Periodization in Big History

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International Big History Association
SAC 253
Villanova University
Villanova, PA 19085 USA
jbh@bighistory.org

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Introduction to the *JBH* Special Issue on Big History Periodization

David J. LePoire
Argonne National Laboratory

Correspondence | **David J. LePoire** dlepoire@anl.gov
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This issue examines big history periodization as part of the JBH series that reconsiders big history fundamentals. This issue is divided into two major sections. Developing periodization frameworks is the focus of the first four papers. The second set of four papers explores some fundamental aspects of periodization in greater depth.

Periodization might provide a framework for further understanding the relationships of big history events, transitions, or models. In addition, the periodization might make big history easier to understand for a broader audience. In Volk and Henriques' first paper, they explore the idea of complexity and information processing evolving through combination. According to Anton and Leonid Grinin's second paper, common themes exist between and among the various phases in order to build an environment that facilitates the further evolution of complexity. This third paper by Solis and LePoire addresses some of the original periodization concerns. In addition to the standard Threshold approach developed by David Christian, a great many other periodization frameworks contain common themes. A final paper in this section, written by LePoire, lays out a set of criteria for how different frameworks might be evaluated and then formulates a framework based on findings, starting in the mid-20th century, in big history.

The second set of four papers explore disparate fundamental aspects of periodization, often focusing on particular evolutionary phases (e.g., physical, biological, human, and civilizations). The aspects include fundamental units and how they relate to each other, the evolution of human communication as a means of connecting with students, examining recent ethical issues and how they have changed over time, and determining how periodization might continue in the years to come. In the first paper by Jagers, fundamental units, such as atoms and cells, are analyzed based on how their processes form different closures of physical and dynamic processes. The next paper, by Hasse, examines how the development of human storytelling resonates more with students than the term collective learning. A third paper by Katayama explores how human ethics have evolved through different forms of humanism and makes an appeal for a new cosmic humanism. A final paper by Christian examines the historical periods and asks where we are headed and where we would like to go.

These papers are meant to be pondered and questioned by the reader. As these paper demonstrate, periodization is challenging in the best of circumstances. For example, evolving systems typically take extended periods to transition and develop new features (even under punctuated equilibrium). In an early human society, for instance, starting farming was not just an idea and then implemented the following day. Rather, farming developed over thousands of years through accident, chance, and trial and error. Not only do these papers in toto delineate some of the challenges to formulating a "good" periodization scheme, they bring up other questions and propositions as well: In what ways can we connect with established academic fields, without losing important perspectives of the big picture? How does periodization affect our understanding of big history? The discovery of trends might give us hope that things can be changed in the future. They might provoke us to wonder if there are "laws" of evolution that can provide insight into where we came from, or outline limitations of where we could go in the future, or perhaps propose approaches to our current challenges.

We would like to keep the discussion going, so please respond with letters to the editor or longer comments about papers that the authors might respond to. This will help us demonstrate our professional capacity to engage each other respectfully. It is important to keep in mind that readers and authors come from a wide variety of backgrounds, experiences, and expectations.

Toward a Big History 2.0: A brief position paper

Gregg Henriques
Professor, Graduate Psychology, James Madison University
Tyler Volk
Emeritus Professor, Biology and Environmental Studies, New York University

Correspondence | **Gregg Henriques** henriqgx@jmu.edu, **Tyler Volk** tyler.volk@nyu.edu
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Abstract: We propose a "Big History 2.0" framework based on a time-by-complexity relationship that the two authors converge on, a synthesis from their prior independent work. In particular, the framework distinguishes a line of levels of combogenesis from quarks to culture, in contrast to patterns of emergence involving larger aggregates or groups. The framework identifies major transitions to novelty marked by innovations in general evolutionary dynamics (PVSR; propagation, variation, and selective retention), which have occurred multiple times following the Big Bang. As in Henriques' Tree of Knowledge System, we take the Mind-Animal plane of dynamics as one of these major transitions because of the innovative PVSR-dynamics in the mindedness of animals. We note the need to simultaneously attend to patterns and processes of formation, and we describe avenues of further consideration that follow from this framework. This position paper has been improved and slightly expanded from the version originally presented to the Big History Research Group for general discussion on November 20, 2022.

Keywords: Big History, Tree of Knowledge (ToK) System, combogenesis, dimensions, dynamical realms, general evolutionary dynamics, general evolution, thresholds, emergence.

1 Introduction

In their work in the *Journal of Big History* and elsewhere, both Tyler Volk (e.g., Volk, 2017; 2020) and Gregg Henriques (e.g., Henriques, 2022; Henriques et al., 2019) lay out new ways to conceptualize the "time-by-complexity" relationship that allows us to trace the line from the Big Bang to the present. This time-by-complexity relationship is at the center of the Big History formulation[1]. However, despite this being a fundamental frame, it also is the case that there are many questions regarding how scholars should conceive of the evolution of complexification that has taken place since the beginning of the observable universe until the present, and do so in a way that effectively includes humans building knowledge systems to map this process.

The traditional BH formulation as pioneered by David Christian (see Christian, 2018, and his other papers and books) has been to frame the evolution of time by complexity via different thresholds that have been crossed to add levels of complexity to the system. Although the eight thresholds are a useful starting point, we argue that they are not sufficient to map the nature of the transitions. The reason is that the thresholds are mostly educational anchor points (e.g., see Spier, 2022); they do not provide a clear enough model of a sequential emergence that can be debated through scholarly discourse to make progress in a big history 'science' of the process of complexification. Here we propose changes to advance in that direction.

Because of close overlaps in our models, independently developed, and the fact that our papers in the *Journal of Big History* were scheduled targets for discussion by the big history research group on November 20, 2022, we collaborated through zoom talks and emails to draft this position paper prior to that meeting. We have improved and slightly expanded it for this publication.

2 Five Key Points to Frame Big History 2.0

Here we share our convergence model of emergence that seems to result in a clearer and more comprehensive map of the time-by-complexity relationship. Its core consists of five key points of agreement that may set the stage for a shift to a "Big History 2.0" framework that advances from the initial model based on eight thresholds.

The first point to be clear about when we follow the trail from the Big Bang to the present, is to recognize that we are not following all things and processes of emerging complexity across the cosmos. Rather, we are tracking what Volk (2017) calls "combogenesis." This refers to the specific path of complexification that is the rhythm of sequential combination and integration of things from prior levels into patterns, in a "grand sequence" that ultimately connects the dots to us. Why is this relevant? Because it highlights that some major types of things as aggregates, or collections (like stars, solar systems, and galaxies), which, although crucial, are not part of the direct stepping up through a sequence of levels that moves from quarks to culture.

This analysis sets up the second key point, about process itself, which is that there is an important logical distinction between the systematic and repeated level-creating process delineated by combogenesis and processes that results in those large-scale aggregates of things like stars and galaxies (i.e., threshold 2) and planets (i.e., threshold 4), or in biology's aggregates such as communities or ecosystems. As such, and related to the first point about the actual things or systems, it is crucial we distinguish the nested build-up lineage of complexification by combogenesis from the more general, aggregate patterns of emergence.

Near the end of his book *Quarks to Culture*, Volk (2017) makes the point that the threshold transitions from molecules to life and from life to human culture are marked by novel kinds of evolutionary dynamics (for the purpose of this essay, let us call them *PVSR-dynamics*). PVSR-dynamics can be framed as a braid-like process of propagation (or propagatability), variation, and selection and retention. Volk goes further and identifies Life and human cumulative culture as new evolutionary realms that have a fundamentally different character to them than a more standard "level" of integration. That is, whereas the jump from atoms to molecules is a leveling up of integration on the combogenesis trail, the jump from molecules to cells is a different kind of jump into a new evolutionary realm, because it put into place biological evolutionary dynamics (biological PVSR-dynamics). Similarly, we see a level jump from prokaryotes to eukaryotes in Volk's analysis, but the emergence of cumulative human culture is of a different kind (i.e., it results in a generative cultural PVSR-dynamic processes).

This brings us to our third key point, which is that there are foundational differences between thresholds that are either levels of ordinary combogenesis or the aggregates noted above in contrast to those thresholds that emerge by giving rise to new forms of PVSR-dynamics. The PVSR-dynamics are generative and produce new realms of complex adaptive behavior that allow and facilitate further ordinary levels.

Fourth, these insights all align with the formulation given by Henriques in his Tree of Knowledge System (Henriques, 2003; 2011). Specifically, with his Periodic Table of Behavior (PTB) Henriques (2022) explicitly separates combogenic levels of integration (such as particles to atoms or cells to multi-cells) on the complexification trail from the Big Bang to modern science from the larger aggregate patterns, such as Stars/Galaxies or Earth/Solar System thresholds, or ecosystems. In addition, Henriques' PTB also differentiates ordinary levels of emergence from emergence processes that give rise to novel realms. In Henriques' system of understanding, these realms of complexification are complex planes of adaptive existence, or new "dimensions." Thus, Henriques' model aligns directly with Volk's on these points.

Although these aspects align directly, there is one notable difference, which leads to our final key point. Specifically, Henriques offers a new map that adds a whole new realm in addition to Volk's original three. In addition to the Life-Organism plane that emerges approximately 4 billion years ago, and the Culture-Person plane that has emerged in the last several hundred thousand years, Henriques adds the Mind-Animal plane of existence. Consistent with both Skinnerian behavioral science and modern cognitive science, Henriques frames the Mind-Animal plane in much the same way that Volk does (but as an ordinary level), in terms of an emergent plane framed by PVSR-dynamics. Specifically, complex adaptive patterns of neurocognitive/behavioral activity in animals can be framed by the processes by which animals engage in a PVSR relation with their world specifically through learning, involving the selection from trials and retention of novel patterns of animal behavioral investment. As such, we now together arrive at our fifth key point, which is that the mindedness of animals is akin to the livingness of organisms and the cumulative cultural processes in human persons. This realm of the animal using senses in networks is missing entirely from the BH 1.0 classical thresholds, which do not use PVSR as markers, and represents a significant shift in the map related to our framework.

3 Summary

To summarize, for BH 2.0 we are suggesting the following crucial revisions to the BH 1.0 modeling of the time-by-complexity relations as set forth by eight thresholds.

- We recommend an explicit shift from the emergence of complexity in general to the combogenesis layering process of complexification that tracks us from the Big Bang to human culture.
- We advocate for a difference between emergence that is characterized by combogenic leveling and other emergences that arise from aggregate patterns.

- We also advocate for a difference between emergence that characterizes levels versus emergence that characterizes entire new realms of existence formed by new PVSR-dynamics and containing multiple levels.
- In aligning Volk's analysis with Henriques', we argue that in fact there is an entire realm or complex adaptive plane that needs to be clearly identified, which is the Mind-Animal realm of existence explicitly delineated by PVSR-dynamics of the animal brain and behavior in Henriques' ToK System.
- We summarize our model of convergence and agreement as follows. If we define the emergence of major realms by the creation of new types of evolutionary dynamics (PVSR), we have the realms of:
  1. the physical-chemical (Henriques' dimension of Matter; Volk's dynamical realm of physical laws). But this realm's start was not necessarily from PVSR dynamics, see below.
  2. the biological (Henriques' dimension of Life; Volk's dynamical realm of biological evolution). A new form of PVSR-dynamics.
  3. the animal-mental (Henriques dimension of Mind; Volk's combogenesis level 8 with animal-cognitive PVSR). A new form of PVSR-dynamics.
  4. the human socio-cultural (Henriques' dimension of Culture-Person and Volk's dynamical realm of cultural evolution). A new form of PVSR-dynamics.

4 Additional Considerations

There are several possible auxiliary arguments that are potentially relevant. First, given the general pattern for new realms post-Big Bang, the question arises whether we might model the emergence of the Matter dimension in the Big Bang as an example of PVSR. There are some models like Lee Smolin's (1992) cosmological natural selection that suggest we might be able to do that. But given current knowledge, this is significantly more hypothetical than the known transitions to new realms of PVSR-dynamics described above.

Second, can we identify aspects of evolutionary dynamics leading into the emergence of a full scale biological PVSR evolutionary dynamics? For example, there are numerous suggestions of a kind of era of "chemical evolution" that may have given rise to Life, prior to the Last Universal Common Ancestor (LUCA) and the origin of classical Darwinian biological evolution (Pross, 2012; Tang, 2020).

Third, can we consider the human social process of science as a new form of PVSR-dynamics (as articulated by scholars such as Karl Popper and Donald Campbell, etc.) emerging from older cultural evolutionary dynamics (see, e.g., Cziko, 1995; Azarian, 2020)? Furthermore, can we consider cultural evolutionary dynamics as dual-scale (within the human mind, i.e., making personal decisions; and socially among people, i.e., group decisions making)? What happens to cultural evolutionary dynamics during the combogenesis of early human groups with plants and animals into agrovillages, and then with the discovery of takeover and expandable hierarchies into the level of geopolitical states (writing) and eventually to science? We suggest it would be of interest to look into shifts in PVSR-dynamics within the Culture-Person realm. Finally, exosomatic evolutionary dynamics involving technology is now occurring, for better or worse, which can be debated.

Our proposed start to a Big History 2.0 sets these questions up to be tackled by big historians, while also providing a core taxonomy of emergence into aggregates, levels, and realms that represent, we submit, an advance over the current threshold model because of a consistent way to define types of patterns and processes.

Acknowledgments: We thank the anonymous reviewer for supportive comments and for suggestions we have incorporated. We also thank BH board member David LePoire for his initiative as organizer of the big history research group and his encouragement to place this paper in this special issue of the journal.

Notes: 1. As we noted in the meeting of November 20, 2022, we cannot cover all prior BH work in this brief position paper. For example, in addition to the classic BH 1.0 formulation of thresholds, there has been significant work in using energy to define the time-complexity relation. We also recognized that one of the scheduled respondents, Anton Grinin, has developed BH models with the emergence of kinds of evolutionary dynamics, and we noted that we look forward to his comments on our approach and collaboration in the future. Here we also include David LePoire and his work on periodization in this acknowledgement.

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Evolutionary Phases of Big History

Leonid E. Grinin
National Research University Higher School of Economics , Moscow
Institute for Oriental Studies, Russian Academy of Sciences, Moscow
Anton L. Grinin
Moscow State University

Correspondence | **Leonid E. Grinin** leonid.grinin@gmail.com, **Anton L. Grini**n algrinin@googlemail.com
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Abstract: The present article is devoted to the issue of unity of laws, patterns and mechanisms of evolution at all its stages and levels of Big History and megaevolution. Despite the enormous differences between cosmic, planetological, chemical, biological, and social evolutions, there are many similarities. There are a lot of important and insightful works on the development of complexity in our Universe and in the course of Big History. Unfortunately, much less studies are devoted to analysis of universal similarities, patterns and rules within Big History. Mostly such research is focused on a few laws of Big History which are usually connected with development of complexity. However, laws in terms of the typological similarity of many patterns and rules in star-galaxy, planetological, chemical, biological and social phases of Big History, are of great importance. In the present article we will consider a number of such important similarities, which, in our opinion, clearly demonstrate the systemic-structural and functional-evolutionary unity of the world at its different levels and in different areas. The understanding of these similarities deepens our perception about all stages of Big History and its regularities, and leads us away from the false idea that social evolution in all aspects is different from the evolution of previous levels. In the first section our key goal is to give our own definitions of evolution which would cover as many variants of evolutionary changes as possible. In the second section we will try to give a rather voluminous and dialectical picture of the unfolding universal evolution instead of a short scheme: cosmic – biological – social. The notions of main and transitional phases of Big History are introduced; and the importance of its planetary and chemical phases is shown. In the third section we will show that one can reveal a number of similarities at all levels and phases of megaevolution, which can be generalized in universal laws, rules, mechanisms, patterns and principles of evolution. One should note that in fact none of the important laws and principles, not any of the important rules of evolution, have been 'lost' in the process of transition from lower to higher levels. They were only modified and became more complicated, and there also appeared some new principles and rules (and in retrospect one can see their rudiments at the lowest levels of evolution). Some of these laws and rules are described in this section. In the fourth section we will try to present some evolutionary and philosophical ideas that explain the profound similarity in the laws and patterns of megaevolution at all its levels and phases. In the conclusion we will discuss evolutionary and non-evolutionary matters.

Keywords: Big History, evolution, universal evolution, megaevolution, pre-cosmic evolution, cosmic evolution, planetary evolution, chemical evolution, social evolution, phases of evolution, main phases, intermediate phases.

1 Introduction. The Similarities Between Different Types of Evolution

There are a lot of important and insightful works on the development of complexity in our Universe and in the course of Big History. Unfortunately, much less studies are devoted to analysis of universal similarities, patterns and rules within Big History. Mostly such research is focused on a few laws of Big History which are usually connected with development of complexity. (see Jantsch, 1980; Spier, 2010; Christian, 2018; Azarian, 2022; LePoire, 2020; LePoire & Chandrankunnel, 2020)). However, laws which can be found in terms of the typological similarity of many patterns and rules in star-galaxy, planetological, chemical, biological and social phases of Big History, are of great importance.

Evolution is a category whose definition provokes endless disputes. The matter is that 'evolution' (as well as 'progress', 'development', 'change', *etc.*) is among the terms with a broad meaning. Evolution is a process that started simultaneously with the emergence of our Universe (if there had ever been such a beginning). In any case, evolution can be considered as a form of matter existence. In the present article we will use the terms Big History, 'universal evolution' and 'megaevolution' as synonyms. We will use these terms for the process encompassing all evolutionary levels and lines from the Big Bang to contemporary phenomena; they are used simultaneously in two meanings, namely: the evolution of the Universe and evolution as a universal process.

Despite the enormous differences between cosmic, planetological, chemical, biological, and social evolutions, there are many similarities (for more details see Grinin, Markov, & Korotayev 2009, 2011; Grinin, Korotayev, & Markov 2011; Grinin *et al.* 2011; Grinin 2013, 2015, 2017, 2018, 2020; Grinin L. & Grinin A. 2019). Unfortunately, quite a few works are devoted to their identification. In the present article we will consider a number of such important similarities, which, in our opinion, clearly demonstrate the systemic-structural and functional-evolutionary unity of the world at its different levels and in different fields. The understanding of these similarities deepens our perception of every stage of evolution and its regularities, and leads us away from the false idea that social evolution in all aspects is different from the evolution of previous levels.

It seems undoubtedly fruitful to present all forms of evolution as a single and universal process, or as phases of *Big History*. By analyzing these phases, conventionally speaking, in the 'horizontal' dimension, as manifestations of evolutionary laws in different forms of matter, one can clearly figure out the general evolutionary similarities. However, we consider the transitions to a new level within the Big History framework already in the frame of 'vertical' dimension as qualitative breakthroughs in the framework of the Universe's development.

The 'vertical' view of Big History is generally accepted while the 'horizontal' approach is infrequently used. In the present article we tried to combine these two approaches. The first section will show the way to the elaboration of universal definitions of evolution, which will demonstrate profound similarities of all phases of evolution. In the second section, we will reconsider the vertical structure of Big History that had never been done before. In the third section, we will describe some of the universal evolutionary properties that manifest themselves at all phases of Universal evolution including social evolution which comes as one of the number of forms of evolution and then as an outcome of the preceding development. In the fourth section we will analyze at the profound (philosophic-evolutionary) level what defines the unity of evolutionary mechanisms and laws at all its phases and in all lines.

2 The Definition of Evolution

The concept of evolution was introduced into scientific discourse by Herbert Spencer, and it is important that he did it before Charles Darwin (who actually borrowed the term from Spencer), and that he attributed this definition to any type of evolution (for more details see Grinin *et al.* 2011: 5–6). Later on, biologists largely 'monopolized' the concept. Although Spencer's definition of evolution as a change 'from an indefinite incoherent homogeneity, to a definite, coherent heterogeneity' in the process of differentiation (Spencer 1972: 71) has retained its conceptual and even aesthetic appeal up to the present time, yet today it looks obviously narrow, covering only one, albeit very important line of evolutionary changes.

