Thus, it is important to realize that chemical reactions:

a) can occur when the temperature drops to 5,000 degrees Kelvin, but in fact the most favourable condition for them is at relatively low plus temperatures[1];
b) take place constantly in space, even at deep sub-zero temperatures; some of the characteristics of such chemical reactions are known from the studies of gas and dust clouds;
c) should be even more active within the framework of evolution of planets and other bodies (including comets), as can be inferred from studies of the bodies of the Solar system.

Chemical Evolution as a Peripheral and Parallel Line of Big History

Chemical evolution can be regarded as a peripheral and parallel line of Big History. Why? From the argument above, one can make the following important conclusions: firstly, the chemical evolution could only begin after the cooling of the Universe. Secondly, it always evolved not in the main sequence, that is, not in stars and galaxies, but at the periphery of the Universe. It developed mainly in gas and dust clouds and on peripheral celestial bodies, especially on planets. And consequently, for many billions of years, the 'achievements' of chemical evolution have been somewhat invisible (see Figs 1, 2). Thirdly, since the formation of the Solar System the planets can no longer be considered as peripheral bodies, because the planet Earth played a significant role in the further course of evolution and Big History. However, the peripheral character of chemical evolution was preserved. As shown below, chemical evolution only in one case appeared in the center of the mega-evolution development, namely, during the abiogenic phase of Big History. This phase turned out to be very important, but nevertheless, it was transitional one. Fourthly, later, the role of chemical evolution was important,

[1] Therefore, chemical compounds cannot form in stars, but only on the surface of not hot or cooling stars. It is also possible after the collapse of stars, when a significant amount of matter is ejected into space and rapidly cools down.

but it was supplementary rather than central, so it can be considered as peripheral, sometimes approaching the central line of Big History and mega-evolution. The question may arise: If life is not peripheral and is only known to us on a planet, how can we argue that chemical evolution is peripheral just because it occurs on planets? Of course, life is the most important phase of Big History and mega-evolution. And life would be impossible without the powerful development of chemical and biochemical evolution. But here one should take into account the additive nature of chemical evolution. It is extremely important, but it does not play a central role, it only has an additional or co-evolutionary role. At the same time, the role of chemical evolution in the biosocial and social phases, although still significant, decreases compared to the biological phase.

All this gives reason to regard it as a peripheral and parallel line of Big History. However, since the terms 'peripheral and parallel lines of Big History' are new and are first introduced in this paper, the distinctions between parallelism, peripherality and co-evolution need to be clarified for a better understanding. We hope to do this in our future works.

Let us now return to the question of why so little attention is paid to the chemical evolution. I believe that one of the main reasons is the parallel development of chemical evolution within Big History. Other reasons are its co-evolution with geological and biological evolution and the fact that we know very little about the abiogenic chemical evolution. This, however, in no way diminishes the role of chemical evolution; but, on the contrary, it makes its study really relevant.

Chemical evolution began even before the star-galaxy era, that is, already in the first millions of years after the Big Bang, in gaseous hydrogen-helium clouds. This is where the first molecules were formed. But, of course, this evolution could not proceed actively without the formation of a sufficient variety of chemical elements. Thus, chemical evolution progressed in parallel with the star-galaxy evolution. At the same time, (in clouds, on planets, in comets and meteorites, etc.) there are many dozens of different not only inorganic but also many organic substances, including water, alcohols, acids, monosaccharides and even amino acids, in particular glycine. The synthesis of simple organic substances constantly occurs in various cosmic environments.

We do not know when the first planets formed, but with their emergence, the rate of chemical evolution increased considerably due to the variety of chemical processes on the planets, including in different gaseous and liquid media.

The scheme (see Fig. 1) demonstrates the unfolding of Big History, the structure of which consists of ten phases – five major phases and five transitional ones. On the left one can see the line of chemical evolution.

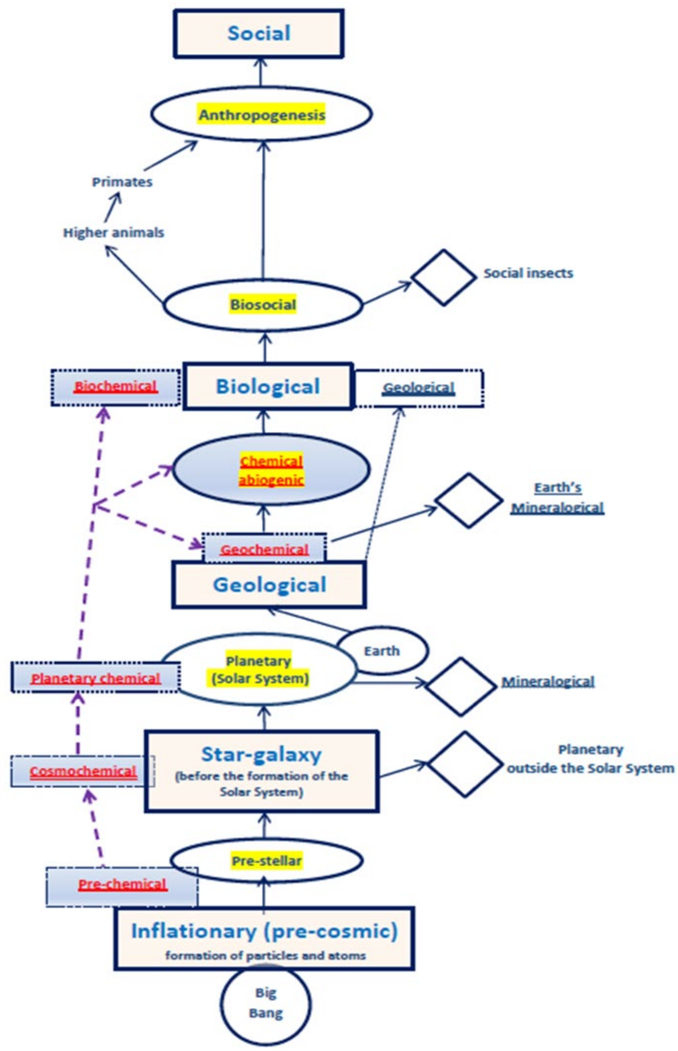

Fig. 1. *Unfolding of Big History (Megaevolution). Phases and lines of Big History*

Periodization of Chemical Evolution

We distinguish the following sequence of stages of chemical evolution before the origin of life:

1) the formation of atoms of the first elements (hydrogen, helium, and lithium);
2) the formation of atoms of heavier substances up to

iron, as a result of which a small number of the hydrogen and helium in the Universe has been transformed into the wide array of elements on the periodic table (Johnson 2019: 474);

3) the formation of atoms of elements heavier than iron[2];
4) the formation of simple compounds (inorganic and organic). [However, it is important that the second and third stages could take place in parallel with the fourth one, but in different environments: the second and third stages in stars, while the fourth one in less hot environment.]
5) the formation of compounds associated with the formation of minerals on planets;
6) synthesis of more complex organic compounds like nucleotides taking place already on the Earth;
7) synthesis of more complex substances and polymers, including proteins, not yet capable of replication; and
8) synthesis of replicators and substances associated with the origin of life.

Now let us consider the correlation between chemical evolution and Big History.

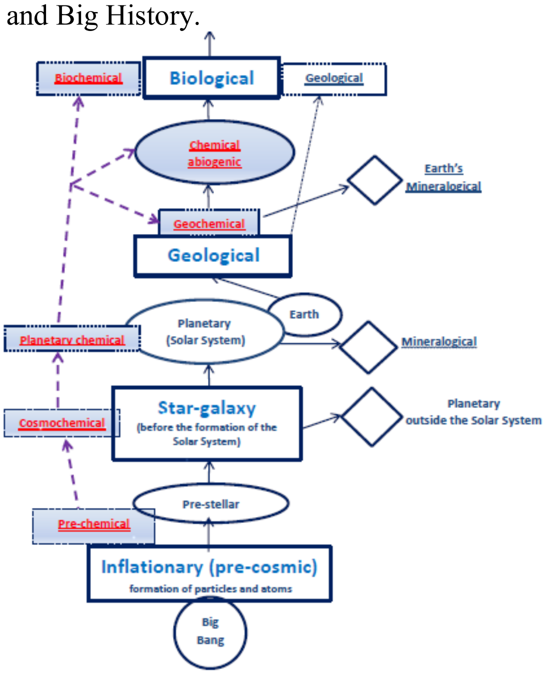

Fig. 2. *Chemical evolution as a peripheral and parallel line of Big History*

The Distinctive Features of Chemical Evolution from Other Forms of Evolution in Big History

Figs 1 and 2 show the important features of chemical evolution which distinguish it from other forms of evolution. These features are as follows:

1) All other forms of evolution are separate phases of Big History. Thus, one form of evolution, having been realized at a certain phase of Big History, is replaced by another form.
2) However, chemical evolution goes parallel to the course of Big History. More precisely, it co-evolves with different phases of Big History as a constituent part of each of them. Thus, one can see that chemical evolution acted as a part of a co-evolutionary tandem at all phases of Big History (see Fig. 3).

Let us now briefly consider the development of chemical evolution in its relation to the phases of Big History.

Chemical evolution after the Inflationary phase appears as a part of the Pre-stellar phase. I have pointed out above that chemical evolution began in pre-stellar clouds. But it was still pre-chemical evolution.

The star-galaxy phase, which includes the formation of planets outside the Solar System, corresponds to Cosmochemical evolution. It is during this phase that the first chemicals are formed. Thus, a new qualitative stage in the development of chemical evolution (where the temperature was much more favourable for chemical reactions than in stars), began on ancient planets. However, we know practically nothing about this evolution.

With the formation of the Solar System and the beginning of the Planetary phase, one can talk about the Planetary chemical evolution since we know quite a lot about chemical processes and substances on the planets of the Solar System.

[2] But here, as we have seen above, the formation of the elements heavier than iron occurred in two ways. For more details about when and how the process of nucleosynthesis made elements in different ways, including dying low-mass stars and white dwarfs see Johnson, 2019.

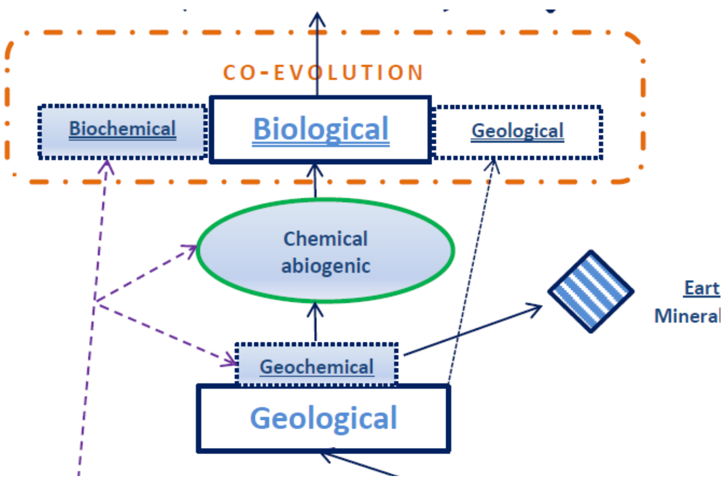

Fig. 3. *Chemical evolution on the Earth and its increasing evolutionary role. Phenomenon of co-evolutionism*

The formation of the Solar System means that the main line of Big History begins to focus on the Earth, where geological processes begin. Finally, on the Earth, chemical evolution developed first as a part of geological and then as a part of biological evolution. This development is still ongoing.

Thus, for the first time, chemical evolution moves to the center of evolutionary development at the level of chemical abiogenic phase (see Fig. 3). In this phase the role of chemical evolution rapidly increases to the level of a transitional phase.

The period between the formation of the Earth and the emergence of life was pivotal for the whole Big History, and at the same time, the least known and the most obscure. During this period chemical evolution was integral and interrelated with geological, mineralogical and biological evolution. It was the co-evolutionary tandem mentioned above.

From the Abiogenic Phase to the Origin of Life

Strengths and Weaknesses of Evolutionary Hypotheses about the Origin of Life

There are various hypotheses about abiogenic chemical evolution and the origin of life including the so-called RNA world. Although some progress has been made in many respects, especially in the last fifteen years, none of them seems to be completely satisfactory yet. This is mainly due to the extreme complexity of the problem itself. But from the point of view of evolutionary theory, the weaknesses of these approaches are in the following points:

1. They deliberately or involuntarily reduce evolution to one of its lines.
2. They take one evolutionary mechanism as the main one in all cases.
3. The achievements of later periods, already related to the biological phase, are extrapolated to the abiogenic phase.

We believe that the possibility of a major breakthrough exists only if there are a number of different development lines and paths. Moreover, each of these lines is limited and usually develops only one mechanism or innovation. But these lines compete and complement each other. As a result, there comes a time when the innovations of different lines are merged and formed into a fundamentally new system. This means the beginning of a powerful breakthrough to a new level of complexity. However, the beginning of such a breakthrough, after the formation and development of the new level is difficult or even impossible to detect. This corresponds to the important idea of Pierre Teilhard de Chardin (1987) that transitional forms leave no visible material traces. We have also formulated the rule of archaic character of primary systems. Systems do not emerge in the mature form. They usually require several transformations to reach maturity and sustainability, including cycles of destruction and reforming. Primary systems as a rule look archaic and are unlikely to survive.

Therefore, the first pre-living systems (the so-called protobionts) should not be considered as direct ancestors of the first living organisms, but as their analogues. These analogues were already comparable to the most primitive living systems in a number of functions. But in general they were organized differently (it is now extremely difficult to say how exactly). In addition, one should also take into account that the conditions on the young Earth were peculiar. Consequently, such structures could have formed, but modern scientists are unlikely to believe in their existence until concrete facts are available.

The Evolutionary Directions of Abiogenic Organic Substances

Thus, one can argue that the evolution of abiogenic organic substances occurred in the following different directions:

a) increasing complexity of chemical compounds and structures;
b) increase in energy output and reaction rate;

c) selection of elements and compounds according to certain parameters;
d) concentration of substances;
e) the ability of complex compounds and proto-organisms to expand and grow fast.
f) the selectivity and recognition of some substances by others, according to the important evolutionary pattern for self and non-self discrimination.

The Most Important Pre-Adaptations for the Beginning of Biological Evolution

The important pre-adaptations are worth special mentioning. The most important ones for the beginning of biological evolution are:

1) creation of a system isolated from the external environment, in which constant cycles of chemical and biochemical reactions could take place;
2) constant maintaining of conditions, concentrations, energy balance, the desired rate of reactions within this isolated environment, *etc.*;
3) effective responses to external conditions and stimuli;
4) replication (*i.e.*, the ability to reproduce);
5) preservation without major distortions of the initial code;
6) control of complex chemical processes through the use of increasingly advanced catalysts and substances;
7) autocatalysis and the ability to self-assemble.

These breakthroughs and pre-adaptations laid the foundation for biochemical synthesis and expansion. Especially important were the ability to store energy, and the ways to speed up reactions and to increase the concentration of a substance. Along with this, a new type of information (chemical and biochemical) emerged, which reached a very significant development later in biological evolution.

These and other achievements, of course, could not combine immediately and simultaneously. They combined much later when the basic mechanisms of life and the living cell were formed.

The primary conditions after the origin of the Earth were unique. Without them the transition to the emergence of pre-life and then life was impossible. Will these unique conditions ever be precisely known? Probably, they will not. But in any case, there must have been an abundance of available energy. Consequently, the fundamental difference between abiogenic chemical evolution and the previous stages of evolution was *the acquisition of the ability to store energy through chemical transformation during a system's lifespan and to use it for its own benefit.*

Protoviruses

There may have been one more intermediate phase between the abiogenic chemical and biological phases – the phase of protoviruses (see Fig. 4).

Below we will show the possible place of this phase in the megaevolutionary process. One should take into account that chemical reactions played a great role in the origin and development of protoviruses.

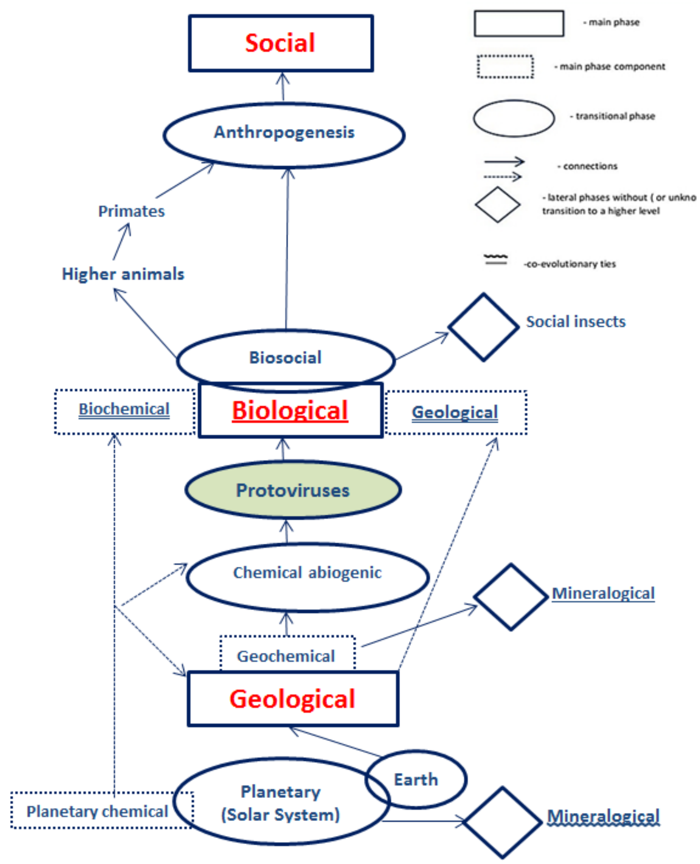

Fig. 4. *Evolutionary phases of Big History including the phase of protoviruses*

Conclusive Remarks

For a long time, the abiogenic organic chemical evolution was only lateral and marginal in the general flow of inorganic chemical evolution. Then it was able to advance to a new level of evolution, *i.e.,* to life, taking place in a complex co-evolutionary movement. Abiogenic chemical evolution was involved in a whole bundle of evolutionary developments: geological, mineralogical, and geochemical. Thus, one can assume that initially one of the most important directions of chemical evolution was the integration of protobionts into geochemical processes, such as sulphur springs, and the development of the ability to use these processes for one's own benefit.

Thus, gradually abiogenic chemical evolution gained momentum.

However, the role of chemical evolution remained very important. It again becomes a part of a larger – the biological – phase. In the scheme of the phases of Big History, we do not trace a further development of chemical evolution, but one should remember that it has also become an important component of social evolution, which can be called sociochemical. At the same time, its importance begins to appear already in the phase of anthropogenesis, from the moment when humans learned how to control fire. It is widely known that there is no point in talking about the further role of chemical evolution in the social phase of Big History, it is widely known. Nevertheless, one can argue that neither technology nor ordinary life would be possible without continuous efforts to master new chemical substances and reactions.

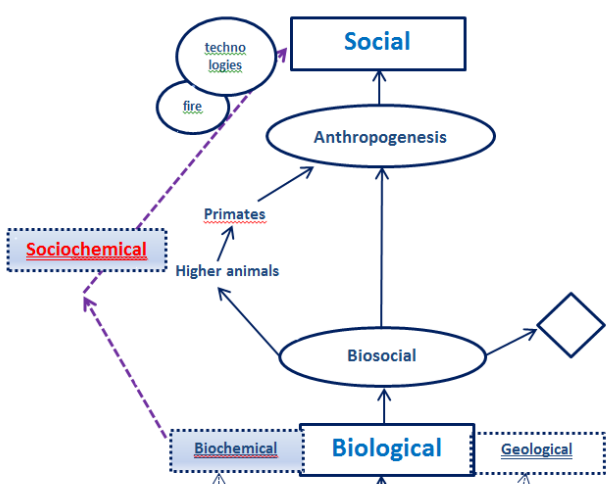

Fig. 5. *Sociochemical evolution*

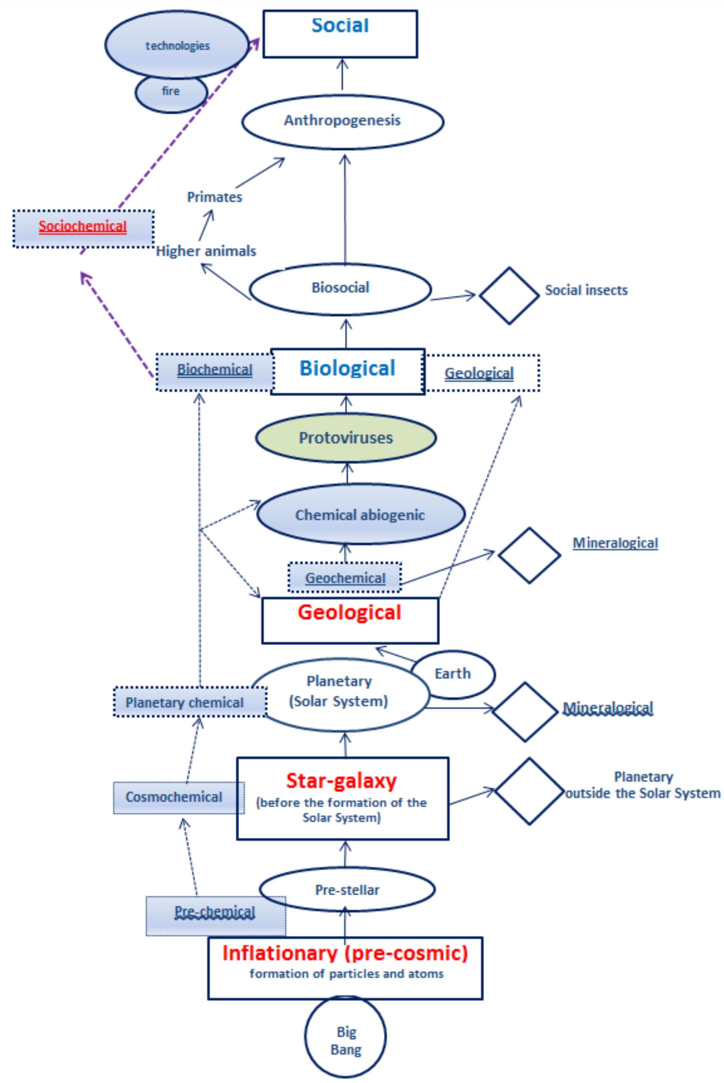

Fig. 6. *The complete line of chemical evolution from the Big Bang to social evolution*

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Complexity: A Rationale for the University

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Abstract: Complexity provides a unifying theme that responds to fundamental questions about the emergent structure of the universe as well as human nature. It offers an intellectual framework for disciplines throughout universities. It structures a universe of knowledge across natural sciences, social sciences, and the humanities – from quarks to global societies and human fascination with inter-galactic relations. Ideas of complexity begin with its unidirectional emergence from the big bang to us now. The idea is developed by its multidirectional emergence that includes narratives from the big bang to planets, galaxies, and life forms other than our own. Furthermore, complexity often entails stasis, with levels of complexity remaining as they are, reversing to simpler levels, or all or parts of nature ending altogether. Speculations about multiple universes lead to an idea of infinite complexity.

1. Introduction

The topic of complexity draws on a universe of knowledge and presents an intellectual rationale for the contemporary university. The topic, like the contemporary university, is predictably complex. Universities house multiple schools, colleges, departments, centers, and other administrative units. Unifying key evidence from each of its disciplines to substantiate an account of a universe of knowledge provides an intellectual rationale rather than just the administrative organization of a university. Complexity is one theme that lends itself to that rationale. It includes the ideas of unidirectional and multidirectional emergence, statis, devolution, and infinity.

Emergent complexity responds to age-old fundamental questions. "Like our ancestors, we look up at the heavens and wonder. What is the structure of the universe? How significant are we? Are we alone?" (Library of Congress, n.d.) How did we get here? What does that mean for who we are now and what we can reasonably expect in the future? Complexity is one theme that permits all the disciplines within universities to contribute to a coherent set of responses to such questions.

Disciplines from the natural sciences, social sciences, and humanities contribute evidence towards a substantiated account of development from quarks, protons and neutrons, atoms with 1 or 2 protons and electrons, stars and galaxies, atoms with more than 2 protons, chemicals, second and third generation stars, terrestrial planets like Earth, the origin and increasing complexity of life forms, one of these forms being hominins and then humans, and increasingly complex relationships among humans in kinship groups, villages, cities, nations and empires, and global systems. Humans, each with a hundred billion neurons and maybe a trillion synapses, now number some 8 billion, with more humans connected digitally to each other than ever before. And throughout the human experience, our species has looked to the skies and wondered what our place is in the cosmos.

Emergent complexity does not only go from the big bang to humans, although it does do that as well. Rather, it is multidirectional. It leads to different types of stars, galaxies, planets, and life forms. The known life forms are still those on Earth, but astrobiology suggests that they may well be evolving elsewhere as well.

Also, complexity does not always continue to emerge. Those units within each new stage of complexity often remain in stasis; they do not become more complex. Additionally, complexity includes reversal as well as emergence and stasis.

What complexity has existed often breaks down into simpler levels. The emergence to increasingly simple levels of complexity eventually leads to endings or death. There is informed speculation at the universal level about this leading to rebirth or a new cycles, as well as about the greatest complexity being an infinite number of types of universes.

2. The University, the Universe, and Unidirectional Emergence

Unidirectional emergent complexity, the traditional big history account, which leads us from the big bang to humanity, offers an important rationale for contemporary universities. The International Big History Association defines the field of big history like this: "Big History seeks to understand the integrated history of the Cosmos, Earth, Life, and Humanity, using the best available empirical evidence and scholarly methods." Some major sources on big history include books, presentations, and textbooks (Stokes-Brown, 2007; Chaisson, 2006; Christian, 2004, 2008, 2010, 2011, 2015; Christian, Stokes-Brown, Benjamin, 2014; and Spier, 2015).

Contemporary universities very often cover portions of this account in their departments and disciplines. Evidence about the cosmos is especially included in physics and astronomy. Material from chemistry is included in all four areas. Geology and geography are especially important in the history of the Earth. Biology is central to the discussion of life's origin and evolution. Physical anthropology presents the origins and evolution of hominins to humans. Once we get to human studies, the range of social sciences, humanities, law, nursing, medical, business, and engineering provide material about collective learning that big historians examine. The many departments and colleges within universities have been able to provide so much important knowledge because of their disciplined foci. This often comes at the expense of synthesizing knowledge from different disciplines. The tremendous work that has been done within disciplines has overwhelmed universities' attempts to provide an intellectual rationale for themselves within a universe of knowledge. Directionless programs in "General Studies" rarely make an effort to synthesize knowledge. Universities rarely seek to succinctly offer students a single course or major which value synthesis of all disciplines. Expertise and intellectual skills from the dissection of knowledge are the best many have to offer.

Universities have sometimes come to operate as holding companies for a variety of colleges. A college is often a holding company for a variety of disciplines. Even disciplines are sometimes uneasy collections of sub-fields without clearly stated definitions. Specialization and expertise are often seen as the key intellectual virtues and the only justification for research support. Hiring, prestige, tenure, and promotion are generally tied to recognition by disciplinary programs and journals. College and university administrators struggle to meet budgets, allocate available funds and hiring lines to departments and colleges, and generally keep the trains running on time. Deans and provosts do not always have the luxury to reflect on intellectual mission.

The study of unidirectional emergent complexity seeks to overcome this difficulty and provide an intellectual rationale – a complex universe of knowledge – to which all disciplines of the university contribute. Each part of this account has been made possible only through disciplinary focus. The account as a whole would be possible through the synthesis of each of these parts all within a university; this needs to be done within a course or a series of courses far more often than it is.

3. Disciplines and Unidirectional Emergent Complexity

3.1 Physics and Astrophysics

3.1.1 Big Bang

The beginning of our story is the big bang of 13.82 billion years ago, sometimes thought to have emerged from an infinitely hot and dense point without mass, or nothing (Sing, 2004). Or not. It may be that nothing is really something; it is always pulsating and foaming and regularly turning into a variety of forms of something. Perhaps we live in a popcorn multiverse with an infinite number of big bangs going off all the time in ways we cannot detect or imagine (Greene, 2011). Other universes with different fundamental laws and forces may be sharing our space or off in other locales. Or maybe our own yo-yo universe has an infinite set of cycles of trillions of years (Steinhardt, 2007).

We used to think there was only one galaxy, that the Milky Way was the universe with a few clouds of something or nebulae circling around it. Then we wondered if there were other inhabitable planets. We now know there are great numbers of both, many or most of which we cannot currently see as they are now. Why should ours be the only universe? However, for now we will prosaically restrict our attention to our own universe.

The extraordinarily hot and dense radiation and plasma immediately after the big bang was dramatic. A second after the big bang, the temperature is said to have been 10^{32} Kelvin degrees, or 18 billion degrees Fahrenheit (Hooper, 2019). It was as largely as uniform a situation as has existed in our universe's history.

All but immediately after our own universe's big bang, when energy first congealed into normal or baryonic matter, six types of quarks appeared. They can appear again if protons and neutrons are smashed into each other at sufficient energy levels, which is done rather routinely at Fermilab and CERN. Four of these quarks lead extraordinarily brief lives before returning to energy; they do not go on to form more complex forms of matter. However, two of them – the up and down quarks – did form relationships as they appeared. This will be a pattern. Some things go on to participate in emergent complexity. Many do not.

For a billion and one bits of matter that appeared, a billion bits of anti-matter did as well. "Antimatter particles share the same mass as their matter counterparts, but qualities such as electric charge are opposite. The positively charged positron, for example, is the antiparticle to the negatively charged electron" (CERN,n.d.). Rather than playing well together, matter and anti-matter annihilate each other. This mayhem is a rather good thing from our point of view, since if all the matter that appeared survived, the universe would have been just too crowded to ever have developed into us. And plenty remained. Enough matter to eventually make a hundred billion galaxies each with an average of a hundred billion stars all have been formed by the leftovers of the great annihilation. Those quarks that survived formed relationships that have lasted billions of years. Destruction can be very creative.

The lucky surviving quarks did not exist in isolation; they formed pairs or threesomes. Their relationship is structured by the strong force that is mediated by the exchange of the charmingly named gluons. Two quark pairs are mesons (often very short-lived); threesomes are often very long-lived baryons, whether protons or neutrons. Two up quarks and a down one form a positively charged proton; two downs and an up form a neutron. All that were formed were single or double protons, what would become later the nuclei of hydrogen and helium with a very small smattering of deuterium and others. It was too hot and dense for protons to form relationships with electrons, so there were no atoms yet.

Why is the strong force exactly as strong as it is and not weaker or stronger? Is it different in other universes? Who knows? It is just the way we do things in our universe. But if it differed at all, we would not be here and neither would anything else that we know of.

The quarks do not merge into one undifferentiated blob. Each proton and neutron is constituted by two different types of quarks. Relationship includes individuality. The one and the many exist together. The quarks relate to each to other through the strong force, but they keep their distance as well. Relative to their own size, quarks have a rather pronounced need for personal space. Each of these three move in a constant dance around the others. They are always related, always moving, always distinct. Nature at rest is hard to find. Nature is spinning, moving, and restless.