The attempt to expand the concept of evolution by including any change into it has led to definitions of evolution such as those given by Fred W. Voget (1975: 862) and Henri J. M. Claessen (for a more detailed analysis of this definition see Grinin and Korotayev 2009, 2020). Claessen bases his definition on Voget's approach and considers evolution as '*the process by which structural* *reorganization is affected through time, eventually producing a form or structure which is qualitatively different from the ancestral*' (Claessen, 2000a: 7; see also Claessen & van de Velde, 1982: 11ff.; 1985: 6ff.; 1987: 1; Claessen, 1989: 234, 2000b; Claessen & Oosten, 1996).

This definition has undeniable advantages because the structural reorganization is a crucial point for many processes, it also shows a complex and long-term character of changes, and focuses on a new form or structure which is *qualitatively different* from the ancestral one. However, it also has serious drawbacks that generally complicate further evolution research. The main thing is that this definition is intended, most likely, to describe the changes within one evolutionary phase (in fact, it was intended for social evolution). Although it points out qualitative differences, it does not pay sufficient attention to the most important process of formation of the fundamentally new that has not yet happened and that may lead to a new level of evolution, level of complexity. In other words we mean the lack of attention to the aromorphic evolution (about aromorphic evolution see Grinin, Markov, and Korotayev 2009, 2011), to the line of complexity rise. Besides, the word 'reorganization' is not precise enough. It implies that an already existing object is evolving and its structure is changing while the process can be described: a) as self-organization, *i.e.*, creation of a new structure from an unstructured mass, or b) as an emergence of a new structure via combining of smaller structures (cells, societies, *etc.*), or c) in another way.

Therefore, in evolution one should distinguish: a) reorganization; b) emergence of a new structure as a result of self-organization or association; c) division; d) complication; and e) other. In addition, evolution may not at all be related to the changes in structure only. It may be a change of function, productivity, adaptability, appearance of new lines, divergence and convergence of existing species, lines, *etc.*, in other words, everything that promotes positive changes. Or to be more exact, with *a positive balance of changes* since the positive and negative changes always go side-by-side, in other words if something is gained then something is lost. The general balance and outcome are important.

Positive changes can be widely presented as: complication; increasing ability to self-regulate along with growing variability and diversity; increased sustainability; better adaptation to changes and environment; formation of new elements or complexity, optimization of existing properties and functions, *etc.*

It is necessary to distinguish between *narrow* evolution (*i.e.* within individual systems and taxa) and *broad* evolution (within the Universe or phases of megaevolution). Within the division into narrow and broad evolution, it becomes even a more nontrivial task to determine what a positive balance of changes is. The fact is that positive changes for certain objects or sets may mean negative changes for other objects, systems or amalgamations that have, for example, been swept away by selection, absorbed or restructured, as well as within individual subsystems of a system. Thus, certain evolutionary success can be provided by other failures, which we have formulated as *a rule of payment for aromorphic progress*[1] (Grinin, Markov, and Korotayev 2008: 80–81; see also below). This rule means that the emergence (strengthening) of positive qualities implies a simultaneous disappearance of some organs, subsystems, functions and qualities antecedent to evolutionary changes. But as a result, some evolutionary success ensures the movement of a large set of systems in a certain direction, since the acquisition of features equally suitable for a wide set of environments is carried out, in general, to 'master' the environment and to increase the number of relations with it (Timofeev-Resovskij *et al.,* 1969: 282).

Our key goal is to give our own definition of evolution which would cover as many variants of evolutionary changes as possible. One should present evolution both as a) progressive evolution, *i.e.* a movement from a lower stage to a higher one, and b) as transformations within a single stage or sideward movement, which often contribute to the formation of large areas of reality (the scheme of Universal evolution clearly shows all of them).

Taking this into account, *one can denote evolution as the process of changes through time of forms, structures, functions, properties and other aspects of objects, systems, subsystems, natural groups and complexes of different size systems and objects, due to which there appear qualitative changes in comparison with the previous state (up to the formation of new areas or development levels)*[2]*. At the same time, the overall balance of such changes should be generally positive (taking into account the level of generalization). In other words, the sum of changes should be positive and appear immediately or in a more distant period. The positive balance can be manifested in relation to* *individual systems (objects) and/or to their narrow or wide set.*

So if the general balance of changes is positive, we deal with evolution; if it is negative, we speak about devolution or involution.

3 Big History, Its Main and Transitional Phases

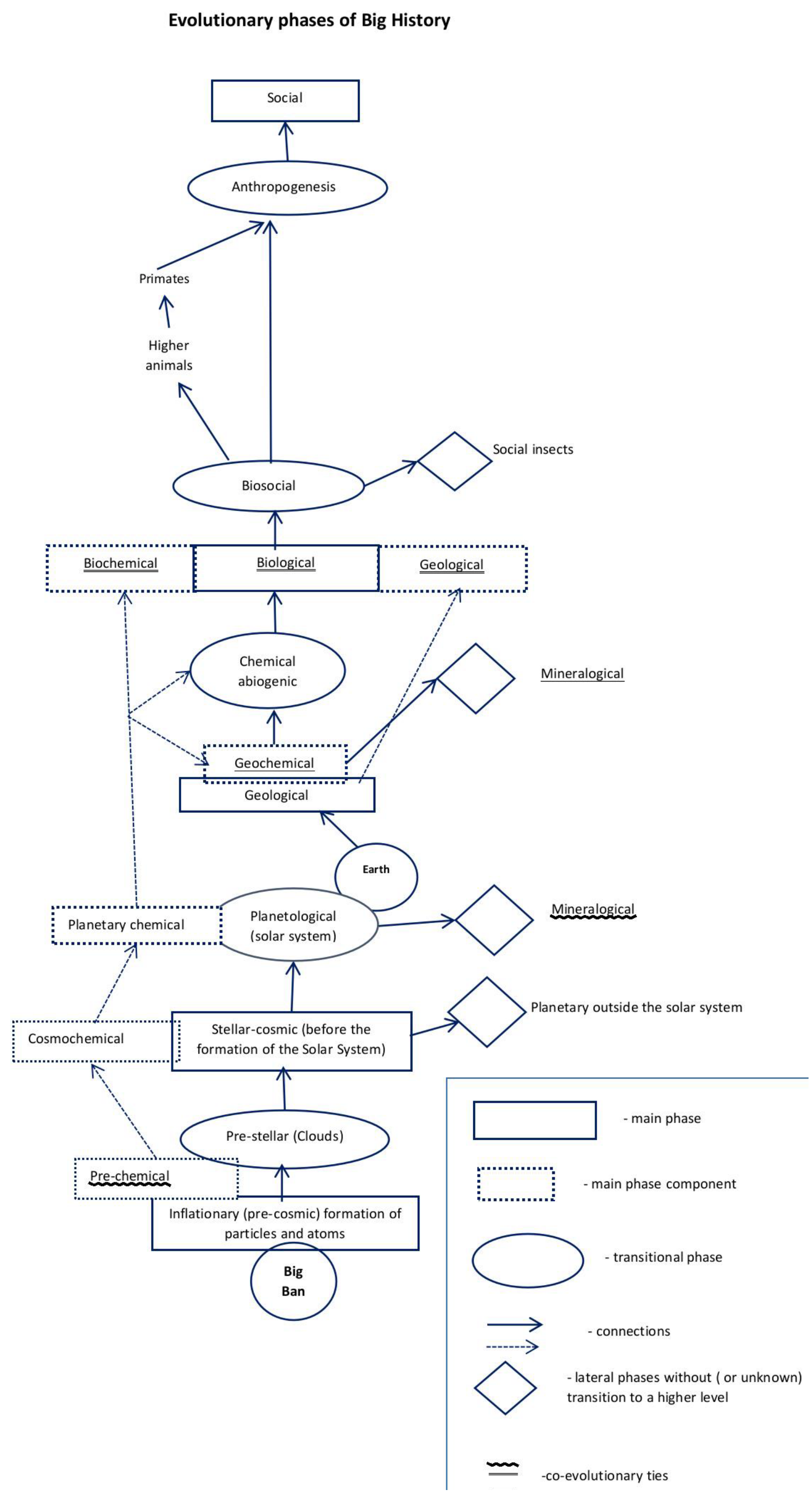
Let us consider our scheme of megaevolution movement which in comparison with usual schemes is much more complete and relevant. As has been mentioned above, here we reconsider the vertical structure of Big History. Such a full picture of Big History has never been created before. We tried to give a rather voluminous and dialectical portrait of the unfolding evolution instead of a short scheme: cosmic – biological – social/cultural. However, even this scheme does not fully reflect the complexity of Big History lines and phases.

Let us take a closer look at this scheme: what is new?

1. Big History is presented starting from the Big Bang as consisting of ten phases and not of three or four as is common.

2. In addition to the main phases, we have introduced intermediate or transitional phases of evolution. These are: a planetary phase within the Solar system, the abiogenic chemical phase, biosocial phase and anthropogenesis.[3] It would be fruitful to consider the planetary evolution within the Solar System as a special level of evolution which is transitional between the cosmic evolution and evolution of the Earth. In a way, this is a new idea in evolutionary studies (for more details see Grinin 2020). The division into main and intermediate phases: a) reduces the qualitative gap between the main phases of megaevolution; b) shows the mechanisms of evolutionary development and the mechanisms of its transition to a higher level; c) reflects previously failed attempts of evolution to find the way to a higher level. For example, biosocial evolution paved the way to social one at different times through different directions, including

Figure 1. Phases and lines of Big History



social insects, until it became possible to make this breakthrough through primates.

3. Thus, *Big History appears as an alternation of five main and five transitional phases.*

4. We have introduced pre-cosmic evolution (see Grinin, 2013, 2014, 2015), which is called inflationary here. Its introduction makes sense since this evolutionary phase was associated with the formation of conditions for the origin of the Universe and its certain order. This phase was characterized by: a) fast and rapid changes of parameters due to temperature drop and expansion (inflation) of the Universe; b) formation of primary structures of the microworld (protons, neutrons, electrons and other particles) and then of atomic nuclei and atoms of the first elements. In other words, it was simultaneously pre-chemical evolution (which is distinguished separately). During this phase the evolutionary processes were very specific, since this was actually the process of self-organization of both the Universe in general and of its macrostructures[4].

5. We have also introduced the idea of continuous lines of evolution, one of them is the chemical evolution in the Figure 1. It is easy to notice that the latter appears to be a component of larger types of evolution at each phase of megaevolution, forming a lateral but necessary part of the latter. Only in the phase of abiogenous chemical evolution does the role of chemical evolution rapidly increase to the level of a transitional phase. Then it again becomes a part of a larger phase, the biological. In the scheme, 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 could be called sociochemical. At the same time, its results begin to appear already in the phase of anthropogenesis, from the moment when humans learned how to control fire.

6. Some lines are singled out as lateral or dead-end. The dead-end lines may be defined when development has almost or completely stopped. For example, this is the case with mineralogical evolution on some planets and satellites like Mercury or the Moon, where it stopped billions of years ago (see Grinin, 2020). The lateral lines are by no means insignificant. They just did not 'go' further, *i.e.* they did not become a starting point for transition to a higher level. And still they have created new evolutionary domains in which development continues. This refers, for example, to social insect species numbering many thousands species. Among the lateral lines, it is worth noting the planetary evolution within the framework of the space-stellar evolution prior to the formation of the Solar system. It is mentioned as a dead-end line because we do not know exactly how and where the evolution took place on the myriad planets in the Universe. But it is very likely that there occurred transitions to some new levels. Such dead-end lines show that any transition to a higher phase was preceded by several dead-end lines which reflect the complex process of finding the ways to higher levels, the need for a number of attempts to do this in different directions (according to the rules of evolutionary preparation and payment for evolutionary progress; see below).

7. One of the most important ideas is the idea of co-evolutionism, when two or three (or even more) directions of evolution become inseparable. Co-evolutionism implies an increasing rate of development due to a synergistic effect, and increasing complexity and development of opportunities for a breakthrough. Co-evolution may have different scales and manifestations. For example, it may comprise minor but very important lines within a larger phase (line), like in case with biochemical evolution in the framework of biological one. Geological evolution is in co-evolution with the latter (more precisely, its part which is related to the influence of life on changes in the Earth's outer shells, including the atmosphere).

4 Some General Evolutionary Laws and Patterns

As already mentioned, in different areas of the Universe, at all levels and phases of megaevolution, one can reveal a number of similarities both in the ways and principles of construction and functioning of objects (systems) and in their change and development, which can be generalized in universal laws, rules, mechanisms, patterns and principles of evolution. One should note that in fact *none of the important laws and principles, not any of the important rules of evolution, have been 'lost' in the process of moving from lower to higher levels*. They were only modified and became more complicated, and there also appeared some new principles and rules (and in retrospect one can see their rudiments at the lowest levels of evolution). Some of these laws and rules are described in this section (see also Grinin 2017, 2018, 2020; Grinin L. & Grinin A., 2019, 2020b).

4.1 The Law of the Age Stages/Phases of Objects' Life

Oswald Spengler (1991) and Arnold Toynbee (1962–1963) became renowned for their theories of civilization according to which every civilization passes through certain stages of life (birth, youth, maturity, and decline) before the collapse. This approach still arouses discussions but nevertheless, the idea of certain phases of social organisms' life is rather reasonable. But while in social life a society can prolong its life and retrieve its dynamism at the expense of innovations and reformations, in the case of evolution we clearly observe that all material objects and systems have a certain lifespan and pass certain phases. It is quite obvious with respect to biological organisms and even species. Stars also have certain life phases. After the phase of ordinary thermonuclear reactions, which is called the main sequence phase, depending on the size, a star transforms either into a white dwarf (after passing the red giant stage) or (if having a large mass) into a neutron star. One can find certain phases within the life span of many other objects as well.

4.2 The Rule of 'Block Assemblage' in Evolution

We formulated this rule (see Grinin, Markov, & Korotayev, 2008; Grinin *et al,.* 2009) for the analysis of similarities between biological and social phases of Big History. However, it is quite relevant for its cosmic, chemical and geological phases as well. The essence of this rule is that in the course of evolution there emerge some elementary or more complex units, systems and constructions which are used in different variations. The elementary particles are the units which form atoms. With the emergence of atoms there also emerge stellar systems, and in the stellar interior new types of atoms including heavy elements are formed from additional elementary particles. Due to the diversity of emerging atoms one can speak about chemical evolution. Atoms are the universal units and components for the formation of various molecules and this marks the beginning of planetary and geological evolution. Thousands of different minerals, materials and substances are formed from molecules. Then a complex molecular organic evolution leading to life. The cells become 'bricks' for the formation of living organisms; there progressively emerge whole blocks of organs and systems which are surprisingly similar in different classes and even types of living organisms. One can recall genes and chromosomes as standard components and blocks of biological systems. One can insert a gene of a mouse into an elephant DNA, and the gene of a dog – into the human DNA! Thus, there is a striking standardization of elements and 'components' at all evolutionary levels; and since entirely new objects within evolution are created for 90–99 % from the already existing components, the speed of evolution increases dramatically. Let us also add that in human society borrowing occurs rather frequently: societies borrow (sometimes to the full extent) religions, legal, political and technological systems. Thus, 'block assemblage' allows modernization of societies.

4.3 The Circulation of Matter in Nature and Increasing Diversity in Evolution

The circulation of matter, energy and information occurs at any level. At the same time, together with circulation of matter and energy, there also occurs a circulation of states of objects. This process provides a huge potential for the search of new options. The more new objects are created to replace the old ones, the more diverse they are. Nature's workshop is based not only on the selection from the diversity but also on a constant remaking of objects. Every object has its own lifespan (see above), therefore its decaying substance is involved in the circulation and formation of new objects. New stars are formed from exploded stars but they differ from their predecessors and this brings about an increasing diversity and enhances chances of the emergence of something brand new. Decayed biomass is a source of nutrients to support the reproduction and life of other living creatures. The debris of a destroyed empire gives rise to a new power. *Thus, the decay and revival (in different ways) of objects (organisms) is a general law of evolution/Universe*. We speak about the Universe since these processes ensure the continuity and laws of perdurability of matter and energy. We speak about evolution because these processes allow some constant testing of new variants (in biology they also include mutations, and in human society – deliberate changes which accelerate the given process).

Thus, the collapse of one object implies to some extent the origin of the other one. This provides an opportunity to reap the benefits of long processes. For example, a supernova explosion results in accumulation of heavy elements that played an important role in the formation of the Solar system (*e.g*., Bizzarro *et al.,* 2007). To an even greater extent, this manifests itself in biological evolution with its myriads of trophic chains. And to a great extent this also refers to social evolution, in which, for example, the invaders' societies inherit the culture of the invaded. Here we deal with a 'creative destruction' when the new is created at the expense of destruction or elimination of the old (see below). At the same time, the new is already somewhat different from the old, and sometimes to a significant degree, and this provides continuity and space for advancement to the new. Thus, the change of the ruler does not necessarily lead to fundamental changes in society, but every new ruler is somewhat different from the predecessors, he acts in a somewhat different manner; and thus, historical experience is accumulated (Grinin, 2013: 140).

4.4 The Typical and the Unique Objects

On the one hand, one cannot help wondering at the natural 'production-line' capable of creating millions and billions of exceptionally similar copies of the same objects. But, on the other hand, the variability among similar objects is unquestionable. In fact, every star is very different from another even if it belongs to a narrow classification group (and there are lots of such groups). And even if stars are formed (like enzygotic twins) from one gas-dust cluster (as a result of a single outburst of supernova, *etc.*), still they differ in mass, chemical composition, the presence or absence of planetary system (and in the planetary system types), brightness, characteristics of reactions, and position, *etc.* Not a single biological individual is identical with another. The same refers to human beings (various papillary patterns on the fingers, unique genetic code, *etc.*). Not so long ago we believed that animals act like mechanisms guided only by their genetically determined instincts. But at present, ethology has identified a large range of individuality among animals as well as among insects (see, *e.g.*, Reznikova & Panteleyeva, 2012). Thus, typical and unique (individual) characteristics are peculiar to all macro-objects in nature. Individuality has been also discovered in the microworld. But it is quite possible that molecules, atoms and even elementary particles might also have something like individual features. Thus, such features as, for example, uniqueness which seems typical only of humans may appear also inherent to all natural objects. The variability of typical objects (belonging to one class, species, group, *etc.*) is the most valuable tool of evolution which allows selecting variations of attributes (as well as their concentration, *etc.*) which are the most appropriate for a number of tasks. A qualitative breakthrough can occur only as a result of the emerging unique circumstances (whose possible occurrence is significantly increased through variability). Finally, only the endless variety of stars, planetary systems, planets and preceding events could be a trigger of emergence of life on the Earth. But one should remember that individuality increases as evolution develops. The number of attributes of variability increases together with the complication of systems (*e.g.*, in human society, language, social position, nationality, *etc.* are added).

4.5 Selection and Struggle for Resources

Social evolution is largely a struggle for resources and for living space (and not only at its initial phases). The same refers to biological evolution. However, the study shows (Grinin, 2018, 2020; Grinin L. & Grinin A., 2019) that the struggle for resources is a common selection mechanism at all levels of evolution, including cosmic evolution. Therefore, it can be defined as a law of evolution which is unfair from the moral point of view but very effective from the point of view of evolution. Only at higher phases of social evolution are there attempts at eliminating the most acute forms of injustice. The struggle for resources is connected with evolutionary selection, which can be traced at all levels of evolution, including the cosmic one. Thus, during the formation of the planetary system within the Solar system those planetesimals were selected that eventually formed the protoplanets, while many of the other planetesimals and asteroids became asteroids and small planets (Grinin, 2017, 2018; see also Bottke *et al*., 2012).[5] Moreover, certain advantages, including random ones, which may play a role in the selection process, become very important. This method of trying out different variants and constructions is a mechanism by means of which evolution performs 'creative destruction'. The selection simultaneously increases and decreases diversity by creating new options and destroying old ones. Evolutionary selection is also the most important tool for regulation of processes. The environmental influence on selection can be traced in most types of selection. However, in the pre-biological world, the selection mechanisms were different from Darwin's selection (Grinin, 2020).

It is evident that the role of selection in biological and social evolution is more significant. Therefore, it would be interesting to consider similarities and differences in their selection mechanisms. The similarities lie in the fact that in both cases selection contributes to growing adaptation, emergence of new elements and functions, disappearance of less successful organisms and forms, greater adjustment between an organism and environment, *etc.* In short, the selection drives the evolutionary process. But at the same time, the selection mechanisms in social and biological evolution are significantly different. The reasons for this are the following. In the biological world, the main source of stable and heritable innovations is mutational and recombinational variations which are characterized by a high degree of randomness and unpredictability. In this situation, 'the post factum selection', the selection among the already emerging deviations that find their realization in the phenotype, becomes the only way to give the process certain direction (in this case – to secure the adaptive character of changes). In the social world the main source of heritable innovations are not random errors of copying and reproduction but conscious and purposeful changes (and over the last centuries and decades this awareness and purposefulness tend to increase). At the same time, people are certainly unable to foresee many consequences of changes, that is why purposeful actions may sometimes seem stochastic and random in the short term while from another point of view they may seem quite rigid and quite a strong trend, not perceived by people.

Another important aspect of selection, which is absent in biological evolution, is the struggle for the selection of a certain model (model of reforms, model of unification, ideological model) at the level of individual societies, as well as at the inter-societal level because in social life from time to time there occur aromorphoses associated with integration, including the violent one. For example, independent communities (sometimes voluntarily, but more often forcibly) are unified into a multi-communal chiefdom, polis communities (or the polity of another type). And accordingly, it is the most 'successful' community (no matter what was the reason for its 'success') that becomes the center, quite often some peculiarities that determine advantages of the successful societies show up incidentally. The same can be said about the struggle for the main dialect of the language, for religion, god, myth, city, for unification of tribes and chiefdoms into a confederation, or of principalities into a large state, *etc.* Selection can be seen everywhere, for example, selection of a leader, model, course, central position. At the same time, the decisive advantage may vary: from the size to the leader's genius, from geographical position to a happy coincidence (a successful fight between representatives of two armies, an eclipse at the right time, rumor, *etc.*).

4.6 Discontinuity and Catastrophes

Within evolution, the periods of slow changes (accumulations), that is of an evolution in its narrow sense, are alternated by rapid metamorphoses and qualitative transformations (which sometimes look like revolutions) and the periods of explosive growth are followed by catastrophes. Thus unevenness, discontinuity are a very important characteristic of evolution, which rate, smoothness or abruptness, tempo, etc. is changing constantly. In geology and paleontology there were hot debates between proponents of catastrophism (the school of the famous paleontologist George Cuvier) and adherents of gradual changes (the outstanding geologist Charles Lyell and his followers). The victory of the latter was a progress; however, later it became clear that it was very difficult to explain many things only by slow and insignificant changes. Thus, evolutionary theory was enriched by the ideas of leaps, revolutions, and catastrophes enabling us to understand how and why the world kept changing. It is important to note that catastrophism is an essential part of evolution at all its stages. The idea of 'Big Bang', the biggest 'catastrophe' in the history of the Universe, underlies its origin (about Big Bang, see Guth, 1997, 2002, 2004; Diemand *et al.,* 2008; Gorbunov & Rubakov, 2011; Grinin, 2019).

However, it would be more correct to speak about *the principle of synthesis of gradualism and catastrophism*. The combination of both principles in evolution is obvious. But, in our opinion, at any other levels of evolution they are not so naturally combined as in cosmic evolution, for example, in destinies of individual stars. The main sequence of stars, during which there is a very long process of hydrogen burning – an obligatory stage for any star – demonstrates the gradual character and importance of slow and long processes. However, disasters of this or that scale may take place during the lifetime of stars. This leads us to the formulation of the *rule of cyclical alternation of abrupt and gradual changes*. It consists in the fact that evolution naturally combines the processes of slow and almost imperceptible growth with explosive one and consequently, the periods of slow accumulation of changes with periods of rapid transformations, often associated with destruction or even collapses. This may finally lead to the formation of objects with qualitatively new characteristics. So the order can again be replaced by disorder.

Thus, catastrophes appear to inevitably accompany development and evolution, to be a kind of compensation for the development and rapid growth (and at certain evolutionary stages – a compensation for progress).[6] In cosmic life, catastrophes are an inevitable result of the long life of stars which, after having depleted their energy reserves, turn into the white dwarfs or red giants and sometimes they produce extremely bright outbursts of light – the outbursts of supernovae. In biology, catastrophes are the great extinctions which freed space for new progressive species to appear and flourish. It should be noted that it is just catastrophes that provide abundant data for the scientific reconstruction of past events. Thus, as a result of the study of supernova's outbursts, the spectrum shift analysis served a firm foundation for the discovery of antigravitation of cosmic vacuum (the so-called dark energy which constitutes the vast majority of the total mass of the Universe; about dark energy and matter see Guth, 1997, 2002, 2004; see also Grinin, 2013).

In general, one can talk about the pattern of *catastrophes as one of the main selection mechanisms at all phases of Big History*, including social one, and not only at its early phases, when catastrophes could have a huge impact on the direction of future development (suffice it to recall the great plague epidemic – the Black Death – in the 14th century [McNeill, 1998] and Covid-19). Thus, dramatism is characteristic of evolution at all its levels. The pattern of catastrophes is closely connected with *the cycles of alternating order and chaos*. The order from chaos is one of the main patterns of evolution (Prigogine & Stengers, 1984). The alternation of order and chaos, the transitional from the latter into an order, and the break of order again before moving to a new level make an inevitable sequence of many processes. The creation of a stable order often requires elimination of many 'superfluous' objects. Such elimination in evolution often takes the form of mass extinctions or other catastrophic events.

4.7 The Principle of Creative Destruction

By studying the relationship between catastrophes and evolution, one can formulate the *principle of creative destruction* for phase transitions, transformations and expansion of diversity if to use Joseph Schumpeter's expression (1994 [1942]). 'Creative destruction' is the creation of a new one by destroying or removing the old one from active operation. At the same time, the new is already essential and different from the old. As already mentioned, this provides both continuity and space for moving towards the new. However, the destruction itself cannot be creative. It turns out this way only after a great amount of preparatory work. At the same time, first this often leads to regress and only then (*i.e*. much later) evolution, as if taken a run-up, starts a new movement forward. In social evolution, one can find many such cases. The most famous examples are the barbarization of Europe after the fall of the Western Roman Empire after the German invasion and destruction of prosperous countries resulting from the Mongol invasion. Both catastrophes would launch a rise based on a new synthesis which, however, would take much time. Therefore, one can speak about *the rule of preparatory work of evolution*. It means that an evolutionary breakthrough resulting from unique circumstances is never a coincidence, but it is always prepared by a huge and longtime 'work' of evolution to advance changes in a certain direction. However, the emergence of unique circumstances in the right place at the right time often depends on chance. At the same time, a phase transition or transformation of an object often needs an impetus or a trigger to start. On the one hand, of course, the latter will not work without the internal readiness of the system; but on the other hand, even a high level of internal readiness by itself cannot launch the transformation process like the gunpowder cannot explode without fire. Without a trigger, a system may remain in a state of potential readiness for transformations for a long time. In this case, the analogues of evolutionary typical/recognized systems are formed (about the analogues in social evolution see Grinin 2003, 2004; on analogues in cosmic evolution see Grinin 2013, 2017, 2018; Grinin L. and Grinin A. 2019).

5 Why Do We Observe Unity and Similarity in the Mechanisms and Patterns at Different Levels of Big History?

In this section we will try to present some evolutionary and philosophical ideas that explain the profound similarity in the laws and patterns of evolution at all its levels and phases.

What defines this unity? This is one of the most important questions, the answer to which can significantly change our approach to the study of evolution. But it can only be provided by a long and diverse work on the development of *evolutionary studies*. As far as we know, almost no one has performed such work in a consistent manner, although a number of researchers left very insightful ideas and assumptions. In this section we would like to demonstrate some opportunities and dimensions of such research.

5.1 The Causes of Evolution

First of all, let us speculate why evolution is possible at all? Some general reasons are: 1) the gradually changing conditions which make it necessary to adjust structure, functions, *etc.* to the changed conditions; the aspiration for the most harmonious congruence with external environment is caused by *the pursuit to the most favorable energy state*, but the process of this adjustment sometimes leads to an unusual result that can provide some advantages; 2) competition due to limited resources; 3) the desire for self-preservation; and 4) the circulation of matter (see above). But, as already mentioned, in every cycle this circulation has some differences which tend to accumulate.

It would be safe to assume that the unity of processes is determined by the following causes and factors:

- all processes unfold in a unified system, that is, in the Universe. It is clear that a common system to some extent defines common means and principles. In fact, since everything happens within one system and one Universe, it would be strange if each line of evolution had its own peculiar laws and patterns;
- during the formation of this unified system there was imbedded some common unity;
- all processes and systems have a common base of elementary particles and lower structural units (atoms and molecules), which canalizes the processes and development to a certain limit. Although *the law of emergence* states that the sum of properties of the parts is not equal to the sum of properties of the whole; nevertheless, there is undoubtedly some meaningful dependence on the sum of properties of the smallest parts;
- the fundamental laws of the material world always work. These are the laws of conservation, the law of gravitation, the basic forces of physical nature, the reaction of bodies and particles to changes in external parameters, *etc.*;
- the mass-energy unity. If mass and energy form two poles of the state of matter, the ratio between mass and energy must be traced at all levels.

5.2 The Systemic Character, Environment, and the Laws of High Abstraction

There are also quite obvious situations, laws and patterns that are present at all levels and in all systems.

1) For example, objects or systems exist in the environment and there should be some interaction between them. Despite the variety of environments and situations, there are quite a few basic interaction models; so, they can be quite similar at different levels. 2) The systemic character by itself leads to certain similarities; this was established back in the 1950s and with respect to a number of relations even earlier. 3) The laws of dialectics, formulated by Georg Wilhelm Friedrich Hegel, also have in their abstract form a rather clear mechanism. For example, the law of transition from quantitative to qualitative changes manifests itself because any forces have limits beyond which their impact declines and becomes insignificant, so when the quantitative accumulation reaches this limit, the former structure (order, *etc.*) must inevitably transform. The law of the unity and struggle of opposites as a part of an even broader pattern of binary (duality, dichotomy) is determined by the fact that any structure or change requires at least a couple of opposing forces, elements, *etc*. 4) The binary is also related to the universal symmetry, which determines the opposite parts or paired relationship between elements (*e.g*., of the positively and negatively charged).

5.3 Parsimony of Evolution

The presence of common laws and patterns is logically explained by the fact that in all aspects it is more advantageous to have a few universal rules than a set of special ones for each case. Here, it is worth mentioning *the rule of rarity of new evolutionary rules*. According to this rule, evolution is wasteful in its ‘experiments,’ but rather stingy with respect to mechanisms and patterns and ‘prefers’ to use the already available rather than to invent new ones. Each new rule (or pattern) is related either to the peculiarities of filling evolutionary niches or to the emergence of some new sub-levels, levels or blocks. This perspective allows us to hope that in the future it will be possible to identify a group of primary (basic) rules and laws of evolution that have already manifested themselves in the first hundreds of millions of years, and then new ones that would appear later. In addition, self-organization does not require a large amount of forces or rules, their quite a limited number would suffice (Grinin, 2017). One should remember that the diversity of manifestations is based on a limited number of basic rules.

5.4 More Specific Mechanisms

Much is canalized by rather rigid constraints: energy, efficiency, and previous development. Thus, the choice of the most energetically advantageous regime can occur at different levels; the same concerns, respectively, the choice of forms and other things. But, of course, revealing the specific mechanisms united by a common law or rule of Universal evolution is of special value. Thus, some things are determined by *the rule of minimization of evolutionary efforts*, when the ready-made solutions are used, and also by the above-described *rule of 'block assemblage'*. So, the increasing complexity of structure at all levels – from atom to society – is often carried out, conventionally speaking, by *polymerization*, that is by assembling standard 'details'. All chemical elements of Mendeleev's periodic table can be represented as gradual complication of the structure of their atoms through adding an atom of hydrogen. The same can be said about complex molecules, multicellular organisms, expansion of the society by adding small structures (like a family, community, *etc*.).

5.5 Differences and Similarities Are Two Sides of the Same Coin

We would like to present the following methodological idea. To show the path of evolution, how it became more complicated and moved to new levels, it is crucial to investigate, figuratively speaking, its vertical development (from simple to complex). But if we study it from the general point of view, it is logical to present different levels as different manifestations of changes in the horizontal dimension, in other words, as a multi-line manifestation of general development. In fact, we are talking about changes, transformations in different parts or spheres of the *single* Universe: stars, planets, minerals, molecules, living beings, *etc.* At the same time, it is important to keep in mind that the developing higher forms are a part of a broader evolution. Thus, abiogenic chemical evolution was actually a lateral line of geochemical evolution, and the latter, in its turn, was a part of geological evolution. And this mere fact determines the similarities. In addition, some types of evolution develop in co-evolution which imply mutual influence, transformation and support (see above). Such an approach allows understanding that there are some basic patterns which are differentiated and acquire specific forms related to the peculiarities of the form of matter in which they manifest themselves. It is quite possible to distinguish these common patterns. The more so in the case of evolution on the Earth, where all its forms and levels are very closely connected by a common place of development. Thus, if we consider megaevolution horizontally, that is in terms of emerging new lines, then we reveal a common basis and if we consider megaevolution vertically as a tree, then we find 'genetic' relationship. As we have already mentioned, this 'genetic' relationship to a great extent determines not only the direction of evolution and its canalization, but also similarities in mechanisms and patterns of different levels and lines.

The rule of evolutionary inertia (formulated by Ludwig Doderlein and Othenio Abel for biological evolution) can be used for predetermined character of evolution. It deals with the general dependence of subsequent evolution on the previous one, when the past largely determines not only the present but also the future. This is reflected in the significant dependence of subsequent phylogenetic events on the preceding ones, which is interpreted as evidence of the inertial influence of the past evolution on its future. The inertia manifests both in the similarity of development mechanisms and in the fact that every transition to a higher level more and more channels the direction of development. Meanwhile, we are too accustomed to seeing an insurmountable barrier between higher and lower levels of evolution, absolutizing the differences between living and non-living, human and animal. *But one should rather be surprised not by the similarities, but by the differences. The similarities between the levels are more natural, since the birth of a new one does not mean the rejection of the old one.* Until recently, evolution has been mainly additive in nature, so the new did not reject the old, but added to it: elementary particles did not disappear with the emergence of atoms, and the latter – with the emergence of molecules; inorganic molecules remained, but organic molecules were added to them, *etc.* Therefore, the old has a continuous effect on the new, but the new also affects the old where possible. A number of evolutionary rules, namely: localization of evolutionary breakthrough; preparatory work of evolution; necessity of preadaptation for the transition to a new level (direction) of evolution; necessary heterogeneity of components in the system; continuum of evolutionary states and characteristics; dependence of the evolution rate on its narrowing scope (see Grinin, 2017, 2020) show that the new is not only different from the old, but also related to it, and that it breaks through only in certain directions (in fact, where the old allows it to break through), and that it is formed not in all, but only in some aspects.

5.6 Evolutionary Memory

One can also make some assumptions that development (evolution) has some kind of a code and memory, which are fixed with the help of some imprints, and also function on the basis of *the rule of minimization of evolution efforts* (see above). Of course, it remains unclear how this memory becomes fixed but there is no doubt that it is based on some rather material things.

For example, everybody knows about the so-called golden ratio. But why does this ratio have such proportion?[7] Why do some patterns become common at all? Probably, because some discoveries of nature and evolution reveal a certain code, a set of ancient and longstanding solutions and combinations, thanks to which, on the one hand, the already available solutions are used to create a new one, while on the other hand, the evolution related to those solutions is canalized and becomes autoevolution, according to Antonio Lima-de-Faria (1988).[8] But this defines certain limits, since the fundamentally new solutions are already made far from easily and only as a result of some rarely occurring breakthrough created by peculiar circumstances.

It is still impossible to reveal how these universal solutions and patterns are encoded, but there probably exists some mechanism. However, if we speak about the 'genetic' connection between higher and lower levels of evolution (see above), why should we deny the possibility of 'genetic' memory and 'genetic' code of evolution? Even relatively simple structures have memory. A kind of 'memory' can be observed in self-organization and the activation of this 'memory' is promoted by the fact that order often turns out to be energetically beneficial. Another aspect of this assumption is the universal character of information. We learn more and more about different kinds of information, in particular, about chemical signals which even the simplest organisms (bacteria) appear to be able to perceive; probably, viruses also exchange some information (Solé & Elena, 2018). In fact, one can observe information already at the level of elementary particles, where it seems to be syncretic with the energy form. But, in any case, it is important that the information interaction can occur only if the properties of objects correspond to each other (Yankovsky, 2000). Also the electromagnetic and other interactions provide adjustment, as a result of which, for example, negatively and positively charged particles 'recognize' each other. In fact, they exchange 'codes' and turn out to be complementary, and therefore can create stable structures. It bears repeating that at this level the energy and information aspects are inseparable but still different. A greater difference between the energy and information aspects can be observed in catalytic interaction (*Ibid*.) when one substance-catalyst changes the rate of chemical reaction between other substances, which are reactive chemicals in this case. Without information that activates the reactive chemicals, the reaction would be much slower or could not take place at all under existing conditions. In other words, information is mostly separated from energy processes so the catalyzers can only impact the speed but not participate in chemical reactions. But the condition that information between objects is transferred by means of substance or energy exchange is fully fulfilled. In the general theory of information, the law of information preservation is also formulated: the latter *keeps its significance unchanged as long as the information carrier – memory – remains unchanged*. The information exchange at the lowest levels, already in the micro-world, evidences the existence of memory (in particular, in the form of recognition). It seems that preservation and transfer of information at different levels and in different systems is not only one of the foundations of interaction between different objects, from particles to galaxies, but also a way to react to environmental changes, and most rules, laws and patterns manifest themselves just in the interaction with the environment.

Thus, there is a common base, a 'common denominator' in the continuity of motion and energy processes, in interactions involving information exchanges, in destruction and new assemblage, and other aspects so that the common may manifest itself in the behavior of different objects. At the same time, it should be implemented not only in standard but also in unusual conditions which are the most interesting for evolutionary studies because it is just the unusual responses to unusual challenges that may give rise to fundamentally new things.

We have already mentioned above the circulation of matter, energy and information. However, such circulation could not take place without some kind of memory which made possible the new assemblages and new processes of self-organization. Hence, we inevitably return to the fact that there must be some mechanisms of coding, some organizational and system-forming memory. *However, similar to non-specialized stem cells, which can* *differentiate into different cell types and organs, the matter with such memory in different situations can transform into different types and forms of matter.*

6 The Capacity for Development, Self-Preservation and Self-Organization

Evolution, that is the changes of objects, actually means the destruction of their stability and identification. From this point of view, at any stage and in any sphere of evolution the matter can be divided into two types: the one that is capable of self-preservation and the one that is capable of self-transformation (of course, these characteristics are manifested in different objects and systems in different proportions). In other words, one may speak about *evolutionary and non-evolutionary matters*. Within human society there also exist rather conservative elements and there still exist societies which are not quite prone to changes, and this phenomenon was even more strongly pronounced in the previous epochs. An average lifespan of a biological species is less than 10 million years. At the same time there are species which have endured for 200–300 million years. Thus, the presumable age of blue-green algae is several billions years, and they have not changed significantly since the Archean Eon. Thus, in biology one can observe species that have existed for hundreds of millions of years without radical changes as well as species that have given impetus to powerful typogenesis (*i.e.,* the formation of new taxa), or species that are disappearing rapidly in biological terms within hundreds of thousands of years. One of the most important discoveries of the second half of the 20th century was the discovery of the so-called dark matter whose abundance in the Universe far exceeds by mass the visible (or baryonic) matter visible to us. But at the same time, it seems that dark matter is hardly able to evolve in comparison with light matter.

At any phase, the evolving matter makes up the minority; thus, the light (baryonic, stellar) matter according to some current views amounts for only 3–5 % of the total mass of the Universe. It is amazing that this proportion is relevant even to human society in which, according to some reports, the number of innovators is also 3–5 %. Actually, any object, system or any form of matter can evolve, but this ability differs so much among various types and objects that it is reasonable to talk about the evolutionary rule *of inability of some objects to evolutionary changes.* In addition, evolutionary changes require a certain time rate of change of external conditions (or special conditions), which is far from always available. At the same time the inability to evolve means the ability of the matter to self-preservation. And in some cases this turns into a clear advantage, while in others it becomes a disadvantage. Thus, one can see that the diversity of forms of existence (and development) in our Universe is also manifested in a hugely varying ability of different objects and forms of matter to change and evolve.[9] In short, existence fluctuates between stability and variability over a huge continuum.