The protons and neutrons that were formed quickly after the big bang are with us still after almost 14 billion years. In fact, they are us, and everything else that we can see or feel. The structured relationships among individual quarks have been remarkably sustained. There are a lot of them that make each of us. As inventive and creative as nature is, it also keeps certain things around for a long time. And as we will see, lots of very new and more complex types of relationships keep forming. If liberalism is about change and conservatism about keeping things the way they are, we can answer an interesting question. Something came from nothing (or something else) at the big bang. That is change. Quarks can maintain their relationships for tens of billions of years. Can't get much more of a status quo than that. So is the universe liberal or conservative? And the answer is – yes.

About three hundred and eighty thousand years after the big bang, when the universe had expanded enough to cool to around 3000 degrees Kelvin, the electromagnetic force mediated by the exchange of photons could structure a sustained relationship between protons and electrons. Atoms appeared. Hydrogen, with one proton and one electron, appeared in the greatest numbers. If you add up their mass, about three quarters of all atoms in the universe are still hydrogen. If you count atoms by number, they constitute about 90% of all atoms. They also constitute 63% of the number of atoms in your body (10% by mass). As has been said, hydrogen is an odorless, colorless gas that, given enough time, becomes you. And me.

Helium, with two protons and two electrons each, formed about a quarter of all atoms' mass that then existed (9% by number). There was also a dash of deuterium, or heavy hydrogen (one proton, one neutron, and an electron), helium isotopes, and lithium (three protons and electrons). It's possible that a handful of other atoms existed as well. Vast primal clouds of hydrogen and helium atoms, millions of light years across, still majestically float in certain areas of space nearly 14 billion years later. Some have gone on to form greater complexity; many have not. As Eric Chaisson has pointed out, "Far many more atoms are alone and isolated; only ~0.4% of the universe comprises bound atoms within complex, structured systems, roughly ten times that is loose baryonic (yet still normal) matter, which floats amidst the intergalactic beyond (all else, i.e., the remaining ~96% is "dark," at least to our senses.)" Sometimes complexity emerges; more often it doesn't.

Once formed, and left on their own, these atoms tended to keep their distance. While the strong force bound quarks together and protons and neutrons together within atoms, these atoms left to themselves generally liked their own company. They might approach each other as they moved about, but usually swerved off, avoiding connections with each other.

We sometimes hear about an "atomistic society." This usually refers to a rather asocial condition in which individuals have little to do with each other. The analogy might be a billiard table, with hard billiard balls usually sitting by themselves, but occasionally knocking into each other, sending each other off in various directions. Atoms may be the basic building blocks; but in our experience, blocks usually just sit there by themselves. We are each made of about $6.7*10^{27}$ atoms. What are we then like at our most constitutive level? Are we like the individuals discussed by Hobbes in the *Leviathan*? Do we live lives largely isolated from others? The only natural relationship is hostility; a war of all against all. By nature, are we as asocial as atoms? Should Libertarians seek out new sympathizers among the universe's vast majority of unaffiliated atoms? If we seek to form relationships, do we need to find ways to overcome our natural proclivity for individualism? Are atoms the ultimate existentialists, destined to live lives of lonely desperation and then die alone? On a dark, rainy night. And since we are built from atoms, is that what we are really like, all niceties aside?

But what if the story of which we are a part is one of emergent communitarianism rather than the individualism so celebrated in Western Liberalism.? Recall that even the simplest of atoms – those that have only one or two protons and are still the most abundant in the universe – are each a set of sustained, structured relationships. Quarks which just moments before had not existed, started to be related through the exchange of gluons mediating the strong force. Atoms, which had not existed before the big bang plus 380,000 years, added a relationship between protons and electrons. Atoms are sets of sustained, structured relationships.

At our most constitutive core, we are built more from relationships than from building blocks. Quarks and electrons are more fuzzy than blocky. Their "hardness" comes from forces defining their relationships. What exists between things is as real as the things themselves.

3.1.2 Stars

But what about atoms naturally avoiding each other? Relationships within atoms are fine, but beyond that, they naturally stay at a distance. Well, atoms are not left to their own devices. They exist within a larger framework that acts upon them.

When they did form, atoms were not perfectly distributed, if by perfect you mean absolutely equally. They were a little more densely distributed here, a little less there. This asymmetry, unequal distribution, or imperfection was another very fortunate occurrence. Inequality can contribute a lot. Gravity has no force at the relatively small distances between quarks. However, the space between slightly densely packed atoms can be just enough to let it start operating. A larger clump of atoms here can exert gravitational attraction on a smaller clump there. If all atoms had been equally distributed, their gravitational attraction on each other would have canceled it all out, and they would never have been drawn to each other. However, with the asymmetry, the denser regions could start drawing in the slightly less densely packed atoms. Gravity kept pulling them together, increasing their density and heat. (It may be that there just is not enough normal matter to have created enough gravity to have had the effects that we will soon see. It seems to be that there is "dark matter" that actually creates the additional gravity necessary to form the universe's structure that developed.)

As atoms were pulled closer together, they began to spin faster like a figure skater drawing in her arms. Once sufficient density and heat developed, with atoms moving about more and more quickly, the atoms overcame their preference to stay away from each other. More accurately, the Coulomb barrier refers to the electrostatic interaction that two nuclei need to overcome so they can get close enough to fuse. The protons needed to "tunnel" through this barrier to overcome the Coulomb barrier and fuse into one heavier element. The result of the quantum tunneling was to produce a two-proton helium nucleus. all held together by the strong force. Most protons remained separate, but enough fused to maintain a star's fusion reaction.

Each newly fused atom was less than the sum of its parts. Each new helium atom weighed slightly less than the two hydrogen atoms which had combined to form it. The missing matter had turned into energy. The fusion caused energy to burst out. Gravity kept trying to draw the atoms in. The uneasy equilibrium between these two forces resulted in the formation of stars. The black sky began twinkling. The dark age was over.

As the helium was formed, gravity drew it in more, until it heated up enough for it to start fusing into heavier elements, such as nitrogen. This released energy and permitted gravity to draw the newly formed elements further in, until they too began to fuse, forming carbon and neon. This was repeated as oxygen, magnesium, silicon, and sulfur were each fused. The largest stars with enough mass to permit gravity to keep drawing the newly fused elements further in developed an onion like structure, with the lighter elements on the periphery; the heavier ones successively formed layers closer to the core. Not only can there be new things under the stars, the stars themselves were something new. The strong force, electromagnetism, gravity, and fusion formed relationships between atoms within the structure of a star.

Gravitational attraction between stars and dark matter formed galaxies or groupings of stars in distinct patterns. Galaxies formed relationships due to gravity in local groups and even larger patterns. The theoretical work of Fr. Georges Lemaître, confirmed by the evidence collected by Edwin Hubble, demonstrated that not only were there more galaxies than our own Milky Way, but that once they got to be further away from each other than those in the local group, they are racing away from each other. It may be that dark energy or anti-gravity is causing the galaxies to keep falling out, with space and the universe expanding at ever faster speeds the further from each other they are. It may also be that the relative amount of dark energy has been changing over the course of universal history.

When the largest of the stars began to make iron with its 26 protons, energy was consumed rather than released. The equilibrium between gravity and fusion was broken. Almost immediately, the star exploded in a supernova. The sudden increase in temperatures during the explosion permitted the almost instantaneous formation of all of the elements with more than 26 protons per atom, all sent streaming into space at incredible speeds, often mixing with pre-existing clouds of hydrogen and helium that had been floating since the big bang.

3.1.3 LIGO and NANOGrav

Another way of forming all the elements in the universe could come from the collision of neutron stars, which could be detected a billion or more years later as having also produced gravitational waves. In 2016 the Laser Interferometer Gravitational-Wave Observatory (LIGO) detected the gravitational waves predicted by Einstein a century before. Two observatories used mirrors that were placed four kilometers apart and could detect a wave of less than one ten-thousandth the diameter of a proton that had been traveling across the universe for a billion years since two neutron stars collided. Adam Frank (2023) lyrically writes of observations of the North American Nanohertz Observatory for Gravitational Waves (NANOGrav):

> *The whole universe is humming. Actually, the whole universe is Mongolian throat singing. Every star, every planet, every continent, every building, every person is vibrating along to the slow cosmic beat.*
>
> *That's the takeaway from yesterday's remarkable announcement that scientists have detected a "cosmic background" of ripples in the structure of space and time.*

In addition producing waves, colliding neutron stars are, along with fusion within stars, another way of fusing elements with fewer protons into element with great numbers of them, or virtually all the elements. So your gold ring could have been made in a supernova or in a neutron star collision. In one way or the other, we get the full range of atoms.

3.2 Chemistry and Molecules

Atoms form in such a way that electrons orbit protons in shells. The innermost shell is full with two electrons, the second with eight, the third with eighteen, the fourth with thirty-two, the fifth with fifty. Hydrogen, with its one electron, has a vacancy sign out in its only electron shell. That shell seems to want one more electron to form a full house. Oxygen, with its eight electrons, has two in its first shell and six in its second. This leaves two vacancies in its second shell. This is a match made in the heavens. If two hydrogen atoms hook up with an oxygen atom, each sharing their electrons, each hydrogen atom can have two electrons in its only shell and oxygen can have 8 in its second shell. Everybody is happy because a new relationship between atoms is formed: H2O – water. This molecule has a new property. At the right temperature, it has the property of wetness, which did not exist before. Water, which is abundant throughout space, is not the only molecule that forms. Dozens of molecules with 2, 3, 4, 5, or more atoms evolve naturally. Many atoms due to the way electron shells work led to the formation of these new relationships called molecules.

Not all atoms are anxious to form molecules. Helium has two electrons in its only shell and has a No Vacancy sign well lit. It is called a noble gas. Having all they need; nobility does not require additional relationships with the lesser types that are needy. Relationship added to relationship is not much part of helium's story. While hydrogen becomes us, helium often just goes floating off into space. Not everything is social. Not everything forms polity, or sustained, ordered relationships. We saw that same aloofness with four of the six quarks. A subatomic particle formed in nuclear fusion, neutrinos, are much the same. Like photons, they go shooting from stars off into space, but almost never interact with anything. They can sail through twenty miles of lead and never hit anything. It has taken extraordinary measures to detect them at all. History and polity are not built on the backs of two thirds of quarks, neutrinos, helium, or other asocial phenomena. They are indeed the rugged individualists of the universe. The story of emergent complexity is not uniform.

3.3 Geology, Earth

After a nearby supernova shot its star dust out into neighboring space, disturbing pre-existing clouds of hydrogen and helium, gravity again began pulling together the mixture of elements and molecules. A second-generation star with mostly hydrogen and helium but also with traces of heavier elements in it – including oxygen, carbon, neon and iron – eventually began shining. This process may have been in its third round when our sun formed 4.6 billion years ago. It is not big enough to permit gravity to create densities high enough to fuse elements heavier than helium. This is good for us, since huge stars live fast and die young. Our sun goes along at a nice leisurely pace of fusing 600 million tons of hydrogen each second, turning it into 596 million tons of helium and more energy than mankind has ever produced in our species' entire history. It is because of all their mass that stars like our sun produce so much heat and light. Surprisingly, once you get down to the energy released bit by bit, the energy density flow is about the same as a reptile's metabolism.

The sun's rate of consuming its stock of hydrogen will permit it to continue shining for a total of about 10 billion years, meaning it is at mid-life now. Its five-billion-year history has provided energy and the time for earth to develop. We've got billions more years before the sun turns into a Red Giant, evaporates the oceans and engulfs the earth. There is time before anyone needs to get tickets for a trip to another solar system.

While gravity drew together 99.86% of the total mass of the Solar System to make the sun, the left-over debris was put to good use. On the outskirts of the spinning disk that eventually ignited as the sun, these leftovers from part of the supernova started accreting through the power of gravity. Gases and chunks of iron, nickel, silicon, and bits or gold, silver, uranium and other elements and molecules bumped into each other and stuck together. The planets, planetoids, comets, and asteroids were formed. On the emerging new Earth, all this knocking together that created kinetic energy, not to mention the radioactive decay of uranium and other such elements. This made for a molten, hot planet that formed its own structure from thousands of molecules and the minerals they produced. Heavier iron and nickel sank into a dense core that is still as hot as the surface of the sun. Silicon and other lighter elements rose to the top. Eventually, a thin layer made of basalt made for oceanic floors and the frothy granite cooled enough to permit land to form. Lighter, cooler outer layers spinning around denser iron and nickel produced a magnetic shield around the planet that protected it from solar winds that might otherwise blow away earth's atmosphere.

3.4 Biology and the Emergence of Life

The process of chemical evolution that had begun in space continued on earth. The most common elements on the surface of the earth continued to combine in many ways. Hydrogen, carbon, nitrogen, oxygen, sodium, magnesium, phosphorus, sulfur, chlorine, potassium, calcium, iron, and other elements on earth interacted to form over 4,700 minerals. Around black smokers at the bottom of the oceans where tectonic plates separated and mineral rich heated waters bellowed up, on the relatively cooler white (alkaline) smokers, or on sun-soaked pools of water on rocky beaches, the process of chemical evolution continued. Lipids that created films formed, eventually forming membranes. Carbon, with its four electrons in its second orbit and a total of six overall, was able to combine with many other elements, and was central to the Krebs cycle which spins off amino acids. These molecules continued to combine until they integrated membranes, metabolism or access to energy, and RNA and DNA that permitted reproduction with variation in response to environmental changes. The Last Common Universal Ancestor – LUCA – was combined in the most complex relationship in universal history to date – that we know of. The first prokaryote cells were earthlings, formed of the commonly available chemicals and elements on earth's surface. They were also children of the universe, with elements forged in stars that had died long before.

3.4.1 Biological Evolution

It has been said that the dream of every bacterium, the simplest of cells, is to become two bacteria. Reproduction has to be important for any species that plans on surviving, since the death of any given individual is part of the way life works. Sustained relationship is not eternal relationship. The nice thing about being a bacterium is that your dreams can come true about every twenty minutes. Reproduction with variation in response to environmental changes is a skill perfected by prokaryote cells. You just can't argue with success. They live in virtually any setting, however extreme the condition on earth can be. From deep underground to thermal waters, prokaryotes are there. There are more bacterial cells in and on your body than there are cells that constitute your body. They help you digest food. And when you die, they will digest you. These types of cells have survived for almost 4 billion years. They will be on earth long after humans have vanished. Many prokaryote cells follow a plan that isn't broken and doesn't need fixing, although they do keep adjusting to new conditions such as antibiotics. They evolve quickly, but as a group, they have not become fundamentally more complex.

However, after a couple billion years of happily reproducing at their same level of complexity, some did become more complex. A prokaryote cell may have tried to eat and digest a mitochondrial, but instead somehow managed instead to form a long-lasting and mutually beneficial relationship with it instead in a new, more complex type of cell. About two billion years ago, eukaryote cells appeared with a membrane covered kernel in which more complex DNA was kept. Hosting the mitochondrial cell created a new way of obtaining energy; it was now able to burn carbohydrates and eventually permit us to enjoy eating donuts.

A more complex set of relationships within the cell led to more complex relationships among cells. Films of bacteria on the surface of the ocean or accretions of them in rock like formations of stromatolites in tidal pools were steps towards multicellular life forms. One generation of cells died off, only to be covered by future layers of descendants. Another step in multicellular cooperation came with creatures like sponges. These are formed by the same type of cells that could still specialize in serving different functions. Some cells drew in nutrient rich water, others expelled nutrient drained water. Same type of cells; different tasks. Push these cells through a sieve so that they are separated as they fall to the bottom of a tank, and they scoot back together to form another new sponge. These are cooperative cells, not hardy individualists.

Relationships among increasingly complex body structures formed by different types of cells are seen in such examples as cnidarians, or jellyfish, first seen about 800 million years ago. They have little harpoons that can inject prey with poison, have such structures as a mouth / anus, and have two layers of tissue. Their nervous system is pretty uniformly spread out throughout the animal. Jellyfish are still around and doing fine. The Scarecrow in the *Wizard of Oz* seemed to get along pretty well without a brain, and so have the cnidarians. They have existed 4,000 times longer than *homo sapiens* have. They see no reason to develop more complexity.

Still, there were additional mutations that worked out in the environment of the time. Flatworms introduced a body plan about 590 million years ago with a right and a left side, an up and down, and a front and a back. Sense organs were put up front, along with a ganglia of nerve cells to interpret the incoming data. Chordates like the currently existing hagfish put a cord along its back to protect the flow of information from the ganglia to the rest of the body, as well as putting the mouth up front and an anus in the rear. About 525 million years ago, vertebrates started breaking that cord into bony segments, offering better protection and definition. The first animals to venture out from the seas onto land, such as Tiktalik, had wrists to help scoot on land and a neck to help look around. About 360 million years ago, the first amniotes could recreate the watery world in which reproduction had originally taken place, and start producing eggs with a protective shell and watery interior. About 360 million years ago, mammals first appeared, which had, among other things, a more complex auditory system with more parts that helped them hear better. The story of evolution is in part a story of increasing complexity of body structures, with more complex relationships among greater numbers of parts.

3.4.2 Relations among animals and plants

Relationships among quarks, protons and electrons, atoms, molecules, cells, and body parts were followed by increasingly complex relations among and between species. Edward O. Wilson's *The Social Conquest of the Earth* analyzes this phenomenon. From quorum sensing of bacteria to schools of fish, bee hives, ant colonies, flocks of birds, herds of bison, troops of chimpanzees, and many other examples, animals often live in groups and groups often form ecosystems.

Not all animals live in groups. Many seem to exist in splendid isolation for most of their lives, coming together just long enough for reproduction without any care for offspring after birth. Mother guppies and sharks would just as soon eat their babies. Sea turtles lay their eggs on the beach, return to the sea, and may hope for the best for their offspring, but likely don't think about them. Crocodiles help their offspring out of their eggshell and out of the nest; after that, the kids are on their own. Childcare is of course more of an issue for various lengths of time for many species. From weeks of care to a couple years is common. Mothers, fathers, and others are involved in different ways, depending on the species.

3.4.3 Physical Anthropology and Hominins

By the time we get to hominins, our ancestors' survival strategy and increasingly complex sociability went hand in hand. *Australopithicus* and its ancestors were the hunted rather than the hunters. They may have scavenged, eating bone marrow of leftover carcasses, but gathering fruits, nuts, tubers, and leaves likely provided a main stay of their diet. Other than that, they tried to stay out of the way of predators.

They had few natural weapons. Their teeth and fingernails were no match for lions. Their speed was no match for cheetahs. They had no shells for defense nor wings for flight. No wonder that there do not seem to have been huge numbers of hominids, that most species went extinct, and that our own ancestors came close to extinction. They just did not have that much going for them.

Bipedalism may have been an advantage when a drier climate led to more savannah grasslands and fewer forests with tree to swing from. Standing on two feet exposed less of the body to the hot sun, made it easier to see over tall grasses, and freed the use of the arms, hands, and opposable thumbs. A parent could hold a child and pick fruit all at once. But every benefit comes with a cost. It also altered the skeleton, restricting the birth canal, making child birth more painful and dangerous.

This problem was aggravated as hominids' greatest advantage developed. Brain size from *Australopithicus* to *homo sapiens* tripled, with Neanderthals winning the brain size competition. (Brain size for *Australopithicus* averaged between 375 and 550 cm3, *Homo habilis* from 500 to 800, *Homo erectus* 750 to 1225, *Homo Sapiens* 1200 – 1750, and Neanderthals 900 – 1880.) Hominids couldn't outfight competing species, but they could start to outthink them. Brains rather than brawn would eventually win the day.

The development of the hardware enabling life forms to think reaches back to bacteria using their flagella to scoot towards light and away from toxins. From there to hominin brain development is a long process. Brains gave species from jellyfish to humans all kinds of abilities. The eighteenth-century naturalist, Carl Linnaeus, first placed us as *Homo sapiens* within the Latin binomial nomenclature he developed for species. There are other types of men, but we are wise men. Our brains are what we most identify with. They grew in size and complexity; but why? Maybe it was originally because earlier species were *Homo habilis* – handy men who developed and used tools. It is the technological prowess that our brains gave us that is our central advantage. Or maybe it was a positive feedback loop between greater brain sized and complexity that permitted and was selected by more complex social relationships and cooperation that provided what little advantage we had early on.

Even with only partial brain development and soft skulls at birth, delivering children had become highly risky. To permit time for the brain to develop to maturity, grow a fused, bony skull, and learn all that they required to survive, childhood for hominids took years. Breastfeeding and childcare-giving mothers developed close relations with offspring over long childhoods.

Child mortality was still likely high. For a handful of children to reach sexual maturity, birth would need to be given to a number more. Especially for those with life-spans in the 30s or so for adults who got through childhood, this meant that most or all of a female's adult life was involved with pregnancy and childcare – and more. Working mothers were the norm. They likely provided the bulk of the calories through gathering and carried out many other important tasks. Still, they would have needed support as they did the primarily important work of getting children to adulthood so the species could survive. Long term relations between mothers and children and between child care-taking females and males were necessary for the fat-headed hominids to survive.

It is one thing to get together briefly to copulate. That is all sharks need to do since childcare is not a problem. Once they give birth, offspring on their own. A sea turtle female lays its eggs on a beach and never sees her offspring even hatch. Hominins faced a wholly other set of problems. Long childhoods required care-takers to work together for many years to raise children, a problem that hominins had to figure out if the species was going to survive. Resolving the issues of food, shelter, and other necessities for a kinship group over years takes problem solving and relationships to a whole different level. The increased demands of a long childhood and the long-term adult relations it required selected for an increased ability to figure out how to live together for many years at a time. The gender relations made necessary by being a big brained bipedal species is a root of hominin polity. Sexual politics has changed markedly recently with longer life spans and lower mortality rates. Mothers no longer spend their entire adult lives dealing with pregnancy and childcare and have the time and energy to do much else.

As Michael Duffy, who writes within the Montessori tradition, notes that as we go through evolution, "organisms produce fewer and fewer offspring and require longer and longer periods of care, leading to more important and deeper relationships. Fish produce thousands of eggs and rarely care for their young, reptiles produce hundreds of eggs and have only limited contact with their offspring, most mammals produce only a litter of a half dozen young and care for them for a long time through nursing, and humans have one or maybe two babies at a time and produce the most parent dependent creatures on Earth!" (Gustafson, 2013).

Many species have long developed their own ways of developing and maintaining relationships. Baboons groom each other, checking for parasites in the fur. Frans de Waal discusses how bonobos use sex for much the same purposes. Social primates, who were not genetically identical like ants within a colony are, developed a "theory of mind;" they could understand each other's reactions. They could even sometimes "feel for each other," or empathize. The law of the jungle, as de Waal argues, includes the social practices and understandings that would later be self-consciously developed into ethics.

Picking lice out of children's hair and having sexual relations has forever been part of hominid mothers' lives as well. Hominids' survival strategy led to developed abilities to relate to each other. For their relations to develop, they would need to exchange a lot more than just gluons and photons. If you thought physics was hard to grasp, just try politics as previous types of hominins evolved in *homo sapiens* with all the complexities of human memories, imagination, symbolic thinking, trade, and culture.

3.4.4 Migration

In addition to the relationships among genders for the purpose of child raising has been the relationship of hominins and other species with the land that supports them an on which they make their nests of various sorts. When land can no longer support the number of people living on it, that is one common reason for some of them to move to new territory. Hominins were not the first group of species who intentionally migrated. Queen bees will look for a new place to nest. Matriarchs will guide elephant herds to water over long distances, often making adjustments to age old routes in response to changed circumstances. As noted earlier, prokaryotes with flagellum seem to move intentionally. Movement in response to environmental changes requires complex thinking at various levels. It is a form of creative activity. *Homo erectus* migrated by about two million years ago from Africa to as far as Asia. *Homo sapiens* left Africa about 70,000 years ago. From the time that some humans left Africa, perhaps due to climate changes that were making available food sources more limited, people gradually spread out to inhabit the entire world, except for Antarctica, over the next 50,000 years. Humans reached the Americas via Beringia by 15,000–20,000 years ago. The many cultural adaptations that made survival in varied geographical and climatic variations are made possible by cognitive abilities. Piecing together now through the use of archaeology and genetic analysis, we are able to reconstruct the movements of people into new territories. The current story is one of very early human creativity, imagination, and courage.

3.5 Cultural Anthropology: Memory, Imagination, Symbolic Thinking, and Exchange

Defining what humans are is notoriously difficult. But somehow it includes a collection of physical characteristics such as bipedalism, opposable thumbs, a large brain, and smaller teeth. It also entails some combination of behaviors and cultural characteristics, such as memory, imagination, symbolic thinking, exchange, and empathy or having a "theory of mind."

3.5.1 Memory

Memory is an incredibly complicated topic. Virtually all species remember, although in very different ways. The long childhoods in which each person remembers their period of dependency creates long term memories of caretakers. Hominid adults still remember their own childhoods and their caretakers. They remember how these important experiences were carried out by those who are now old or dead. What was so important is now gone, but remains important in memory. Memories of what is no longer may be pondered while going about present tasks.

Child bearing for hominids also entails the expectation of repeating a long term set of relationships. I am going to have to do for my children what was done for me. This baby will require years of nurture to get it to sexual maturity. What is a baby now will in a number of years become an adult if I do what I need to do to help it survive. I can imagine a long-term future which does not yet exist, but which I can help create. Memory, imagination, planning, and execution go hand in hand.

3.5.2 Symbols and Language

Being able to remember what no longer is – and imagine what is not yet – is facilitated by symbolic thinking and language. Vervet monkeys will make one call for threats from above such as an eagle, another for threats in trees such as snakes, or those on the ground such as big cats. When one monkey makes such a call, others in the troop look in the right direction. One screech signifying eagle causes other monkeys to look up. A sound and an expressed / perceived meaning is linked correctly, helping the group's survival. However, the monkey does not make the sound in the absence of the threat. It does not discuss how to better prepare for a future threat. Vervet monkeys do not sit around at night discussing that day's eagle attack. They do not draw pictures of eagles. They do not intellectually manipulate or exchange symbols.

The development of syntax or grammar and vocabulary went along with that of symbolic thought. Being able to consider words and meaning in the absence of immediately present referents, adjust them, move them around and think of alternative arrangements, was facilitated by language. Being able to communicate these ideas in novel yet understandable ways meant that new meanings could be created.

Remembering and imagining in the absence of the referent is a source of symbolic thinking, planning, and eventually realizing possibilities. The road from the communication of monkeys to the symbolic thinking of hominids is long, complex, and still not exactly understood. But that it took place seems clear. By over two and a half million years ago at the Gona River in Ethiopia, *Australopithecus* or *Homo habilis* was making stone tools. Other species use tools as well. Crows, wolves, chimps and others will use stones and sticks to achieve various purposes. However, the Gona River chipped tools were fashioned by toolmakers. They had to first select which type of rock they wanted to alter. Some types of rock are too soft to make good tools. Then they had to be able to imagine the tool that was in the right kind of rock, to imagine how it could be made into a cutting, scraping, or digging tool. Then they had to carry out a series of steps to create the tool. This was probably done with others looking on and learning how to do this as well. And remember, all of this was going on over two million years before *Homo sapiens* appeared.

Tool-making was added to older tool-using skills when symbolic thinking and imagination was possible due to eye – hand and brain development, relative to earlier species. Those who had emerged from nature now began to adjust what they found in nature. Nature in these complex pockets called hominids could begin to select what helped them survive and live better. Evolution could begin to be not only in response to environment, but determinative of it. Nature became partially self-selecting in hominids.

Nature had long exhibited how creative it is. There was nothing and then there was something. There were not protons and then there were. Same with atoms, molecules, stars, terrestrial planets, and life. The transition from one to the next are times of change and natural creativity, but there were long periods of stasis in between each one. Relative to these periods, the time it took for hominids to develop their tool making was rather quick, even if it seems to be agonizingly slow to us. By the Oldowan period from about 2.6 to 1.7 million years ago, *Australopithicus* and / or *Homo habilis* had developed more sophisticated tools. By the Acheulean period about 1,650,000 to 100,000 years ago, tools had become bifacial, larger, and more varied. The oval or pear-shaped tools were not only functional, they also have shapes that are pleasing to us and perhaps to their makers. Natural emergence had become hominids' creativity. The road from physics to art was being paved.

Adjusting nature was done in various ways. Eating meat and tough tubers was hard on the digestive track of early hominids. Cooking them made them easier to digest and taste better. Exactly when this began is not certain, although it seems to have started between 1,500,00 and 790,000 years ago with the fire altered stones at Gesherbenot-Ya'aqov in Israel. The transition from scavenging to hunting had been made at least by a half million years ago, as indicated by spear points and skeletal wounds in prey found at Boxgrove, England and Kathu Pan 1 in South Africa.

3.5.3 Imagination

Burials indicate a new level of relationship. Other species such as elephants will clearly mourn dead members of the group. But the careful burial of the dead is a human activity. Again, exactly when this began is not clear, but there are burials from 80,000 to 120,000 years ago in Qafzeh, Israel. Here, we have living members of the group remembering the people who had died and imagining they have an obligation to them even after they die. Burial is a relationship with the dead, requiring memory of what is no longer. What is real in the present is only part of what matters. Memories of the past – kept in the electrical / chemical relationships among neurons – can be more important than the hard stuff that one can feel now in the present.

Hunters had long understood the difference between life and death. Causing an animal to bleed from wounds transformed the beast from one running through the woods to one lying on the ground. Did the hunters begin to think symbolically about the "life" being in the blood that sank into the ground? Does the life of the body go into the earth looking for a new form to inhabit? Is the spirit of the dead animal believed to be angry at the hunter, planning to return to the surface world to make trouble if proper steps of propitiation are not taken by the hunter?

Once grave goods become included in the burials, we seem to also have imagination of the future added to memory of the past. Burial goods suggest that people thought they could indeed take it with them. Everything had a spirit: people, mountains, rivers, pots, weapons, etc. The life or spirit of the dead person will need the spirits of various tools or weapons in the next life. Members of the group were socially close to those now dead. They remembered them and valued these memories. They wanted to imagine that their beloved would live on, and that proper actions by the living could help the dead live well. Ancestor worship may be one origin of religion. This seems to indicate the powerful social attachments our ancestors had with each other.

3.6 Art

The discoveries at Blombos cave in South Africa from about 75,000 years ago include an etched, rectangular rock. A net or diamond like design is scratched, with diagonal and parallel sets of lines. This is not just aimless doodling. This is done by a person interested in perceiving and creating patterns. What other patterns were being perceived and analyzed? Seasons? Plant growth? Movements of animals? Behaviors of fellow members of the group? Did the patterned lines have symbolic meaning of some sort in a way that etched crosses, six pointed stars, or crescents often have for us?

Shells with drilled holes were also found at Blombos. The cave is near the coast, and a diet of sea food sustained them. Did they wear the shells as a way to offer the spirits of the dead animals a place to live after their bodies had been ingested? Did they wear necklaces of shells out of a sense of beauty made possible by using or improving on what nature offers? What do these artifacts indicate about their symbolic thinking? By perhaps 48,000 years ago, at the El Castillo Cave in Spain, an artist painted animals and designs from dots and lines on the walls. This was the case later as well at Chauvet, Lascaux, and elsewhere. The animals that were painted were not modeling for them. The artists worked from memory. What purposes did they have in painting these animals and designs underground? What were the artists thinking about the animals and designs they painted? It is hard not to speculate. Was the cave where the spirits of dead animals went to live after their blood drained from their bodies? Were these spirits looking for new bodies to inhabit? What was the meaning of the paintings for those who drew or first viewed them? The artists also spit painted the outline of their hand multiple times. Were they leaving their signature, wanting those who would view the painting in the future to know who painted them? Were they touching the rock behind which the spirits of the animals they painted lived?

The importance of reproduction and fertility is made explicit by the so-called Venus figures found at Hohle Fels in Germany from the Upper Paleolithic period, the Woman of Willendorf from about 24,000 years ago, the Woman of Laussel from about 20,000 years ago and many others. These palm size statuettes of women with exaggerated breasts and hips may have offered comfort to mothers going through pregnancy or delivery, or had any number of other possible meanings. Whoever made the statues did so while thinking about fertility and sexuality rather than engaging in sex. These statues demonstrate symbolic thinking about sex in the immediate absence of sexual behavior.

3.6.1 Music

The emergence from sound to detecting sounds to creating sounds for communication and expression too is a complex topic. The hardware necessary to transforming the waves through a medium such as air into perceived sounds in the brain began with early land dwellers feeling vibrations in their bones. Sight is great, but you can't see around the bend or over the hill. Sound provides crucially important information. The patterns and tones of sound provide important information about the environment.

Many species produce sounds as well as perceive them. Some birds will sing to announce territorial claims or attract mates. Whales and others too will sing to communicate over long distances. Sounds can convey information to others.

With the malleus, incus, and stapes as part of their auditory system, mammals became able to hear in ways that reptiles cannot. Listening to the sound waves caused by ocean waves, lion roars, chirping crickets, and howling winds all had important meanings for hominids. Hearing and responding to a dependent babies cry, parting the lips and calling "Ma" with various inflections of tone elicited powerful responses among caretakers. Different sounds would have elicited other profound emotional responses, such as fear or sexual desire. Rhythmic music and drumming would have enhanced group identity during kinship groups' dances. Eventually, fife and drums communicated information and bolstered courage during battle. Campaign theme songs would identify candidates. National anthems would stir patriotism. Perceiving and making music has a long history of the relationships between animals and their environments, and animals such as humans with each other.

3.6.2 Creativity

Symbolic thinking and imagination made combination beyond natural referents possible. A wonderful example of this is the Löwenmesch or Lion Man from Germany from about 30,000 years ago. A bipedal man's body with a lion's head was not something the artist had ever seen. This was work not from memory alone but from imagination and combination. This indicates the ability to manipulate symbols separate from natural perception. It also indicates a crucially important political ability of combining what had not yet been combined in nature.

Nature had combined much in the past through increasingly complex relationships. Quarks, atoms, molecules, minerals, cells, body parts, animal groups, and ecosystems all kept putting thing together in larger and novel combinations. Now, humans could do this at a faster pace and self-consciously.

Placing value on symbols for their own sake was exhibited by early artists as well. For example, there is a beautiful ivory horse sculpture from Vogelherd, Germany from about 32,000 years ago. The artist did not try to include all the musculature of a real horse. Instead, it is an idealized shape with a series of flowing curves. This is not so much a representation of a physical horse as an ideal one expressing a sense of beauty. The artist took delight in abstraction. Plato was a bit of a Johnny-come-lately with his theory of the forms. Relationships through the exchange of words, music, and symbols developed human relationships. Exchange of goods did too. This too has a long history, going back to sharing food to enhance group relations. Specialized tool production homo habilis sites relatively far from sources of rock that were used indicates trade as much as two million years ago. Trading routes become increasingly extensive and established, until by 14,000 years ago the obsidian trade in the Near East and then the famous Silk Road establish what some see as a central core political system.

3.7 The Social Sciences and Development

Economics, sociology, and political science examine the emergence and structure of various ways of providing the material goods needed to sustain and enjoy life, groups of persons, decision making and implementation – the development of human organization over time. Humanity does not begin with the individual. It begins with the social structure required for our reproductive strategy to sustain the species – kinship.

3.7.1 Kinship

The growth of symbolic thinking and exchange of goods, words, glances, gestures, musical sounds, and artistic images facilitated political development. We have discussed the importance of kinship groups. Long term bonding of child care givers required sophisticated relationships demanding lots of exchanges. Kinship groups within a scavenger / gatherer and then hunter / gatherer economy likely became complex, but were still limited in size to perhaps fifty or a hundred persons. Larger trading routes would have permitted development of complexity of relationship. Family groups needed to exchange offspring for mating in the next generation. This led over generations to complex sets of inter-kinship relations. Terms such as "second cousin once removed" start to indicate such complexity.

In kinship relationships, lineage is important. Loyalties are to caretakers and common ancestors. Family and kinship remain important in our own day. The powerful resonances are indicated by larger groups attempting to appropriate kinship relations. Nationalists sometimes have referred to their country as a Motherland. In the United States, George Washington is referred to as the "Father of the Country." Members of the Roman Catholic church call their priests "Father." *Pope* is derived from the Greek *pappas*: father. Larger, non-lineage groups often seek to call upon the powerful forces of kinship. One of the values of Big History is its scientific story of the real lineage of all persons, going back to a small group in Africa about 200,000 years ago; of all life to LUCA, and the Universe to a single point. It turns out that we really do all have a common background. Big History is the scientific story for a period of Human Politics.

3.7.2 Agriculture and Villages

One of the major thresholds of Big History is the Agricultural Revolution. The transition from hunting and gathering to growing crops and raising certain animals is of crucial importance. It also entails a stage of political development. Hunting / gathering went along with kinship polities. With agriculture came settled villages of increasing size, beginning to include different kinship lines. This presented the village with an enormous political problem: how to establish a sustained, structured set of relationships beyond kinship.

One way to do this was to create dynasties; village lineages that all could be persuaded or forced to adopt. Lineage now became a symbolic political category rather than a biological one. In many regions of the world, mounds and other monumental burial sites enshrined the lineage of the village. Those within one lineage might still have the right to rule, but all needed to exchange the symbols that helped nurture loyalty to it.

The political leaders of these settlements or villages during the early agricultural era were sometimes those who had access and control over the best growing areas. We start to see increased social stratification and inequalities in wealth as the agricultural era proceeded. Some residences and some graves are noticeably grander than others. Hierarchy in the hunter / gatherer era was more likely based on strength, size, or cunning. In each period, leadership could also be exercised by those we call shamans, or those who could impress their fellows with their special insights and relationships. When some went through fasting, whether by choice or necessity, carried out rhythmic dancing while listening to repetitive rhythmic music, added various hallucinogens, and perhaps inflicted self-flagellation, they likely could report any number of special insights and experiences. Shapes would have shifted, experienced as traveling in other realms. These were similar to dream like states. Dreams while sleeping and trances while awake offered symbolic connections with what was beyond normal referents. Imagined relationships with abstract designs, ancestors, and the supernormal by some could have impressed others and established a claim to leadership.

Village identity could be developed and expressed through styles of clothing, certain verbal expressions, or other identifiers. Stories about the village could be told at gatherings. It took enormous effort and creativity to incorporate loyalty to the family within loyalty to the village.

3.7.3 Cities and Empires

Monumental, ceremonial architecture reinforced the claim by some of symbolic leadership that legitimized claims to leadership. Standing in awe not directly of the universe, but of some people's special connections with it were impressive. From Watson Brake in Ouachita Parish in Louisiana from about 5400 hundred years ago to Imhotep's Saqarra in Egypt about 4,700 years ago, grand burial sites began to announce the emergence of full-time leading families. Large, stylized burial mounds called attention if not of the gods, at least of the humbled onlookers who stood before them during ceremonies. Equivalents in modern America are the tall, stiff obelisk in honor to the Father of the Country, or the Jefferson or Lincoln Memorials in which political pilgrims can stand reverently in front of larger-than-life leaders who have mythical meaning and personify the presidential succession that leads to the current national leader.

Large, monumental architecture also announces the emergence of new political units of cities with larger populations and relations of cities within regional associations and nations or empires. Eridu, Uruk, Ur, Çatalhöyük, Jericho, Damascus, Mohenjo-daro, Tenochtitlán, Teotihuacan, Xi'an and other great cities represent a transition to larger, more complex political units. Sometimes these became the hubs of empires; sometimes they were combined with other cities within empires such as the Akkadian Empire of Sargon the Great from 2,400 BCE, the 15th century BCE New Kingdom of Ancient Egypt ruled by Thutmose III, the Assyrian empire of 2000–612 BCE, the Median Empire in Persia by the 6th century BCE, the Achaemenid Empire from 550–330 BCE, the Mauryan Empire from 321 to 185 BCE, the Roman, Han, Byzantine, Qing, Mongol, Arabian, Ottoman, Ashanti, and Mughal empires.

The modern European empires were transformative through their incorporation of the Industrial Revolution. The British, French, Dutch, German, and Japanese empires were built from steel, oil powered ships, railroads, gasoline powered vehicles. The Russian and American empires combined these in the Information Age with nuclear power and nuclear weapons.

Empires have survived for various lengths of time, sometimes lasting for a number of centuries. Imperial overstretch often exhausted them. This happened most recently with the Soviet empire, which broke up as many of its satellite states gained independence. It may be happening now with the American empire, with a state that is quickly becoming hopelessly indebted. Hundreds of US military bases add to a military budget that is equivalent to those of the next twenty states combined – and to US budget deficits that, along with entitlements and the interest on previous borrowing, add to the skyrocketing of American borrowing.

The struggles for power within empires and between some of them are the stuff of traditional history. The endless lists of battles and army flanks can make for a depressing account of the human past. Homer's account of the Trojan War is heroic enough, but it is also just another deadly battle scene. And things don't seem to have improved much. We started the twentieth century with a war to end all wars, followed by a horrific Second World War twenty years later. Since the end of WWII, there have been about 250 wars with over 50 million people killed, tens of millions more wounded, and countless made homeless. Emergence is at best a very mixed bag.

4. Multidirectional Emergence

The substantiated account from the big bang to ourselves today is a phenomenal accomplishment of humanity that can be told if the evidence offered by the disciplines in a university is integrated. How nations and civilizations emerged and developed are meaningful to many; placing humanity within our common universal context needs to be as well. The answer to the question of where we came from and how we got here is fantastic and as true as we can know it now. This account, told briefly above is marvelous in itself. It also may well have profound effects on its readers and listeners. Perhaps this story teaches us to be not only national citizens, but in a way, global and universal ones as well. All of us have common origins in the big bang, LUCA, and small bands in Africa.

However, complexity is not only a universal Great Chain of Being from the big bang to ourselves now. The big bang leads not only to our Milky Way, our sun, our planet, and our species - although it does do that as well. It also leads to many types of stars: main sequence, red giants, white dwarfs, neutron, and others (NASA, n.d.). Stars are often categorized by how hot to cool from O, B, A, F, G, K, and M. Each star within one of the letter classes is placed along a spectrum numeric spectrum from zero being hottest and nine being coolest. It leads to a trillion other galaxies of various types: spiral, elliptical, lenticular, "irregular, active, seyfert, quasars, and blazars." (NASA, n.d.). It leads to many other types of planets than Earth. Within our own solar system, there are gaseous and terrestrial planets of different sizes and structures. And in recent years we have increasingly learned about the range of plants in other solar systems about five thousand light years from us or less. These nearby Milky Way exoplanets are divided into four types: gas giants, Neptune-like, super-Earth, and terrestrial (NASA, n.d.). And then there is the matter of life forms in addition to humanity. There is a dizzying range of life forms on Earth, with astrobiology and habitable planets suggesting that there may well be an even greater number elsewhere. The universe has by no means developed in only one direction.

It is important to be well aware of how the universe has led to so much more than ourselves. If we think that we are the most important outcome, or the only one worth studying, we might wonder what is the point of the rest of such vast universe? Who needs galaxies billions of light years away? This sort of species solipsism is similar to the unfortunate existence of the pathological and narcissistic individualist who sees everything only in relationship to him/herself. Humanism is a valuable antidote to various forms of groupism; but it can lead to its own dismissal of the value of non-humans. A mature person is aware of, and values, other persons for themselves. A mature species cares about other species and other worlds. Reveling in a universal emergence that leads to so much other than ourselves is a joy. Studying and caring about the emergence of other species on Earth and other types of planets, stars, and perhaps universes changes and enriches our own perspective here and now.

4.1 The Humanities

The account of emergence of many different types of galaxies, stars, planets, life forms – and perhaps even other universes – creates a recognition of, and appreciation for, all kinds of diversity. There is no one privileged story in our story. When we measure the red shifts of other galaxies, it appears to us that we are at the center of the universe and everything else is racing away from us. However, if we were sitting in another galaxy, it would look the same. We are the center of the universe. So is every other place. We live within a magnificently large and complex and diverse whole.

This makes the universe story of complexity more consistent with post-modern humanities disciplines than is often thought. Post-modern scholars often see science and modernity as going together. The fear is that modern science is an attempt to establish claims to objective truth that are used to develop a grand narrative in the service of power. Modernity comes out of a mostly Western European process from the Italian Renaissance, French Enlightenment, English scientists and mathematicians as Isaac Newton and Charles Darwin, the German Albert Einstein, and many others. The intellectual hegemony of Western Europe dismisses non-Western cultures, a form of neo-colonialism.

As a rule, the sciences carry out experiments in laboratories in order to analyze nature. The humanities as a rule study and produce written texts in libraries and archives in order to examine and imagine humanity. As Carl Sagan (2020) said:

> *"What an astonishing thing a book is. It's a flat object made from a tree with flexible parts on which are imprinted lots of funny dark squiggles. But one glance at it and you're inside the mind of another person, maybe somebody dead for thousands of years. Across the millennia, an author is speaking clearly and silently inside your head, directly to you. Writing is perhaps the greatest of human inventions, binding together people who never knew each other, citizens of distant epochs. Books break the shackles of time. A book is proof that humans are capable of working magic."*

Among the key teachings of the study of the humanities, of reading books and other materials that have been produced throughout the world, is the stunning variety not only of the natural world, but also of the human experience. The big bang develops into many varieties of nature and human nature.

4.2 Static Levels of Complexity

So far, we have been tracing some of the thresholds or transitions between increasingly complex sets of relationships within relationships. However, it is usually more common for each level of complexity to remain more or less as it is. There are still vast clouds of unattached atoms of hydrogen and helium in the interstellar medium. They have not become anything more than that. There are vast numbers of planets that do not have the tectonic plates nor the layers that Earth has, and no live has emerged on them. On Earth, there are huge numbers of single cell organisms that have not become more complex life forms. The "Boring Billion" between 1.8 and 0.8 billion years ago showed minor tectonic developments, climatic change, and or biological evolution. Things can stay pretty much the same many times and places for a very long time.

Once we move into biological evolution, it is important to recall that there was no steady rise from simplicity to complexity. LUCA presumably was a prokaryote cell nearly 4 billion years ago. There are still enormous number of prokaryote cells that evolve without ever becoming eukaryote cells or multicellular life forms. With each new level of biological complexity, many species stay with their level without change. Sponges, cndarians, colelacanths, and many life forms that are millions and hundreds of millions of years old remain at their level of complexity.

Within humanity, there are many people who might be considered tribal or national and who have no interest in more complex forms of relationships. They count how many medals their nation's athletes win at the Olympics and care little for vague notions of the three values of Olympism: excellence, friendship and respect. which "constitute the foundation on which the Olympic Movement builds its activities to promote sport, culture and education with a view to building a better world." (International Olympics Committee, n.d.). Try finding a Human Passport that will get you through customs at the airport. There is no legal global citizenship.

At each level of complexity, from a hydrogen proton to nations, stasis is the more common part of the theme of complexity. There is often considerable time between levels of complexity if there is any emergence. In order to transition to a more complex relationship, it can at times take considerable energy and effort. For example, fusing hydrogen and helium into heavier elements takes enormous heat produced by gravity's creating greater densities. Moving from villages and cities into nations and empires has often required wars.

4.3 Greater Simplicity

In addition to the emergence of more complex relationships within relationships, multidirectional emergence, and statis, there is also a common experience of greater simplification. Relationships break down. Stars burn out and "die" or blow themselves up in super novae. Cells fail to relate as well as before and life forms age and die.

Various reasons for extinction have often killed off many complex life forms and sent the story back to simpler times. Five major extinction periods between 450 mya and 65 mya caused huge interruptions. And those followed the even more destructive Oxidation event. This is only part of the reason why over 99% of the species that have ever existed are now extinct. We may be going through a sixth (self-induced) extinction period that we hope does not conclude with our own species' disappearance. It would be a shame to be a mere 300,000 year-long flash in a pan. If we are, we may well have left an Earth with lots of extinct life forms and a host of simpler ones.

Dark energy seems to be pulling galaxies apart, perhaps followed by pulling apart even elements, and may pull everything apart into an end of existence as we know it. Origins and emergent complexity are more fun to discuss, but decline, disarticulation, collapse, endings, and death are just as real – and may have the last word.

Our sun will become increasingly hot until life on Earth may be impossible within a few billion years. It will become a Red Giant within five billion years, expanding until it evaporates Earth's oceans and fries any creature still hanging onto life. There will be a long universal future after the Earth is gone. However, eventually, dark energy may pull all the galaxies in our universe apart. Many keep vanishing beyond an event horizon, never to be seen again by us. Given enough time, most of the galaxies in our universe will have sped out of our view, leaving us with a mostly black sky. And then, our own local galaxies and even matter might come apart. William Butler Yeats (1919) and Chinua Achebe (2010) were indeed right; things do indeed fall apart. Or things get ripped apart. In the long run, everything. In this view, the Big Rip follows the Big Bang. It is not only we as persons and as a species that will end, it is our solar system and our entire universe – perhaps. And the Big Chill follows the Big Rip, with a return to absolute dark and cold. Or perhaps that is not the end.

4.4 Emergent Complexity from Conflict and Destruction?

There can mistakenly be a comforting feeling about emergent complexity, where it does exist. Optimists have long hoped that there is progress, that the arc of the universe is long, but it bends toward what is good, that it is getting better all the time. Emergence is often associated with violence of some sort. The beginning of the universe is probably misnamed, but the term big bang does not get the story off to a peaceful start. Gravity creating the densities that force protons together produce the fusion and energy of hug number of nuclear bombs going off every second just in our own sun. Exploding stars in their death throes, or neutron stars colliding, are needed to produce elements heavier than iron. Once we have biology, we have a never ending arms race. Creatures are endlessly creative in devising toxic chemical assaults, infections, harpoons, fangs, talons, wings, shells, brains, and any number of defensive and offensive weapons. Once we get to human politics, there is a bellicist theory of the state that sees that war has often made the state and the state often makes war. If humanity ever does get itself structured globally, it may well be an outcome of violent struggle.

4.5 Infinite Complexity

The end of our universe may lead to the birth of new ones. And new universes, some still born and others different from anything we can imagine, or others almost identical to ours, may be already be out there in infinite numbers. We have increasingly seen our own universe as so much more complex than we had imagined it to be. Now many suspect that our notions of complexity need to become infinitely more complex.

So, there we have it. Existence includes emergent complexity of relationships within relationships, the multidirection of emergence, stasis, emergent simplicity and the breakdown of relationships, or an infinite multiverse that is beyond our imagination. This draws on all the natural science, social science, and humanities disciplines of contemporary universities. It offers a theme that synthesizes knowledge rather than dissecting it. It points to a universe of knowledge that provides a rationale for a university. Every person from every location, every life form, every planet, every galaxy is included in the account of complexity. This is a story of unity and diversity, fact and imagination, and relationship and individual uniqueness that could reanimate a new idea of the university in our time.

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Complexity Science and Myth in Big History

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Abstract: From early on, David Christian's vision of big history as a "modern creation myth" faced criticism for introducing elements of spirituality. This essay contends that the resulting controversy arises from a misunderstanding of the nature of myth. The mainstream model of myth depicts it as fanciful stories of supernatural agents that members of a society use to address their anxieties. While this is often the case, the author argues that myth can be more profitably explored as a neurobiological imperative that plays a critical role in cultural evolution. To make this case, he examines how the principles of complexity science helped him understand how human history has gone through periods, such as the Axial Age and Modernity, when the change produced by societies' greatest successes demanded new ways of thinking about the world *in order for those societies to survive*. He then examines current neurobiology to explain how reinventing myth has allowed such societies to transform in ways that enabled them to meet the challenges produced by change. With this understanding of myth, the essay concludes with a discussion of how the myth of big history can allow us to contribute to the new ways of thinking that are emerging today, as culture evolves so we can meet our current existential challenges.

Introduction

David Christian opens *Maps of Time* with the hope that the story of our universe from the Big Bang to the present could become a "modern creation myth," providing what he'd later call a "shared map" to help navigate our often confusing world (2004; 2018). This hope wasn't revolutionary. E.O. Wilson had described this story as "probably the best myth we will ever have" (1978, 201). Yet, by the time of the first IBHA conference in 2012, Christian's use of the word "myth" had become controversial. It was much discussed at that and subsequent conferences, as well as in print (i.e., Katerberg 2015). Many thinkers in big history feel that, as a scientific study, big history should not deal with the issues of religion and spirituality implied in the word "myth." Christian himself pulled away from the idea that the big history story is myth, switching to the term "origin story," as in his 2018 volume by that name.

In this essay, I want to look at myth from a different perspective and explain why, from this perspective, myth can enrich the study of big history. For the most part, the mainstream understanding of myth is reflected in Scott Atran's description: Myth is composed of stories about "a counterfactual and counterintuitive world of supernatural agents," which people use to address their anxieties (2002, 4). While this way of thinking about myth is accurate in many cases, especially with Western monotheism, it overlooks a vital historical function myth has served. That is, myth seems to serve as a neurobiological imperative that helps drive cultural evolution. At its deepest levels, myth addresses the key challenges of any society, and, historically, when those challenges shift, social survival can depend on reinventing myth to reflect the new challenges. As such, the study of myth is invaluable to big history.

Just this sort of cultural transformation appears to be going on today. It has been examined by thinkers ranging from Nobel Laureate in Physics Robert Laughlin (2005) to astrophysicist Lee Smolin (2013), and is key to Metamodernity, a recent movement in philosophy (e.g., Azarian 2022). I wanted to discuss it in this collection of essays on complexity, because complexity science offers a series of principles that, at least partly, inform this emerging worldview. The point I want to make is that, myth, apart from its spiritual or religious purposes, has served a key role in similar transformation throughout human history. By understanding myth as a matter of cultural survival, we in big history can reexamine Christian's description of our story as myth and, thereby, make a valuable contribution to constructing the emerging "shared map" of our world today.

To make this case, I'll examine five topics:

- How I stumbled, much to my own surprise, onto this realization
- The concept of *symbolic orders*
- Three key patterns from complexity science that illuminate cultural evolution

- Myth as a neurobiological imperative that allows societies to shift their worldviews
- How incorporating complexity science can help big history create a shared map for the 21st century.

Complexity science and history

I started studying complexity science in the late 1990s when I joined what would become the Institute for the Study of Complexity and Emergence (ISCE), which applied complexity science to human organizations. Although I never mastered the math behind its science, I soon realized that its principles offered the best model I knew for studying human behavior. At an ISCE workshop in 2007, I first applied complexity science to history and met Dmitri Bondarenko, with whom I would write *The Axial Ages of World History* (2014), a short book that explores the similarities between the Axial Age (c. 800-200 BCE) and Modernity (1500 CE-the present). Both periods, we agreed, were times when increases in population, advances in technology and communication, and rising available wealth combined to overwhelm the dominant social structures across Eurasia. Both periods would also witness vast social experimentation, horrifying warfare, and the emergence of new ways of thinking about the world. The most surprising discovery we made, however, was that the transformations we studied in both periods were largely driven by social elites *rewriting their mythologies*.

We also agreed that the 21st century seemed similar to the end of the Axial Age. At that time, the societies that successfully transformed themselves – China, India, Israel, and Greece – learned the lessons of their transformative experiences and defined the ways of thinking about the world that would bring them into the age of empires that followed the Axial Age.[1] Moreover, we speculated that, just as their Axial Age transformations made it possible for these societies to thrive in an age of empires, the modern transformation could enable societies around the globe to enter an age of global coordination, whether as a global government or a network of more local entities. At the heart of both these transformations is a reinvention of their societies' symbolic orders.

Symbolic order

As part of the process by which we perceive the world, our ancestors' brains evolved to organize our experience around a symbolic order. As I'll explain in more detail later, the process that creates human perception works as an act of subconscious storytelling so that we can decide what to do in any situation. So the perceptual world each of us constructs is unique. Organizing experience by a shared symbolic order made it possible for people throughout any society to experience the world similarly enough that they could cooperate. Discussing this shared symbolism as part of religious rituals – he calls them "Ultimate Sacred Postulates" – Roy Rappaport (1999) notes how they enable people to link the cosmological order they observe to social life.

Terrence Deacon finds this ability so critical that he calls *Homo sapiens* "the symbolic species." For him, this process allows us to "inhabit a world full of abstractions, impossibilities and paradoxes," the "defining attribute of human beings" (1997, 21-22). As a result, we live in a self-created "virtual reality," much of which members of any society share, due to their common symbolic order. Merlin Donald goes even further. Symbolic ordering, he notes, made

[1] In periodizing human history, Bondarenko and I focused on what we thought of as the three stable socio-politico-economic states that dominated Eurasian politics – hunter-gatherer bands (up to the end of the Ice Age, c. 9000 BCE), mostly agricultural kingdoms (c. 3000 to 800 BCE), and vast empires (c. 200 BCE to 1500 CE), interrupted by transformational periods – the Neolithic Revolution (c. 9000 to 3000 BCE), the Axial Age, and Modernity. Our intent wasn't to suggest that other periodization are mistaken. For example, Leonid Grinin's (2012) periodization – hunter-gatherer, craft-agrarian, industrial, and information-scientific – or Tyler Volk's (2017) – animal social groups, tribal metagroups, transplantable agrovillages, and geopolitical states – both seem accurate *from their point of views*. Bondarenko and I, however, focused on what we saw as the overall patterns of social organization. Consider the differences between kingdoms and empires, for instance. Kingdoms, from Greece to China, were generally limited in geographical size and culturally homogeneous; governed by semi-divine kings, supported by the loyalty of their inner circles; practiced polytheistic religions; depended on bronze technology; and were still learning how to use writing to manage their cultures. Empires, on the other hand, were vast territories with multi-cultural populations; governed by emperors, supported by bureaucracies; generally practiced religions that were universalistic and moralistic; depended on iron technology; and had become expert at managing their cultures with writing. In this paper, I focus mostly on the Axial Age for examples, because there are no written records for the Neolithic Revolution and the modern transformation is still ongoing. For a fuller discussion of the effects of writing, see Assmann (2011).

it possible for humans to create the mythic culture that characterizes our species' history, because "symbols 'define' the world (rather than vice versa)" (1991, 219). Brian Fagan adds that this ability was "the real edge" that *Homo sapiens* had over the Neanderthals who preceded us, making it possible "to plan ahead and to think of their surroundings as a living, vibrant world … that changed constantly over the generations" (2010, 14).

The symbolic order of any society seems to reflect the critical challenges its members face. For instance, Ancient Egypt relied on the annual flooding of the Nile and the abundant harvests it made possible. As a result, its symbolic order is grounded in a cycle of birth, death, and rebirth. Consider the myth of Isis, Osiris, Seth, and Horus. Osiris (the abundance of the Nile) is murdered and dismembered by his brother Seth (chaos), and Osiris' consort Isis (fertility) gathers the pieces of his body and brings him back to life long enough to impregnate her with Horus (protector of the abundance of the Nile), who grows up to engage in an ongoing battle with Seth. In this way, the Pharaoh, represented by Horus, is responsible for fighting off the powers of chaos (Seth) that beset an agricultural state dependent on a thin strip of fertile land on the Nile River, surrounded by desert chaos. This myth, then, is *not so much a story about a world of gods as it is a way for people to learn about the nature of the invisible forces that challenge them*.

While the *scientific* symbolic order most of us grew up with is very different, it reflects the key challenges of early Western Modernity just as Egypt's symbolic order reflected its challenges. The Western symbolic order – the clockwork universe[2] – emerged with the beginnings of scientific astronomy. At a time when mathematics was being perfected, astronomers such as Nicholas Copernicus, Johannes Kepler, Galileo Galilei, and Isaac Newton were astounded at the precision with which the heavenly bodies moved and began to think of the universe as a machine. The key to the map for this symbolic order appeared in Newton's *Principia* (1687), but, like all mythic symbolic orders, would be what Donald (1991) describes as debated, disputed, and filtered in its society over generations. As Stephen Gaukroger notes (2020), the mechanical symbolic order wouldn't be generally accepted until the mid-19th century.

This worldview teaches us to understand reality as a collection of solid, independent "things" that respond to other things in causal chains, just as one gear in Big Ben drives the next. These "things" are passive: Like atoms of gas in a bottle, they can move only when the invariable laws of nature drive them to move. As a result, events unfold deterministically, as one thing responds predictably to another (Berman, 1981). This is the logic that underlies most mainstream thought today. For instance, until recently biological evolution was understood to occur mechanically, with random mutations leading to changes in an organism's phenotype, and then tested by natural selection in the environment. According to this model, it is impossible for organisms to evolve as acts of intentional adaptation to environmental shifts. Change is driven purely by chance and the forces created by the laws of nature (Gould, 2002; Jablonka and Lamb, 2014). Grounded in such mechanical thought, our social institutions tend to operate mechanically. In contemporary public education, for instance, this model teaches people to think of students as little machines that teachers program with important information. That has resulted in an emphasis on measuring what students learn and teachers having to "teach to the test."

In many ways, this mechanical symbolic order has been wildly successful. It has allowed the West to create scientific medicine, to produce a wide range of consumer products available to the vast majority, to create mass literacy, and to generate an enormous, rapidly growing body of knowledge. Its calculations have allowed us to put people on the moon and send exploratory devices out of our solar system.

At the same time, it has driven the evolution of existential challenges, which seem insoluble. For the last century, we've treated the planet as a machine that exists for our own benefit, like a clock or printing press. The result is deforestation, major oil spills, and burning fossil fuels, contributing to a climate change that could destroy our world's ability to support complex societies. Yet, in spite of international conferences and widely signed treaties, these conditions continue to deteriorate.

What we need is a different way of thinking about the world – a new symbolic order, with a new shared map, that will create a shared virtual social reality where it *is* possible to address these challenges. Fortunately, scientific advances, in fields ranging from physics to paleoanthropology, have also revolutionized our understanding of the world. The world, we have learned, is composed of dynamic energy systems, continually responding to the changes around them, an

[2] As Kepler noted, "My aim is to show that the machines of the universe is not similar to a divine animated being, but similar to a clock" (as quoted in Dolnik 2011, 182).

evolving nested network of systems that are all interconnected. This is the model of the world developed in complexity science,[3] a model that we can apply profitably to big history.

Complexity science studies the patterns that emerge as complex, non-linear systems evolve. The world it describes is far more interconnected – and interesting – than the mechanical model of the world as a clockwork universe, which I had learned in school. As a result, applying its principles led me to see history differently. I want to focus on three of these principles:

- The world as a nested network of energy storage systems
- Evolution's oscillation between stable states and phase transitions and
- Evolution as emergence.

These principles can enhance our ability to contribute to developing Christian's shared map to help us meet today's existential challenge.