Both characteristics – stability and variability – have great advantages, as well as disadvantages; they are both necessary for the existence of objects, species and the world in general. This can also be observed in social evolution. There are more stable institutions which remain fundamentally unchanged when undergoing transformations; there are nations that have adapted to their way of life, so that they can exist without radical changes for a long time (millennia); and in some societies and situations the evident rapid changes lead to considerable qualitative transformations. We believe that such an inability is not genetic or race-related (although for the period of anthropogenesis it is quite possible), but depends on the certain societies' circumstances including natural and social environment, the role of factors, like the emergence of outstanding personalities, *etc*.

A Short Addendum: As we above mentioned, even our scheme (Fig.1) does not fully reflect the complexity of Big History lines and phases. We suppose that we can discuss some more transitional, lateral or, even may be, main phases of megaevolution. On the Fig. 2 we show the way of Big History since its biological phase with possible addition: the virus' kingdom transitional phase and the hypothetical posthuman phase (about the latter see Grinin L & Grinin A., 2015: Introduction; 2016: Introduction; 2020a; 2021). Both of them are demanded a special discussion which, we hope, will be possible in the future.

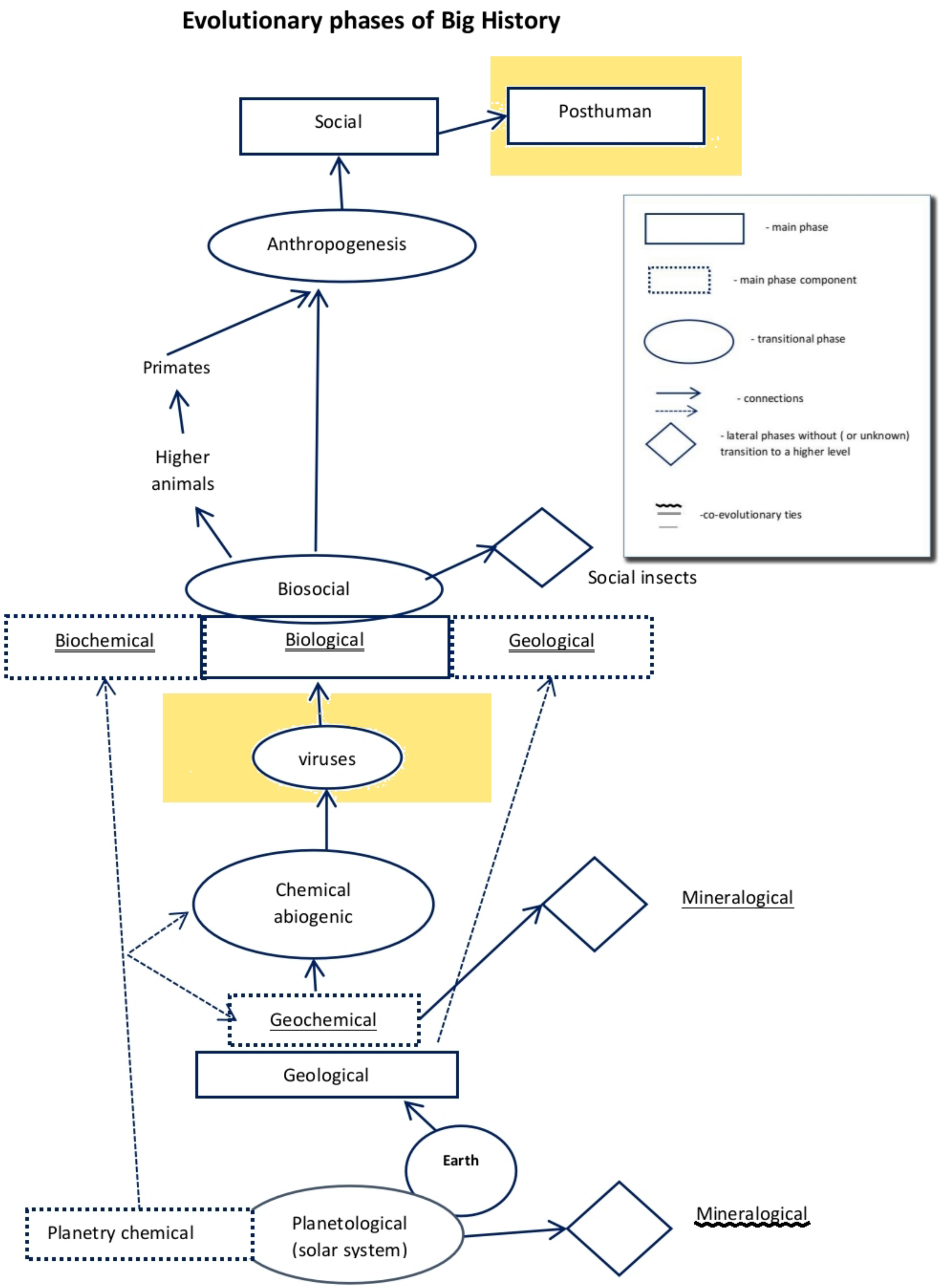


Figure 2. Phases and lines of Big History with virus and posthuman phases

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Endnotes

1 The term is connected with the biological concept of aromorphosis which is "an increase in the organization level that makes it possible for aromorphic organisms to exist in more diverse environments in comparison with their ancestors; this makes it possible for an aromorphic taxon to expand its adaptive zone' (Severtsov A. S. 2007: 30–31). It is worth to add one more definition 'Aromorphosis is an expansion of living conditions connected with an increase in complexity of organization and vital functions' (Severtsov A. N. 1967).

2 For the social evolution definition it is worth adding after 'with the previous state' 'and also the ability to accumulate such changes, including their purposeful usage and training in activities that lead to such changes'.

3 The planetary evolution outside the Solar system is distinguished separately (see below).

4 The concept of inflation phase in the early Universe, of course, covers more than the traditional accepted phase introduced by Guth (1997, 2002, 2004).However this subject is beyond the scope of this article. For detail see Grinin 2019.

5 The struggle for resources among stars and galaxies may proceed in the form of weakening of another object or its destruction (*e.g.*, through a direct transfer of energy and matter from one body to another), in the form of 'incorporation', 'capturing', *i.e.* 'annexation' of stars and star clusters by larger groups (*e.g.*, Gibson *et al*. 2007). Another example connected with Jupiter and other gas giants were probably the first planets to form and take almost all gas, while the Earth-type planets got quite a few resources (Lin 2008; Batygin *et al*. 2016; Batygin and Brown 2016).

6 In his book *A Choice of Catastrophes* Isaac Asimov (1981) analyzed all possible types of catastrophes (real and possible) starting from the Big Bang, the supernova explosions, possible collapse of the Sun to glaciations, continental drift, seismic sea, biological and social catastrophes and made some predictions.

7 Let us remember that in the rounded percentage value the golden ratio describes the relationship between two proportions which is 62 % to 38 %. This ratio equals 1:1.62 (a common proportion in the construction of objects).

8 That is in the most general form, the mechanism is similar to that in the genome of living beings, in the form of so-called genomic ballast combinations of genes of which are used only in extreme cases.

9 One can assume that dark matter is not completely devoid of the ability to change, it only requires much more time than the light matter for such changes. The stars also used to seem unchanged.

Review and Analysis of Big History Periodization Approaches

Ken Solis
Member American College of Physicians,
Alpha Omega Alpha medical honor society,
and the Wisconsin Medical Society, retired
David J. LePoire
Argonne National Laboratory

Correspondence | **Ken Solis** kensolis@drjump.com; **David J. LePoire** david.lepoire@anl.gov
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Abstract: Big history may in fact be one very long "one damn thing after another,"* but even if we experience time as a continuum, dividing its expanse makes our discipline more "manageable" for psychological, teaching, research, discourse, and other reasons. Big history related books, like David Christian, Cynthia Stokes Brown, and Craig Benjamin's 2014 textbook, *Big History: Between Nothing and Everything*, and several papers also often divide the time continuum into periods, but unlike other disciplines such as geology, we have no broadly agreed upon conventions for doing so. Big history pioneer, Fred Spier, in a recent *JBH* paper, "Thresholds of Big History – A Critical Review" (Vol 5, No. 1), criticized Christian's "thresholds" schema for periodization and seemed skeptical of the very idea of periodization. As noted above, we believe that periodization is a worthwhile project to be undertaken, preferably by an ad hoc IBHA "working group." We then suggest a general framework for how big history might be divided into time periods, and then anticipate some of the major challenges to developing any coherent periodization schema. So that we can better illustrate some of these challenges, we will end by taking deeper analyses of three possible big history "events" that might be used for demarcating one time period from another.

1. Introduction – Thresholds to Big History?

Big history is, well. . . BIG! 13.8 billion years of events, processes, and "things" are a lot to wrap our minds around. Consider – the thickness of a sheet of paper sitting on top of the Prudential skyscraper in Boston, or the top floor of the Eiffel Tower represents the relative length of time covered by traditional histories compared to big history. Geologic history is much longer than traditional history, of course, but still is only about 1/3 as long as big history. We seem to have an inborn tendency, even need, to divide large "things," probably so that we can better apprehend and comprehend them. This tendency to divide large pieces of information is called "chunking" in psychology (Gobert, 2012). The division of human areas of study is , of course, one example, and one that big historians often rail against: physics, biology, ethics, chemistry, astronomy, music, literature, and history are in the end just different aspects of the universe that are all interconnected. For example, Pythagoras, the ancient Greek philosopher, discovered that the harmonics in music have a physical basis in "nature" – not just our minds (Stewart, 2015). Despite the ultimate unity of knowledge, our mind begs to parse it into manageable chunks, and so we also have a strong tendency to do the same with the universe's 13.8 billion years of time.

Personal communication with David Christian confirmed that he periodized big history into 9 "thresholds" in his *Great Courses* lectures series "*Maps of Time: An Introduction to Big History* (2011), and the text book *Big History: Between Nothing and Everything* (2014) only for pedagogical purposes. Regardless, dividing time by some type of periodization schema might make sense at face value to the great majority of those interested in some aspect of "deep time." After all, geology divides time by several levels like "eons," "epochs," and "eras." Paleontology has the paleolithic, and neolithic as well as other time divisions. Traditional history divides time in a myriad number of ways (Kisak, 2022).

Hence, at first blush, Fred Spier's objections to big history periodization in his paper (Spier, 2022), "Threshold of Increasing Complexity in Big History: A Critical Review," in JBH Volume 5, number 1, seems surprising. Furthermore, David Christian is generally considered the founder

*An apocryphal quote often attributed, likely mistakenly, to the historian, Arnold Toynbee.

of contemporary big history, and Fred Spier is amongst its earlier pioneers as well. Hence, given the status of those with opposing views only "adds fuel to the fire" and begs for further examination:

Spier's major contentions against Christian's "thresholds of increasing complexity" include the following:

- The periodization scheme and its terms are Earth-centric once the Solar system forms and fails to acknowledge that advanced complexities likely occurred earlier elsewhere in the universe.
- Similarly, the scheme and its terms are also anthropocentric beginning about 7 million years ago when the evolutionary lines split between the great apes and the line that led to Homo sapiens.
- Christian's "thresholds" lack precision in defining or characterizing what qualifies as a significant advancement in complexity so that they warrant being markers for a new period in big history.
- Thresholds also fails to identify processes and conditions that favor increases in complexity, i.e., "Goldilocks" circumstances,"
- It ignores other advances in complexity that occurred, or conversely, declines in complexity that occurred.

The first two objections can be readily and briefly addressed: At this time, big history is *necessarily* Earth-centric and anthropocentric. First, while we are progressively detecting evermore planets, including solid ones, with more advanced telescopes and other detection strategies, our knowledge of them is small compared to what we know about Earth, e.g., primarily their approximate size, mass, and year length. We know much more about the planets and moons of the Solar system, and Earth is arguably its most complex member. It is the solar system's only solid heavenly body with plate tectonics, Van Allen belts, a liquid hydrosphere, and a relatively large moon that causes secondary phenomena that help it support complex life. The Solar system's gas giants have complex weather systems, many moons, and Van Allen belts, but they almost definitely lack a biosphere because their gaseous nature would not allow for the Goldilocks circumstances that promote life as we know it. Life in turn rapidly advances the complexity of systems in a myriad of ways that even the most complex physical systems like planets, stars, black holes and galaxies do not.

Big history is also necessarily anthropocentric if only because we cannot ask even advanced Earth species like chimpanzees and dolphins about their perspectives because they lack grammatical language. Of course, humans are more advanced complex life forms compared to Earth's other species in many more ways than we can recount here. Life on other planets outside of Earth is likely, even very likely, but it remains a point of conjecture until there is demonstrative empirical evidence of its existence. In short, once the Solar system forms, we are left with only our own perspective to examine and contemplate. If and once we can gain much more information about other exoplanets, and perspectives from other communicative, sentient beings, big history will likely have to adjust.

In his book, *Big History and the Future of Humanity*, Spier (2015) also acknowledges that big history is necessarily Earth and anthropocentric (p8). His book does proceed to list different events from the Big Bang to contemporary "emergences" in chronological order. Apparently, however, he feels that a *periodization* scheme like Christian's "thresholds of increasing complexity" implies a cosmic reach in its application. We believe that semantics aside, there is little difference in proposing a periodization scheme versus more simply a chronological listing of events (that typically give rise to greater complexity) over the expanse of time. An author *still* must decide *which* events are significant enough to warrant them being described, even if just being the heading for a chapter, e.g., "Chapter 5. Life on Earth: The Widening Range of Complexity," and the included subchapters, e.g., "The Emergence of Multicellular Organisms." Note that we are not criticizing the listing of events in a chronological or hierarchical manner, and in fact, we endorse it. However, there is not a great distinction between a mere listing of important events and a somewhat more formal periodization of time based on important events.

Spier's other objections to Christian's thresholds of increasing complexity do deserve much more discussion, however.

2 Why Should We Periodize Big History?

Perhaps the most immediate reason for periodization is to accommodate the human mind's tendency to divide large entities so that we can better apprehend and comprehend them – as mentioned earlier, psychology refers to this tendency as "chunking." (Gobert, 2012). Big history periodization is but one example. We also divide the living organisms into clades, the electromagnetic spectrum according to ranges of wavelengths, and areas of human knowledge into various disciplines – even if the matter at hand is a continuum.

Another pragmatic purpose is to facilitate the teaching of big history in discrete modules according to the most relevant scientific discipline for a time period, e.g., astronomy, geology, paleontology, traditional history, and so on (Kisak, 2022). As David Christian did at his big history course at Macquarie University, inviting different lecturers from different disciplines to teach the how and why their subject matter varied over time was undoubtedly beneficial for both him and his students. For example, while most historical professors can learn to recite the events that occurred in the three minutes after the Big Bang, an astronomer would be able to better articulate the deeper reasons of *why these* events occurred as they did, or other questions relevant to astrophysics like the formation of higher chemical elements. Students will also benefit by being able to better compartmentalize how different types of processes and entities drive change depending on the time being studied, e.g., physical processes before life appeared on Earth, then various genetic and epigenetic processes, leading eventually to the many factors at work in the modern age.

Big history research and academic discourse would benefit from a widely agreed upon periodization scheme by helping to crystallize certain concepts or prompt various research agendas – perhaps one of most direct being the exploration of various characteristics, processes, "Goldilocks" (i.e., optimum) conditions, and other parameters that make the very periods of time distinct. Such projects help to make big history "deeper" than the mere compiling of events. These concerns are already demonstrated in books by David Christian (2008, 2011), Eric Chaisson (1996, 2001), Tyler Volk (2017), Fred Spier (2015), and many others.

Finally, assigning names to different periods of big history serves as an informational heuristic – a shortened or condensed way of including a lot of information with a brief word or phrase. For example, if someone tells you that animals with a nervous system first appeared during the "Cambrian explosion," you would know to place that occurrence to about 540 million years ago. Nevertheless, even if a big historian had to look up the exact date of the Cambrian explosion, they would already know basic information, such as: life had been established on Earth for a long time; there was a high concentration of oxygen in the air; multicellular life and sexual reproduction had already developed; dinosaurs had not yet appeared; etc. A short phrase can encompass a lot of information!

This list of reasons for purposefully and thoughtfully periodizing big history is unlikely exhaustive, but illuminates some of the key reasons of why it is a goal worthy of the needed creativity, rigor, energy, and consensus for this academic discipline.

3 How Has Big History Been Divided by Others?

David Christian is not the first to divide the expanse of time from the Big Bang to present. Table 1 includes an overview of just a few authors that have periodized big history in the past, even if their primary intention might have been to illustrate another thesis such as the apparent mechanics or dynamics of evolution. Because Christian is widely recognized as contemporary big history's founder and was the inspiration for Spier's polemic to such a schema, we will look briefly at his method first.

In his 2018 book *Origin Story: A Big History of Everything*, Christian (2018) divides big history into 8 "thresholds," with a future projected 9th threshold: "A sustainable world order?" (p13-14). The 8 thresholds in chronological order include: 1. Big Bang, 2. The first stars, 3, New elements forged in dying stars, 4. Our sun and solar system forms, 5. Earliest life on Earth, 6. First evidence of our species, *Homo sapiens,*7. End of the last ice age, and 8. Fossil fuel revolution begins. He notes that each threshold "highlights major turning points when already existing things were rearranged or otherwise altered to create something with new, "emergent" properties, qualities that had never existed before."

We should note that Christian also offers a number of events that occur between some of the thresholds (e.g., "The first large organisms on Earth"), but does not state if he used any particular criteria for deciding which ones to include. The listing of events such as "an asteroid wipes out the dinosaurs," (and even the "threshold" of "End of the last ice age") indicates that he is not exclusively noting new levels of complexity emergences to periodize big history, but sometimes a major geologic event that might have made a new level of complexity possible, or at least more likely.

However, Christian is not the only one who lacks rigorously defined criteria for identifying big historical events or defining new time periods. In Eric Chaisson's (1996) book, *Epic of evolution: Seven Ages of the Cosmos,* the astrophysicist and fellow big history pioneer, includes seven "epochs:" 1. Particle, 2. Galactic, 3. Stellar, 4. Planetary,

5. Chemical, 6. Biological, and 7. Cultural. The criteria he used to arrive at these divisions are not made clear and the term "epoch" is not defined. Admittedly, he notes that the principal epochs he lists are overlapping (p248) and his focus is on "the story of cosmic evolution" rather than an attempt to periodize this evolution in some rigorous manner.

On the other hand, Robert Aunger, a professor of evolutionary public health, wrote "A rigorous periodization of 'big' history," in 2007. Hence, his paper anticipated the topic at hand (Aunger, 2007). He proposed dividing big history into "eons," "eras" and "periods," the former being longer in time duration than the latter. Time "periods" include 16 divisions that are determined by the appearance of a new non-equilibrium steady-state transition (NESST) that is also persistent through history (i.e., does not become extinct). Each successive NESST is a novel system that uses a new energy source to maintain a structure's "work cycle." Hence, during the "Atomic period," atoms capture electrons, as controlled by the electro-magnetic force. During "Cell period," living cells use metabolism to maintain themselves, and the control mechanism is found in the genetic code, and so on.

Aunger's four "eras" - a longer duration of time that spans over several time periods - are determined by the *kinds* of energy source used to maintain a system. For the "material" era, systems are driven by nuclear fusion, the "biological" era by metabolism, the "cultural" era by new kinds of human-made tools, and the "technological" era by machines like windmills and watermills. Finally, Aunger names two long eons that span over several eras: the "cosmological eon" and the "terrestrial eon" Aunger notes that during the span of time from the Big Bang until the origin of terrestrial life, the duration of time between the appearances of new systems using a novel energy source, *and* the time duration it took for new type of system to become "mature" was increasing. In other words, the rate of the appearance of new types of physical bodies like galaxies, stars, and planets, was slowing. Once life appeared on Earth, at least, new systems (i.e., living organisms) began to appear much more quickly due to their inheritable and alterable genetic material.