A universe of nested networks

The complexity science model of the world begins with Einstein's theory of relativity. Matter, he tells us in the well-known equation $E=mc^2$, is a form of energy, structured to store that energy. In the words of Mae-Wan Ho, matter can best be understood as "domain[s] of *coherent* energy storage" and the average time the energy remains in these domains is "a measure of the *organized* complexity of the system" (2008, 81; author's italics).

As opposed to the mechanical model's world of distinct, passive things, complexity science portrays the world as a deeply interconnected nested network of domains of energy storage that are continually adapting to each other. At the simplest scale we're aware of, quantum particles such as quarks, combine to form a variety of larger particles, including neutrons and protons. These entities can then network to form atoms, and atoms, sometimes with less complex particles, can network to form molecules. And so it goes – with networks all the way up – in material networks, such as minerals, planets, solar systems, and galaxies; living networks, such as macromolecules, cells, organs, organisms, and ecosystems; and cultural networks, such as hunter-gatherer bands, tribes, chiefdoms, kingdoms, and empires.[4] At each more extensive scale, these systems develop new capabilities, often difficult or impossible to predict by understanding only the smaller networks that make them up.

As an example, consider an oversimplified picture of the human body. The human body is a nested network of organ systems, such as the respiratory system, which, in turn, is a network of organs like the lungs. Those lungs, in turn, are a network of groups of cells, and each cell group is a network of cells. Similarly, each cell is a network of smaller structures, organelles, which are further networked from macromolecules like DNA, molecules, atoms, and quantum particles. *To be healthy, the body needs the cooperation of structures at all these scales*. Consider the way that the body needs the iron in red blood cells to pick up oxygen in the lungs, travel through the circulatory system, and drop the oxygen off at a cell. The fullness (and messiness) of such complex systems becomes even clearer when we put it in the context of the many other processes in the body – from cognitive to immune systems, from those that control motor activity to waste removal.

But the activities of these sub-systems of the body are not isolated. The body as a whole develops a series of capabilities as these sub-systems interact with each other to meet the challenges of the outside world, giving rise to one common definition of complex systems: The whole is greater than the sum of the parts, although it might be more accurate to say that the whole can do things which are only possible as its parts interact. In addition, each human body can be part of a variety of more extensive social and ecological systems – from families and organizations to the cultural ecosystem of New York City. When I think about an energy storage domain like New York City and all the scales working down to molecules, I can begin to understand why we call it a "complex system," as well as why the term has been so difficult to define.[5]

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[3] This model is also studied in other disciplines, such as systems thinking (see Capra and Luisi 2014), for example. I use complexity theory because I've studied it for more than 25 years now.

[4] This description of our world of nested networks is oversimplified. For a fuller, more precise discussion of this network formation, see Tyler Volk's *Quarks to Culture* (2017) or Gregg Henriques' *A New Synthesis for Solving the Problem of Psychology* (2022). They also provide a deeper dive into the three varieties of nested networks – material, living, and cultural.

[5] Readers who want to know more about the problems of defining complex systems can consult Landyman, *et al*. (2013). For a quicker insight into some of the ins and outs of defining the term,

Perhaps the reality of complex systems is too, well, complex to capture in a short definition. Still, even the example of the body makes a variety of qualities evident. Complex systems are composed of many different component systems, often on many scales, systems that have access to the information they need to adapt to and innovate in the changing world they're part of, without the assistance of an outside intelligence. At each scale, we can examine these complex systems in three ways – as a functioning whole, a component in a functioning whole, or the environment for other systems. At the scale of each functioning whole, the behavior of the components creates the behavior of the whole; the nature of the whole limits the behavior of its parts; and the conditions of the environment shape the nature of the whole. As a result, to study the behavior of a family, we must also study the behavior of each member of the family, their interactions, and the environment of communities in which they are grounded.

One interesting controversy concerns at what scale complex systems become full-fledged, decision-making *agents*. Many physicists, such as Nobel Laureate Murray Gell-Mann (1994), agree that quantum particles, atoms, and molecules respond mechanically. Others insist that it's decision-making agents all the way down. However, starting with macromolecules – that is, at the point around which they begin to be living systems – many become what are often called *complex adaptive systems* (CASs), which can learn and adapt, sometimes in unexpected ways. For instance, sub-systems in the body's immune system are able to identify and attack pathogens that their organism has never previously experienced. Similarly, some neural networks are able to filter out select objects that the senses perceive, so they don't appear in conscious perception. These omissions may occur because the unconscious mind judges them as creating contradictions, which may compromise the ability to make decisions (Gazzaniga 2011; Ramachandran 2011).

This understanding of the world as a highly interconnected nested network of energy storage systems, as opposed to the mechanical understanding of the world as a collection of passive things, suggests other important differences. The process of evolution, itself, becomes more dynamic, as these energy systems, embodied as matter, oscillate between periods when they are stable, acting from long-held habits, and those when they are transforming themselves through experimenting with alternatives.

Stable states and phase transitions

With the mechanical symbolic order, evolution had been presented as linear. For example, in school, I'd learned that evolution occurred gradually, one change at a time in chains of cause-and-effect. For example, *Homo sapiens* evolved in a chain of precursors, one leading inexorably to the next – through a string of australopiths, to *Homo habilis, Homo erectus,* Neanderthals, and then us**.** With this symbolic order, human evolution was viewed as "a long, gradual slog from primitiveness to perfection," as Ian Tattersall and Jeffery Schwartz put it. But, in recent decades, scientists realized that human evolution wasn't so linear – that evolution seemed more like life struggling to find its way, through the trial-and-error of mutational experimentation, in a continually changing world. In this way, *Homo sapiens* emerged in "a history of experimentation, of constant exploration of the very many ways there are to be hominid" (Tattersall and Schwartz 2001, 46; 52). Moreover, current research indicates that the origin of this development is not merely random mutations, which mechanically produce body changes to be tested by the environment, one at a time. This was the model of evolution I had learned in school.[6] Rather, the new environments our ancestors faced when they became nomads on the savannah resulted in a wide variety of genetic shifts that interacted, enabling them to meet new challenges (see Rappaport and Corbally 2020, and Turner, *et al*. 2018).

Complexity science suggests that with this dynamic model of the world, evolution follows a pattern alternating stable (orderly, gradually changing) and dynamic (chaotic, experimental) periods. Here's the back-of-the-cocktail-napkin diagram I drew when I was thinking about this conception of evolution:

compare two first-class definitions – in Cilliers (1998, 3-5) and Mitchell (2009, 13).

[6] For a full examination of this model – the Modern Synthesis – as well as the theory of Punctuated Equilibrium we'll examine shortly, see Stephen Jay Gould's *The Structure of Evolutionary Theory* (2002).

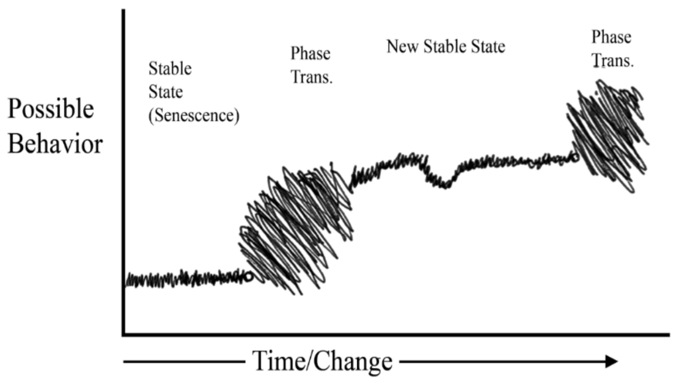

Figure 1: Life Cycle of an Attractor (Baskin 2008)

Some readers will immediately recognize that this figure illustrates punctuated equilibrium, the theory Niles Eldredge and Stephen Jay Gould developed to explain the evolutionary jumps that follow mass extinctions (Gould 2002). I call this figure the life cycle of an attractor. "Attractor" is a term from higher math that complexity scientists use to indicate those behaviors, among all possible behaviors, that a complex system tends to evolve toward in a particular set of conditions. That is, an attractor defines a system's habitual behaviors – its default responses – in its environment.

For instance, when you throw a chunk of ice into a pot and heat it on a stove, it will cycle through three "phases" – solid, liquid, and gas. At first, it will remain ice, until it approaches the melting point, becomes turbulent, and turns into liquid. It then remains liquid until it approaches the boiling point, again becomes turbulent, and becomes gas.

Or consider what happened, when earth was struck by a comet about 65 million years ago. Starting at the far left of the figure, we see that, the end of the period during which earth's ecosystems were dominated by dinosaurs. The comet destroyed those ecosystems, driving them into a 10 million year phase transition, leading to the dominance of mammals. Mammal dominance then proceeded until our own period in the senescence of human domination, followed by the possibility of another phase transition (far right).

Similar dynamics appear in market cycles of boom and bust, or in human development, where a stable childhood personality is interrupted by adolescence, leading to a stable adult personality, often ended by a mid-life crisis. The figure can also represent the period that Bondarenko and I wrote about, starting, from the left with about a century before event that undermined the kingdoms, like Ancient Egypt or Zhou China, that preceded the Axial Age. We then see the Axial Age as about 600 years of social experiments, ending around 200 BCE, as vast empires, such as the Roman Empire or the Han Empire became dominant powers. Finally, as the line approaches the far right, we can see another experimental period in Modernity, after about 1500 CE. In this way, order begets chaos, which, in turn, begets order, in a positive feedback loop, and this tension between order and chaos "is at the heart of all creativity" (McGilchrist 2021, 818).

Once we get beyond the simplest examples, such as heating ice, the dynamics of this pattern shows how evolution works in a world of nested networks: Toward the end of the stable state, the component systems have a long successful history of following a limited number of all possible behaviors. Their survival had depended on interacting successfully with other component systems, whose behaviors may have had an equally long history. As conditions shift over time new challenges are likely to emerge. Yet the old, habitual behaviors, which allowed them to survive, are likely to continue, in a period Stan Salthe (1998) calls "senescence," until some kind of catastrophe reinvents the environment and breaks the hold of the old "attractor," and a phase transition begins. I saw how senescence works up close in the early 1990s, when I worked for a bureaucratic corporation that was trying to institute a culture change. Managers talked a good game, but even though they recognized the problems that had to be addressed, actually doing anything about them was so dangerous – to their prestige and even their livelihood – that even attempts to change pushed them back into old behaviors.

In the phase transition, the system's components – free of the constraints of the old attractor – experiment with new behaviors with which they may be able to succeed in their new conditions. Those experimental behaviors may be entirely new – the downward strokes moving forward in time – or the reintroduction of old behaviors – the upward strokes that appear to be going *backward* in time. Which, of course, is impossible. But I wanted to suggest that component systems don't merely innovate; they also try out old experiments that may not have been successful. Finally, when the component systems find the range of behaviors that do work in current conditions, their interactions will develop a new attractor for the system as a whole. So, in human personality development, people in adolescent phase transition experience new powerful feelings and, most often, are expected to behave in a far less dependent way. To meet these shifts, they often begin experimenting with new behaviors that will lead to new habits and an adult personality.

Let me finish this section with a thought I offer provisionally. The way complex systems evolve by moving through stable and transformational periods is a result of the way existing complex systems combine to form more complex systems with new capabilities. Unstructured energy is chaotic. Order appeared in the universe with the big bang, which led to energy structured as quantum particles, and that order increased as the universe cooled following the big bang. Over time, those particles formed matter at scales that became more and more complex, until, today we have galaxies, which average 100 million stars; relatively small four-square-mile patches of rainforests that can contain more than a thousand flowering plants, several hundred species each of trees and birds, and more than 100 species of butterflies; and cities with populations as large as 30 million humans, as well as ways of accessing all the goods and services that they need.

However, as Marc Widdowson noted (2023) at a recent IBHA conference, the more complex – and highly ordered – these energy storage systems become, the more likely it is that they will not be capable of addressing the challenges emerging *in a continually changing world*. To put it another way, order makes it possible for domains of energy storage systems to remain stable, but it also restricts their ability to adapt in innovative ways. In order for their sub-systems to survive, they may need to be released from the attractors that hold them together. It is only when they are plunged into the resulting chaotic phase transition that they are able to fully explore the environment for new, more appropriate behaviors.

From this perspective, then, order and chaos are not diametrical opposites, but "contraries [that] *fulfil* one another" (McGilchrist 2021, 816), a perception recognized in many cultures. This dynamic is the central significance of the ongoing battle between Horus (order) and Seth (chaos) in Ancient Egyptian myth, as it is in the concept of yin and yang in Chinese philosophy. This understanding, however, is denied in the mechanical modern Western model of the world. On the other hand, the model embodied in complexity science indicates that such opposites *are complementary*. As one of my mentors in complexity science, Jack Cohen, used to love to point out, in complex systems, opposites are frequently both true. In presentations, he would show a photograph of a "lost and found" sign.[7] This is also the dynamic Peter Turchin (2023) identifies through much of human history as societies oscillate between stable and "disintegrative" periods.

This last set of comments is still in a rough form. They require more research and exploration. But they also point to an understanding of how complex systems unfold that differs from the one we find in the clockwork universe model. Here, we are talking about emergence.

Emergence

In a world composed of nested networks, many of which can become decision-making agents, events unfold as agent/networks at many scales adapt to the changes in other networks, sometimes cascading to produce surprising combinations. Consider the recent COVID pandemic. It began with changes in the genetic macromolecules of a virus – whether they resulted from random mutations or intentional manipulation in a laboratory – and quickly spread across the globe. What made the pandemic so damaging was the combination of how easy it was to communicate the virus, advances in travel technology, the effort of Chinese officials to hide it, and the refusal of some governments and portions of their populations to treat the pandemic as a threat. As a result, the changes in that tiny virus's genome would lead to extensive social, economic, and political damage, as all these CASs interacted, resulting in cascades of adaptation.

This is a far cry from the mechanical clockwork universe of the late 19th century, whose causal chains no longer seem adequate. In a world populated largely by CASs, a wide range of events have many causes. As a simple example, apple trees don't simply grow because someone plants one. Soil, weather, and temperature conditions all have to be in the right range. And if a passing bird digs into the soil and eats the seed, no tree will grow. What is needed is not a chain of causes and effects, but the *emergence* of the apple tree, as a result of a wide variety of interactions. And when we get to a phenomenon like the evolution of human life, the relative simplicity of the emergence of an apple tree is transformed to a level of improbability that approaches the mysterious (Theroux 2023).

The concept of emergence is so critical to complexity science that Henrik Jensen titled his textbook *Complexity*

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[7] Evolutionary biologist Jack Cohen wrote about complexity science with mathematician Ian Stewart, including their primer of the subject, *The Collapse of Chaos* (1994). He presented frequently, emphasizing this point, at workshops sponsored by the Institute for the Study of Complexity and Emergence, between 1998 and 2006, where I met him. It was at the last of those conferences, on complexity and philosophy, where I met Dmitri Bondarenko.

Science: The Study of Emergence.[8] As opposed to the linear causality of a mechanical model, a symbolic order grounded in complexity science suggests that such events emerge, as the component systems of any CAS interact with each other and all the complex systems around them. In systems as extensive as an ecosystem, a language, or a large city, so many CASs are continually interacting with other systems that it becomes near-impossible to predict what will happen, as with the COVID pandemic of the 2020s. Ironically, the United States had quite literally written the book, a formal plan of government action, on how to minimize the effects of such a pandemic in today's world. But political concerns – and perhaps some human frailties – made it impossible for authorities to implement that plan.

Emergence is an especially good way to understand complex human phenomena, such as history. Think, for instance, about all the political, economic, and religious sub-systems that interacted to cause the Thirty Years War. On one hand, the Mongol invasions of the 13th century created a world trading system from Beijing to Brussels, accelerating the growth of the commercial class throughout Europe. Then, the Black Death (1346-1353) killed off enough members of the ruling class – an alliance between the Catholic Church and regional aristocracies – to tantalize the growing commercial chance with the opportunity of political power. So when Protestantism arose, it offered that commercial class a power partner to replace the Catholic Church/aristocracy. Add the printing press in the mid-15th century, and a new method of communication amplified all these other shifts so that the opposition between these two alliances could spread across Europe, leading eventually to the Thirty Years War. Here, agents ranging from the microorganisms and rats that brought the Black Death to the horses of Mongol soldiers, the trade their conquests resulted in, and a flood of new technologies – all contributed to the Thirty Years War.

It was this way of thinking about history in terms of complexity science that led Bondarenko and me to the realization of the importance of myth. So we turn now to the view of myth that emerged as we apply complexity science to history.

What is myth?

The mainstream model of religion defines "myth"[9] as Atran does – as another world, inhabited by "*supernatural agents … who master people's existential anxieties*" (2002, 4; his italics). In this model, believers accept the world of myth as literally true. As Daniel Dennett tells us, if worshippers don't believe literally in their mythic agents, then, in his opinion, their belief system "is not really a religion" (2006, 10). In many ways, this conception of myth answers a question my wife found on Reddit: "Why do we talk about Christian religion, but Norse mythology?" For Christians, the stories of God, Jesus, and the Devil are true, while those of Odin, Freyja, and Loki are merely fanciful imaginings of people who don't have the truth.

Another way to think about myth is more symbolic, much more like Christian's "shared map." Thinkers who use this model range from Joseph Campbell to Merlin Donald. For Campbell, myth is a society's symbolic "field in which you can locate yourself" (2004, xvi); for Donald, it is "a unified, collectively held system of explanatory and regulatory metaphors," whose "symbols 'define' the world" (1991, 214-19).

I was surprised to realize that I agree with much of both these models. For me, myth is the stories people in any society tell about the gods or spirits of *another* world *and* the symbolic map of *this* world. Note that neither of these popular models of myth explores the issue in this essay – myth as a driver of cultural evolution.[10] The reason that it can serve all three of these functions also surprised me: Myth is a *neurobiological imperative*, grounded in the way our brains transform the chaotic world around us into an ordered cosmos of coherent stories that allow us to make the decisions we must make to survive.

The process by which the brain acts as a subconscious storyteller has been discussed widely.[11] Here's a brief summary of it: The senses take in vast fields of fragmented information. For example, each retina has more than a million rod and cone cells, each of which records a single spot of light.

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[8] For my take on emergence, see Baskin 2022.
[9] Throughout this paper, my focus is on myth as an element of religion, rather than the popular use of it to mean an explanation that is untrue, such as the "myth" of a flat earth. One point I will be making is that myth is symbolically true for the cultures that create it.
[10] Only a very few writers on the subject even suggest that myth can function as a driver of cultural evolution. Among those who do are Robert Bellah, in *Religion in Human Evolution* (2011), and Anthony Wallace, in *Religion: An Anthropological View* (1966).
[11] I have explored this issue in more detail in Baskin (2023). My key sources were Gazzaniga (2011), Ramachandran (2011), and, most importantly, Laughlin, et al. (1990).

This fragmented information is delivered to the brain, where it is mixed with memory, decoded into images, and compared to our mental models of what we've learned the world should and should not be like. These mental models filter out any images that our unconscious minds don't believe will enhance our survival and are then connected with what we have perceived before, turning our experience into coherent, story-like perceptual models.

It's important to remember that this process seems to have evolved *not to create accurate perceptions, but to ensure we see those things that are coming to help and, even more so, to threaten our ability to survive.*[12] As a result, our perceptual stories have to answer three questions: 1) What is happening? 2) How should I respond? 3) Why did it happen? To answer these questions, our perceptual stories are almost always both *coherent* and *frequently unreliable*. They are coherent because coherent stories, where everything fits, make it far easier to decide what to do. Besides, if the action such a story leads to produces undesired results, we can always do something else. But, if they are *not* coherent, we can be frozen to the point of not reacting when survival is at stake. Moreover, these stories are frequently unreliable because the need for coherence drives our brains to make up information we don't have and present it as "true," so that we can make needed decisions. Anyone who's been in a long-term relationship is likely to recognize times when they had major arguments only to discover one element of their perceptions, often answering the third question, was, as psychologists put it, "confabulated."[13]

From this perspective, the process by which we perceive the world is a form of subconscious storytelling. And *myth-making is storytelling that is negotiated among groups of people* – "the debated, disputed, filtered product of generations of narrative interchange about reality" (Donald 1990, 258). More specifically, myth is the stories that answer the three perceptual questions *for entire groups* faced with the powerful, invisible forces we live among: *What* are both the existential threats and the awe-inspiring forces we experience? *How should we respond* to them, both as individuals and in cooperation with other? And *why* do they happen?

What makes this definition of myth so interesting is that it includes much of the other models of myth. Among the invisible forces myth addresses are those that produce birth and death, abundant crops or being invaded. These are all forces that myth accounts for in what Christian calls a society's shared map. They can also be the anxieties that Atran and Dennett point to as the reason for myth. For me, the key difference from the mainstream myth of Atran and Dennett is that myth must answer the three perceptual questions. The gods and other spirits of myth, then, emerge as *symbols* that allow people in any society to understand and respond to these forces. However, from this perspective, myth is not fiction; rather, it is an attempt to understand the invisible forces around us using poetic symbols, similar to the way science uses numbers.

As a result, myth is generally so powerful that it is used for a variety of other purposes. From organizing people into groups of like-minded associates to create a feeling of belonging (King 2007) to a way for politicians to mobilize communities for war (Harris 2004). For those of us who study big history, especially when we apply it hand in hand with the principles of complexity, this concept of myth offers a variety of advantages.

Applying these complexity patterns

For me, one of the first of these advantages is the ability to explain today's most disturbing events as part of a process that has occurred before. I grew up in the 1950s and '60s, so I experienced McCarthyism, the Civil Rights movement, and the Vietnam War. But, even with the violence each of them created, I remain astounded at the current worldwide political polarization and disregard for long-practiced norms. And that doesn't even touch on the constructions of widely different realities that has become commonplace.

Yet, complexity science, coupled with this understanding of myth can make sense of all this: Societies across the globe have entered the chaos of a full-blown phase transition. Especially among political leaders, behaviors demanded by old cultural attractors no longer hold. In just about every institution in every society, people seem to recognize, if only unconsciously, that the old attractor's ways don't work, but

[12] For a fascinating examination of this conclusion, see Donald Hoffman's *The Case Against Reality* (2019).

[13] In his discussion, Ramachandran notes that this process of perception uses many of the same processes as hallucination: "One could almost regard perception as the act of choosing one hallucination that best fits the incoming data …." (2011, 229). So it's no wonder that confabulation enters the process so seamlessly.

no one knows what the new ways will be. Most of us are understandably terrified and the result is a sort of global psychosis, reflecting a disturbingly wide range of experiments. As my back-of-the-napkin figure predicts, these experiments both look forward and back, in efforts to find what will work.

What we need, then, is a new symbolic order, embodied in a scientific myth, like Bacon's myth of the scientist extracting nature's secrets to make human life better.

That is, as in the Axial Age, today we face a series of existential challenges that demand a different way of thinking about the world. In that period, the societies that did transform successfully did so by rewriting their myth. Especially important is what I've called a "mythic twist."[14] For example, in Axial Age Greece, the 5th century BCE was a century of chaos. First, the Persians invaded Greece in 490 and 480, when the Persians burned Athens, but were eventually defeated by the alliance of Greek city-states. After their victory, those city-states competed for political dominance, with alliances led by Athens and Sparta, resulting in the Peloponnesian Wars (431-404 BCE). Those wars would also cause a plague, further reducing the power of Athens and undermining confidence in the myths of the gods of Olympus. We can see this shift in the criticism of the gods in Greek tragedy, where basically good people, such as Oedipus and Orestes, suffer intensely because of those gods' whims. Combined with Greece's experimentation with science, a new, more rational symbolic order emerged, taking its mythic form in the philosophies of Plato and Aristotle, whose mythic elements became especially important in Medieval Christian theology.

A similar mythic twist helped drive the emergence of the modern scientific symbolic order of the West, a rewriting of the myth of Late Medieval Christianity.[15] The key to this twist came in the works of Thomas Aquinas in the 13th Century, which explained that God and his creation were rational (Gillespie 2009). This position would be largely absorbed by the Late Medieval Catholic Church. The mythic twist that would shape Western science came from Francis Bacon, in works like his *Novum Organum* (1620), during a chaotic period that culminated in a century and a half of religious wars. To create a society that would be far more safe and comfortable, Bacon explained, the source of human knowledge should come, not from the speculative methods of Medieval churchmen, but from scientific research. The scientist's job would be to "torture" nature into giving up its secrets, thereby enabling life-enhancing innovations, such as the printing press. In this mythic twist, the attention to nature that Aquinas had praised now moved from the act of knowing God to the attempt to improve human life.

As a result, by incorporating complexity science, big history's creation myth can help people understand how those challenges arose and how other societies, facing similar challenges, were able to overcome them. Already, big history can act as a platform on which knowledge of the widest variety of disciplines can become available. With the addition of complexity science, we can show how, as terrifying as the current situation is, it is also what can be expected in our continually changing world. We are living through a typical cultural phase transition, whose experimentation can generate new symbolic order which can generate a new myth, different types of behavior, and, eventually, a new attractor. By focusing on the experience of societies that did reinvent themselves, our origin story can create the map for how we can similarly transform the way we think about the world.

Most important, complexity science offers one possible symbolic order for reinventing our modern myth. The current version of this "evolutionary epic" was created at a time when few people doubted our mechanical symbolic order. So it's worth asking whether a mythic twist, grounded in complexity science, might yield a different way of thinking about our world. For example, as it's currently told, that story often seems linear, with a clear beginning in the big bang, a linear evolution from less to more complex material structures, and an expected ending in heat death. What would happen if we processed the same facts through the lens of complexity thinking? This is not to say that the current version is "wrong." Rather, the big history community would profit from a discussion about these two ways of interpreting the facts of our origin story. After all, there are legitimate scientific problems with the current approach (e.g., Hossenfelder 2018) and fascinating speculation on alternatives (e.g., Sheldrake 2012). And the far more interconnected order suggested in complexity science seems more appropriate to the challenges we face today.

Conclusion

[14] For a deeper dive into this dynamic, see Baskin. 2023.

[15] For a full discussion of how deeply Western science was grounded in Late Medieval Christianity, see especially Gillespie (2009) and Freely (2012).

Of course, one could argue that believing big history should contribute to developing a shared map of the world for our time demonstrates intellectual arrogance. And there may be some truth in that. However, our world today faces very real existential challenges, and, as the saying goes, "Extreme times call for extreme measures."

Still, the explosion of knowledge over the last half century is changing the way we understand the world. Sciences from astrophysics to neurobiology have found that our universe is far more complex and interconnected than we thought. Combining history, neurobiology, and complexity science, it's also clear that any society's symbolic order shapes how its people think about and even perceive their world. Moreover, if my analysis is mostly accurate, myth has historically provided a driving force for the cultural evolution required when old symbolic orders no longer work for people. Even the transformation from Late Medieval Christianity in Europe to Modernity came as a result of a mythic twist, as the Thomistic myth of studying God's creation moved from an act of worship to Bacon's myth of torturing nature to access her secrets.

Today, our species faces the existential challenges of moving from being a pre-computer, mildly industrialized set of empires, a half-millennium ago, to our present status, as societies capable of AI, extremely industrialized, and connected as a global community. What we need seems to be a mythic twist that will help us think of our world as the deeply interconnected nested network that complexity science suggests it is. And where better to do that than in big history, which operates as a platform in which so many other disciplines can interact?

At the very least, we owe ourselves a discussion of what we might learn if we conduct the conversation on whether big history's shared map would profit from such a mythic twist.

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Last Stop on the Cosmic Journey: An Estimated Time of Arrival

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Abstract: History is here imagined as a moral, intellectual, and physical journey whose destination involves: penetration to the furthest reaches of the cosmos, complete understanding of the laws of nature, and a perfect system of ethics with respect to the management of society and nature. It is suggested that the exhaustion of material potential implied by the Second Law of Thermodynamics is counterbalanced by the augmentation of informational potential in a process of ephemeralisation or doing more with less. Evolution is modelled as a process of hyper-exponentially increasing combinatorial complexity interrupted by occasional restarts or episodes of creative destruction. Drawing on these speculations, a calculation is developed leading to the necessarily rough and impressionistic conclusion that humanity will reach its above-defined destination some twenty millennia from now.

1. Introduction: a three-stranded journey

The start of the Upper Palaeolithic, traditionally dated to some 40,000 years ago (40 kya), has typically been seen as a turning point representing the onset of modern human behaviour (Gowlett, 1984, p. 120; Pfeiffer, 1982). Although instances of modern behaviour like art have been discovered much earlier, perhaps as early as 200 kya, the Upper Palaeolithic remains a critical horizon after which social evolution became continuous, rapid, and obvious, proceeding through an accelerating series of milestones like microlithics, agriculture, and urbanisation. This turning point is not a biological one. There was no change in morphology. It seems to be a cultural phase transition, perhaps involving the emergence of the first fully general language. For this paper, the issue is that, since the Upper Palaeolithic, global human experience has been characterised by a march of progress whose key themes are demographic increase and technological advance. These themes are chicken-and-egg-wise interdependent insofar as technological advance has made demographic increase possible, while demographic increase has made technological advance necessary.

Some argue that the march of human progress is crescendoing towards a new phase transition, perhaps only a few years or decades away, after which it will shift to a new regime of demographic stability and only modest (exponential rather than hyperbolic, or perhaps decelerating) technology growth (Kurzweil, 2005; Korotayev & LePoire, 2020; LePoire & Devezas, 2020; Korotayev, Malkov & Khaltourina, 2006b, p. 33). I do not wish to reject those arguments, which are well supported by theory and evidence, and which I accept as highly plausible. Nevertheless, I do wish to consider the implications of a rather different, more speculative possibility, which is that human progress will continue to accelerate at its accustomed heady pace, leading to future transformations of human capabilities as profound as those that have taken us from the flint axe to the silicon chip. Specifically, this implies that humans will move beyond earth, first to the solar system, then to other star systems, and eventually throughout the universe, which offers unimaginably vast amounts of living space, energy, and raw materials for a super-abundant human population possessing technologies that today seem impossibly expensive and difficult.

It could be objected that the speculated continuing explosive growth of humanity into the cosmos is contradicted by certain hard limits: (1) the birth rate is constrained by physiological factors, and its ceiling is already being reached; (2) the hostile environment of outer space and other planets precludes human habitation; (3) practicable interstellar travel is in contradiction of the laws of physics. This paper assumes that, like previous limits such as heavier-than-air flight, these are soft limits, which will eventually be overcome by new technological and scientific discoveries, for example artificial wombs, terraforming, and warp drives.

The vision of this paper is of long-term human experience as a journey that not only has a physical dimension, from let us say Africa's Rift Valley to the furthest corners of the cosmos, but also has two other dimensions. The second dimension is scientific-technological or equivalently an intellectual journey, i.e. from very limited understanding of the nature and workings of the cosmos towards complete understanding of those things. The third dimension is a moral journey. This is more controversial and harder to define. It could be said that, with something like same-sex marriage for example, what one person regards as moral progress, another might regard as moral regress (Akpan, 2017). This moral journey, while relevant to the concept of a cosmic journey, is not critical to the calculations presented below and will be left vague. Suffice it to say that a look around the world suggests humans are characterised today by extensive moral failings and they cannot be said to have completed their cosmic journey until they have overcome those failings once-and-for-all, even though we are currently as far from moral perfection as we are from the far-flung galaxies it is suggested we will one day explore and populate. That humanity is at the very beginning of its journey, only just peeking over the side of its cradle, means we do not have the capacity to describe moral perfection or grasp how it could be achieved.

To sum up, this paper proceeds from the idea that humanity is embarked on a journey of physical, intellectual, and moral discovery whose endpoint is complete penetration to the ends of the universe, complete understanding of the laws of nature, and complete adherence to a yet-to-be-manifested system of perfect ethics. This end-state will be called pleroma, a Christian theological term meaning something like the completeness of divine power and knowledge that infuses and sustains the universe. The intended implication is that humanity's destination on its cosmic journey is not only effectively divine omnipotence and omniscience but a kind of identification with the cosmos and responsibility for its existence. Clearly, these ideas, which will be elaborated on in the next section, are highly conjectural and the aim here is not to work towards them in the manner of proof but to start from them and see where they lead.

2. Further speculations

I will discuss three issues that provide additional background for the philosophical context of this paper. These issues are: the Fermi Paradox, the Anthropic Principle, and the Second Law of Thermodynamics.

The Fermi Paradox is as follows (Ćirković, 2018): while it is reasonable to think that intelligent life exists elsewhere than on earth, it is also reasonable to think that, compared to earthlings, some of those forms of life would be say a million years—the blink of an eye cosmically—further on in their development, in which case—remembering how far humans have come in just the last 10,000 years—the signs of their activity ought to be visible in the heavens and they might be expected to be aware of us and to have already made contact. Since we are not in fact aware of any alien life, one or other of those seemingly reasonable propositions must be wrong. There are many proposed resolutions of the Fermi paradox that preserve the idea extraterrestrial intelligence exists (Webb, 2015), for example: that interstellar communication is impossible; that we are being kept in quarantine until we are mature enough to be contacted; or that aliens have indeed already visited us as say Erich von Däniken claims. While any of these resolutions might be true, they can be seen as post hoc rationalisations designed to explain the contradiction rather than things we would naturally predict in advance. For this paper, I will assume the alternative resolution, namely that the reason we are not aware of alien life, even though, if it exists, we ought to be, is because there is none, earth is unique, and humans are alone in the cosmos. It is not suggested the Fermi paradox proves this conclusion, only that it is a reasonable and simple solution to it. At any rate, this assumption is the most convenient one for the present discussion because it does not really make sense to think of humanity being on a special journey towards pleroma if there are countless other species doing the same. This assumption keeps the discussion simple and does not require us to consider say the merging of alien civilisations into a common journey although that is another possibility.

The Anthropic Principle describes the observation that the properties of nature seem to be improbably favourable to the emergence of intelligent life (Vidal, 2014; Barrow & Tipler, 1986; Davies, 2008). To give one example, the stellar fusion reactions known as the CNO (carbon-nitrogen-oxygen) cycle can only occur because of a coincidence in some of the quantum energy levels involved. If it were not for that coincidence, there would be no CNO cycle and no elements heavier than helium, thus eliminating the possibility of the complex chemical reactions that constitute life. There are many other ways in which the laws of physics seem 'just right' like this. The weak anthropic principle says that this is because, if it were otherwise, we would not be here to make the observation and it is ultimately just chance. The strong anthropic principle rejects the idea of chance and suggests that there is something inevitable about it or even that the universe has been designed this way. This paper will assume the latter, i.e. that the universe and its laws are the way they are because of the requirements of producing life. In other words, the universe depends on life as much as life depends on the universe, even though we may not yet properly understand the meaning of that claim. It is relevant to this paper because it chimes with the idea that humanity has a unique cosmic role as its journey takes humanity towards pleromatic identity with and responsibility for the cosmos. One facet of the principle may be that it is humans' conscious awareness that creates the universe as a definite phenomenon out of a sea of possibilities, in the same way that it is the act of observation that causes Schrödinger's cat to take on a determinate state of alive or dead rather than retaining the potential for either (Goswami, Reed, & Goswami, 1993; Kafatos & Nadeau, 1990). Another facet of the principle may be that it is humans who give the cosmos purpose and meaning—perhaps the universe exists in order to create intelligent life which, through its journey to pleroma, is ultimately capable of bringing the universe into existence in a kind of closed causal loop. Again, these statements, which may currently seem grandiose and even absurd, are perhaps comprehensible to a species that has achieved the full understanding of cosmic existence implied by pleroma. What makes them seem more than just idle speculation is that say the idea that consciousness creates reality arises both from spiritual inquiry and from theoretical physics. The fact that philosophers and mystics have in some respects arrived at the same places as modern science (Capra, 1976) suggests that the laws of nature may ultimately be very simple and it is only because our understanding is partial and our perspective is misaligned that we currently need abstruse mathematics to describe them, just as an arch under construction is a mess of scaffolding until it is complete and its simple form revealed.

The Second Law of Thermodynamics tells us that the universe is, in effect, running down to a state of maximum disorder or maximum entropy, the universe's 'heat death', when all its energy will be in a useless form unable even to make stars shine let alone power chemical reactions and living organisms. The disorderly state is the most likely state, to which everything tends. Thus, the universe was created in a highly unlikely, highly orderly state of high thermodynamic potential, and its subsequent evolution has involved the steady consumption of that thermodynamic potential, which will be reduced to zero at the time of heat death. The important question is 'where did the original thermodynamic potential come from?' and that, as Kenneth Boulding has remarked, is something we know nothing about (Boulding, 1981, p. 35). Our understanding of the destruction of thermodynamic potential is well developed; the creation of thermodynamic potential is a mystery.

Consideration of the Anthropic Principle suggests that consciousness—the ability of the universe to be aware of itself—is a mystery similar to the creation of thermodynamic potential. It is fundamental to human and perhaps cosmic existence and yet it is also a topic where we are profoundly ignorant. We know that we humans have conscious awareness, though we are less sure of the extent to which it is present in other organisms or even non-living matter. For some, consciousness is not real but rather an illusion created by high-level neural processes, a point of view supported by demonstrations that conscious awareness follows rather than precedes human decision-making (Edelman, 1992; Dennett, 1993). To others this 'solution' to the problem of consciousness, i.e. declaring it does not exist, is strange if not perverse since, as argued by Descartes and depicted in the Matrix films, our consciousness is the one thing that we can be sure is real and it is the material world that may be an illusion. The fact remains that, while theories abound, there is no real understanding of this phenomenon.

The relevance to this paper is that these two mysteries—the creation of thermodynamic potential and the nature of consciousness—are ones that a pleromatic civilisation, to be worthy of that name, must solve. The Anthropic Principle suggests that the two mysteries are linked: in some still obscure sense, thermodynamic potential was created for the benefit of our conscious existence, and in some other also obscure sense, it is our conscious awareness that gives thermodynamic potential its determinate materiality.

3. Tracking progress towards pleroma

To estimate the time for humans to reach pleroma, or in other words the time for the universe to achieve full understanding and mastery of itself, we need some way of tracking progress towards that end. What is offered here is a rough-and-ready, back-of-the-envelope calculation, to give a feel for how we might approach it and for the magnitude of the answer. It is unlikely that we can do better than a rough-and-ready calculation since it involves properties of future discoveries and developments that we cannot know until pleroma has actually been achieved.

The approach taken revolves around the evolution of technology, which it regards as a process of increasing combinatorial complexity. Chemical and biological evolution could be regarded in the same light, i.e. as involving the creation of new elements from the combination of existing elements, with the new elements becoming available for use in further combinations, resulting in the growth of increasingly complex entities. Thus, although the discussion focuses on technology, it develops principles that ought to have application to cosmic evolution in general.

Technology, as used here, should be understood to include social technologies such as legal systems, which may be just as important as things like agriculture in making it possible for people to live better and at higher densities.

An obvious candidate for tracking humanity's growing technological capabilities on its journey into the wider universe is the Kardashev scale, which characterises civilisations in terms of their management of cosmic resources (Kardashev, 1964). We will use a simple version of the scale whereby a level 1 civilisation manages an entire planet, a level 2 civilisation manages an entire solar system, a level 3 civilisation manages an entire galaxy, and a level 4 civilisation manages an entire universe. Typical estimates of the current Kardashev level of human civilisation range from 0.3 to 0.7 (Lunan, 1983).

The question becomes that of objectively measuring Kardashev level. One suggestion is to consider energy. We know, for example, that the amount of energy available on earth as incoming solar radiation is around 4 million exajoules per year. We could therefore say that when the power consumption of human civilisation reaches this amount it is at Kardashev-1.

The problem with using energy turnover as a measure of civilisational level is that one of the effects of improving technology is to increase energy efficiency. The earliest mobile phones consumed more power than those of today, and yet they were less sophisticated. Thus, more advanced civilisations may use less energy, at least per capita. Figure 1 shows that per capita energy consumption has been stagnating in more advanced countries despite continuing technological progress. It follows that the relationship between energy consumption and civilisational level is complex and energy is far from ideal as a metric.

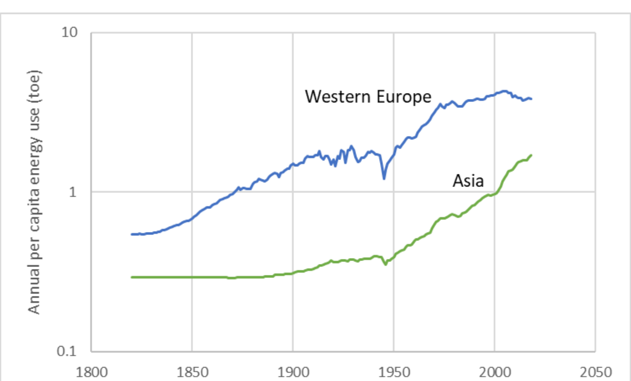

Figure 1: Annual per capita energy consumption (tons of oil equivalent per person). Data: Malanima, 2020.

Let us take another approach, based on technological evolution understood as a combinatorial process. New technologies tend to be built out of combinations of existing technologies. In early times, say, the technology of a carved stick could be combined with the technology of string to create the fire-drill, while the stick could be combined with the technology of flint axes to create a spear. The fire-drill and spear technologies could in turn be combined to create the bow and arrow. Each technology not only is a combination of others but becomes a component for further combinations. There is increasing complexity as more recent technologies incorporate ever more levels of combination.

We must understand a technology not as the gadget that is its end result but as the nexus of human activity that goes into its production. It is the know-how and organisation needed to create components and bring them together in the right way that is the key to a technology. A civilisation cannot acquire a technology simply by being given the gadget. It must have the necessary know-how and organisation if it is to be said to have reached that technological level.

This implies a close connection between technology and population. A technology like the bow and arrow requires a small number of rather simple inputs, and the relevant know-how and organised activity can be supplied by a population of perhaps a few hundred to a few thousand. However, the technology of the smartphone requires a vast array of inputs, not just in terms of computer chips, software, microwave systems, and touch-sensitive screens, but in terms of the machines that make those components and everything going back to the mining of ores and even the cultivation and transportation of food to sustain the retail assistants who market the devices. It seems that such a technology, involving an incredibly large and intricate network of know-how and organised activity, can only be supplied by a population reaching into the billions.

Technology therefore orders human activity—by which is meant purposeful flows of matter and energy—on ever increasing scales. In other words, technological evolution increases order. This is in direct contradiction of the Second Law of Thermodynamics, which says that order must decrease.

A possible resolution of the contradiction is to argue that the increase in order of human civilisation is made possible by decrease in order elsewhere, for example as solar nuclear fusion and fossil fuel burning, which provide the energy for technology networks, are contributing to the heat death of the universe. Thus, local increase in order is offset or more than offset by global decrease in order, so that the Second Law is maintained. If this interpretation is correct, it means that the zone of order must decrease as the zone of disorder expands and, in the long run, human technology and civilisation, along with all life, must eventually be obliterated as the universe succumbs to a state of maximum entropy. This would preclude the possibility of humanity achieving pleroma or Kardashev-4 and full command of the universe, since it will instead cease to exist.

Here, let us adopt an alternative resolution, proceeding from the idea that the know-how and organisation that are the real content of technology represent information, which is non-physical and therefore not bound by the Second Law. Thus, the combinatorial evolution of technology generates ever-increasing amounts of information, and, because the more technology that already exists, the more scope there is for new combinations, this growth of information feeds on itself. As information increases, it can generate new information at an ever faster rate. Thus, while the physical universe began with maximum thermodynamic potential and is steadily using up that potential, the non-physical, informational universe began with minimal potential and is steadily increasing its potential to generate information. While physical matter exhausts its potential in accordance with the Second Law, non-physical information augments its potential in an anti-Second Law.

This process in which information content increases as material content decreases has been described by Buckminster Fuller as ephemeralisation or 'doing more with less' (Buckminster Fuller, 1972). The modern smartphone is lighter, more compact, and less demanding in raw materials than the notorious 'bricks' of forty years ago, yet it is far more capable. Similarly, telephone services that once relied on immense quantities of copper wire are now supplied by intangible microwaves.

If the answer to evolution's contradiction of the Second Law is that information obeys an anti-Second Law, developing in the opposite way to matter through ephemeralisation, we may say that the logical endpoint of doing more with less is to manage an entire universe with nothing. This is pleroma. If we reword slightly to say that the logical endpoint of doing more with less is to create an entire universe from nothing, we may see how a pleromatic civilisation can be expected to achieve divine-like powers, and we perhaps glimpse a solution to the mystery of the origin of thermodynamic potential.

4. Reverse evolution

Technological evolution is not always one-way. Sometimes it becomes necessary to abandon technologies that have led down a blind alley and back up to explore another path. Horse transportation, for example, evolved increasingly sophisticated forms, from the solid-wheeled cart to properly sprung stagecoaches that not only improved passenger traffic but also interacted with printing technology to establish the viability of newspapers and mass communication. Nevertheless, further development became difficult and the horse was never going to facilitate heavier than air flight. There occurred a switch to the internal combustion engine, which meant dismantling the old technology networks focused around the horse at the same time as constructing new technology networks focused around the motor car. This new technology did have the potential for invention of the aircraft.

The phenomenon of shrinking options as one proceeds down a certain path, creating the need to back up and restart, has been called a Sample Space Reducing Process and explored through computational and mathematical modelling (Thurner, Hanel, & Klimek, 2018). Consider the technological evolutionary tree shown in Figure 2. Here each node represents a gadget or technological function, while a technology is the whole network of activity that feeds into providing that function. (This diagram must be understood as a gross simplification intended to show the principle. Because technologies are typically combinations of multiple precursor technologies, there is not really a simple tree but a complex, intercrossing web of functions.) Referring to Figure 2, suppose that technological evolution proceeds down the path shown by the green arrows. The number of further functions that are still accessible shrinks at each step, or in other words each step reduces the remaining sample space. By the time the process has reached function Y, the remaining sample space is reduced to two. If the process is reversed back to point X, the sample space opens up again and many more functions become accessible.

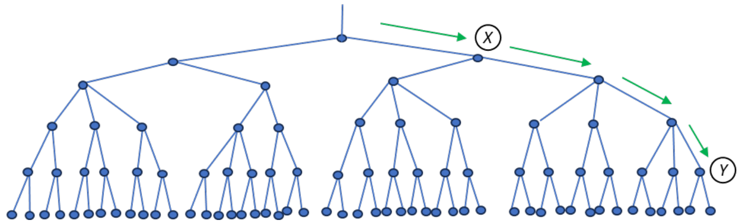

Figure 2: A technological evolutionary tree. Each node represents a gadget or technological function. Descending lines show further functions reachable from that function.

Reverse evolution, i.e. reopening of sample space, can be painful or costly. The switch from the horse to the motor car meant that many businesses and individuals, such as stagecoach companies and stable lads, lost their livelihoods. They eventually found new livelihoods as garages and petrol pump attendants, and indeed the switch created more jobs than it destroyed. Nevertheless, the switch would have been uncomfortable to many as it required learning new habits and it would not necessarily have been obvious that all would be well in the long run.

Reopening of sample space is, in Schumpeter's terms, creative destruction (Thurner, Klimek, & Hanel, 2010; Schumpeter, 1939). The greater the destruction of existing activity networks, the more scope there is to build newer, better networks. The higher the number of companies that go out of business in a recession, say, the larger the amount of land and workforce that becomes available for new companies and new industries to get the economy moving again. In 1945, German planners contemplating the advance of the Soviet armies considered the idea of moving Berlin to a more defensible location after the war. It soon became clear that this was not just a case of relocating the city itself but would require a prohibitively costly reshaping of Germany's road, railway, and electrical distribution systems, which converged on Berlin's existing location (Sauvy, 1974, pp. 444-445). Even the Second World War did not reopen sample space to that extent.

5. Power law

Episodes of creative destruction are power law distributed, meaning that the probability $\text{prob}(x)$ of an episode of creative destruction of size x is related to x by

$$\text{prob}(x) \sim x^{-\beta} \quad (1)$$

where β is a constant. This is illustrated in Figure 3 in terms of the sizes of England's economic contractions, which are episodes of creative destruction in socio-economic networks. The straight line of the rank-size relationship on a double logarithmic plot is the signature of a power law distribution.

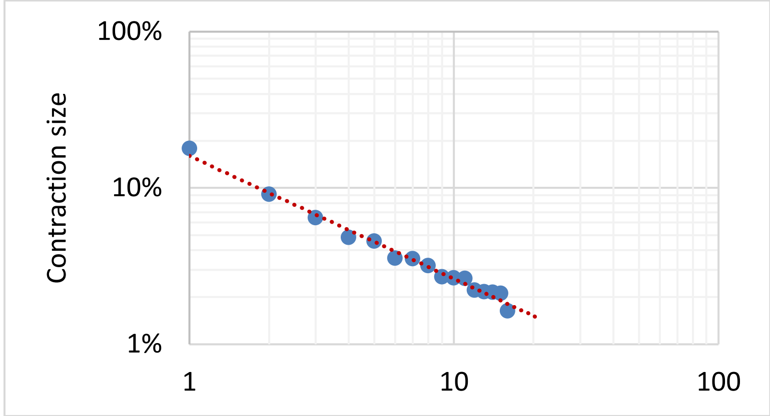

Figure 3: Rank-size plot of economic contractions in the United Kingdom, 1870-2015. The fitted line has R2=0.99. Data: OWID, 2017.

We can understand this mathematically with a rough argument as follows. Suppose that the probability of a reversal by one function is p. Then a reversal by three functions, as from Y to X in Figure 4 below, has a probability of p^3 and, in general, a reversal by F functions has probability p^F, or in symbols

$$\text{prob}(F) = p^F \quad (2)$$

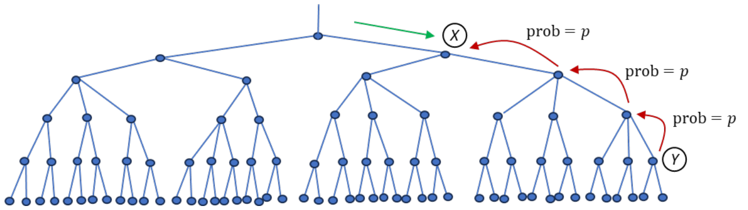

Figure 4: Reverse evolution in a technological evolutionary network.

The number of a society's functions has been found to be proportional to the logarithm of the population of its largest settlement (Ortman, Blair, & Peregrine, 2018). We will make the approximation that the population of the largest settlement is equivalent to the population of the whole society. This is true for many simple societies that have only one settlement, and is roughly true for more complex societies because of Zipf's law of cities (Zipf, 1949) which means that the populations of smaller settlements depend on the size of the largest settlement in a systematic way and therefore so does their total. Writing F for the number of functions and P for population, we have

$$F \sim \ln P \quad (3)$$

We will also say that population is proportional to technology. This follows from the work of Kremer and Korotayev et al., where it is in effect taken as an assumption in deriving the hyperbolic growth of world population (Korotayev, Malkov, & Khaltourina, 2006a; Kremer, 1993). The validity of the assumption is implied by the fact that the population growth has indeed been hyperbolic. The relationship between population and technology essentially expresses the idea that technology affects carrying capacity and that, from a long-term perspective, population tends to be close to carrying capacity (e.g. the new technology of farming allowed the human population to grow to a new limit). Strictly, the relationship holds only for a fixed area, which is however the case for the world as a whole (when area is not fixed, we need to replace population with population density). In symbols, with T for technology, we have

$$P \sim T \tag{4}$$

Substituting in Equation 3 gives

$$F \sim \ln T \tag{5}$$

By a standard identity of probability theory

$$\text{prob}(T)dT \sim \text{prob}(F)dF \tag{6}$$

or

$$\text{prob}(T) \sim \text{prob}(F)\frac{dF}{dT} \tag{7}$$

We have $\text{prob}(F)$ from Equation 2 and we can obtain dF/dT by differentiating Equation 5, so that Equation 7 becomes

$$\text{prob}(T) \sim p^F \times \frac{1}{T} \tag{8}$$

Substituting for F again from Equation 5 gives

$$\text{prob}(T) \sim p^{\ln T} \times \frac{1}{T} \tag{9}$$

If we let $\alpha = \ln p$ or in other words $p = e^{\alpha}$ and substitute this in Equation 9, we obtain

$$\text{prob}(T) \sim e^{\alpha \ln T} \times \frac{1}{T} \tag{10}$$

which, since $e^{\ln T} = T$ while $1/T = T^{-1}$, becomes

$$\text{prob}(T) \sim T^{\alpha} \times T^{-1} \tag{11}$$

Finally, combining the exponents and writing β for $1 - \alpha$, we obtain

$$\text{prob}(T) \sim T^{-\beta} \tag{12}$$

which may be compared with Equation 1 and shows that the sizes of technology reversals, i.e. the magnitudes of episodes of creative destruction, would be expected to have a power law distribution.

6. The cosmic equation

The next question is how fast technology can increase. Again, we can offer a rough argument, using the above suggestion that technology evolution is a combinatorial process.

If technology grows through combination of existing technologies, the rate of technology growth should depend on the number of possibilities for combination among the technologies already in existence. If there are T technologies and each can combine with any of the remaining $T - 1$ technologies, that gives $T(T-1)/2$ possible combinations, where the division by 2 is because A combining with B is the same as B combining with A. This is approximately $T^2/2$ combinations, or if we accept the possibility of a technology combining with itself—for example, string might combine with string to create weaving—then there are exactly $T^2/2$ possible combinations. We have said the rate of technology growth, dT/dt, increases with the number of possible new combinations, so we have

$$\frac{dT}{dt} \sim T^2 \tag{13}$$

The construction of Equation 13 assumes only pair-wise combinations of existing technology. This keeps things simple for the purpose of a rough calculation. In any case, it could be argued that combinations involving more than two precursors are just a series of pairwise combinations. For example, a combination of three technologies could be seen as first a combination of two technologies and then that combined technology joins with the third.

Remembering that technology is an ordering of flows of matter and energy, and that higher technology implies more complex flows, we can see Equation 13 more abstractly as describing the growth of complexity in a combinatorial process. Insofar as chemical and biological evolution also involve the growth of combinatorial complexity, this equation describes the growth of cosmic complexity in general, from molecular synthesis through natural selection to human-mediated elaboration of socio-technical systems. Using y to represent this generalised cosmic complexity, Equation 13 can be seen as a special case of the more general equation (cf. Korotayev, 2018)

$$\frac{dy}{dt} \sim y^2 \qquad 14$$

Equation 14 says that cosmic complexity grows in proportion to the potential for combination within the existing complexity, and this potential for combination is proportional to the square of the existing complexity as argued above for the special case of technology T.

We can rearrange Equation 14 to give

$$\frac{1}{y}\frac{dy}{dt} \sim y \qquad 15$$

While Equation 14 describes the absolute rate of complexity increase, Equation 15 describes the fractional or percentage rate of complexity increase. It says this fractional rate of complexity increase is proportional to the existing complexity. This is again because of combination. While a certain fraction of the existing complexity gives rise to new complexity per unit time, it does so not at a fixed rate but at a rate that depends on the amount of existing complexity with which it can combine.

Alternatively, we can differentiate Equation 14 with respect to y to give

$$\frac{d}{dy}\left(\frac{dy}{dt}\right) \sim y \qquad 16$$

where differentiating y^2 with respect to y gives $2y$ and we have absorbed the 2 into the proportionality sign. Equation 16 says that the complexity growth rate increases with complexity at a rate proportional to the existing complexity. Once again, the statement reflects combination. When existing complexity is low, a given increase in complexity only produces a small number of new combinatorial possibilities. When existing complexity is high, the same increase in complexity makes a much larger number of possible combinations available.

Using dot notation to represent differentiation with respect to time and dash notation to represent differentiation with respect to y, Equation 16 can be written especially succinctly as

$$\dot{y}' \sim y \qquad 17$$

or, if we can choose units for y that make the proportionality constant equal to unity, just

$$\dot{y}' = y \qquad 18$$

Equations 14, 15, 16, and 17/18 are all equivalent and each implies the others. It is a matter of personal preference which one is taken as the baseline ‘cosmic equation’. They all have the same solution for y as a function of time, which is

$$y \sim \frac{1}{t_0 - t} \qquad 19$$

This describes hyperbolic growth reaching a singularity (infinite growth) at time $t = t_0$. Such a hyperbolic, ‘hockey-stick’ or ‘J-curve’ growth pattern has been demonstrated in population and technology (Korotayev, Malkov, & Khaltourina, 2006a) and seems to be generally characteristic of socio-technical processes (Stiner, Earle, Smail, & Shryock, 2011).

7. Evolutionary envelope

While the cosmic equation predicts that technology and other evolutionary processes will undergo hyperbolic growth up to a singularity, such a point of infinite growth cannot be reached in practice. It is avoided because evolution is not only combinatorial but is sample space reducing. Evolution tends to reach dead ends and needs to be restarted via episodes of creative destruction that have a power law distribution. In other words, evolution encounters resistance and is subject to frequent, small hold-ups and rarer, larger hold-ups.

The resulting evolutionary trajectory is illustrated in Figure 5. It consists of a series of truncated hyperbolas with restarts at irregular intervals. The successive restarts define an envelope curve that represents the overall, long-term path of evolutionary change.

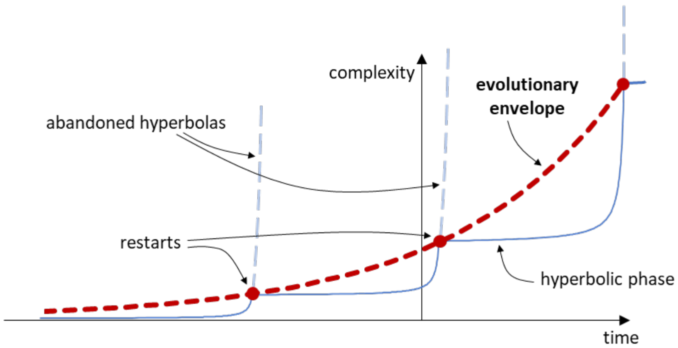

Figure 5: Restarts of the hyperbolic growth process due to the reduction and reopening of sample space.

This pattern has been observed in global population and technology growth, with a shift from an Older to a Younger Hyperbola around the time of the 'Axial Age' in the final few centuries BC, when important new religious, philosophical, and social ideas were introduced (Korotayev, Malkov, & Khaltourina, 2006b, pp. 147-162). Closer examination hints at a series of such shifts, each staving off the approach to singularity by different amounts at different times (Widdowson, 2020, p. 193).

8. Time to pleroma

We now have the equipment to calculate the time to pleroma, which depends not on the hyperbolic growth predicted by the cosmic equation but on the envelope of the repeatedly restarting hyperbolic phases.

First, let us assume that pleroma corresponds to Kardashev-4, i.e. command of an entire universe. Then the problem is to calculate the time to reach Kardashev-4 given what we know about the rate of increase of humanity's Kardashev level so far.

A planet, solar system, or galaxy can be regarded, once it has come under the management of a cosmic civilisation that exploits it in the pursuit of that civilisation's aims, as a tool or gadget, i.e. as a technological function. Kardashev level is therefore a measure of function. Using K to represent Kardashev-level, we can write

$$K \equiv F \qquad 20$$

i.e. Kardashev-level is equivalent to the quantity 'functions'. In making this equation, we are introducing another major assumption, which is that the Kardashev scale of 1, 2, 3, 4 is not just an ordinal scale but a genuine metric, i.e. the leaps say from planet to solar system and from solar system to galaxy are in some sense equal. Since, by Equation 5, functions are related to the logarithm of technology, this would be a geometric rather than arithmetic scale from a technological perspective. That is, the assumption implies that, if it takes say a thousand (1000) technologies to manage a planet, then it takes a million (1000^2) to manage a solar system, a billion (1000^3) to manage a galaxy, and a trillion (1000^4) to manage a universe.

Given Equation 20, Equation 5 can be written

$$K = \gamma \ln T \qquad 21$$

where we also introduce a proportionality constant γ.

While Equation 12 was derived by considering the probability of a technological reversal opening up sample space by a given amount, for our back-of-the-envelope calculation we can postulate that it equally well describes the probability of a technological advance by a given amount—as with the shift from horses to the internal combustion engine, the reversal and the advance are two sides of the same coin. Meanwhile, the probability of Equation 12 is really a probability per unit time. Since the expected time to achieve an event is the reciprocal of the probability of that event occurring per unit time, the expected time t to achieve technology T is

$$t = \frac{1}{\text{prob}(T)} \sim T^{\beta} \qquad 22$$

Or, introducing a proportionality constant A,

$$t = AT^{\beta} \qquad 23$$

Taking logarithms, Equation 23 becomes

$$\ln t = C + \beta \ln T \qquad 24$$

where $C = \ln A$. Substituting from Equation 21 for $\ln T$ and defining $\eta = \beta/\gamma$, this becomes

$$\ln t = C + \eta K \qquad 25$$

This describes the envelope curve representing the overall growth of Kardashev level, which is related to the overall growth of technology via Equation 21.

Since we have two unknowns, η and C, we need at least two points (t_i, K_i) on the envelope curve so that we can solve for them. We can recognise points on the envelope curve as they are points at which the underlying growth shifts from one hyperbola to another, as illustrated in Figure 5.

One such shift point is the present day, insofar as global population growth has recently left its hyperbolic trajectory and is slowing down rapidly, perhaps reaching a ceiling some time in the next century (United Nations, 2019). Another such point is the shift from the Older to the Younger Hyperbola in the Graeco-Roman era.

We now need to make some estimates regarding the times t_i of the turning points and the Kardashev levels K_i of global civilisation at those turning points. For this purpose, we will set the time $t = 0$ as corresponding to the emergence of modern human societies c. 50 kya (rounding up the 40 kya mentioned at the beginning of this article), which is when the process of continuous combinatorial technology growth seems to have got started in earnest. This means the current time is $t_N = 50$ ky (subscript N for 'now'). The current Kardashev level will be taken to be at the low end of typical estimates, i.e. $K_N = 0.3$. This reflects the fact that humans have hardly begun to exploit the oceans, which cover 70% of the earth, while near-earth space is also only inhabited by a handful of people. The time of the shift from Older to Younger Hyperbola will be taken, in round numbers, to be around 500 BC or at time $t_X = 47.5$ ky (subscript X for Axial Age). To assign a Kardashev level, we will assume that, below Kardashev level 1 (command of a planet) is Kardashev level 0 (command of a continent), and below that is Kardashev level -1 (command of a natural geographic area). The Roman Empire that emerged around the relevant time was somewhere between these two levels. Arguably, it was closer to level 0 than to level -1 because, while it did not control any one continent, it did span three continents and it was larger than any Mediterranean polity of today. Let us estimate its Kardashev level as $K_X = -0.3$.