Admittedly, the foregoing is a brief description of Aunger's significantly more profound proposal. Although Aunger's schema for big history periodization is subject to criticism (e.g., many systems of the "material era" are not driven by nuclear fusion, and arguably many important "epochal" events during Earth's history are ignored), his general approach has great merit. Like geologic time scales, he not only has different resolutions of time durations as indicated by his eons, eras, and periods, but he also strives to be rigorous and consistent in defining and applying his criteria.

Theodore Modis, a physicist and futurist, periodized big history by collating important events from 12 different sources to arrive at his list of 25 major "milestones" (2002). He also assumes that each of these milestones has similar importance and plotted them on a semi-logarithmic graph to demonstrate what appears to be a geometric rate of progression of complexity across the expanse of time. This is similar to the events constructed by Panov (2019). He also analyzed the apparent dynamics of evolutionary change to argue that the overall rate of complexity progression had embedded "S" shaped logistic curves that portended a slower rate of complexity progression in the near future, rather than the increasingly vertical curve predicted by the futurist, Ray Kurzweil (2005), of "technological singularity" fame. Regardless of the paper's primary intent to demonstrate the logistic progression of complexity, his collated milestones periodize big history in yet another manner.

David LePoire (2015, 2023) concurs with Modis' that complexity progression's dynamics follows a modified logistic curve. To determine a key new complexity progression, he considers not only a consensus of other authors in this area of research, but also their increase in rates of energy flows, informational processing, and organizational stages (an" integrative approach"). His "cumulative learning acceleration" schema includes 17 historical events, and like Aunger and the "geologic time scale," (see below) he also believes that it is desirable to have different resolutions of time periodization.

The numbering of new major events in the range of 20-30 seems to be a common occurrence. The biophysicist Harold Morowitz lists 28 new emergent events (an equivalent to the progression of complexity) in his book, *The Emergence of Everything* (Morowitz, 2002). Similar to Christian's "thresholds," Morowitz focuses on the intuitive importance of a new emergent phenomenon itself rather than looking for a deeper underlying thermodynamic, evolutionary, or other mechanistic thread.

Volk (2017) cites 12 hierarchical evolutionary "levels" that have been attained over the expanse of time. Like many other authors cited in this paper, his primary intent is to explain a major mechanism that drives evolution: the combi-

Approx Time	Cumulative Learning Acceleration	Christian (2014) "Thresholds"	Aunger (2007) "Eons/Eras/Periods"	Modis (2002) "Milestones"	Morowitz (2002)	Chaisson (1996) "Epochs"	Volk (2017) "Levels"	ICS Geologic Time Scale (2022) "Eons/Eras/Periods/ Epochs
13.8 BYA	Cosmic/ BB	Universe (1)	Cosmological/ Material/ Atomic	Big Bang(1)	Primordium(1)	Particulate (Chaos, Hadron, Lepton, Nuclear, Atom) [Radiation]	Fundamental Quanta(1), Nucleons(2), Atomic Nuclei(3),	Early Universe
	Cosmic/ structure	Stars(2)/ Elements(3) Sun(4)	Stellar Galaxy	Origin of the Mily Way(2)	Large-Scale Structure (2),Stars(3), Elements(4), Solar system(5), Planets(6), Geosphere(7)	Galactic, Stellar, Planetary [Matter]	Atoms(4)	Stelliferous Era (1MY from BB)
5 BYA	Life/ Chem & Prokayotes	Life (5)	Terrestrial/ Biological/Cell	Origin of Life(3)	Biosphere(8), Prokaryotes (9)	Chemical, Biological [Life]	Molecules(5) Prokaryotes(6)	HADEON(4.6BYA) ARCHEON (2.8BYA)
1.5 BYA	Life/ Eukaryotes		Complex Cell	Eukaryotes	Eukaryotes(10)		Eukaryotes(7)	PROTEROZOIC (2.5-0.539 BYA)
500 MYA	Life/ Multicellular		Multicell	Multicellular Life(5) Cambrian explosion(6)	multicellularity (11) neurons (12), bilateral(13), vertebrate(14), fish(15)		Multicellular(8)	PALEOZOIC , MESOZOIC [Triasic (251MYA) Jurasic (201MYA)
150 MYA	Life/ Land			First Mammals(7) First Flowering Plants(8)	Amphibians (16), Reptiles(17)			Cretaceous(145MYA)]
50 MYA	Life/ Mammals			Asteroid Collision(9) First Hominids(10)	Mammals(18)		Animal Social Groups(9)	CENOZOIC [Paleogene(66MYA)
15MYA	Life/ Primates		Tool	First Orangutans(11)	Arboreal mammals(19), primates(20), Great Apes(21)			Miocene(23MYA)
5MYA	Humans/ Bipedal	Hominines, Humans(6)	Fire	Chimps & Humans Diverge/ Bipedalism (12)	Hominids(22)			Pliocene(5.3MYA) {Lower Paleolithic}
1.5 MYA	Humans/ Tools			Stone Tools/ Language(13)	Toolmakers(23)			Pleistocene(2.6MYA) {Middle Paleolithic}
500 KYA	Humans/ Fire			Homo Sapiens (14) Fire(15) Human DNA types(16)				
150 KYA	Humans/ Language		Neanderthal Culture Revolustion(11) from 150 KYA	Modern Humans (17)	Language(24)	Cultural	Tribal Metagroups(10)	
50 KYA	Humans/ Migration		Upper Paleolithic(12) from 40KYA	Rock Art(18)				{Upper Paleolithic}
15 KYA	Humans/ Agriculture	Agriculture (7)	Neolithic Revolution(13) 12-9 KYA	Agriculture(19) Techniques for starting Fire / First Cities(20)	Agriculture (25)		Agrovillages(11)	Holocene Mesolithic Neolithic Copper Age
5 KYA	Civ/ Ancient & Classical	Cities (7.25)	Ancient Urban Revolution (14) from 6-5KYA; Imperial Antiquity, Iron Age, Axial Age(15) from 2.800-2.500 KYA	Wheel/Writing (21) Democracy(22)	Technology and Urbanization(26), Philosophy(27)		Geopolitical States(12)	Ancient & Classical History (Bronze & Iron Age)
1.5 KYA	Civ/ Trade		Middle Ages(16)	Zero and Decimals(23)				Middle Ages
500 YA	Civ/ Commercial	Brink (7.5)	Modern Period (17)	Renaissance & press(24)				Early Modern
150 YA	Civ/ Industrial	Modernity (8)	Industrial Revolution(18)	Industrial Revolution(25) Modern Physics(26)				Late Modern
50 YA	Civ/ Information	Anthropocene (8.25)	Information Revolution (19)	DNA, Transistor, nuclear energy (27) Internet, human genome (28)				(Anthropocence) {Contemporary}
	Future Cone	Future(9)		Predicted slow down	Spiritual(28)			

Table 1. *Comparison of major events or periods in various big history frameworks.*

nation of an ever greater number and hierarchy of components to arrive at larger, more complex systems. Hence, the Big Bang begins materially with the formation of quarks. Quarks combine to make nucleons, nucleons combine to form atomic nuclei, and so on to arrive eventually to living cells and even later to our contemporary geopolitical states. Volk's primary aim does not appear to be to periodize big history, which is true of many authors in this area, but rather to primarily explain an important facet of evolutionary mechanics.

The international geologic time scale (GTS) standards are set and maintained by the International Commission on Stratigraphy – a standing committee in the International Union of Geological Sciences (IUGS). Table 1 includes a greatly condensed version of their complete chart (International Commission on Stratigraphy, 2023; Cohen, 2013). Importantly, GTS is actively "maintained" or updated periodically by this committee as the relevant sciences make new discoveries that can alter the timing or explanation of relevant events. To its credit nearly everyone interested in a discipline that involves deep geologic time is familiar with GTS. Even young children who love dinosaurs might tell you that dinosaurs lived during the Mesozoic era, or at least be familiar with the movie called "Jurassic Park." Like Aunger's and LePoire's schemata, time is divided by different gradations with the addition of "epochs'' and sometimes, "ages." At present, we are in the Phanerozoic eon, Cenozoic era, Quaternary period, Holocene epoch, and Meghalayan age (Geological Society of America, 2023). Some geologists and others argue that we have recently left the Holocene era and entered the "Anthropocene" epoch (Crutzen & Stoermer, 2000).

GTS is not concerned with citing significant progressions in the complexity of systems, although correlations often occur. Instead, GTS divides time periods according to different geological and paleontological events that have occurred as evidenced by changes that can be detected in Earth's rock layers or strata. Those changes can be indicated by differences in rock qualities (lithology), magnetism, and embedded fossils. For example, the Cretaceous period ended, and the Tertiary period began when a large asteroid struck Earth and left a layer of Iridium in rock strata around the globe. As a correlation, dinosaur fossils are no longer present in rock strata after the Cretaceous period as well. Of course, GTS does not and cannot be extended to time periods before the formation of Earth.

4 How Should We Periodize Big History (broadly considered)?

The foregoing noncomprehensive list of formal and informal big history divisions of time strongly suggests that it is unlikely that there will be only one reasonable periodization scheme. Differences in perspectives, goals, metrics, and other factors will in turn make varying ways to divide big history reasonable and even necessary for the task at hand. Nevertheless, it would be desirable to have one periodization scheme for one large group of people and purpose: the teaching or review of big history for the layperson and undergraduate audience. Having general consistency for those with an initial or more casual interest in big history would be desirable so that we make teaching and learning it more coherent, lessen confusion should the interested person consult different sources, and even facilitate communication amongst big history's more dedicated scholars. The actual work of developing such a periodization scheme would be best accomplished by a "working group" of big historians from several nations and disciplines to better ensure that different perspectives are included in the scheme. Furthermore, any such scheme, like GTS, would be considered a "work in progress" that should be periodically updated to include new findings as the sciences and humanities advance.

Regardless of which periodization schemes might eventually be created, the following factors should be considered during its development:

- As with GTS and Aunger's proposal (2007), there should be **different levels of resolution** such as "eons," "eras," and "periods" and the like. Varying the resolution better allows us to accommodate the fact that after the momentous Big Bang, changes and variations in processes and systems occurred slowly for the first 10 billion years. However, once life began on Earth, as David Christian, Ray Kurzweil (the futurist) and many others have observed, changes have subsequently occurred ever more quickly. Indeed, even GST's time duration of "ages," which lasts a few thousand years, does not have the resolution needed to demarcate the substantial change that has occurred on Earth contemporaneously due to our rapid rate of cultural and technological innovations.

- It is likely that periodization will be based on **some aspect(s) of increasing complexity**. Christian, Chaisson, Spier, and most other big historians have all noted implicitly or explicitly that the increase in complexity of systems over time is big history's most intriguing overarching theme. The increase in complexity to the level of "life," even if it occurred in only one miniscule corner of the universe, is also the most intriguing phenomenon that spans time. Other varied, but yet somehow coherent phenomena that span the breadth of time since the Big Bang might exist, but none seem to have generated the level of interest as provoked by increasing complexity. The interest is due at least in great part because complexity offers a rich fount of inquiry with its multidisciplinary roots in thermodynamics, information theory, general systems theory, and, of course, complexity science to name a few. With a broad, but still reasonable conceptual characterization, complexity can also span the disciplines from cosmology and physics to history and sociology. Adoption of increasing complexity by big history for periodization would also set it apart from geologic time scales that use a variety of terrestrial events to demarcate time rather than a deeper, binding universal theme. Of note, traditional history lacks any widely agreed upon method of periodization that spans its past approximately 5,000 years.
- Spier's contention that complexity does not just progress, but also declines should be noted. However, the apparent surprisingly nearly perfect geometric rise in complexity since the Big Bang has been noted by several disparate authors (LePoire) despite decreases in local complexity (e.g., viruses devolving from bacteria, the Greek "dark age") and mass extinction events. Of note, after each mass extinction event, renewed diversification occurred relatively quickly from surviving species, some of which (fortunately) were as complex or nearly as complex as any that preceded these cataclysmic events (Jablonski, 1994; Kaplan 2016). For example, the Cretaceous-Tertiary (a.k.a., Cretaceous-Paleogene) extinction event witnessed the loss of about 75% of all species on Earth (Jablonski, 1994). Within 3-5 million years, however, the number of species is believed to have recovered to that which preceded it - a brief time in geologic terms (Renne, 2013; Kaplan 2016). Furthermore, birds and mammals were equivalent or near equivalent to even the most complex dinosaurs, so that the "thread" of the central nervous system's advancing complexity remained intact.
- Aunger's big history periodization proposal is based on examining different aspects of system energy flows. More important than what he attempted to base periodization on, was his attempt to be consistent and rigorous in its application. Besides energy sources or energy flows (Chaisson, 2001; Niele, 2005; Fox, 1988; Smil, 2010), other candidates for being markers for periodization include the appearance of new emergent phenomena (Kauffman, 1995; Christian, 2011; Morowicz, 2002), information processing, storage, or transmission (e.g., Sagan, 1977; Kurzweil, 2005), organization (Gunderson & Holling, 2002; Volk, 2017), and an integration of the above (Jantsch, 1980). Admittedly, these and other authors who describe a variety of changes or dynamics of change, are not usually attempting to periodize big history as their primary or even secondary goal. Still, their analyses offer a variety of other potential ways to demarcate periods of time.
- **Clear definitions or characterizations** of key terms need to be given to minimize ambiguity and confusion. This goal often requires more than a "cut and paste" from a dictionary because some terms like "energy" and "time" are so fundamental that their more basic nature is still actively debated even in theoretical physics. Others like "complexity" and "life" are perhaps best defined by a list of characteristics rather than a seminal core feature. The definition and nature of terms like "emergence" and "consciousness" are debated actively in both science and philosophy with

> no consensus regarding how the terms should be fully understood. Despite these challenges, a periodization schema should be accompanied by the best and most relevant definition or characterization that we can formulate.

Opining further on how to periodize big history could be interpreted as usurpation of a task that would be better undertaken by a qualified working group, preferably under the auspices of IBHA. Nevertheless, it might be worthwhile to anticipate some of the other challenges that anyone or any group will face when working to periodize big history.

5 Some Other Challenges to Periodizing Big History

Indeterminacy**.** It seems that you only need to pick up the latest National Geographic or any science magazine that covers the latest in paleoanthropology to learn that the dates and branches of hominid evolution have been changed yet again – usually with origin dates being pushed back further in time, or another species being identified. Hence, many time periods that are defined by dynamic areas of inquiry like human evolution will need to be adjusted. This challenge can be easily addressed by simply noting that periodization is a "work in progress" as it is with GTS.

A few temporal demarcations lend themselves to ready consensus amongst big historians as well as a more definitive time period for their occurrence – at least relative to the time scales of the period in question. For about a decade now, the Big Bang dates to 13.8 billion years ago – perhaps *the* seminal event in big history, which astrophysicists state unfolded over seconds to a few minutes. Future discoveries might alter the date or make its occurrence more and more precise – as of 2018, the date was set at 13.787 +/- 0.020 billion years ago (Planck Collaboration 2020). A similar argument can be made for the end of the Cretaceous period, which concluded with the rapid strike of a massive asteroid 66.043 +/- 0.011 years ago (Renne et al., 2013).

Many, if not most seminal big history "events," however, are actually prolonged processes as Spier pointed out (Spier, 2022). Deciding which date should be chosen for periodization purposes is not immediately clear for many events that would be candidates for demarcating time periods. The origination of "humans" provides a salient example as will be discussed below. The same kind of challenge will be present regarding the onset of multicellular life (e.g., differentiated versus undifferentiated multicellular organisms), or the appearance of "consciousness" – at face value a truly remarkable development in big history even if it is not typically acknowledged with a few exceptions like Henriques et al's "Tree of Knowledge" schema (Henriques et al., 2019).

Perspective(s)? Deciding on a single definitive schema for periodization will also be difficult because different disciplines and researchers with different purposes will likely base a schema on different criteria. For example, someone teaching big history at a non-graduate level especially, or writing for a mass audience, will likely want to avoid abstractive criteria like free energy flow rates or negative entropy (~syntactical information), and base periodization criteria on more easily understood and memorized criteria like major "interesting" events. Although conjectural on our part, perhaps this was Christian's primary motivation in creating his particular "thresholds" for big history.

Those who study and research big history and other related disciplines, however, will likely desire some binding thread for major event through cosmic time to determine if there is a discernible pattern, and if so, what factor(s) might be responsible for that pattern. A physicist might wish to focus on complexities' free energy flow rates which they not only well understand but can also often be quantitatively measured or at least approximated (Chaisson), a biologist might prefer one based on information content and transmission because DNA provides a glaring example of information's role in biotic system diversification and progression. The traditional historian might prefer a schemata that focuses on events for the "simple" sake of their glaring importance. This option might have more merit than it first seems. Schemas that rely on complexity progression due first and foremost to some aspect of information or organization, might diminish the role of aerobic metabolism, control of fire, or even agriculture. Each of these "events" are arguably most important primarily for increasing the availability of energy. Conversely, if events are chosen because of novel energy sources or increase in energy flow rates, a schema might then ignore the origination of multicellular organisms (organization primary) or grammatical language (information primary).

Differences in the desired focus due to varied purposes or disciplinary backgrounds can be viewed as perspectives occurring across a horizontal plane. Another orientation is "levels of abstraction" (LOA's) that looks at perspectives on a vertical plane with low levels of abstractions being more detailed and higher levels being less detailed but more of something's entirety. There is no set number of levels of

LOA for any one issue. If we look just at the LOA's of a living organism, we can readily (and coarsely) discern 5 or more LOA's according to a few relevant scientific disciplines: from lowest to highest LOA we can proceed to examine its: physics, chemistry, physiology, general biology, on "up" to the study of the organism or class of organisms itself (e.g. ornithology).

6 Examples of Analyses for Choosing Events for Big History Periodization

We offer three events below that would likely serve as markers for big history periodization, and some of the reasons that might or might not be relevant to them being chosen by those who might undertake such a project. Admittedly, we are choosing events that demonstrate a new, significant emergent phenomenon or progression in complexity, with the caveat that such changes likely have occurred elsewhere in the cosmos before they did on Earth. We are also not carefully defining terms below, but a "common sense" understanding of them will work for these brief illustrations.

<u>The Origin of Life</u>**.** Life began ~ 3.7 billion years ago (Bya) (Ricardo, 2009) . The date is likely to have a high confidence level (+/- 3%) because the preceding Hadean eon made life unlikely due to frequent meteorite bombardment which made Earth inhospitable. The details of how life began remains a mystery. Nevertheless, it is likely to be a major and widely recognized event that will separate, , a "prebiotic" and "postbiotic" epoch because the onset of life demonstrates an entire new host of changes compared to the physics, chemistry and range of the purely "physical" phenomena that preceded it. For example, as Chaisson points out, the free energy rate density (FERD) increased through living systems compared to "stable" physical systems like stars. Living systems also derive their energy from metabolism, and ultimately from high energy ATP molecular bonds rather than gravitation, radiation, and nuclear fusion. Authors who are proponents of an information theory approach, however, would point out that living systems contain the information required for their formation, sustenance, reproduction, and variation in their genome which is typically composed of DNA molecules. Those in favor of a hierarchy of combinations approach would likely favor analysis that explains how the organic molecules constitute these systems instead of the non-organic molecules, atoms, and ions that predominate in the structures of preceding physical systems. Finally, but certainly not comprehensively, a biologist might be most impressed with life's extensive and varied evolutionary potential while a philosopher might note the beginnings of "agency," (e.g., an entity that has purposes and identity).

All these and other profoundly new and emergent phenomena will likely prompt anyone deciding on a periodization schema to consider making it a major demarcation, or the equivalent of GTS's "eon" – their broadest time scale. Furthermore, the date of life's origination Earth is not likely to change to any significant degree which makes it reliable temporally as well.

<u>The Origin of "Humans."</u> If the origin of life is Earth-centric, then demarcating the origin of humans would obviously make big history periodization anthropocentric. Besides self-interest, a periodization schema that shifts to being anthropocentric is arguably warranted for several other reasons. From a thermodynamics perspective, humans have likely used a greater amount of energy per unit mass (and simultaneously created more entropy) than any other species, especially once we began to use fire (Niele, 2005). The continued increase in FERD of the modern era in turn dwarves that of our primitive fire toting ancestors to a remarkable degree.