Substituting our values (t_N, K_N) and (t_X, K_X) in Equation 25 gives us a pair of simultaneous equations in η and C that can be solved to give $C = 0.9$ and $\eta = 0.09$.

Knowing C and η, and taking the Kardashev level at pleroma to be $K_P = 4$, we can use Equation 25 again to calculate t_P, the time of pleroma. This turns out to be $t_P = 68.6$ ky. In other words, pleroma will occur 68,600 years measured forward from 50,000 years ago, which corresponds to 18,600 years from today or around AD 20,600.

Thus, we estimate that humanity will reach the destination of its physical, intellectual, and moral journey sometime in the 21st millennium AD. We call this final destination 'pleroma' and what we mean by it is that: (1) humans will have fully traversed, explored and occupied the entire universe, domesticating it in the way that landscapes on earth have been domesticated; (2) humans will understand every remaining mystery of nature, in particular, consciousness and existence, and, through ephemeralisation, they will in effect be able to do everything with nothing; (3) humans will have achieved some kind of ethical perfection that we cannot currently comprehend and that means their custodianship of the universe will be benign and creative.

9. Conclusion

Contemplating the long-term path of humanity, meaning its travels, discoveries, and ethical practices thousands of years in the future, is clearly an imprecise and risky undertaking. This paper has relied on many arbitrary and debatable assumptions and some of its conjectures may seem to veer into the realms of religion, particularly those concerning a self-explanatory or self-referential universe that imagines its way into existence, derives meaning and purpose from one of its own creations, and evolves both towards and away from its beginning through anti-parallel processes of material exhaustion and information augmentation. The possibility of moral perfection may also seem to be far from what can be discussed objectively and scientifically. There can therefore be no authoritative answers and it is certainly not suggested that either the reasoning or the findings of this paper should be regarded as definitive. The calculation that humans will have 'conquered' the universe just 18,000 years from now strikes the author as far too low. Others who are expecting a singularity in the next few decades may find it far too high. Still others, expecting humanity to blow itself up (Rees, 2004), or to be confined to earth by physical law, may regard it as something that will never be achieved at all.

This paper has served as a vehicle to introduce some thoughts about pleroma, humans' place in the universe, and the 'origin and goal of history' (Jaspers, 1953). It is a counterpoint to other theories, not a rejection of them. It takes some assumptions—such as what history so far tells us about where humanity is headed and what the apparent silence we have so far encountered in the heavens tells us about life on earth—and follows where they lead. While those assumptions might be wrong, it is by identifying and exploring them that we gain understanding of the issues they raise. The paper has pondered how seemingly contrasting spiritual and scientific investigations into the nature of the cosmos may converge and collaborate to answer the fundamental questions entertained by both strands of inquiry. It has argued that a suitable way of measuring and modelling the progress of technological civilisation and perhaps of cosmic evolution in general is in terms of combinatorial complexity. A practical consequence of this is the suggestion that singularity-avoiding interruptions to hyper-exponential growth, such as the shift from Older to Younger Hyperbola, might be seen as restarts of a Sample Space Reducing Process, which could be checked, given data with sufficient resolution, by testing whether they have power law statistics.

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Exploring the Human History: Cybernetic Modeling, Systemic Perspectives, and Applications in Archaeological Eras

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Abstract: Since the 1970s, cybernetic modeling of evolutionary processes has progressed, particularly with the development of the informatics-cybernetic model (ICM). This model conceptualizes humanity as a self-regulating hierarchical network system, continuously tracking energy-based target crite-ria through search optimization algorithms. The outcomes are recorded in the system memory of corresponding hierarchical subsystems. Within the ICM framework, the spatio-temporal charac-teristics of global evolution exhibit modifications reminiscent of the Zhirmunsky-Kuzmin number series, a geometric progression they identified in the exploration of critical levels in biosystem development. The study also showcases applications of mathematical-cybernetic modeling results in understanding historical processes examined by archaeologists and historians.

1. Introduction

Estimating the age of global human history has been approached through various lenses, including the emergence of ancient civilizations, the Upper Paleolithic revolution, and the advent of Homo sapiens. To elucidate this choice, a systemic method becomes imperative. Cybernetic modeling of these processes, a field pioneered by V.F. Turchin (1977), N.N. Moiseev (2001), A.P. Nazaretyan (2004), M.B. Ignatiev (2006), and others, offers valuable insights. Particularly, the informatics-cybernetic model (ICM) conceptualizes Humanity as a self-regulating hierarchical network system. It consistently tracks energy-based target criteria through search optimization algorithms (Rastrigin, 1968, 1979, 1980, 1981; Pervozvanskij, 1970), storing results in the system memory of corresponding hierarchical subsystems (Grinchenko, 2001, 2006, 2007; Grinchenko & Shchapova, 2020a, b) (see fig. 1).

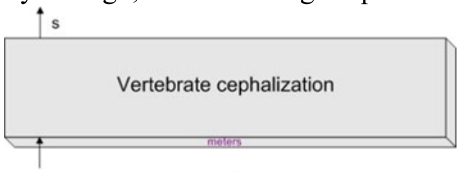
The spatio-temporal characteristics of global evolution within the ICM framework reveal modifications of the Zhirmunsky-Kuzmin number series—a geometric progression with the denominator of e^e, (=15.154..) as identified in their study of critical levels in biosystem development (Zhirmunsky & Kuzmin, 1982, 1988, 1990). This series was found when investigating biological growth where the growth rate is proportional to level at a previous time (i.e., a delay). If there is no delay, then the equation becomes one characterizing simple exponential growth. To generalize, the proportionality constant and the delay might also be time dependent. If they are both not dependent on time, the equation again characterizes exponential growth. As an organism grows, the growth rate follows discrete periods of allometric growth (where the growth rate is inversely proportional to the time). Each distinct growth period has a different scaling factor. The times at which the allometric scaling factors change is called a critical point. The ratios of the critical points seem to follow the ratio of of e^e, (=15.154..). Throughout the process the growth rate decreases with time.

Applications of mathematical-cybernetic modeling results in the archaeological era, along with their alignment with empirical data from paleontologists, archaeologists, and historians, are detailed in the monographs by Shchapova & Grinchenko (2017) and Shchapova et al. (2019).

2. Stages of the global evolution of Humankind's Self-controlling System

From the standpoint of ICM, the stages of complication of information technologies (IT), production technologies (PT), socio-economic formations (SEF) and civilizational structures of the Humanity system in the course of its historical development look as follows (Fig. 2).

0). Cephalization of vertebrates ~428 million years ago, culminating in the emergence of the neocortex ~140.1 million years ago, in catfish ranges up to ~4.2 m in size.



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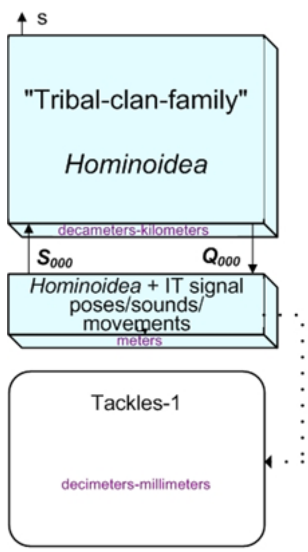
1). The emergence of "pre-pre-humans" *Hominoidea* and the beginning of their development of IT signal postures/sounds/movements ~28.2 million years ago, culminating in the emergence of *Hominidae* ~9.26 million years ago, in the "yard"/ "family" in territories (radius of a circle of the same area) up to ~64 m in size, and with an accuracy of anthropogenic impacts up to ~28 cm.



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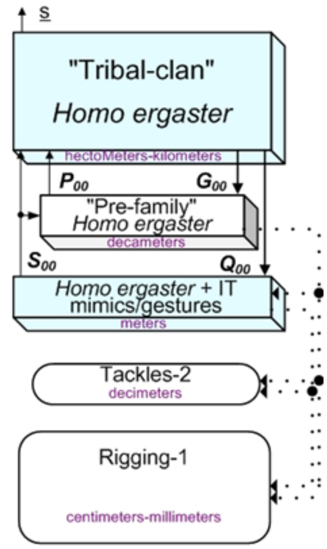
2). The emergence of "pre-humans" *Homo erectus/Homo ergaster* and the beginning of their development of IT facial expressions/gestures ~1.86 million years ago, culminating in the emergence of *Homo heidelbergensis* ~0.612 million years ago, in "settlement" areas up to 1 km in size , and the accuracy of anthropogenic impacts up to ~1.8 cm.



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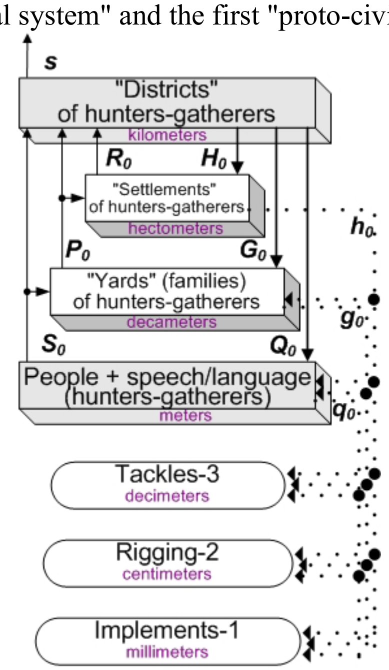
3). The emergence of *Homo sapiens-1* man and the beginning of his development of IT speech/language ~123 thousand years ago, with a culmination (Upper Paleolithic revolution) ~40.3 thousand years ago, in the areas of the "okrug" up to ~15 km in size, and the accuracy of anthropogenic impacts up to ~1.2 mm. The beginning of the development of the General Public Fund "Primitive-communal system" and the first "proto-civilizations".



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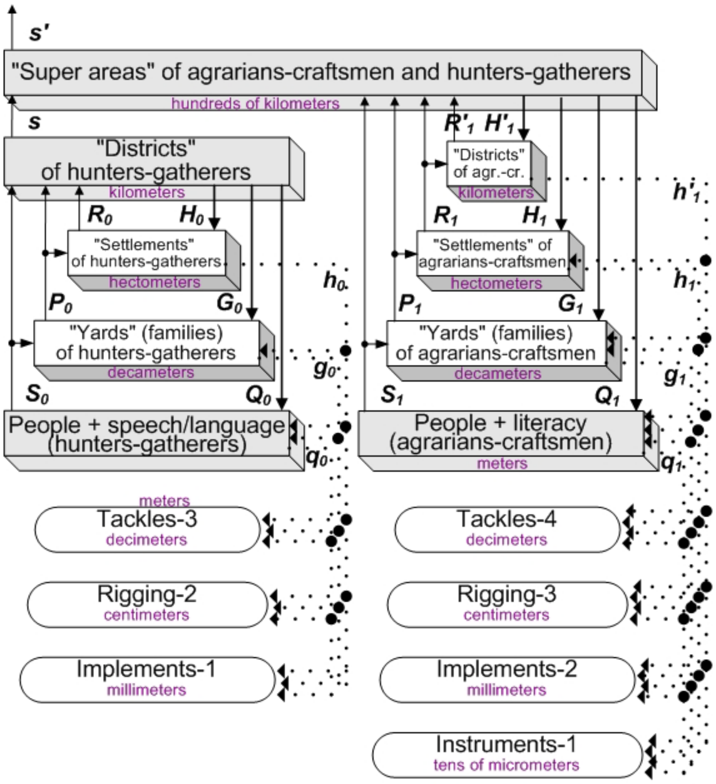
4). The emergence of a complicated human *Homo sapiens-2* and the beginning of his mastery of IT writing/reading ~8.1 thousand years ago, with a culmination (urban revolution of the axial time) ~2.7 thousand years ago, in areas of "super-district" up to ~222 km, and the accuracy of anthropogenic impacts up to ~ 0.08 mm. The beginning of the development of the OEF "Feudalism" and local civilizations.



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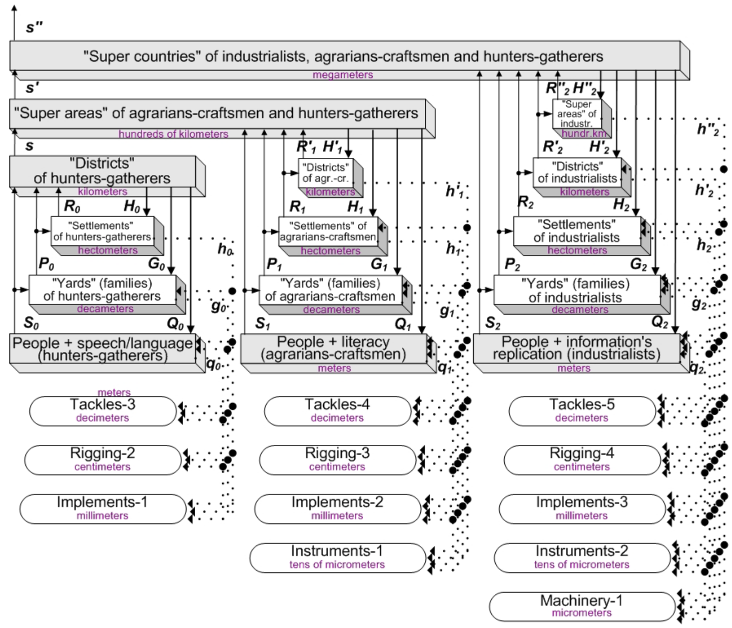
5). The emergence of a more sophisticated human *Homo sapiens-3* and the beginning of the development of IT replication of texts ~ 1446, with a culmination (industrial revolution) ~ 1806, in the areas of the "supercountry" up to ~ 3370 km in size, and the accuracy of anthropogenic impacts up to ~ 5 µm. The beginning of the development of the OEF "Capitalism" and regional/subcontinental civilizations.



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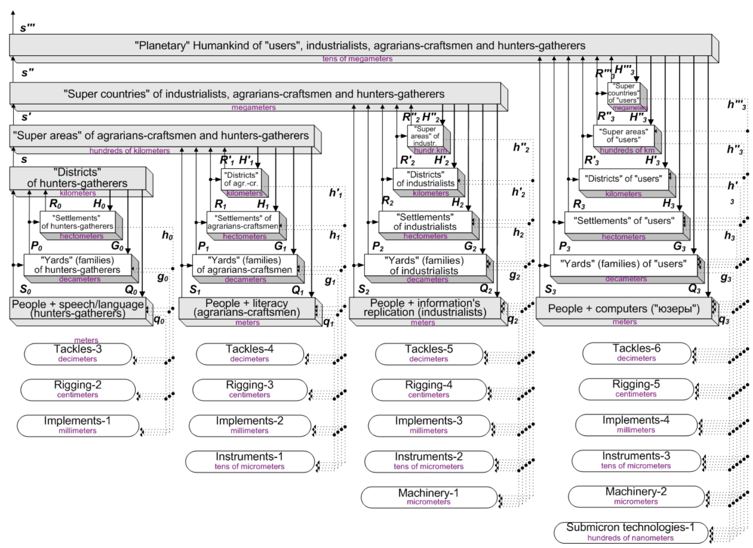
6). The emergence of an even more complicated man *Homo sapiens-4* and the beginning of his development of IT local computers ~ 1946, with a culmination (microprocessor revolution) ~ 1970, in the “Planet Earth as a whole” area up to ~ 51 thousand km in size, and accuracy anthropogenic impacts up to ~0.35 µm. The beginning of the development of the OEF "Digitalism-1" and Planetary Civilization.



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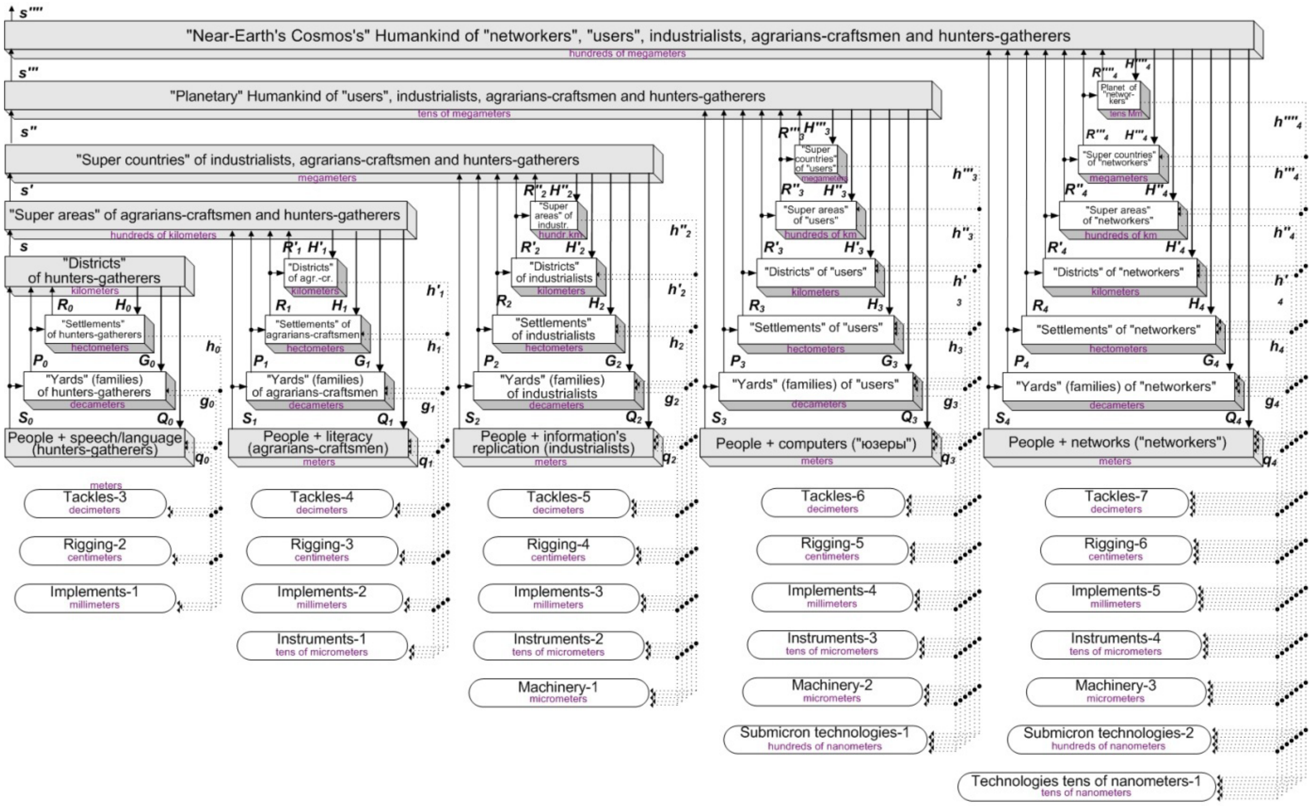
7). The emergence of a more complex human *Homo sapiens-5* and the beginning of his development of IT telecommunications / networks ~ 1979, with a culmination (network revolution) ~ 2003, in the “Near-Earth Space” area



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with a size (radius of a ball around the Earth) up to ~773 thousand km, and the accuracy of anthropogenic impacts up to ~23 nm. The beginning of the development of the OEF "Digitalism-2" and the Civilization of the Near-Earth Space.

8). The emergence of an even more complex human *Homo sapiens-6* and the beginning of the development of promising nano-IT ~ 1981, with a culmination (nano-revolution) ~ 2341, in the Intermediate Space area up to 11.7 million km in size, and accuracy anthropogenic impacts up to ~1.5 nm. The beginning of the development of the OEF "Cyphralism-3" and the Civilization of the Intermediate Space.

At the same time, the following is fulfilled: the principle of systemic cumulation: the emergence of new systemic entities does not mean the elimination of similar ones that have previously arisen; and the principle of systemic consistency: this emergence is accompanied by cardinal complications in the structure and adaptive behavior of those that have previously arisen, with a decrease in their relative role (Grinchenko, 2020).

The evolution of basic information technologies stands as a distinct "stream" within the broader context of systemic global evolution for Humankind. This progression intertwines with various parallel sequences, encompassing the development of production and macro-structural technologies (Grinchenko, 2007), shifts in socio-economic formations (Grinchenko, 2021a, 2022a), the evolution of civilizations in diverse forms (Grinchenko, 2011, 2021b, 2022b), the configuration of the substratum of the collective unconscious (Grinchenko, 2020c), the phenomenon of "multidimensional hierarchical territorial sovereignty" (Grinchenko, 2022c, d, 2023), classifications of informational and military weapons (Grinchenko, 2022e, f), challenges related to global Internet dominance (Grinchenko, 2022g), the dynamics of "communication" (Grinchenko, 2022h), the intricacies of "upbringing" (Grinchenko, 2022i), the stages of cultural development as a "second nature" (Grinchenko, 2020d), the systemic education level of individuals (Grinchenko, 2022j), the phases of global educational system evolution (Grinchenko, 2021c), and the phylogeny of personality (Grinchenko, 2019), among others.

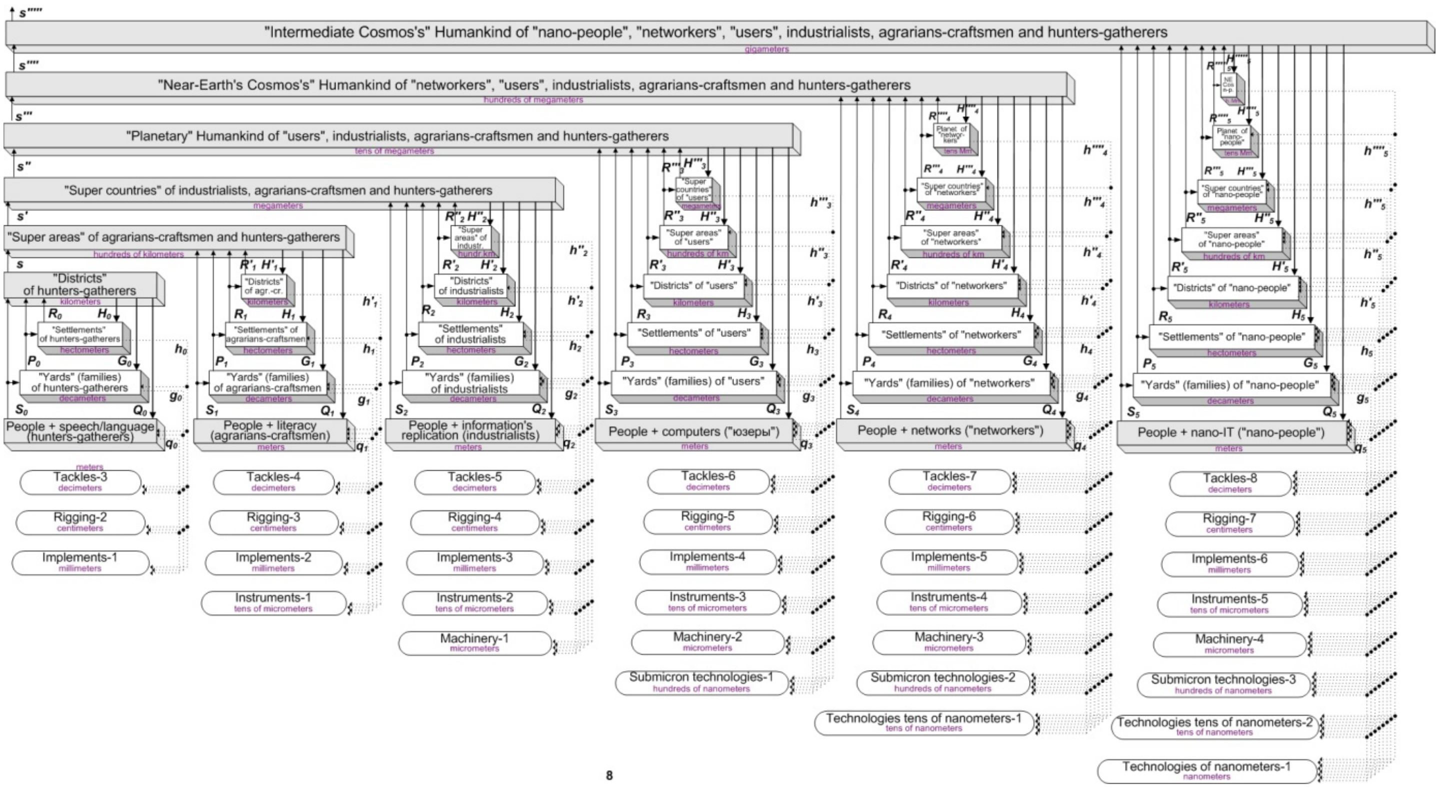

Fig. 1. (Stages 0-8 above) Hierarchical structures of the global evolution of the personal-production-social nature

***Notes to the figures**: ascending arrows, having the "many-to-one" structure, reflect the search activity of representatives of the corresponding tiers in the hierarchy; descending solid arrows, having the "one-to-many" structure, reflect the target criteria for search optimization of system energy – extreme, with constraints such as equalities and inequalities; descending dotted arrows, having the "one-to-many" structure, reflect the systemic memory of the personal-industrial-social – the result of the adaptive influences of representatives of the overlying hierarchical tiers on the structure and behavior of the underlying ones embedded in them.*

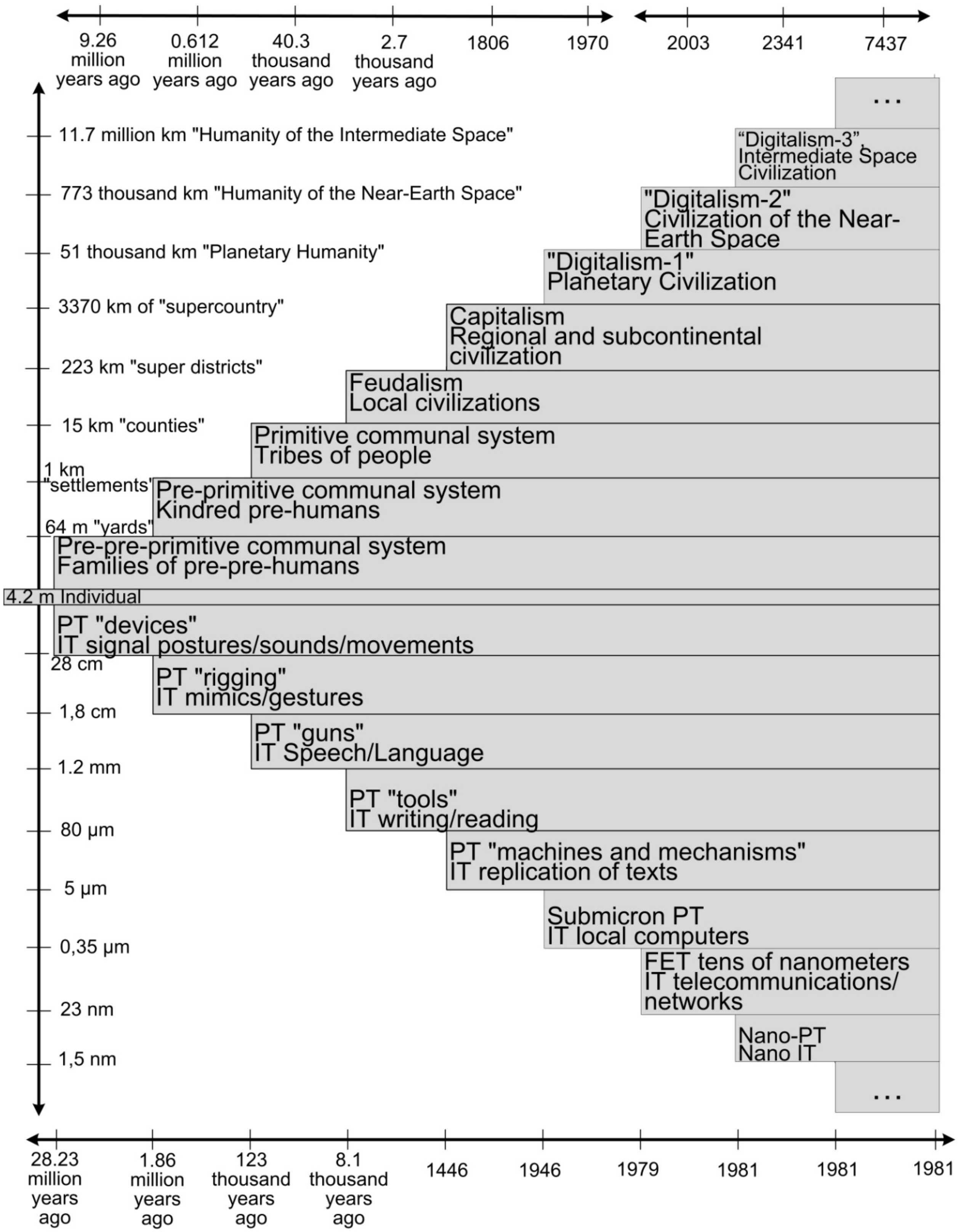

Fig.2. Stages of the global evolution of a self-controlling system of Humanity.

Conclusions

Cybernetic interpretation of the self-regulating hierarchical network system of humankind, indicates a rich unfolding across its sequence of stages. The increase in complexity of information, production, and organizational processes can be identified and diagrammed during these 7 evolutionary stages—from the emergence of Hominoidea about 30 million years ago to the present. This sequence presents promising insights for future predictions for the next stage.

Furthermore, the fact that a specific natural process can be delineated by a mathematical expression (often of the simplest kind) implies its inherent reliance on fundamental laws of the universe. This paper extends this characteristic beyond the realms of inanimate and living nature explored by Zhirmunsky to also encompass cultural aspects as a unified whole. This suggests that regardless of the perceived "freedom" exercised by individuals and the societies they forge, the laws of the universe persist, determining the primary coarse trajectories of global evolution within the overarching narrative of Big History.

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Applying a Big History Analogy to Facilitate Information Sharing

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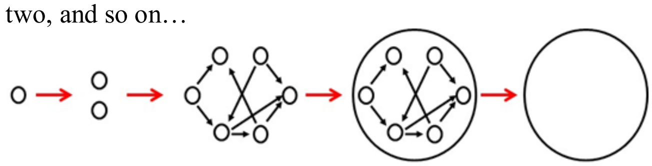
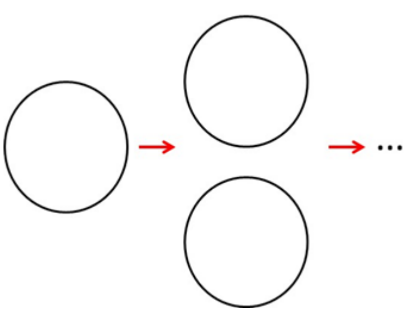
Abstract: Using analogies we generalize Tyler Volk's combogenesis concept. A pedagogical application is a narrative that allows us to include some milestones of mathematics and physics in Big History courses. Applying the concept to books and book collections we suggest a philanthropic idea. This simple and potentially powerful application mixes low and high technology: using online bookstores, we propose the reproduction of personal book and video collections in public libraries. We give an example, at Simón Bolívar University in Venezuela, where this has already happened. We finish by proposing to use this idea to create a Big History book and video collection that could be donated to educational institutions around the world where a Big History course could be taught remotely.

1. Introduction

Once upon a time, there was one unit, then there were two, then three, and so on. Eventually many of these units had several relations among them and they became a new unit of a higher level. Then, at that new level, the story starts again: there was one unit, then two, and so on…

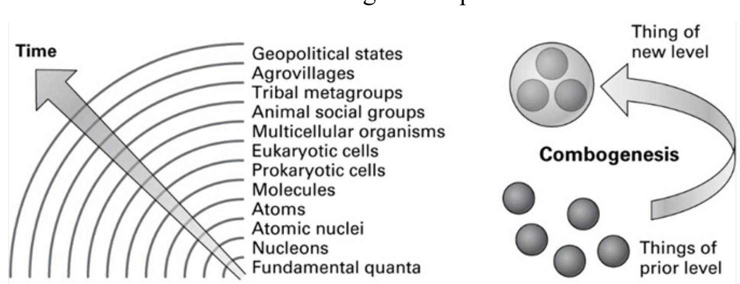




What interpretation can we give to this abstract story? Based on what we teach in the Big History courses, we can list the following interpretations:

Small units		Relations		Larger units
Elementary particles	→	Fundamental forces	→	Atoms
Atoms	→	Chemical bonds	→	Molecules
Molecules	→	Biochemistry	→	Cells
Unicellular organisms	→	Symbiosis	→	Multicellular organisms
Individuals	→	Social relationships	→	Societies

These examples are part of what Tyler Volk (2017), in *Quarks to Culture*, calls combogenesis: "*The genesis of new types of things by combination and integration of previously existing things, restricted in this book to the types along the levels of the grand sequence.*" The image below, taken from Tyler Volk (2017), shows how he defines the levels of his grand sequence:



We can see that Volk restricts the term to tangible things and social groups. In this paper we are going to generalize the concept to other things that are not necessarily tangible. We call this generalization the bottom-up story.

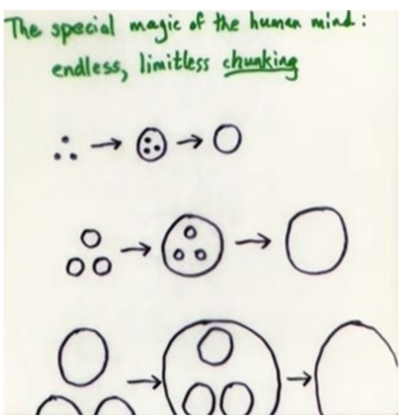
2 Concept formation narrative

Based on *Surfaces and Essences: Analogy as the Fuel and Fire of Thinking* by Douglas Hofstadter and Emmanuel Sander (2011), there is this bottom-up story:

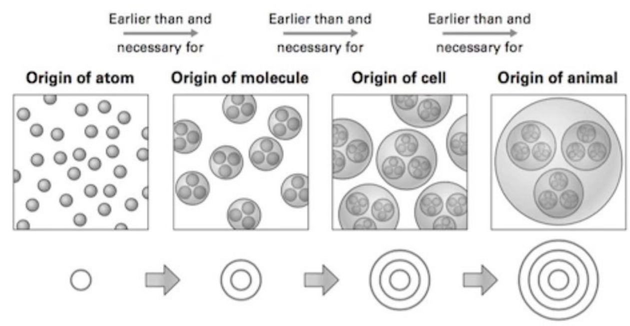
Small units	Relations	Larger units
Perceptions →	Analogies →	Concepts
Concepts →	Analogies →	More abstract concepts

For example, when we are very young kids, from the perceptions of some animals we create the concept of cat. Later, from groups of animals or objects, we create the concept of numbers and we go, for instance, from "four apples plus two apples is six apples" to just 4 + 2 = 6. At school, in our first encounter with algebra, we go up in abstraction and we learn to use letters instead of numbers to write, for example, x + 2 = 6.

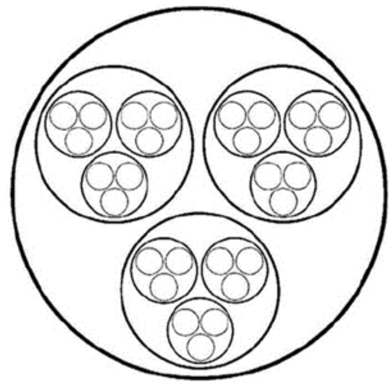
The thesis of Hofstadter and Sander is that repeated analogies create and expand concepts. Note that to introduce the concept of the bottom-up story we used repeated analogies instead of a formal definition. In the video [Analogy as the Core of Cognition](), Hofstadter defines chunking as the process by which primordial concepts in some interrelationships become a larger conceptual unit:



This Hofstadter diagram is strikingly similar to this one shown by Tyler Volk (2017):



Arthur Koestler (1967), in *The Ghost in the Machine*, introduced the concept of the *holon*: something that is simultaneously a whole and a part. He also showed, as an example of hierarchy, three circles within circles:



In *Janus: A Summing Up*, Koestler (1978) said that "*The term 'holon' may be applied to any structural or functional sub-system in a biological, social or cognitive hierarchy*" but in the diagram above he was describing a structure, he was not telling a story, while Hofstadter and Volk describe how the structures came to be. They are telling bottom-up stories.

There is a similarity between the perceptions/concepts interpretation and the way that David Christian, Cynthia Stokes Brown and Craig Benjamin (2013), in *Big History: Between Nothing and Everything*, describe symbolic language:

> *Rather than using sounds or gestures to refer to one particular thing, we can use sounds as conceptual parcels that refer to whole categories of ideas and things.*

In the [OER Project Big History course]() the only threshold that is not tangible is collective learning. All the other thresholds have to do with matter or energy. Collective learning is the only one that is only about information. We propose to teach some collective learning milestones using the bottom-up story: concept formation narrative. This could be in a separate History of Science course or in lessons within a Big History course. In particular, we can use the concept formation narrative as tool to help tell the stories of mathematics and physics.

A common misconception about mathematics is that its objects of study are only numbers and figures, when it is really more about abstractions. The history of mathematics is full of examples of higher and higher abstractions, here are some of them:

Small units		Larger units
Geometry, algebra	→	Analytic geometry
Clocks, evens and odds, . . .	→	Modular arithmetic
Arithmetic operations, Rubik's cube moves, . . .	→	Group theory
Area, volume, probability, . . .	→	Measure theory

In the history of physics many milestones can be seen as the unifications of concepts:

Concepts		Unified concepts
Terrestrial mechanics, celestial mechanics	→	Newtonian mechanics
Electricity, light, magnetism	→	Maxwell's equations
Heat, sound, gravitational energy, . . .	→	Energy
Space, time	→	Minkowski spacetime
Energy, mass	→	Einstein's $E = mc^2$

Many of these syntheses have been achieved using increasingly abstract mathematical theories. For example, Newton invented calculus to find how planets move based on his laws of motion and his law of universal gravitation.

A more ambitious project would be to teach the Big History of information. Here are some sources for this possibility:

- In the preface of *The Origins of Life: From the Birth of Life to the Origin of Language*, John Maynard Smith and Eörs Szathmáry (1999) state that:

> *…evolution depends on changes in the information that is passed between generations, and …there have been 'major transitions' in the way that information is stored and transmitted, starting with the origin of the first replicating molecules and ending with the origin of language.*

- In *Where Good Ideas Come from: The Natural History of Innovation* Steven Johnson (2010) draws many analogies between biological evolution (starting with theories about the origin of life) and cultural innovations and analyzes how their stories are told.
- Ken Solis (2018) and Ken Solis and David LePoire (2020) take an even broader perspective, including before the origin of life. Additionally, they mention a form of information well-known in economics but not so much by the wider public: price signals, which are the information conveyed by prices to producers and consumers. They are an abstract form of communication.

3 Publication narrative

This narrative could start with Lawrence Husick's (2011) concept of *intentional pedagogy*. He says:

> *Innovation #0* [at the top of his ranking], *in my view, is one that outshines and underlies every other innovation we have discussed. That is the concept of intentional pedagogy…. It's the idea that humans can intentionally transmit culture and generalize knowledge from the specific instance to that which is teachable, and then intentionally give that knowledge to another person across time and space.*

Therefore the first times that humans performed intentional pedagogy can be thought of as the first instances of publication, albeit with a primitive, possibly just gestural, communication.

David Christian's (2004) influential *Maps of Time* contains this table:

TABLE 10.4. INFORMATION REVOLUTIONS IN HUMAN HISTORY

Era	*Approximate Date*	*Ways of Moving Information*
Paleolithic		
	Paleolithic, beginnings of human history	Modern forms of language; information sharing between different groups
	Upper Paleolithic	Cave paintings
	From Upper Paleolithic?	Communication at a distance using drums, beacons, smoke signals
Agrarian		
	From ca. 3000 BCE	Writing as congealed information
	From ca. 2000 BCE	Syllabic writing
	Era of agrarian civilizations	Government-sponsored or military courier system
	From 8th c. CE	Printing using wood blocks
Modern		
	16th c. CE	Global world system; worldwide systems of communication and transport
	18th and 19th c.	Print used for mass communication: newspapers, postal services
	From 1830s	Telegraph
	Late 1880s	Telephone
	20th c.	Electronic mass media: radio, film, TV
	Late 20th c.	Internet; instantaneous global communication of information

That table omits the following bottom-up story, which we suggest to emphasize in the publication narrative:

Small units		Larger units
Published books	→	Libraries

In the series/book *Cosmos*, in episode/chapter 11, *The Persistence of Memory*, Carl Sagan (1980) pays tribute to books and libraries:

> *Books permit us to voyage through time, to tap the wisdom of our ancestors. The library connects us with the insights and knowledge, painfully extracted from Nature, of the greatest minds that ever were, with the best teachers, drawn from the entire planet and from all of our history, to instruct us without tiring, and to inspire us to make our own contribution to the collective knowledge of the human species. Public libraries depend on voluntary contributions. I think the health of our civilization, the depth of our awareness about the underpinnings of our culture and our concern for the future can all be tested by how well we support our libraries.*

In that episode of *Cosmos*, Sagan states:

> *The units of biological evolution are genes. The units of cultural evolution are ideas. Ideas are transported all over the planet. They reproduce through communication. They are selected by analysis and debate.*

Perhaps Sagan was influenced by Richard Dawkins (1976), who introduced the term *meme* in *The Selfish Gene*. There, in the chapter *Memes: The new replicators*, Dawkins explains:

> *The analogy between cultural and genetic evolution has frequently been pointed out …The analogy between scientific progress and genetic evolution by natural selection has been illuminated especially by Sir Karl Popper.*

In the book *In Search of a Better World*, in the chapter *Books and Thoughts: Europe's First Publication*, Karl Popper (1994) describes a hypothesis:

> *…for some time I have had the idea that the Greek miracle, and especially the Athenian miracle, might perhaps be partially explained – and surely only* very *partially – by the invention of the written book, of book publishing and of the book market…*
>
> *…My hypothesis is that, by making books available for sale in Athens, Pisistratus had put in train a cultural revolution comparable in its importance to that started by Gutenberg two thousand years later; but my hypothesis is of course not testable. …Of course there are authors who work in a different way, but as a rule thoughts can be criticized and improved most effectively when one attempts to write them down for the purpose of publication, so that they may be understood by others…*
>
> *…This thesis of the powerful role of feedback, especially the feedback between the world 3 of books*[1] *and the world of our mental experiences, is important. That there are such objective contents we owe almost entirely to the invention of our specifically human language. For the first time in the history of the evolution of life on our wonderful planet, the invention of language made it possible for objective thought contents to exist; and by making it possible for us to look upon our thought contents as objects, it became possible for us to criticize them – and so to become critical of ourselves.*
>
> *The discovery of writing was the next step. But the most momentous step was the invention of the book and of the critical competition between books.*

Popper's hypothesis seems plausible because, as can be seen in Ancient Literature, in Classical Greece (the 5th and 4th centuries BC) there is an explosion in the number of known authors that have some books that are still published nowadays. Popper argues that the publishing of books created a positive feedback cycle of learning. That is why we call this bottom-up story the publication narrative. Popper's hypothesis fits very well with David Christian's ideas about positive feedback loops:

> *Transitions to new levels of complexity often depend on positive feedback mechanisms* (Christian, 2004).
>
> *In studying collective learning and human history we find many positive feedback cycles. Let's look at one particular type: those based on improvements in the way information is exchanged, stored, and circulated within networks – in essence, innovations having to do with communication and transportation* (Christian, 2023).

Therefore, we suggest continuing the publication narrative with the impact of book publication in Classical Greece, during China's Song and Ming dynasties and in Europe after Gutenberg's movable type printing. We could also include the histories of postal systems and of personal and public libraries. Many things could be said about the relationship between personal and public libraries. Merlin Donald calls them memory palaces and revolutionary (Donald, 2001). A famous personal collection of books in Classical Athens was Aristotle's one. Some think that such a collection could

[1] We can listen to Popper explaining his three worlds terminology in the video Karl Popper on the Three Worlds (1989).

have been the basis for the Library of Alexandria (Casson, 2001; Norman, 2014), others do not mention that possibility (Donald, 2001).

In the last centuries there are numerous cases of people influenced by personal and public libraries. The story of William Kamkwamba is a prime example of how one book helping one young person can have great impact. The image below is from the film *The Boy Who Harnessed the Wind*. This takes us to a donation idea.

4 Philanthropic proposal

The trick is to know which books to read.

—Carl Sagan, *Cosmos* (1980)

Applying the bottom-up story concept leads us to wonder: could we reproduce and publish personal book and video collections?

Small units		Relations		Larger units
Published books/videos	→	References, similarities, contrasts, sequence, …	→	Personal book/video collections
Personal book/video collections		→		Public libraries

The answer, thanks to online bookstores, is that it is easy (given enough purchasing power).

As an example, Bill Gates writes in his blog, *How energy makes life possible* (2017), "*I'm a fan of Vaclav Smil …I've read nearly all of his 37 books. I wait for new Smil books the way some people wait for the next* Star Wars *movie.*" In another entry, *Three cheers for the dull, factually correct middle* (2022), he writes, "*I have learned more about energy and its impact on society from Vaclav than from any other single source.*"

The philanthropic proposal in this case is that Bill Gates could donate copies of a collection of Vaclav Smil's books to universities in developing countries. That would not only promote the books in those universities but also would generate publicity for Vaclav Smil's books around the world. The reviews of Smil's books in Bill Gates' blog would be like a guided tour of that part of his personal library. In this image, from the Netflix documentary *Inside Bill's Brain: Decoding Bill Gates*, we can see him showing his collection of Vaclav Smil's books:

We don't need to be Bill Gates to use this philanthropic idea. There are thousands of professionals that have emigrated from developing countries to developed ones. They could choose the best books from their disciplines and donate them back home. The donations could be "live", in the sense that as soon as new worthwhile books are published, they can be donated and made accessible in countries where those books may never be published.

It is very common to assume that the new information network, the internet, replaces the old one of books and libraries. This philanthropic proposal implies using the new network to improve the old one. As the *Keep it simple* article from *The Economist* says: "*High tech is not the only tech.*" In the video *It's Not Information Overload. It's Filter Failure*, Clay Shirky argues that we should have better information filters (Rosen 2014). The proposal is to have three filters for the books: publishers, donors, and librarians.

5 Donation of *History of Ideas* Collection

…every subject has a history, and its history is an integral part of the subject.
…No one can claim adequate knowledge of a subject unless one knows how such knowledge came to be.

—Neil Postman, *Building a Bridge to the 18th Century* (1999)

This philanthropic proposal is not just theory. Since 2001 I have been donating a collection of books and videos, called *History of Ideas* to Simón Bolívar University in Venezuela. In general, I bought the books twice, once for me and once to donate. When I started donating the only condition I gave to the library was to keep the books together. The questions that led to this were: why do the history sections of bookstores and libraries focus on political and military history but not on the creative side of history: sciences, arts, technologies, discoveries, businesses, etc.? Could we have a section with the history of everything?

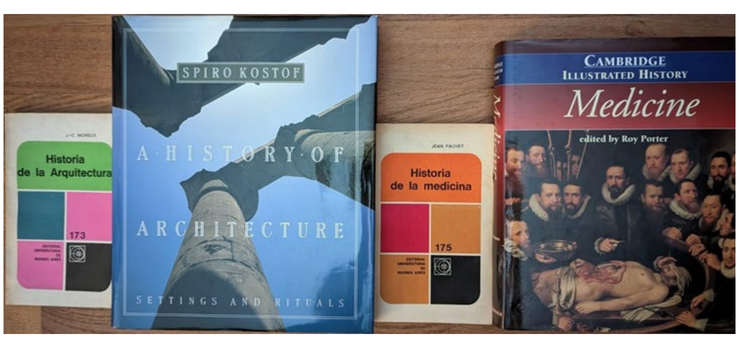
Here are some book lists of the collection:

Universe	Earth
Humans	Life
Mythologies	Philosophy
Some science classics	Science
La Plus Belle Histoire du…	Arts
La historia más bella de…	Cartoons
Nonfiction Pulitzer Prizes	Photography
Children books	Technology
Education	Religions
250 Milestones	

Here are some video lists of the collection:

Universe	Earth
Life	Humans
History of Ideas	

250 Milestones arrival, Simón Bolívar University Library staff including then Director Alejandro Teruel, December 2017



While sitting at home in London, I sent books to Venezuela from several countries using these online bookstores: USA: amazon.com; UK: amazon.co.uk; Spain: fnac.es, casadellibro.com, and iberlibro.com; Argentina: cuspide.com; France: amazon.fr; and Russia: urss.ru.

I had the idea when I read that the family of the late founding president of Simón Bolívar University, Ernesto Mayz Vallenilla, was donating his personal library to the university. I wanted to help my alma mater and I had collected books on the history of a variety of subjects that I thought I could share. I set a goal to reproduce my personal library. I called this copy of it a *telelibrary* because it was like offering to the university community the opportunity to visit my personal library, which is in another continent.

Small units		Relations		Larger units
Published books/videos	→	References, similarities, contrasts, sequence, …	→	Personal book/video collections
Personal book/video collections		→		Public libraries

Popper (1994) says "*thoughts can be criticized and improved most effectively when one attempts to write them down for the purpose of publication.*" Something similar happened with my library. Since I started to "publish" it, I criticized it more and some friends gave me feedback. So I improved it as much as I could. For example, in the image below you can see a couple of pocket books that I had since the 1980s and two other books that I bought after deciding to donate the collection.

This link has a letter that I sent in 2001 to Venezuela's Simón Bolívar University when I started donating this collection and a quote from *The Open Society and Its Enemies* by Karl Popper (1956) about how "*science can be taught as a fascinating part of human history…as a part of the history of problems and of ideas.*" The letter mentions some writings by José Ortega y Gasset (1930, 1935).

6 Donation of Big History collections

I propose to create a Big History book and video collection that could be donated to educational institutions around the world where a Big History course could be taught remotely. How does one choose such a collection? There are many options, here are a couple:

- All the books referenced in the material of the OER Project Big History course.
- All the books referenced in the bibliography of (Christian et al., 2013).

A reader in some developing country may find it difficult to get a hold of some referenced books/videos. If we think of books and their references as a network (directed graph) then the intention of making all the books referenced available is to facilitate navigation in such network. The references would work, metaphorically, like the hyperlinks of web pages. The Big History course of the OER Project is designed to be taught in person. This idea could help to teach the course remotely by giving students the opportunity to investigate more in depth.

Another example of a possible Big History collection can be found in these links: Big History book collection and Big History documentary collection. I suggest to include stories of scientists that could provide inspiration. Not just of old and famous ones, but also some about living scientists. For instance, *The Star Builders: Nuclear Fusion and the Race to Power the Planet* by Arthur Turrell (2021) could inspire future nuclear fusion scientists and engineers.

The donation of such a Big History collection would be a way to promote those books/videos and would be a complement to the resources available online. That would be particularly important where/when electricity or internet accesses are faulty.

7 A small suggestion for YouTube

A final application is a very simple one. Inspired by my experience teaching Big History online, I have a suggestion for YouTube: to allow users to like, dislike and post comments about playlists in the same way that they can do it about videos. YouTube playlists are created for varieties of reasons:

Small units		Relations		Larger units
YouTube videos	→	Sequences, similarities, references, contrasts, …	→	YouTube playlists

For example, the YouTube channel Web of Stories - Life Stories of Remarkable People has playlists where their interviews with notable scientists, writers, and other creative people are split in sequences of small videos. See for instance the interview of the evolutionary biologist John Maynard Smith.

While teaching Big History remotely, I create for each meeting a playlist with videos selected for it, intercalated with videos recorded during the session.

There are many excellent YouTube playlists that can be used to teach Big History, for instance the Human Evolution Learning Playlist from the YouTube channel PBS Eons. It is a pity not to be able to comment or hit a like button for a playlist. It is as if YouTube is focused just on the atoms and not on the molecules! Given that users can create the additional levels of aggregation below, ideally they could also like, dislike and post comments about them.

Small units		Larger units
YouTube playlists	→	YouTube collections
YouTube collections	→	YouTube channel

8 Conclusions

You should keep in mind no names, nor numbers, nor isolated incidents, not even results, but only methods. …The method produces numerous results

—Emanuel Lasker, *Lasker's Manual of Chess* (1925)

This paper shows that we can make pedagogical and philanthropic decisions about the present using Big History stories. This is an example of what Bob Bain describes in the video What Makes History Usable?:

> *…Students, and indeed all of us, must make decisions about the present that involve understanding what happened in the past…we all need to know how to take apart, work with, and create multiple stories about the past that influence how we think and act in the present. Stories are vital and essential in making history usable… Adding narratives to history courses promises to make them far more usable and useful…So, what are your stories? And how will you use them?*

I would like to mention some of my stories that I consider relevant. When I was a teenager my father taught me chess and instead of the many details of chess openings he preferred to teach chess strategy concepts – like piece activity, open files and pawn structure – that are useful to analyze numerous chess positions. A few years later, the Computer Science professors at Simón Bolívar University emphasized to us, their students, that it was more important to learn the concepts of the different programming paradigms instead of learning the particular syntax of numerous programming languages. These were some of the experiences that showed me the power of abstraction.

In the 1990s I read in Steven Levy's (1992) *Artificial Life*, a very abstract condition for life: self-reproduction, which is not necessarily biological reproduction. It could be the self-reproduction of a computer software, for example a computer virus. From the ideas of Dawkins and Popper mentioned above, I understood that what makes humans special is cultural reproduction because any form of communication, from the invention of language to any communication media, implies an attempt to reproduce in the mind of the receiver something that is in the mind of the sender. The term "cultural reproduction", which I see as a synonym to "collective learning", has the advantage of emphasizing the similarity with one of the things that makes life special: reproduction. That was the concept that I had in mind when I decided to reproduce my personal library at Simón Bolívar University.

The course Big History can provide concepts – like positive feedback cycles, bottom-up stories, and reproduction – that can be used in a variety of contexts. For instance, self-fulfilling prophecies, vicious and virtuous circles are particular cases of positive feedback cycles. In clinical psychology there are many examples of vicious circles and an instance of a self-fulfilling prophecy in finance is a bank run.

In this paper, I try to show that sometimes it is enough to have a conceptual model – not necessarily mathematical – and apply analogies to come up with practical applications to something that is very important: education.

In summary, this paper:

1. Introduces a Big History concept, the bottom-up story, which is a generalization of Tyler Volk's (2017) combogenesis. It has as particular cases the concept formation and the publication narratives.
2. Introduces the concept formation narrative:
    a. The appearance of symbolic language as it is usually taught in Big History courses, see for example (Christian et al., 2013).
    b. The way that, according to Hofstadter and Sander's (2011), we use analogies to create and expand concepts.
    c. Many milestones of the history of mathematics and physics can be seen as a series of unifications of increasingly abstract concepts.
3. Introduces the publication narrative:
    a. Lawrence Husick's (2011) concept of *intentional pedagogy*.
    b. Karl Popper's (1994) hypothesis about the impact of book publishing in Classic Athens, see *Books and Thoughts: Europe's First Publication*.
    c. The impact of book publication during China's Song and Ming dynasties.
    d. The impact of Gutenberg's movable type printing in Europe.
    e. A short history of postal systems and of personal and public libraries.
4. Based on the bottom-up story and the publication narrative, makes a philanthropic proposal: the publication of personal book collections in public libraries. This would be a way to do something about a great inequality: some people have access to very good book collections and most do not.

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An Approach to Categorize Big History Papers

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Abstract: There is a growing literature on Big History after four years of the Journal of Big History (JBH) and ten years of the Evolution Almanac series. A study was done to 1) construct a reference database of these papers, which includes abstracts and many web links; 2) propose a framework to categorize these papers so that they can be filtered and searched; and 3) analyze the paper categorization to determine the statistics of frequency and topic combinations..

1. Introduction

As fields mature, common themes of research emerge. Furthermore, shared organizational themes allow researchers to identify prior papers for discussion while still allowing for new ideas and approaches. This paper describes an organizational scheme proposed to facilitate this process based on the analysis of the 70 papers published in JBH (Gustafson 2017) and 90 articles published in Evolution (L. Grinin and Korotayev 2011). In addition, this paper complements that of Spier (2017).

This paper discusses the steps necessary to accomplish this, which includes 1) database construction of the relevant papers, 2) proposing an organizational structure based on a few dimensions of topics, 3) analysis of the database; and 4) implementing the sharable reference database, with searchable tags based on the simple framework, which resulted from statistical analysis of the papers. It is shared using the freely available Zotero citation database system, which allows simple transfers between citation software systems, supports searching tags and text, include integrated tools for common word processors, and allows for relatively efficient maintenance with registered digital document identifiers (DOI).

It is recognized that there are many ways to organize the database and tags. It was set up so that the database can be used in a variety of reference manager software. The reasoning behind the proposed tagging system is presented below along with its possible limitations. For example, it was difficult to assign some papers to a single specific set of tags. However, the tagging system is flexible, so that open search, alternative tagging systems, or modifications of specific reference tags can be performed.

2. Database construction

Reference management software offered by commercial companies can offer more sophisticated capabilities, but they require constant updating and training. The reference format used by software systems used to be unique in the past. There is now a standard that allows reference databases to be easily shared. Many groups use Zotero, a free reference management system that supports highly collaborative teams through web-based tools. Zotero offers a large number of features without being too complex. Tools for integrating it into paper editing software (Google Docs, Word, etc.) and extensions for web browsers (e.g., Chrome) make it easy to capture citation data from a web page.

The database allows the Big History references to be imported as a set from a web database or by sharing a file. The set includes IBHA books, anthologies, as well as chapters/papers from JBH and Evolution Almanac. Footnotes and bibliographies can be produced from the entries using a variety of formats. A subfolder was created for all JBH papers. Papers from Evolution were arranged in folders according to their source books. You can easily add any reference that has a DOI by specifying the DOI; the software then retrieves the reference information. Zotero will attempt to extract reference information from the paper's webpage if there is no DOI.

A public version of the database is available on the Zotero groups' website under "BigHistory.". This database is intended to be updated regularly. It is possible to add database contributors and editors to the formal group by contacting the database owner. A Zotero database can also be exported to a standard reference information system (RIS) format and then imported into another reference management system.

3. Proposed Framework

Frameworks should provide a way to categorize research. While it should provide enough categories to be useful, it should not provide too many so that only one paper fits into each. This can be done with multiple dimensions. An attribute must be specified for each dimension. For example, when specifying a location in a 3 dimensional environment, all three dimensions, x, y, and z, need to be specified. A dimension should have no more than a handful of possible values so that they are easy to remember. The scheme could be extended later by adding more dimensions, or deeper by allowing the tree structure of the values to cascade. For example, a 'vehicle' dimension could support values of car, plane, train, but could be extended with make and model: car.make.model.year).

These papers are research papers on big history topics. Therefore, one dimension of the paper is the research approach (Figure 1). In addition, different phases of evolution are the subject of big history topics (Figure 3). A third dimension can be viewed as an aspect of the evolving complex adaptive system, for instance, organizational, energy, information or interaction with the environment (Figure 2).

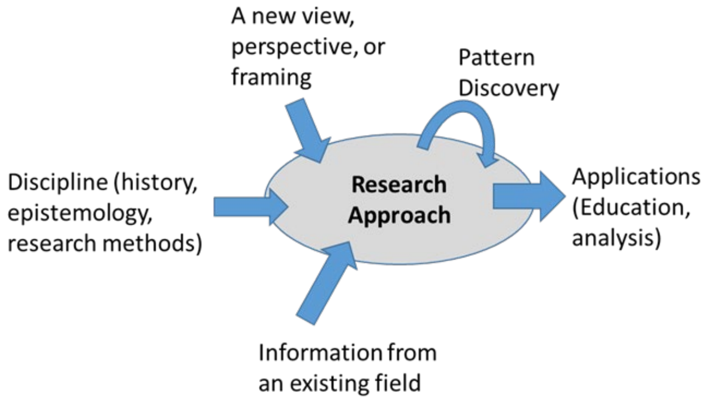


Figure 1 *Research Approaches*

The three dimensions along with examples of their possible values are listed in Table 1. Examples of categorization of specific big history topics are given in Table 2. Each dimension has a corresponding figure (Fig 1-3) showing the relationship of some possible topics. The model for a complex adaptive system is similar to the one proposed by Friston (Friston 2010) for the free-energy model of the brain and ecosystem.