From an information perspective, humans convey more information across space (e.g. via speech, music, mass media, the internet), and across time by oral traditions, rock art, books, and now many forms of electronic media. These abilities prompted David Christian to note that "collective learning" vaulted our species beyond others that were sharper of tooth and law, faster, stronger, or otherwise could have eaten us more than we eat them. More profoundly we process information in a way that no other known organism does with a high degree of self and other-awareness, abstract thought, art, future projections, and so on. Notably, we have also extended our information gathering abilities by microscopes, telescopes, sound amplifiers, x-rays, and the "large hadron collider" at CERN. In short, we have mastered more aspects of information than any other living organisms by many degrees of magnitude. This ability in turn has led us, for better and for worse, to (perhaps temporarily) dominate this planet.

Other justifications for the relevance of human origins being worth consideration for periodization include our ability to create composite tools and machines, abstract based interconnected social groups like "nations," religions, or ideology, and our marked adaptability to different environments and circumstances. Hence, it seems to be easy to objectively cite many reasons for our origins to be worthy of note in any periodization schema.

The imposing challenge, however, is fixing a date for our emergence. As Spier pointed out, human origination is actually the result of a prolonged process perhaps spanning millions of years rather than an actual event. The following are just a few candidates that might vie for the date for the origin of "humans" (Handwerk 2021)– a term which needs to be more precisely defined itself, i.e., ~hominin, hominid? *Homo habilis* onwards? *H. erectus* onwards*? H. sapiens? H. sapiens sapiens?*

- 7 million years ago (mya) – Proconsul last common ancestor between great apes and humans (White et al., 2009)
- 3.9 mya – Australopithecus afarensis the first hominid to walk upright (McNutt, 2021). The unique combination of having free dexterous hands due to an upright gait, and possibly being social might have been what was needed to begin the evolution of our large brains. Also, it was once believed that stone tool use did not begin until Homo habilis arrived about 2 mya. More recent discoveries, however, date to 3.3 mya (Krier, 2023). Therefore, the potential for dexterity might have been exercised by the earlier A. afarensis. This last point also demonstrates the lability in dating many paleoanthropological "firsts."
- 0.4 -1.6 mya – the first purposeful use of fire, usually attributed to H. erectus (Dance, 2017). The former date is more certain at this time, but some evidence supports ever earlier dates (Cowie, 2020) which exemplifies the frequent discoveries, and associated controversies in the field of paleoanthropology.
- 0.2-0.3 mya – the origination of archaic H. sapiens. H. sapiens might have been morphologically indistinguishable from later human beings, but is this our cardinal feature (Callaway, 2017)?
- 40-77,000 years ago – the beginning of abstract thought. H. sapiens were fully anatomically modern by about 100 thousand years ago (kya). Cave art depicting abstract representations of the world were drawn by about 40 kya which was the first proposed date for the origin of abstract thought (Marchant, 2016). Later discoveries in South Africa, however, indicate that it might have begun much closer to the time when our species became morphologically indistinguishable from contemporary human beings.

Other dates might certainly be considered as candidates for the origin of humans. However, the point is that it will likely be challenging for any one person or any group of people to settle on both a characteristic and a date that cemented our origin.

<u>The "Anthropocene"</u> Biologist Eugene Stoermer and chemist Paul Crutzen coined the term "Anthropocene" (Crutzen & Stoermer, 2000) to "describe the most recent period in Earth's history when human activity started to have a significant impact on the planet's climate and ecosystems". While noting that this time period has not been officially recognized by the IUGS, several different demarcations for its onset (and the end of the Holocene) have been proposed: 1. The onset of industrialization about 1750-1800, which would coincide with Christian's proposal that it also marks the beginning of the modern age, 2. The detonation of the first atomic bombs in 1945, and 3. In 1950 when "The Great Acceleration" began (when human activity affecting the Earth greatly increased). Each of these candidates would likely leave a change in global rock strata that could be detected by hypothetical future geologists – to be consistent with GTS criterion.

If big history were to adopt the idea of the Anthropocene, even if not the term itself, determining a fairly exact demarcation date might not pose a great challenge (once a criterium was proposed) because our records of recent history are extensive (Stromberg, 2013). Similarly, we would likely be able to discern the core process(es) that prompted the change, such as the increase in burning of coal that left its soot, the dropping of a bomb that left new radioactive isotopes, or the manufacture of "forever chemicals."

A bigger challenge might be in remaining consistent with prior periodization nomenclature and criteria standards. For example, if we decided that informational aspects were most relevant to a periodization schema, then it might be more important to cite 1948, when both information theory and the transistor were developed. If new combinations of more fundamental "components" are determined to be the binding thread, then perhaps the rise of nation-states in the 1800's or the founding of the United Nations in 1945. (Note the repeated citing for the mid to late 1940's!) The richness of changes that coincide with the Anthropocene will likely make it easy to make its inclusion in a periodization schema both rigorous and consistent. The bigger problem might be in choosing *which* event or process makes periodization in recent times most worthy of being a new age by future big historians who might eschew our choices in favor of another event whose future portent "we did not see coming."

7 "Selling It"

Even a "job well done" is no guarantee of success. For example, Robert Aunger's work (2007) is arguably one of the most careful efforts at big history periodization developed thus far. He also bases his schema on aspects of thermodynamics which is favored by some big history notables like Eric Chaisson and Fred Spier. Nevertheless, his work is not cited by these authors to our knowledge, and his approach does not seem to be well-known in big history circles. Hence, another reason to periodize big history by an IBHA working group is that it would subsequently likely be known by more big historians. Whether it is subsequently accepted and used, however, will depend on how well it meets the objectives noted above and likely several other factors as well. Certainly, the wide acceptance of geologic time scales by multiple disciplines concerned with terrestrial deep time, and some familiarity by even the public (e.g., the movie "*Jurassic* Park") would indeed be a lofty goal for us to achieve.

8 Conclusion

David Christian deserves tremendous credit, not just for founding contemporary big history as a formal area of study, but also for promoting - even if others have preceded him at times - some of its key concepts like increasing complexity, collective learning, and others. Several of Fred Spier's objections to Christian's "thresholds" for the periodization of big history have merit as we discussed above and should be addressed by anyone seeking to periodize the vastness of the universe's time continuum. The propensity for humans to make divisions of "something" large ("chunking") before them should not be ignored even if many are content with leaving big history "whole." We also believe that it is not necessary to be strident in our criticisms of the work of any originator or other author that has good intent and diligence. If such a large project like big history "sprang forth fully formed like Minerva from the head of Jupiter," it would leave us with little to research, contemplate, or advance.

In that spirit, we have suggested a rough framework of possible criteria, along with a variety of challenges, to consider when formulating more rigorous periodization schemes for big history. Hopefully, the resulting schemes would be pragmatic and thought provoking for psychological, pedagogical, research, and even conversational concerns. Any such schema should be made amenable as the sciences and humanities make progress in their understanding of how, when, and why big history unfolded as it did. We suggest that the next step to take forward is for IBHA leadership to set the seeds for the formation of an international, multidisciplinary working group to develop and perhaps occasionally adjust a periodization scheme for the primary purpose of presenting a coherent and consistent way to better parse the expanse of big history for the general and undergraduate audience.

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Synthesizing Historical Research Leads to a Simple, Compatible, and Extensible Big History Framework and Periodization

David J. LePoire
Argonne National Laboratory

Correspondence | **David J. LePoire** david.lepoire@anl.gov
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Abstract: Many questions remain unanswered regarding how Big History events should be organized and interpreted. For example, should Big History be divided into periods or processes, when it is clearly a complex process of simultaneous interacting processes? In such an uncertain environment, how are models constructed and evaluated? When we look at Big History, at what level of abstraction do we start?

This paper gleans important insights from a number of historical papers to develop a consistent view of Big History. It is important to consider many aspects of an evolving system. For example, how does the evolving system 1) learn from its experiences in the environment; 2) extract energy and resources to combat the trend towards chaos and higher entropy; 3) organize itself at multiple levels to meet new challenges?

Various traditional scholarly disciplines contribute to various aspects of Big History, including astronomy, geology, evolutionary biology, evolutionary anthropology, and the history of civilizations. This suggests a base framework of cosmic and terrestrial phases. The terrestrial phase saw the sequential evolution of life, humans, and civilization. Based on this framework, the various disciplines' timelines are consolidated along with their dynamic systems models. This base framework is then expanded to include more details. This simple approach meets many criteria for an effective framework: it integrates with knowledge from other disciplines; it provides a simple, understandable model; it can be extended in detail with nested transitions; and it immediately expresses the acceleration of evolving complex adaptive systems (CAS). Similarly, proposed frameworks offer slightly different perspectives.

1 Introduction

Why should the timeline of Big History be divided (instead of presenting it as one continuous narrative)? One reason is the ability to teach the subject in discrete modules. This seems to be the reason for the Thresholds approach by emphasizing some better known events and exploring their prerequisites of ingredients and conditions along with a new ability to combine them to produce a higher complexity level with new emergent properties (Christian et al., 2014; Christian, 2011; Spier, 2015).

In addition, categorizing the long list of events into groups makes it easier to understand. Research purposes can also be served by categorizing aspects of Big History. For example, categorization might be based on the important mechanisms of complex adaptive systems (CAS, e.g., information, energy flow, organization, and relationship to the environment) over the long time periods of big history (LePoire, 2023). The evolutionary process might also show punctuation leading to periods of accelerated evolution rates.

It is more fundamental, however, to explore the structure of big history for clues to some underlying patterns that will illuminate common processes. It is this last goal that distinguishes big history from a simple compilation of findings from contributory fields. By addressing these questions, we advance the discussion of big history from what happened into how and why. Big history trends have been identified using a variety of measures, including the flow rates of free energy (Chaisson, 2001), changes in the universe's predominant physical form (Loeb, 2006), and advances in adaptation through learning (Sagan, 1977).

A number of questions remain regarding how to organize and interpret Big History events. Big History, for example, is clearly a complex process of simultaneous interacting processes, so should it be divided into time periods or processes? Under such uncertainty, how are models constructed and evaluated? What is the abstraction level at which we view Big History? Do we focus on the diversity of the system, its evolution, its ecology or its pathway to emergent higher complexity? Is it also important to consider the complexity of an organism's supporting environment, its history of development, or its evolutionary potential? Is it more important to consider what actually happened on Earth, what may have happened on Earth, or what might happen on other planets?

1.1 Goals considering Uncertainty

However, these questions need to be explored when there are large uncertainties. A number of factors contribute to these uncertainties, including: 1) the unresolved questions associated with major transitions (e.g., origin of life); 2) the continuous advancement of science (with refined definitions, interpretations, and completing hypotheses); 3) the simultaneous evolution of the environment and ecosystem; 4) the dispersed findings across many disciplines; and 5) the bias of people and research tools. It would be very difficult to construct major models that connect the systems throughout the evolution of big history even if all information had been recorded at an unlimited resolution. Furthermore, evaluating a model's validity is more difficult in historical sciences, e.g., Darwin's theory of evolution, compared to experimental sciences. Often, a first step is to show it provides a consistent interpretation of events, i.e., a proof of principle, which does not necessarily exclude other interpretations. The Darwinian theory of evolution illustrates the possibilities, however, in that evidence may be evaluated at various levels of abstraction to support or refute hypotheses. Combining imperfect data sets with Bayesian analysis is one way to weigh the evidence for various hypotheses. As discussed later in this paper, this Bayesian method seems to be an important evolutionary method.

Many of these issues are still being debated in each of the limited topics of physical, biological, human and civilizational evolution (Kampourakis & McCain, 2019). Big history is even more complex than any of these separate domains because it deals with these topics at a wider range of time scales, spatial scales, and units of analysis. In this article, some issues, expectations, and boundaries will be discussed, but no answers will be found to these questions.

1.2 At what level of abstraction?

To address these questions and issues, it is important to select an appropriate level of abstraction, such that it is not too detailed nor too broad. The level of information abstraction is a major concern with information interpretation. For example, DNA contains the information for all the proteins, cellular specialization, and the organism's development. However, while all the information is present in the linear sequence of nucleic acids, the abstract information about how the information combines with the cellular "decoder" is not evident. There are various layers of abstraction such as the genetic network, the effect of epigenetics, and the specification of development processes instead of specific instructions. Similarly, the extraction of abstract information and its semantic content is not easy as exemplified in recent attempts in artificial intelligence (Vasilescu, 2022).

An engineering example might help clarify some differences in abstraction level (LePoire, 1986). Consider the development of a new remote sensing tool. The groups that were interested include scientists to understand the meaning of the measurement, analysts to apply it to obtain valuable information, and tool designers to optimize performance. These groups developed model through computer simulations, correlations with experiments, and an approximate analogy to a simpler physical system. The computer simulation was useful to designers to optimize the tool for the realistic environment but did not help analysts nor scientists because the meaning and value of the information could not be ascertained. A correlation with measurements identified structural characteristics, which was important for analysts to extract valuable information, however, the scientist was not able to identify the underlying cause of the differences. Only when scientists identified an approximate dynamic characteristic was a simple physical model successfully constructed. While this model was helpful to scientists for understanding, it was not useful to designers and analysts since it was the least numerically accurate model. This shows that although full information might be accessible through detailed modeling, it can take great effort to construct meaningful and useful models. Each model might be useful in different circumstances.

The approach taken in this paper is to 1) gather relevant previous research, 2) develop criteria for forming a periodization and framework, 3) developing a synthesized framework, 4)comparing it to other proposed frameworks, and 5) discussing specific questions and interpretations for addressing big history.

2. Gathering Previous Research

Despite the fact that the term Big History was not used then, Erich Jantsch (1980) examined how energy, information, organization, environment, and evolution work in complex systems during both the physical cosmic development and also in life's evolution on planets like Earth. This evolution has been shaped by genetic life, epigenetic human evolution, and culturally based civilizations. Despite not explicitly stating it, these phases of evolution follow the traditions of astronomy, geology, biology, anthropology, and civilization history. These common disciplines are taught at all educational levels and therefor are widely understood by the public. Each of these high-level phases can be further refined by dividing them into a set of periods. These periods can be identified by examining the stages of growth, development, and evolution of these complex systems. A stage involves a complete cycle of complexity dynamics driven by their growth towards environmental capacity limits before collapsing, reorganizing, or finding new resources.

The next subsections will briefly review how others explored many of the aspects such as information, energy, organization, environment/limits, and evolutionary dynamics. Many of these aspects were identified by Jantsch, including the identification of information as the key aspect of evolution of evolution between terrestrial evolutionary phases, as was also articulated by Sagan (1977). This area of research continues to be fruitful as seen in the proposals of general evolutionary Bayesian models such as those of Friston (2010). Other aspects suggested by Jantsch were further explored, such as, the connection of energy flow and systems by Chaisson (2001); the combination principle of organization by Volk (2017), the interaction with the environment LePoire (2004) and the way evolution relates to individual development by Ekstig (1994). The investigations into the nature of the evolutionary acceleration mentioned by Jantsch was supported previously by von Neumann (Ulam, 1958), von Foerster (1960), Eigen (1971), and continued to be explored by Diakonov (1994), Modis (2002), Nazaretyan (2004), Panov (2005), and Snooks (2005).

<u>Information:</u> Sagan highlighted the importance of evolving information processing in the Dragon's of Eden book (1977). He estimated the growth of information capacity by DNA, brains, and books. Coren further advanced the role of information in evolution by demonstrating a geometric sequence of information innovations throughout evolution that is consistent with a singularity model (Solis & LePoire, 2020).

Understanding the role of information has evolved quite a bit over the years. One of the key integrating theories of evolution is Karl Friston's Free-Energy Principle (Friston, 2010; Azarian, 2022). Despite sounding like an energy perspective, it is primarily concerned with a complex adaptive system's (CAS, for example, a person) interaction with their local environments to learn, survive, and grow. Rather than acting passively, a CAS can conduct "experiments" by predicting (and sensing) environmental reactions to its actions. This drives active learning based on its internal model. When a surprise occurs, we can either alter the model to make it more compatible with reality or change the environment to make it more compatible with the model.

<u>Energy:</u> Several researchers have discussed energy extraction from the environment, storage, and use throughout evolution (Fox, 1988; Niele, 2005; Smil, 2010). However, Eric Chaisson (2001) focused on energy flow. In the course of evolution from galaxies, stars, planets, to forms of life and civilization, the energy flow density (W/kg) has increased. The system, however, had to be defined spatially and temporally in order to make these estimates. As an example, when a galaxy's black hole is active, energy flow through it can increase quite a bit. Based on these assumptions, galaxies are less complex than stars, which is contrary to a Big History textbook (Christian et al., 2014). Structure and dynamics of galaxies appear more complex with many interconnected pieces, though they are somewhat dynamically stable. There are several parts to a galaxy including the central black hole, the central bulge, arms, and a halo of dark matter.

The energy efficiency of natural and engineered systems differs as well. Computers require much more energy flow per mass and are not as complex as the human brain, which works with only 20W. Furthermore, by mitigating increasing entropy, the total energy flow (not just density) through an expanding system should increase as it evolves (LePoire, 2020).

<u>Organization:</u> Organizational change is another aspect of evolving complex adaptive systems. Many transitions occurred when previously independent entities merged, according to Volk (2017). Initially, this was due to the binding energies in the physical world. A combination of these entities (e.g., an electron and proton) would not be stable if the temperature exceeded the binding energy. In the course of expansion, the universe cooled, resulting in a sequence of merging. This occurred during the first five of the twelve steps identified by Volk, namely, fundamental quanta (e.g., quarks), nucleons, atomic nuclei, atoms,

and molecules. The four steps in biological evolution are simple (prokaryote cells), eukaryote cells, multicellular organisms, and social animal groups. Combination steps required previously independent entities to come together to achieve some environmental advantage. The most recent three steps focus on human civilization in terms of tribal groups, agro-villages, and geopolitical states. Again, the entities had to loosen their independence in order to reap the benefits of combining. Possibly this can be seen as a social cooling process, in which disagreements between groups are resolved enough to facilitate sharing common goals, such as economy of scales, a reduction of barriers, or defense.

Several ways were possible to combine the elements of the previous step to create the elements of the next step, resulting in diversity between steps. The combination of nucleons to form nuclei of elements is an example in the physical realm. It was then possible to combine the different elements to form many different molecules. These combinations undergo the evolutionary dynamics of reproduction, variation, and selection. Through this, they are able to explore new spaces in order to maintain the stability of the inherited information.

Information is clearly emphasized in this view of organization, but little is said about energy flow, environmental interactions, and challenges as the systems approach their limits. Apart from combining elements, systems can also develop complexity by growing and specializing. Animal organ evolution demonstrates this.

One information processing mechanism in social systems is the transfer of ideas between smaller systems that have reached their limits to larger systems that offer additional management for further development. One example of this can be seen in the series of leading capitalist countries, which change about once every century (LePoire, 2010). The new leading country had twice the population of the previous one at the time of the transition. Consequently, as capitalism grew, a larger population base was required to support the necessary evolving organizations.

Environment/Limits: The role of the environment is illustrated by the inverse relationship between sequential evolutionary objects and their environments (Jantsch, 1981). This relationship was extended to include modern technological civilizations (LePoire, 2004, 2020a). For example, as a result of gravitational instability, the tiny quantum fluctuations in the early universe later evolved into cosmic structures such as the cosmic web and eventually into galaxies.

Examples of this relationship continued in terrestrial evolution. These examples include single-celled organisms had to evolve aerobic respiration, as the buildup of oxygen in the planetary atmosphere was required for further evolution. A higher level of oxygen in the air allowed multicellular organisms to diffuse oxygen more easily. Also, at about 540 million years ago, the Cambrian Explosion, which occurred after about 88% of Earth's current age, brought about the dominance and diversification of multicellular organisms, which could compete in large ecosystems. Both humans and some of the tools that formed their evolving environment were similar in size during human evolution. However, as human societies grew in scope, their tools depended on technology that is more precise. For example, an environment of microchips are used to evolve a global system that exists today.

Evolutionary Dynamics: The great polymath John von Neumann had identified the acceleration of technological change in the 1950s (Ulam, 1958). Von Foerster (1960) identified evidence that global population was growing faster than exponentially. Kremer (1993) extended this concept into the past. In 1971, Eigen discovered that evolving systems might follow a hyperbolic trajectory. These growth patterns follow increasingly quicker exponential growth as the system adapts to its environment. A singularity trend was proposed by Modis (2002) and Panov (2005) as an explanation for cumulative learning acceleration. It is Panov's event set that comes closest to the extended Jantsch approach, due to the geometric factor of three that he discovered (independently with Snooks (2005)). Compared to the acceleration scheme with a factor of three across 19 events, Modis' list provides 28 events.

Although the difference between hyperbolic and exponential growth equations is small, it makes an enormous qualitative difference in the evolutionary process. A simple exponential growth, such as money collecting interest in a bank, will double in the same amount of time. The value of money invested with a 7% annual interest rate doubles every 10 years, for example. In the simple hyperbolic evolution model, however, progress begins very slowly. Even so, as it approaches a specific time, the singularity time, it accelerates rapidly. (For example, if a population doubles within ten years and then doubles again in half the time it took before, then the singularity time, when the population would become infinite, will only take 20 years from the beginning of the process.) Even though the trend suggests continued acceleration to ever-higher (indefinite) levels, due to finite resource limits, this growth pattern will shift to another. A delay between the growth and the impact of that growth, for example, increases the chances of the system overshooting and collapsing. There are, however, more optimistic scenarios in which growth is restrained before this condition is achieved.

A link was discovered by Ekstig (1994) between the time of an emergent feature's emergence and its expression in a developing organism. In general, the development of a characteristic follows the evolution of that characteristic. The range of characteristics includes animal tissue formation, humans' ability to walk and speak, and cultural learning levels such as reading, writing, and math. The results of this analysis later were incorporated into the identification of a super-exponential growth in complexity (Ekstig, 2012, 2015, 2017).

As discussed in Kay and Schneider (1994) and Azarian (2022), the second law of thermodynamics can be applied to the origin and evolution of life. Physical dissipative systems will self-organize when there is a gradient of entropy (e.g., temperature differences). The formation of Benard cells is a result of fluctuations around the normal conditions that lead to increased energy flows reducing this entropy gradient. In some environments, such as alkaline hydrothermal vents, this principle could even be taken further, suggesting that life originated to reduce entropy gradients (Lane, 2015).

3 Developing Criteria

There will be many ways to divide Big History into various period structures. In general, it would be nice to use what others have found in other disciplines so as to connect with their discoveries without having to reinvent some aspects of the time periods. Once the high-level stages are set based on traditional academic disciplines, further refined levels could be based on some CAS emergent properties as indicated by synchronous changes in energy flow, information/learning, organization, and interaction with the environment. Since there is so much uncertainty, it would be nice to have a simple model, perhaps based on some high-level concepts to interpret and integrate the disciplines. The model should be phenomenological such as the cumulative learning model combined with the panarchy model of system dynamics (Gunderson & Holling, 2002). This could identify some abstracted common processes that apply to all big history. Various measures can be made based on these components such as energy flow, information processing, organization, and interaction with the environment as well as dynamics that might be embedded in the development of new CAS based on the evolutionary steps. The criteria should address how the cosmic development and future might be incorporated into the terrestrial framework. The proposed frameworks should consider limitations but still provide some testable hypotheses at more refined levels to compare with other frameworks and the accumulating evidence. A proposed set of criteria is developed in Table 1 (next page).

4 Synthesizing Previous Research

This section will first introduce a summary of the synthesized framework and periodization scheme. Then this framework will be evaluated based on the criteria of the previous section. Finally, the periodization is compared to other proposed schemes.

4.1 Synthesis Summary

At this point, there have been two major phases of complexity development- the physical phase during cosmic development and the terrestrial phase encompassing the evolution of complex adaptive systems from the origin of life, the development of the biosphere, the evolution of intelligence, and the formation of civilizations. These two phases are quite different in their dynamics. The cosmic phase had a very quick succession of events immediately after the big bang, followed by slowing rates of change as the temperature cooled sue to expansion. However, the cooling led to gravitational clumping on multiple scales that returned high enough temperatures to reduce the nuclear energy potential to generate the heavier elements for formation of planets. On at least one planet, the Earth, the right conditions allowed the self-organizing effects of dissipative systems to form life. After that the complex adaptive systems

Complexity increased at an accelerating rate on earth through evolution of life, humans, and civilizations. The capacity and speed of each information mechanism has been increasing with subsequent phases, transitioning when the previous seems to reach its capacity. These new information mechanisms enabled the development of new complex structures and organization to capture more energy (e.g.,

Criteria	Description
Phenomenological Model	Is there some overall phenomenological model of why evolution to more complex systems arises but most stay simple
CAS Elements	What aspects of a complex Adaptive system does the framework address? Components, Life Cycle (development, ecosystem fit, evolution, reproduction)
List, hierarchical	What is the structure of the framework? Some examples might be lists, hierarchy (nested), major and minor events
Connection to traditional fields	Are traditional fields recognizable and used to help frame? Is there an elevator speech that someone could relate to?
Drivers	What conditions cause the new complexities?
Connection to previous BH research	Does the framework extend or address previous work by others?
Cosmic/Terrestrial split	How does the framework distinguish cosmic development versus agency in life development on Earth?
Handling on-going simpler ecosystems	Does the framework address how the rest of the system interacts with the progressively complex line?
Connections of large and small	Is there a connection between the large and small spatial scales, e.g., elements and stars?
Pattern	Is a pattern hypothesized with evidence (not proven)?
Measure	Is a measure (or combination for weight of evidence) proposed for further evidence?
Future	Does the framework extend various trends into the near (or less confidently, the far) future.
Limitations	How does the framework acknowledge and handle limitations?

Table 1. A set of proposed criteria to evaluate frameworks for periodization.

through photosynthesis). However, increased complexity requires greater energy flow to counteract the natural disordering tendencies (entropy). Balancing the increased energy flow and its wastes (e.g., heat) becomes more difficult. In return, new ways to address the wastes result from new information and organization. This continues the evolutionary process to the next growth phases. For example, multicellular organisms could develop organs that helped make the organism more energy efficient. However, a process was needed to collect and transport metabolic wastes. Eventually, this was solved with the combined respiration and circulatory systems including kidneys.

One interpretation of Big History is that three major evolutionary stages discussed before- life, humans, and civilization, formed the first half of such a transition. (The second half would be in the future.) This learning curve is a bit different as it is formed from many smaller transitions and also changes (learns) at an accelerating rate as it approaches the current time, near middle of the transition. These three major stages started at about 5 billion, 5 million, and 5 thousand years ago. (As mentioned before, while more precise times are known for the beginning of the universe at 13.8 billion years ago, and the formation of the Earth at 4.54 billion years ago, this paper works with geometric factors, so an approximation on a logarithmic scale is used.)

Each evolutionary stage developed over 6 (nested) steps with each subsequent step being about a third of the duration of the previous. These 6 steps then make the stage's geometric acceleration factor the sixth power of 3, which is about 1,000, as seen in the pattern of stages in Figure 2). Furthermore, the duration of the universe from the big bang to the present is approximately one step factor (3) larger than the history of the Earth. However, since this step is qualitatively different in that the evolution takes place through cooling and gravitational attraction rather than through evolution guided by natural selection, it is not really expected to be the same as the factor for the complex adaptive system evolution. The specifics of these stages are provided in previous papers (LePoire, 2015).

To gain a perspective on these factors, if the time values of the 3 major stages are plotted on a line (i.e., 5 billion 5 million, 5 thousand) with the line being 1 kilometer long which represents the age of Earth, then the development of humans would start at 1 meter from the end. All of written civilization history would occur in the last 1 millimeter. If the time between the Big Bang and Earth formation was added, the line would be about 3 kilometers. A human generation scale of 50 years would be 10 micrometers, less than the width of a hair.

4.2 Evaluating Criteria

Some of the criteria identified that should be constraining a periodization or framework include:

1. Consistency with previous research such as a) traditional fields, b) systems science, and c) big history
2. Structure cosmic/terrestrial split
3. Phenomenological models of complexity growth and dynamics
4. Connections between scales such as large and small big history objects
5. Handling quantitative measures, uncertainties, and limitations
6. Integrate potential future scenarios
7. Ability to identify research gaps

What follows is a self-evaluation of these criteria for an extended Jantsch framework. Clearly, there are differing opinions on the adequacy of these arguments for satisfying the criteria. These self-evaluations are provided to encourage continued discussion both on the criteria themselves and on their evaluation for specific proposed frameworks.

<u>Consistency with previous research in traditional fields (1a).</u> The structure of academic historical sciences might give some suggestions for the establishment of high-level periodization. Early courses covering big history topics might include the historical aspects from astronomy, biology, anthropology, and civilizations. Many of these fields are taught at the high school level. Note the beginning of each period is roughly 4.5 billion years ago for Earth formation (or 4 billion years ago for life), 4-7 million years ago for the split between the evolutionary branches that led to humans from the branch that led to chimpanzees, and 5 thousand years ago when "history" started with civilizations that had writing. That is the starting times (and also the durations) of these fields is roughly 5 billion, 5 million, and 5 thousand years ago. This is a geometric sequence that leads to a singular point in time. This means that someone with a simple familiarity of typical high school courses can immediately see the acceleration that is consistent with the more detailed global population data and the simple evolutionary model.

<u>Consistency with previous systems science research (1b).</u> Further lower level substeps can be identified based on complex adaptive system aspects such as emergence, energy flow, organization, environmental interactions, evolutionary dynamics, and information processing. No single measure seems to be sufficient to determine the complexity of one system relative to another. Even the definition of complexity seems to be fleeting (Holland, 2014). Both Panov and Snooks identified an accelerating factor of about 3. Panov found a value of 2.67± 0.15, a value close to e≈2.718, a factor suggested by Kaptiza (1997). This would have six substeps in each major step, since 3^6 is about 1,000 (the acceleration factor of the major steps described above). The 6-step pattern is also what was found in the development of fundamental physics. The factor of three is also the ratio of the initial growth rate to growth rate at the first bifurcation point in a complex system. An uncertainty in this factor can be made by determining the amount of change necessary to change the number of geometric periods by one. This leads to a value of 3.16± 0.22.

<u>Consistency with previous big history research (1c).</u> Each of these three major steps has a unique way to store and transmit information (through DNA, the human mind and language, writing and artifacts). The most debated part of this is the consideration of anthropology as a separate topic from life evolution or cultural evolution. Many researchers will talk about two mechanisms of genetic and cultural evolutionary mechanisms. Among the early pioneers that separated these into three groups were Sagan and Jantsch who focused on the changes in information processes. The human evolutionary period seems to be a mix of genetic evolution within an environment of increasing human control through the use of tools, fire, communication, and social collaboration. This phenomenon was

identified by Jantsch as epigenetics. Currently the terms are co-evolution and dual inheritance (Corning).

Structure of the cosmic/terrestrial split (2). Astronomy is the only discipline that does not directly involve life. Its historical development is quite different in the unfolding of small physical structures through cooling at first. Then the universe cooled down enough for large-scale structure formation through gravitational collapse and reigniting the nuclear potential in stars. Geology (International Commission on Stratigraphy, 2022) is a field that has aspects in each one including planetary formation, the interaction with life, the changing climate, and a place for resources for growth of civilization. Books often have a somewhat equal amount of information for each of these four stages. The age of the universe to that of the Earth is about 3 (13.7 billion years / 4.54 billion years) which is consistent with the terrestrial substep acceleration factor seen above.

Phenomenological models of complexity growth and dynamics (3). The dynamics of complex systems in big history might be separated into those dynamics that apply to general evolving systems and those that apply to integrated evolution within big history. Typical patterns in general complex adaptive systems include growth until limits are reached, which triggers exploration of the environment (Waldrop, 1992; Mitchell, 2009) and the release and reuse of materials to continue another cycle of self-organized growth (Perry, 1995), e.g., the panarchy model (Gunderson & Holling, 2002). Often the evolution of such systems is based on levels of organization with modules being replaceable (Kauffman, 1995; Holland, 2014). When environmental limits are reached, there are negative marginal benefits of additional complexity (Tainter, 1996).

As mentioned before, John von Neumann, expressed in the 1950's that the rate of technology change was faster than exponential and it seemed to be on a path to a singular time in the future where it would be infinite if no limitations were encountered (Ulam, 1958). This singularity theme in global population growth was identified by von Foerster (1960), who predicted the singularity time would occur in 2026, if the trend continued. Again, this assumed no limitations being encountered, which he knew was not true. In fact, this singularity global population trend started showing deviations in the mid 1970's as the growth rate slowed. A singularity trend is not as usual in natural sciences as exponential or logistic growth. However, the fact that simple evolution models of improvement over time, naturally lead to a singularity trend, was found by Nobel Prize winner Manfred Eigen in the mid 1970's. This combination of simple model and its measured reality in the evolution of humans with technology make this an empirically tested phenomenological model. A general model of global growth were developed (Korotayev et al., 2006). The straightforward idea is that the growth constant of an exponential trend changes with time and is based on the accumulated knowledge up to that time, i.e., $dy/dt = k(y)\ y = c\ y\ y = c\ y^2$. This is a formulation of the cumulative (or collective) learning happening throughout the evolutionary history on Earth. This sequence will come to a specific time where this hyperbolic growth pattern is not defined.

Connections between scales such as large and small big history objects (4). Some of the major patterns discovered when analyzing the relationship of large and small units in big history include the Evolution-Development relationship of Ekstig (1994), the relationship between evolving units and its environment by Jantsch (1980), the connection of a few physical parameters to the sizes of big history objects from the atom to the universe (Carr & Rees, 1979; Press & Lightman, 1983).

Handling quantitative measures, uncertainties, and limitations (5). As mentioned before there were many approaches from the various aspects of complex adaptive systems such as energy, information, organization, environment, and dynamics. Jantsch (1980) and Aunger (2007) treated them at the same time. Aunger's non-equilibrium steady-state transitions (NESST) approach satisfies this condition of looking at a consistent combination of the various CAS aspects. The framework is extensible through adding nested levels, as evidence justifies. The framework is also flexible because it defines large phases, which have durations (not just event times). The phases can be defined by the beginning and end of transitions (as it is here) or by shifting perspective to the midpoint of the transitions (similar to the TOK/Combogenesis model of Henriques & Volk). The framework phases differ from the traditional periodization of geology and history, but this is expected for such a simple model with highly uncertain data. This allows for further discussion to refine or explain these differences.

Integrate potential future scenarios (6). The framework might also contain trends to extrapolate into potential future scenarios. Some complex systems demonstrate complexity reversal after reaching some environmental limits

(Stone, 1993). Panov (2020) considers the implications of a singularity growth trend for the development of life in the galaxy. LePoire (2019) considers various patterns that might continue after the trend to a singularity breaks down. The idea of a long-term modified logistic pattern, e.g., a cone is explored. Some have speculated that life is not just a fluke in the universe but rather an important determinant in organizing energy and information to form greater complex organization (Azarian, 2022).

Ability to identify research gaps (7) The framework is consistent with a high-level view of big history's integrated evolution, however, there are many remaining issues. Having a framework can help identify these. For example, in the discussion section of this paper some events that seem to be different are explored. These include how the cosmic phase fits in, why life seemed to originate so fast on Earth, and why human evolution was a combination of genetic and cultural influences. As pointed out in another paper in this issue (Solis & LePoire, 2023) there is much work to be done in grounding the event phases in more quantitative evidence such as overall energy flow and emergent properties.

4.3 Comparison to other frameworks

Some comparisons might lead to insights for periodization (Solis & LePoire 2023). Previous comparisons of different event lists have been analyzed by Aunger (2007) and Vidal (2014). The structure of the time periods can also be compared with the traditional time scales of geologic and historical periods. Selected geologic, human prehistory, and history periods seem to reasonably match with the extended Jantsch framework, which incorporate cumulative learning acceleration periods towards a singularity. The geologic periods (from various levels) covers Earth's history up to the split of the branches that led to humans and chimpanzees. The human prehistory timeline covers from that point forward to the formation of historical civilizations. The historical timeline covers the remaining time. This correspondence of traditional discipline timeline periods and the extended Jantsch framework is shown in Table 2.

To go from the Big Bang to a timescale of a human life (50 years) there are 17 steps expected ($\log_3$ (Age of Universe/Human lifetime)). Modis and Panov proposed sets of events, which led to an interpretation of the cumulative learning acceleration (i.e., a singularity trend). Panov's is the closest to the extended Jantsch approach since he worked with a geometric factor of 3 which he discovered (independently along with Snooks). There are only two of additional events from Panov (during the control of fire by humans, and the division of the ancient/classical civilization period). Modis' list contains 28 events, which is 9 more than the acceleration scheme with a factor of 3. Note that the periods in Table 2 are labeled by the processes that occurred in that period and not just by the specific events at the beginning of the period.

This periodization is also consistent with the Thresholds, Tree of Knowledge/ Combogenesis, and Grinin models (Figure 1). The threshold approach has more detail in the cosmic phase and one additional threshold for the modern era and a mini-threshold brink at the formation of civilizations. Otherwise, the thresholds of life, hominids, and agriculture is consistently aligned with the extended Jantsch model. This points to the need to further develop a separate perspective (in the extended Jantsch framework) during the cosmic phase where the rate of events slowed down over time due to cooling of the universe.

The combined Tree of Knowledge and Combogenesis frameworks of Henriques (2019) and Volk (2017) (respectively) demonstrates their focus on the periods of most rapid change, e.g., at the inflection point of transitions. This includes the Big Bang, the origin of life on Earth, the development of animal brains, the development of human culture, and the development of enlightened and scientific understanding. This notes that during the cosmic phase the rapid changes occurred during the beginning and end, i.e., the big bang, followed by a long duration of structural and chemical change with the development of galaxies and stars, then leading to the relatively quick formation of planets from later generation stellar formation and the surprisingly quick development of life on one of those planets (Earth).

The Grinin and Grinin (2021) production principle timeline identifies 4 stages of production principle of hunter-gatherers, craft-agrarian, trade-industrial, and scientific-cybernetic. Each stage has 6 life cycle phases as it matures and is eventually replaced. Of these four, the craft-agrarian is most misaligned with the extended Jantsch framework. The craft-agrarian stage covers the period from about 10,000 years ago to 600 years ago, whereas the extended Jantsch framework has about 3 stages during this period- the pre-civilization agricultural, ancient/classical

Extended Jantsch Framework	Geologic and Historical Named Periods
Simple cellular (prokaryotic life)	Hadean and Archean Eras
Complex cellular (eukaryotic life)	Proterozoic Era
Multicellular organisms	Paleozoic Era
Land/reptiles	Mesozoic Era
Mammals	Cenozoic Era / Paleogene Period
Early hominoid evolution	Cenozoic Era/ Neogene Period
Bipedal	Lower Paleolithic
Tools	
Fire / Modern Humans	Middle Paleolithic
Modern Humans	
Migrations	Upper Paleolithic
Agriculture	Mesolithic, Neolithic, Copper Age
Ancient & Classical Civilization	Also Bronze and Iron Age
Trade	Middle Ages
Commercial	Early Modern
Industrial	Late Modern
Information	Contemporary

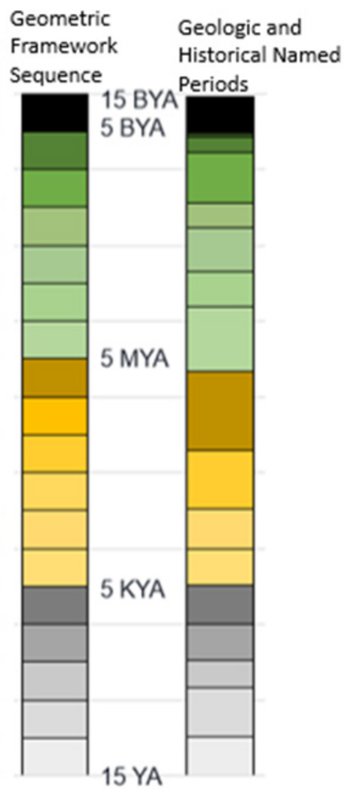

Table 2: Comparison of an Extended Jantsch Framework (with stages for every reduction in time by a factor of three) to the combination of geologic and historical named periods. Left: Corresponding transitions and named periods. Right: Comparison of geometric framework sequence with times of named geologic periods on a log scale from the present.

civilization, and middle ages mercantilism. While pairs of the phases of this craft-agrarian stage might be identified with the three detailed stages. This breakup of this agrarian stage makes sense when considering the social technologies involved from simple agricultural communities, to civilization with urban specialization and a high dependence on forced labor, to the emergence of trade based on freer labor supply supplemented by new energy sources such as wind and water. This breakdown of that period is supported by technological and economic changes (Mokyr, 1990; Gimpel, 1976).