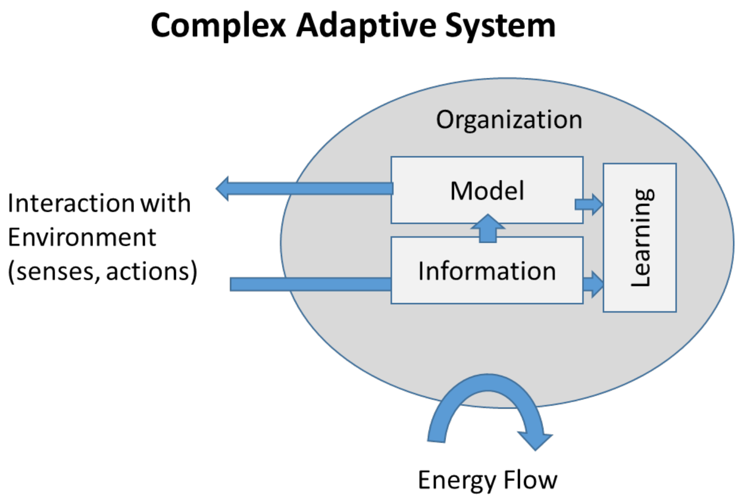


Figure 2 *Complex Adaptive System (CAS) Elements*

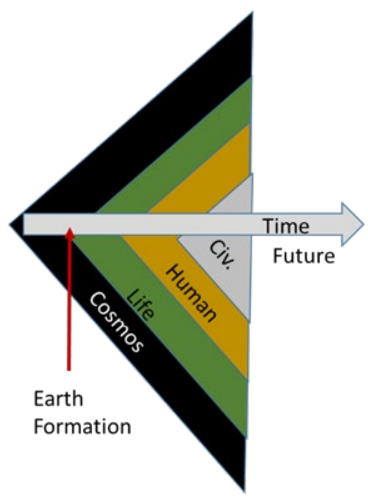


Figure 3 *Periods with time progressing to the right*

4. Analysis

The analysis includes comparing the distribution of papers by each dimension within the two publishers of Big History papers: the Journal of Big History and the Evolution

Dimension	Values	Definition
Research Approach		
	Pattern	A relationship is explored
	View	New perspectives on how existing information can be viewed
	Information	New information found in a contributing field is discussed as to its impact on Big History
	Education	New ways of approaching Big History in education
	Discipline	Either philosophical discussion or history of Big History development as a field
	Application	A way to take lessons from Big History and apply them to issues
Period		
	Cosmos	From the Big Bang to Earth formation
	Planetary	The formation of Earth and its special characteristics to support life evolution
	Life	The development and evolution of life from about 5 billion years ago) including chemical evolution
	Human	The development and evolution of intelligent life such as humans (about about 5 million years)
	Civilization	The development and evolution of civilized societies from about 5,000 years ago
	Current	Topics related to current issues
	Future	Topics related to futures (Scenarios, trends, and paths)
	All	Inclusive of all other periods (Sometimes excluding cosmos, i.e., all periods with agency)
Complex System Component		
	Energy	Energy source, usage, extraction
	Information	Information for collective learning or evolution (DNA, mind, tools, senses, storage, mental models)
	Environment	The conditions and natural resources that a system develops and evolves
	Organization	The arrangement of tasks and information flow to support complexity (Specialization, Symbiosis, Binding, Panarchy, Emergence)
	Growth	Development and evolution of system
	All	Inclusive of all system components

Table 1: Dimensions and Values for tagging system

	Energy	Information	Environment	Organization	Growth
Cosmos	Fusion	Forces	Physics Laws, Temperature		Expansion, Gravitational Aggregation
Planetary	Atmosphere, solar,	Grand Tack	Galactic & solar location	Differentiation	Formation rate
Life	Photosynthesis	DNA	Ecosystem	Cell, Multicellular	Evolution, Development
Human	Fruits, fire, animals	Brain	Grasslands, Forests, Climate Change	Bands, Tribes	Human development, brain evolution
Civilization	Wind, Water, Fossil fuels	Writing, Religion	Rivers, Soil, Climate	Social Organizations	Civilization sizes and technological development
Current	Transition to renewables	Internet	Climate Change, Convergence	Economic, Government	Transition in energy, environment, trade
Future	Fusion, conservation, space	Artificial intelligence, human computer interface	Circular economy, space	Next level of emergence	Improvement indices
All	Energy density flow and complexity	Information capture, storage, retrieval, and processing	Relationship of objects and environmental scale	Panarchy	General evolution/ development processes

Table 2: Example topics in each combination of CAS Aspect and Period.

Almanac. The results are shown in the Figure 4. There are some slight differences between the distributions of paper categories between the two publishing outlets.

- Research approach: The JBH has slightly more education research papers, whereas Evolution has more on patterns.
- Period: JBH has slightly more cosmic/planetary period papers whereas Evolution has more in the Human, civilization, and current categories.
- System Element: JBH has more in the all and environment category whereas Evolution has more in the remaining categories including more in energy topics.

The distribution of papers with the combination of two dimensions (System Aspect and Research Approach) shows high frequency of papers in the Discipline category with no specific CAS aspect. Paper discussing a specific CAS aspect tend to be in the "View" research category (Table 3).

Currently, Google Scholar (evaluated on 1/30/2021) identifies 115 citations to 27 of the 58 JBH papers. Just under half of these citations were to two papers: Andrey Korotayev's "The 21st Century Singularity and Its Big History Implications (Korotayev 2018)" with 25 citations and David Christian's "What is Big History" (Christian 2017) with 22 citations.

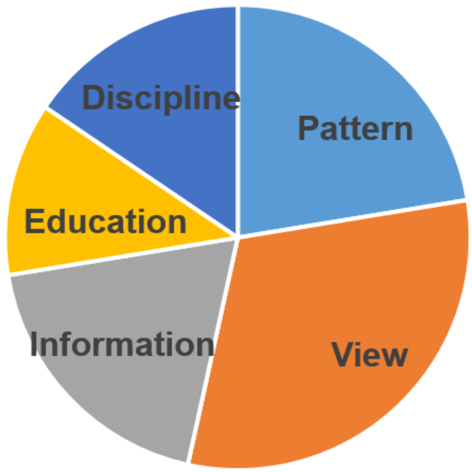
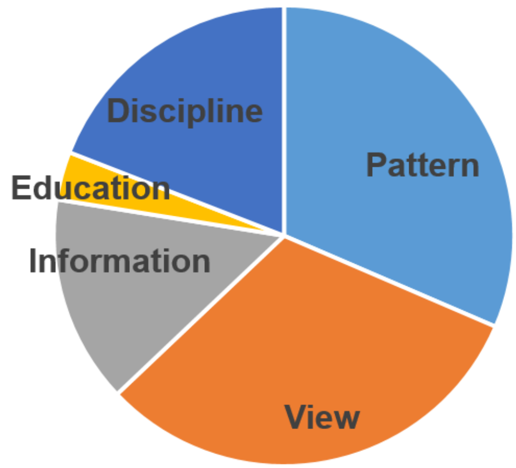
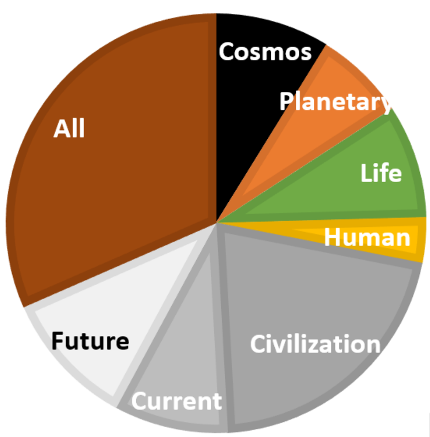
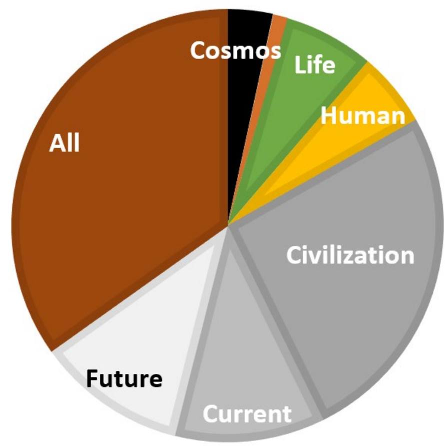
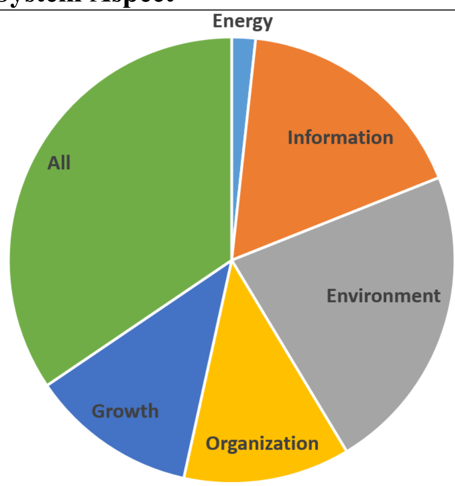
Journal of Big History	Evolution Almanac (Uchitel)
By Research Approach	
	
By Period	
	
By System Aspect	
	

Figure 4. Comparison of Distribution of Topics by Dimension in the two journals.

Table 3. Combination matrix of JBH (top) and Evolution Almanac (bottom)

CAS	View	Pattern	Informat.	Disciplin	Educatio	Total
All	4	4	2	8	2	**20**
Environment	5	1	4		3	**13**
Information	5	2	1		2	**10**
Growth	1	3	2	1		**7**
Organization	3	2	2			**7**
Energy		1				**1**
Total	**18**	**13**	**11**	**9**	**7**	**58**

CAS	View	Pattern	Informat.	Disciplin	Educatio	Total
All	1	3	2	15	3	**24**
Environment	5	2	1			**8**
Information	13	4				**17**
Growth	2	11	4	1		**18**
Organization	5	6	5			**16**
Energy	2	2	1	1		**6**
Total	28	28	13	17	3	**89**

The analysis of authors include the number of authors per paper and the number of papers per author. Details are presented below but roughly 20% of the authors contributed to more than 1 paper (i.e., 80% of the authors have only 1 contribution). Around 70% of the papers have a single author. The highest number of authors on a paper is four.

Evolution has 70 distinct authors of which 24% contributed to more than 1 paper. The ratio of papers to distinct authors is about 1.3. The editors Leonid Grinin and Andrey Korotayev lead the paper count with 22 and 15 articles (including the editors' introductions). There are six authors (8.5%) with 3-4 papers (Anton Grinin, Baker, Hookes, LePoire, Markov, Spier). About 72% of the papers have a single author with the remainder papers mostly split between 2 and 3 authors. Two papers have four authors which is the largest number of authors.

The JBH has 58 distinct authors of which 17% contributed to more than 1 paper. The ratio of papers to distinct authors is about 1.05. Barry Wood has the largest number with six papers. Nine others have more than 1 paper contribution. About 87% of the papers have a single author. Three papers have four authors which is the largest number of authors.

There are nine authors who contributed papers to both (Christian, A Grinin, L Grinin, Korotayev, Spier, Voros, Nazaretyan, Baskin, LePoire).

5. Discussion

This paper was constructed to explore a possible framework for a simple categorization of Big History papers and then applying it to compare the two main publishers, JBH and Evolution. The three dimensions used for categorization include the research approach along with the Big History topic formed by the combination of an evolutionary period and CAS aspect. Big History papers often (compared to other specific fields) include further generalization, views from unique perspectives, and analogies. It is hoped that this is only the beginning of research papers in this form.

Clearly, many papers that would be considered Big History topics are published in other journals, for example, in the "parallel" fields such as astrobiology (Crawford 2019), SETI, existential risks, futures, Anthropocene, Evo-Devo, Cosmic Evolution (Vidal 2008; Chaisson 2011), Anthropic Principle, Entropy-Spontaneous pattern formation, and Complex Systems. It is not clear how these papers should be brought into the system.

Later, it is hope that this analysis could be extended to identify networks of idea flow between authors, the integration of Big History with other fields, and further refinement of categorization. Currently, it seems like there is a small but growing discussion in the Big History community surrounding topics such as common themes, periodization, common vs unique development on Earth (Schwartzman 2020), and ways to integrate the findings of the field to enhance education and identify further applications to help understand and guide potential futures.

6. References

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Crawford, Ian. 2019. "Introduction to the Special Issue on Expanding Worldviews: Astrobiology, Big History, and the Social and Intellectual Benefits of the Cosmic Perspective." *Journal of Big History* 3 (3): 1–1. https://doi.org/10.22339/jbh.v3i3.3310.

Friston, Karl. 2010. "The Free-Energy Principle: A Unified Brain Theory?" *Nature Reviews Neuroscience* 11 (2): 127–38. https://doi.org/10.1038/nrn2787.

Grinin, Leonid, and Andrey Korotayev. 2011. *Evolution: Cosmic, Biological, and Social*. https://www.sociostudies.org/almanac/evolution/cbas/.

Gustafson, Lowell. 2017. "Welcome to the First Issue of the Journal of Big History." *Journal of Big History* 1 (1): 1–3. https://doi.org/10.22339/jbh.v1i1.2240.

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Schwartzman, David. 2020. "Biospheric Evolution Is Coarsely Deterministic." *Journal of Big History* 4 (2): 60–66. https://doi.org/10.22339/jbh.v4i2.4230.

Spier, Fred. 2017. "On the Pursuit of Academic Research across All the Disciplines." *Journal of Big History* 1 (1): 20–39. https://doi.org/10.22339/jbh.v1i1.2242.

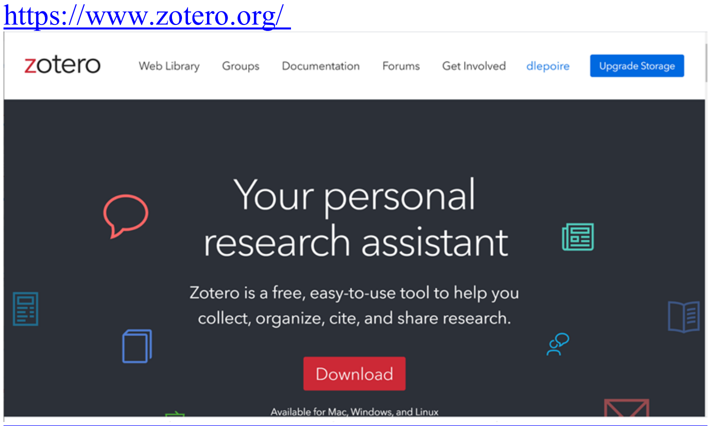
Vidal, Clement. 2008. "A Cosmic Evolutionary Worldview: Short Responses to the Big Questions." *Foundations of Science*, no. Special Issue of the Conference on the Evolution and Development of the Universe. http://evodevouniverse.com/wiki/Main_Page.

Appendix: How to connect and use the Big History Reference Database

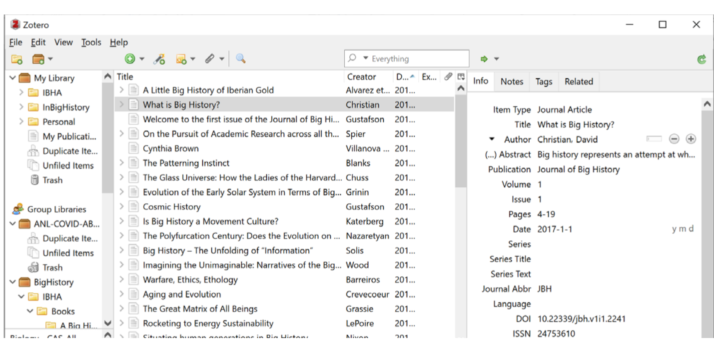
Background: A database of papers from the Journal of Big History and the Evolution Almanacs was created and published online for all to use. The ability to edit and add references can be given upon request. This allows reference/citation tools such as Zotero (free) and similar commercial software to be included in document editors to quick cite and reference the publications. The database also contains searchable abstracts, a simple index system described in the paper, a short description, and identified keywords.

The database was created with Zotero software but can be exported in a standard reference database format: .RIS, which can be read into other similar software.

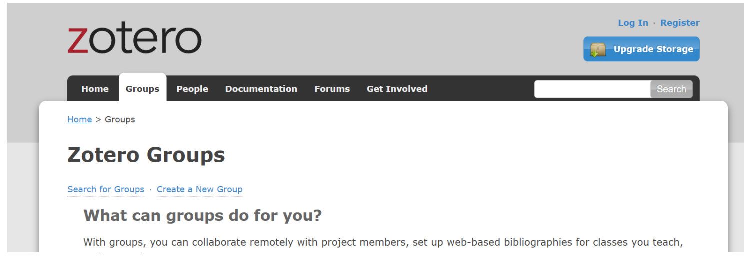
To get started with Zotero:
Download and install the free Zotero software from: https://www.zotero.org/



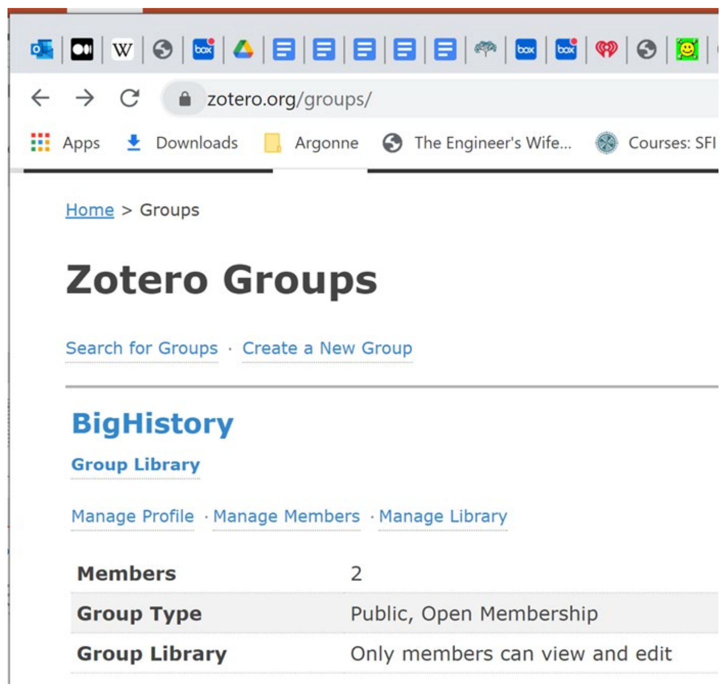
The interface is quite easy to use (but documentation on various topics can be found at: https://www.zotero.org/support/



To connect to the BigHistory shared reference database: register for a free Zotero account (for example, going to the zotero.org/groups page will ask you to login or register as seen in the upper right in the image below).



Then you can search for "BigHistory" and click "Join" to add the web database to your reference collection. It will be placed in the Group Libraries section (as seen on the bottom left of the interface figure).



To use the database

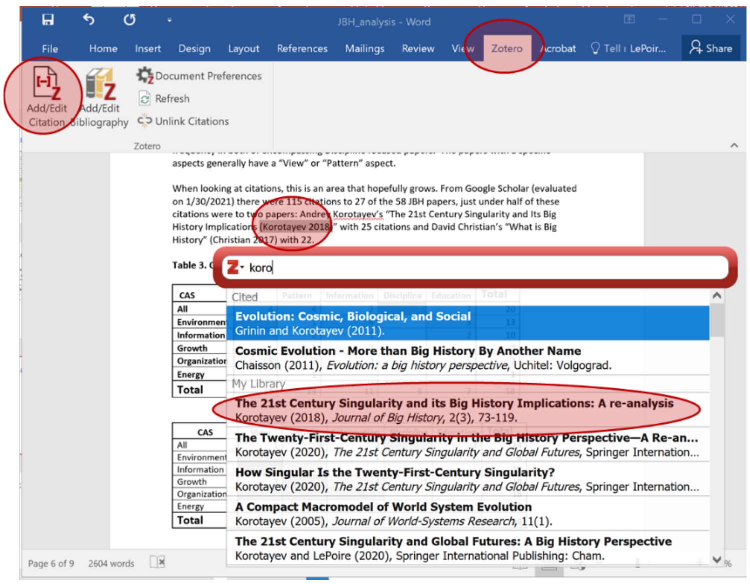
- Install the Zotero app to document editing software (e.g., Word). A Zotero tab should now be available. It has two important buttons: "Add/Edit Citation" and "Add/Edit Bibliography" as shown below.
- To add a citation, move the mouse to the place you want it added and then click the "Add/Edit Citation". A Zotero text box appears with a red outline. Start typing

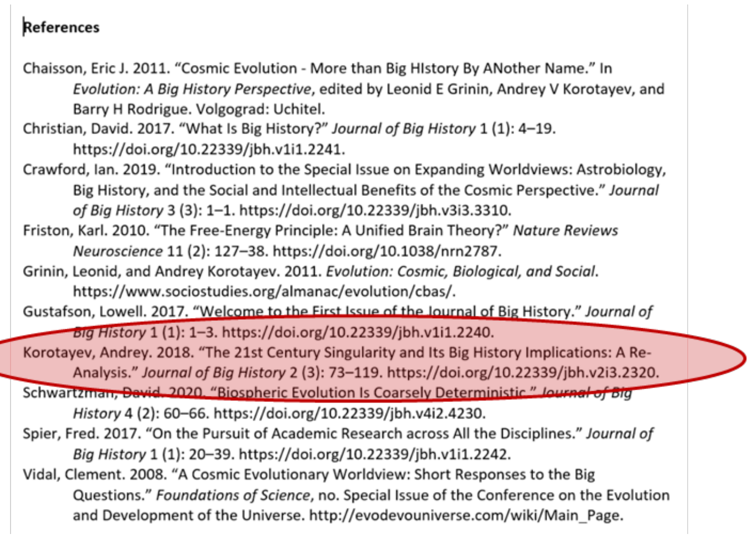
something to search for (e.g., author or title). Zotero will show the matches below the text box. Select one of the matches. Then the citation will be added (with the style set under the "Document Preferences").

- To get the bibliography at the end, Click on the "Add/Edit Bibliography" button and it will be constructed based on the references you have selected.

Adding a citation to a Word file:

It automatically shows up in the paper's reference section.





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Christian, David. 2017. "What Is Big History?" *Journal of Big History* 1 (1): 4–19. https://doi.org/10.22339/jbh.v1i1.2241.

Crawford, Ian. 2019. "Introduction to the Special Issue on Expanding Worldviews: Astrobiology, Big History, and the Social and Intellectual Benefits of the Cosmic Perspective." *Journal of Big History* 3 (3): 1–1. https://doi.org/10.22339/jbh.v3i3.3310.

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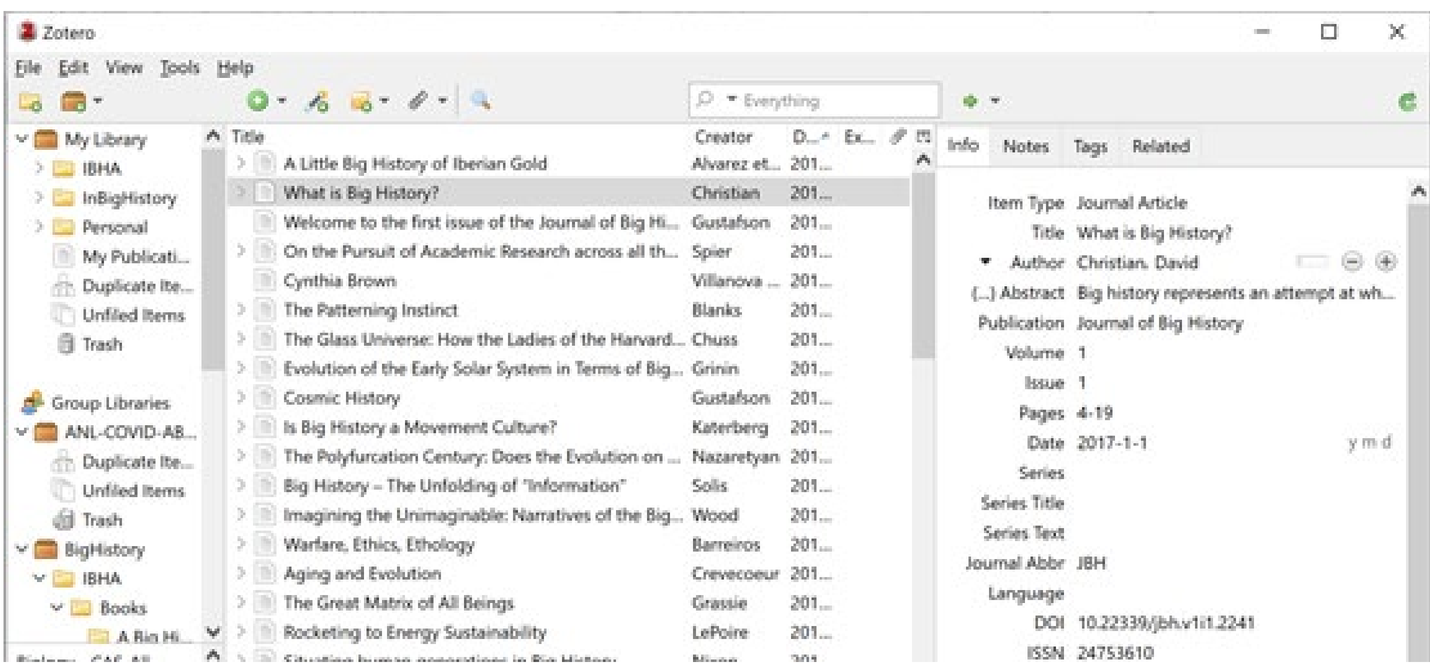

The user interface for Zotero (either desktop or web-based).

Short Author Biographies

Robert Aunger is Associate Professor in Evolutionary Public Health. He has a Masters in Urban Planning from the University of Southern California, a PhD in biological anthropology from the University of California, Los Angeles, and did post-doctoral work in psychology at the University of Chicago and King's College, Cambridge. He has published books on cultural evolution (with the Free Press and Oxford University Press), the evolution of human behaviour (with Oxford University Press), and ethnographic methods (with Altamira Press), as well as papers on hunter-gather nutrition and belief systems, genetic diversity, the psychology of motivation, the evolution of technology, and global history. He is the lead developer of a novel approach to behaviour change called 'Behaviour Centred Design' which has its origins in evolutionary biology, ecological psychology and commercial marketing. For over a decade, he has helped implement research- and large-scale public health projects in water, sanitation, hygiene, nutrition and HIV using this approach in multiple countries on the African and Asian continents, including designing creative materials for mass media and community activation.

Ken Baskin is an independent researcher whose work integrates insights from complexity science, neuro-anthropology, and big history. After earning a PhD in English Literature in 1977, he spent fifteen years writing public-relations material for major firms. His books include Corporate DNA (1998), an examination of how to think about organizations as living things rather than just mechanisms, and The Axial Ages of World History (2014), an exploration of the similarities between the Axial Age and Modernity that he co-wrote with Moscow anthropologist Dmitri Bondarenko. Ken is currently reinterpreting religion as a way that human groups can know and adapt to the powerful forces that surround us. He lives in Philadelphia, Pennsylvania.

Börje Ekstig holds a PhD in physics and is a retired assistant professor at the University of Uppsala, Sweden. Long ago he made a discovery of a regular pattern in evolution, the analysis of which has led to some publications summarized in the recent book, Mechanisms of Evolution, together with important novel discoveries and conclusions.

Erhard Glötzl studied chemistry and physics at the University of Vienna and technical mathematics at the Johannes Kepler University of Linz. From 1972 to 1981 he was a university assistant at the Mathematical Institute of the University of Linz, habilitation in technical mathematics at the University of Linz with work on Gibbs point processes. From 1981 to 1992 he headed the Office for Environmental Protection of the City of Linz and thus decisively co-responsible for the environmental clean-up of Linz's large-scale industry. From 1992 -2007 he was a director of the board of SBL Stadtbetriebe Linz GmbH and Linz AG. He also taught at the Pedagogical Academy (Chemistry), at the Johannes Kepler University Linz (Environmental Information Systems) and at the Danube University Krems (Finance). Since 1995, numerous lectures and publications on the "instability of our monetary and economic system" and on topics in theoretical economics, theoretical physics and theoretical biology. In 2023 he published his book, "General Evolutionary Theory of Everything: From the origin of life to the market economy - Beyond Darwin - On the Origin of species in a broader sense."

Sergey Grinchenko is the Chief Researcher at the Institute of Informatics Problems, Federal Research Centre "Informatics and Control" of the Russian Academy of Sciences, Moscow, Russia. He is also the Vice President of the Biocosmological Association and full member of the International Informatization Academy. Areas of scientific interests include search engine optimization theory, cybernetic biology, cybernetic sociotechnology, cybernetic physics, theoretical informatics.

Leonid E. Grinin is Director of Uchitel Publishing, Volgograd, Russia. Beginning as a teacher in rural schools, he founded his publishing firm to develop educational materials in the 1980s. He then completed a Ph.D. at Moscow State University and expanded Uchitel to serve a global market in Russian and English. A sociologist, philosopher of history, and economist, his work focuses on identifying regularities of macroevolution. Among his thirty monographs are From Confucius to Comte: The Formation of the Theory, Methodology and Philosophy of History (2012, in Russian); Macrohistory and Globalization (2012); and The Big History of the Universe's Development: Cosmic Evolution (2013, in Russian). Leonid co-authored Great Divergence and Great Convergence: A Global Perspective (2015) and co-edits the international journals, Social Evolution and History and Journal of Globalization Studies. A founding member and Deputy Director of the Eurasian Center for Megahistory & System Forecasting, access to his portal, Social Studies.

Lowell Gustafson is Professor of Political Science at Villanova University in Pennsylvania (USA). His course on 'Our Social Nature' uses a Big History approach, and he has also taught it at the Graterford maximum security prison near Villanova. His research has included how science explains the origin and development of polity and how emergent complexity provides anintellectual rationale for universities. He has served as secretary, vice-president, and president of the International Big History Association (IBHA), and as editor of Origins: The Bulletin of the IBHA, and the Journal of Big History.

Nick Hoggard was awarded a Bachelor's degree in Electrical Sciences from the University of Cambridge in 1980, and has mostly worked as a software developer, as well doing some research in the use of artificial intelligence in industrial control systems.

Andrey V. Korotayev is Senior Research Professor at Eurasian Center for Big History & System Forecasting at Institute of Oriental Studies, Russian Academy of Sciences, as well as at International Laboratory of Demography and Human Capital, Russian Presidential Academy of National Economy and Public Administration. He is also Director of the Center for Stability and Risk Analysis at HSE University and Professor at Faculty for Global Processes, Moscow State University, Russia. Beginning as an historian of Arabia, he made focused studies, such as seen in 'Two Social Ecological Crises and Genesis of Tribal Organization in the Yemeni North-East' (1996). Andrey researches topics in quantitative cross-cultural anthropology and seeks to understand biological and social macroevolution, as in 'A Compact Macromodel of World System Evolution' (2005) and 'Mathematical Modeling of Biological and Social Phases of Big History' (2014). He is a founding member of the Eurasian Center for Megahistory & System Forecasting and founder of Evolution, an almanac dedicated to the study of Universal Evolution, and thus is closely linked with Big History. Most recently, he has produced, with David LePoire, a collective monograph, The

21st Century Singularity and Global Futures: A Big History Perspective (2020). He serves as a board member of the International Big History Association.

Gustavo Lau was born in Lima, Peru in 1964 and immigrated to Caracas, Venezuela in 1976. Since 1994 he has worked in finance in London, UK where he is currently a principal of Episteme Capital. He holds a PhD in Computer Science (2019) from the Polytechnic University of Catalonia, Spain, an M.S. degree in Computer Science (1988) and two B.S. in Mathematics (1988) and Computer Science (1986) from the Simón Bolívar University, Venezuela. In his spare time, Mr Lau is a Mathematics Masterclasses lecturer for the Royal Institution of Great Britain and a Guest Professor at Simón Bolívar University, Venezuela. In January 2022 he founded the Big History Club of Simón Bolívar University. Since then he has been teaching informally the Big History course of the OER Project in that club.

David LePoire researches, develops and applies science principles in environmental issues, Big History evolutionary trends, and particle scattering. He has a BS in physics from CalTech, a Ph.D. in computer science from DePaul University, and over thirty years experience at the Argonne National Laboratory in the development of scientific analyses, software, training, and modelling. His research includes Big History synergistic trends among energy, environment, organization, and information.

J.N. 'Nick' Nielsen is an independent scholar from Oregon who studies emergent complexity, especially as it relates to civilization and its future in the context of big history. He has spoken about the future of civilization at several conferences (100YSS, Icarus Interstellar, SSoCIA), including the 2014 IBHA conference in San Rafael, the July 2019 IBHA symposium in Milan (where he spoke on 'Peer Complexity during the Stelliferous Era '), and the 2020 webinar, Being A Good Ancestor (speaking on 'Scientific Approaches to Civilization').

Marc Widdowson is an independent researcher, primarily in government and defence, providing applied history insights in such areas as multinational coalitions, social mood and instability, financial networks, and effects of technology on society.