Niele's (2005) energy framework identifies seven historical sequential sources of energy- physical in the cosmic phase; then a quick series of transitions in early life from thermal, anaerobic solar, and aerobic solar; and then a series of human led energy transitions from the use of fire, the development of agriculture, to the use of fossil fuels. For the human history era, this framework mixes both the extended Jantsch and the TOK/Combogenesis frameworks in identifying key energy source changes at the beginning and inflection points of major transitions. One possible explanation for the difference might be the important of energy use transitions (e.g., animals moving to land, mammals developing ways to regulate internal temperatures (warm-blooded) as compared with the just the energy source transitions of Niele.

5 Discussion

The transitions from different levels of big history are examined as to how they fit within this framework. This includes the transition from the cooling cosmic phase to the accelerating CAS on Earth with the origin of life. At the next nested level of the three terrestrial levels, the emergence of humans is discussed. Then at the lowest nested level, of the six steps in human evolution, the emergence of agricultural society is discussed.

The reasons for selecting these four differ. The cosmic phase is quite different in that the rate of events slowed as the universe cooled through expansion. Yet there are large structures to be formed to set the stage for advances of life. The origin of life is quite surprising since it did not take relatively long but it marked the transition between the cosmic and terrestrial phases. However, it is the least documented since early life left little record in fossils or in genetic material. The development of humans is one of the three major terrestrial phases, so intermediate steps can be

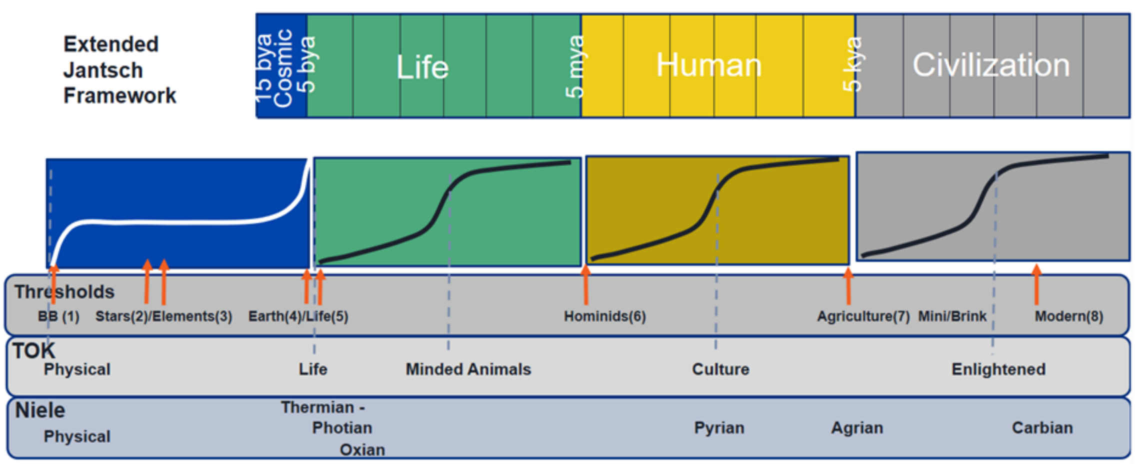

Figure 1: *The Extended Jantsch Framework (top; with stages for every reduction in time by a factor of 3), the same framework showing an expanded cosmic phase and the transitions of the three major terrestrial phases (bottom figure), and the corresponding relationship to events and phases in the standard big history threshold approach, the Tree of Knowledge/ Combogenesis approach, Niele's energy approach, and that of Grinin & Grinin.*

identified. Remember that the time for humans to develop to civilization from the branching from the chimpanzee line was 1,000 times longer than the history of civilization. Since the major biological change was in the size and structure of the brain, mostly external evidence of tool use helps in delineating these developments. While the brain size can be measured from fossil skulls, the new abilities enabled by the brain size are difficult to interpret since we have such little understanding of animal and human brains. The development of agriculture is labeled as a step (secondary) transition between the human evolution and history of civilization phases. There is sufficient archeological evidence to construct a timeline of emergent behaviors to attempt to analyze the transition pattern.

5.1 The Cosmic Phase

In the simple extended Jantsch framework, the cosmic phase is just the first phase followed about two-thirds of the age of the universe later by the formation of the Earth (i.e., a factor of 3 acceleration, similar to the later acceleration in the terrestrial stages). Of course much happened during this time covering the Big Bang, the development of structures such as the cosmic web, galaxies, stars, and planets. The big bang phase saw the cooling of the hot mix of particles as it expanded. For each quadrupling of the age of the universe (during the first few minutes) the temperature dropped by a factor of 2. The various binding energies in the sequence of protons, nuclei, atoms, molecules, and solids is lower by about three orders of magnitude (from 1,000 MeV for protons to thermal energies of 25 meV).

Active debates surround the events and interpretation of the big bang. Peter Atkins (2018) claimed that this unfolding of events of forces and particles during the big bang was quite uneventful as physics laws were followed. Gleiser (2010) takes a different perspective in highlighting all the symmetries that had to be broken to produce an interesting universe. For example, the asymmetry of matter and anti-matter was required so that at least some matter remained (1 part in a billion) after temperatures dropped below the formation of pair production. Hawking (Hertog, 2023) and Davies (2006) consider the possibility that there might have been some self-consistent participatory universe during this phase to explain some of the coincidences that led to a universe, which can harbor life.

The formation of structure in the universe started with the gravitational forces acting on the small density variations of dark matter to help form the cosmic web. Dark matter was able to react before normal ionized matter. Large flows reduced the gravitational potential energy in forming this structure which facilitated the movement of matter to nodes where galaxies developed (Hogan, 2001). This flow of matter continues through galaxies (Walter, 2020) although star formation in galaxies seems to have peaked about 10 billion years ago (Sobral, 2013), which is long before our solar system formed (about 5 billion years ago). The large energy flows resulting from the reduction of the gravitational and nuclear potential (which had led to the dissipative structures of the cosmic web, galaxies, and stars) began to calm down. After a few generations of stars to build up the necessary heavier elements, planets formed, and life formed on at least one. Then true complex adaptive systems (life) could form with the resulting increase in energy flow (Chaisson, 2001).

5.2 Beginning of Terrestrial Life

This event is special since it marks the transition from a physical dissipative system evolution of the cosmos to one based on complex adaptive agents based on information. In the framework, however, it just marks the early phase of life on earth. An ongoing mystery is how life evolved so quickly after the earth cooled enough for the chemical reactions to take place. The first evidence for life has been found anywhere from 3.5 to 4.0 billion years ago, i.e., when the Earth was about half a billion to 1 billion years old. While this is fossil evidence, there must have been many steps taken toward life before some evidence survived.

As an example of one the steps from which life emerged, Manfred Eigen (1977) identified a problem with the DNA genetic processes in that the error rate in constructing a useful length of protein would be too large unless there were a sophisticated process to perform error corrections. While modern and even early cells have these error correcting mechanisms, these processes require the complicated proteins. So just a system of DNA could not evolve to generate complex proteins of useful length because the error rate would be too large in the beginning of the evolution. This is called Eigen's paradox.

However, there are ways self-reproducing molecular cycles might breach this limit without DNA. For example, a system of catalysts which catalyzed each other (but not themselves). A system with more than two catalysts in a cycle, where at least one extracts energy from the outside, is stable and can form self-organizing systems, such as the BZ diffusion reaction. The system can evolve by finding improved catalytic substitutes for each component in the cycle. Catalysts that try to commandeer the system are not successful at parasitism, so the system can evolve further.

Eigen (1977) also found that these evolving systems not only tend to grow and compete for resources of energy and materials, but these evolving systems also improve through this substitution. Improvement (or evolution) and growth tend to speed the process by which the system fits into the environment, causing the learning to accelerate and, as he found, tend to point where the learning becomes very quick in this process of positive feedback. He recognized that this might be a reason that CAS evolution did not take very long (relative to the age of the Earth) for life to originate. Once it started, however, the ability to extract resources from the environment and thrive was sufficient until some challenge directly impacted its environment. One case was the oxygen that the new life produced, which was a poison to early life. One reason it took life so long to evolve from the simple cellular form to one that could utilize the oxygen was that the oxygen level in the oceans around the world had to increase in concentration after being naturally removed by forming rust after oxidizing the iron in the ocean water. A more detailed version of both the processes leading to origin of life and the difficulties progressing to eukaryotic cells process has been explored within the environment of alkaline hydrothermal vents (Lane 2015).

However, the question of how life began has not been resolved. Other hypothesis, such as the origin life off of Earth is being debated (Markov et al., 2018; Sharov, 2018; Davies, 1999).

5.3 Appearance of "humans"

Humans did not one day just appear. Many hominoid species evolved over 4-8 million years, after splitting with the branch that led to chimpanzees, the closest great ape to humans. It should be noted that human history (i.e. writing) in civilizations did not start until 99.9% of this time had elapsed (i.e., 5,000 years ago). This is the same fraction that human evolution is compared to the evolution of life on Earth. This then is a major evolutionary phase. Many steps took place during that time as bipedalism, tool use, controlled fire, language, and agriculture developed over this time before civilization started.

The branch in the primate evolutionary tree leading to humans split from the other apes about 5 million years ago. Weather conditions in Africa's Great Rift Valley led to the expansion of grasslands into the previously forested areas. Hominids adapted to this situation by developing a more general way of living including a more varied diet (e.g., scavenging) and the ability to walk on two legs (about 1.6 million years ago with Homo erectus) which helped in seeing further, carrying food, and running.

The lack of any well-honed predator characteristic (such as claws or sharp teeth) or defensive strategy (such as speed or protection) led groups to form with rudimentary communication to coordinate food gathering and defense. About 0.5 million years ago, the control of fire helped in the digestion process by cooking foods so that energy could be allocated from digestion to increasing brain size. The generalization of humans' capability to adapt to environments enabled great migrations across much of the Eurasian continent.

A positive feedback then continued among larger brain size, social organization, and better control of the environment (through technology). The human brain size mostly increased after about 160 thousand years ago when modern humans, Homo sapiens, first developed with an expanding toolkit of abstract language, which led to refined tools about 50,000 years ago. Pressures on resources in certain locations led to a more intensive use of the land started about 15,000 years ago and later led to the agricultural revolution. These sedentary cultures led to villages that needed to store and protect the agricultural harvests, which prepared the environmental conditions for the development of larger communities in civilization (starting about 5,000 years ago).

The reason that human evolution is treated as a phase, i.e., a top-level evolutionary step, is its unique mode of evolutionary process. While the genetic changes were important to cause differences, humans also gained more control of their evolving environment through the use of tools (sticks, stones, and bones), fire for cooking, security, heat, light, land preparation, and social cooperation. Genetic changes were important in brain growth, hip structure for bipedal walking, gut size, support of larynx for speech, and hairlessness for cooling down- especially since a large brain which took about 20% of the energy resources for a 2% fraction of the body's mass. However, these genetic changes helped the human ancestors survive in an environment over which they increasingly had control. This has also been referred to as dual inheritance or epigenetic processes by Jantsch. In one sense, it was an early form of self-domestication which was later applied to changing the genetics of plants and animals for agricultural lifestyle.

It seems as if the brain growth facilitated grater social cooperation as it was identified by Robin Dunbar that there is a correlation between primate neocortex brain size and the number of relationships an individual could maintain. This number is often quote as being around 150 people which is often the size of groups in schools (e.g. dormitories) and businesses (divisions). The social relationships required the large brain size because of the development of the theory of mind in humans. That is an individual could empathetically view the world from someone else's character and experiences. This included knowing their skills and the other person's relationship with themselves and others in the group.

To summarize, in this stage the branch of primates leading to humans expanded the ability to adapt in various environments with bipedalism, basic communication, control of fire, and an adaptable mind. This led to a positive feedback cycle focusing on refined levels of symbolic language, tools (from stone, bone, and antler), social organization, and the step towards better control of the environment through agriculture. These events followed the time sequence with an acceleration factor of 3 at roughly 5 million, 1.5 million, 500 thousand, 150 thousand, 50 thousand, 15 thousand, and 5 thousand years ago.

The importance of this phase can also be seen in Ekstig evolutionary-development relationship since the important events in development that relate to being human and social take about 1/3 of the time scale. These events include walking, tools use, speech, and socialization.

5.4 Appearance of agriculture

The development of agriculture went through many steps starting with sedentary hunters about 15,000 years ago. This was followed by development of tools to harvest wild grains, formation of villages around natural abundant grain resources, plant domestication through selective reproduction of beneficial plant characteristics, animal domestication, the development of storage systems with pottery, and the political establishment of chiefdoms, and the eventual replacement of more primitive tools with metal tools. These events form a logistic transition with a midpoint of about 9,000 years ago over a duration of about 10,000 years.

The appearance of agriculture is a step in the human evolution phase because the genetic-cultural process continued with the way the domesticated plants and animals evolved through the artificial selection by humans. During this step, many substeps were required as outline by Jared Diamond in Guns, Germs, and Steel. If each of these substeps are of equal importance then the growth can be plotted to show a logistic pattern in which the process started off slowly, sped up when some fundamental techniques were shared, and then slowed as the process hit some limit.

Domestication of other species by humans started long before the agricultural transition. The domestication of wolves into dogs was started about 30,000 years ago by hunter-gatherers. The process was co-evolutionary in which dogs and humans both gained benefits of the increased relationship. The resulting history of civilization shows a continual expansion of cooperation of humans to accomplish more complex tasks while being motivated to create competitive military technology (Nazaretyan, 2020; Turchin, 2016).

5.5 Further work

One factor that might be best for quantitative measurement is the energy flow during the various levels and steps. While Chaisson argues for the energy flow per unit mass (FERD), a complex system that grows through combinations usually has an overall increase in total energy flow, as has been discussed elsewhere. One problem with this later approach is that on the cosmic scale the tendency was for systems to separate into small units instead of combining, e.g., galaxies, stars, and planets. Besides the energy flows identified by Chaisson of mostly stellar nuclear fusion, there have been other energy flows due to the decrease in gravitational potential as matter clouds “collapsed” when cool enough. This started with the cosmic web and continued with galaxies and stars. It is now known that galaxies maintain a matter flow, siphoning off matter through the cosmic web and expelling it when the massive central black hole is active.

Another area of research is to understand the nature of the transitions to better estimate the probability of a successful transition. For historical periods, this might be done with semi-independent civilizations. For life, it might concern the extinction of species and the convergent evolution of emergent phenomena such as eyes and flight. Simple models have been constructed at the phenomenological level and some of the various hypothesis of historical transitions are being tested with correlations of archeological data, such as the Seshat Project (Turchin, 2019).

Finally, there are the questions about the geometric acceleration factors involved of 1,000 and 3. Where do these come from? Would they be different under other circumstances? What happens when a level or step is unsuccessful? (LePoire, 2020)

6 Conclusion

The case has been made for a need to develop a periodization framework for Big History based on previous research and insights, despite the limitations of uncertainty, definitions, and changing understanding. A set of criteria has also been developed which include the alignment with existing fields within Big History such as those in geology and biology, anthropology, and human history. These three major fields have periods of coverage that are close to a geometric sequence with the duration of each phase about 1,000 times less than the previous. Therefore this division is not just a linear list of terrestrial periods but instead motivated by the traditional disciplines it forms a hierarchy of three main phases of life, human, and civilization evolution (forming half of a full logistic curve), which is then recursively each divided into 6 subphases. The beginning and ending times indicate only an approximation, while the events unfold during the period as the complexity increases with emergence of new behaviors.

Various aspects of complexity might be used to characterize these events or transitions. The aspects of complex adaptive systems include in which way the evolutionary information is inherited, the source and amount of energy flow, the levels of organizations, and the interaction with the environment. Patterns from previous research were identified in each of these including the transition of the information mechanism from genetic in a natural environment, genetic in a gradually self-defined environment to cultural evolution. The energy flow density has been estimated to increase over the course of both cosmic and terrestrial evolution of the most complex systems. Organization includes the ability of systems to combine or to grow and then specialize. Environmental relationships tend to show an increasing size of the evolving system while the environment’s scope decreases. The sizes of complex systems in Big History seems to be related to a few simple physical constants.

Three specific “events” were chosen to demonstrate the difficulty in resolving the understanding and timing, and framework placement when applied to big history. The origin of life is clearly a major event in this sequence but while it is not fully understood, a large mystery is why it was relatively rapid, especially compared to the much longer phase of single celled life on Earth. The evolution of the human species is quite distinct from the evolution of life up to that point. It is unclear why consciousness evolved or that such a general characteristic could eventually survive in an ecosystem that was highly tuned. The human evolution is one of the three major evolutionary phases on Earth with the evolutionary mechanism being facilitate by the increasing control over the environment with the use of tools, fire, and collaboration especially coordinated through language. The development of agriculture took place over a long duration of about 10,000 years due to the development of beneficial domesticated plants and animals, and the motivation towards the lifestyle based on the growing population density and environmental stresses.

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Dual Closure: a New Tool for Recognizing Thresholds Between Levels of Organization in Big History

Gerard Jagers op Akkerhuis
Wageningen University and Research, Wageningen, Netherlands

Correspondence | **Gerard Jagers op Akkerhuis** gajm.jagers@gmail.com

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Abstract: Big Historians study the development of the universe and how it passed through different phases. A fascinating trend is the historical increase in the complexity of a part of all systems. To analyse this trend, rankings have been proposed with different scientific and pedagogical aims. For example, they rank epochs, regimes, levels of organisation or dynamic domains. As a result of this variation, the number of levels differs between approaches, while the systems ranked at these levels are the result of unequal processes and belong to different overall types. Such diversity invites a re-examination of the fundamentals involved in these ranking processes. Moreover, if rankings are to be predictive, they must be consistent in their logic. To this end, it would be useful to have a sequence of levels that share a common logic.

As such a common logic, and building on existing systems science and hierarchy theory, a new theory called O-theory proposes the use of a process called 'dual closure'. Each successive dual closure represents a threshold between the old and new types of objects and their respective levels of organisation. In this way a causal logic is obtained, ranking systems from fundamental particles to organisms with brains, all of which are addressed by the generic name of operator. The hierarchy of the operators provides a basic framework that can be used to re-examine existing transdisciplinary classifications and learn more about why they differ in the number of levels they have. It is discussed how big historians might more easily achieve their broad goals if they added the operator hierarchy to their theoretical toolbox.

Introduction

Big historians develop a multidisciplinary historical reconstruction, a timeline, of the phenomena that have shaped the current universe, from the Big Bang to the present. The word history is prominent in the name of the discipline. This has led people to ask whether Big History is an epic, a myth, or a scientific discipline. Science has criteria. Central to it is the construction of theoretical models of the world that support testable predictions. If the predictions can be falsified, the model must be improved. The improved version of the model can then form the basis of new predictions and new tests. The iteration of these steps results in what has become known as the empirical cycle (Geier, 1992). Scientists use this cycle as a tool to construct increasingly accurate predictive models of the world as it was, as it is now, or as it will be in the future.

Building predictive models in Big History is a challenging endeavour for two main reasons. First, the basic data with which to feed a model, or to test the outcome of a model, is always limited because we live in the present, whereas any model of Big History extends into the past and, in the case of predictions, into the future. Fortunately, the past has left traces that can be used as input for modelling and as a reference for checking. Examples include the concentrations of chemicals in rocks of different ages, the layering and folding of rocks, the presence of fossils, the light of ancient stars, or the glow of background radiation in the universe. Second, the processes of cosmic development are inherently complex. The universe contained, and still contains, different types of systems interacting in myriad ways, at different times and on different spatial scales. In addition, new types of systems have emerged from time to time, changing the course of events. The aims of Big History are thus akin to untangling a Gordian knot on the scale of the cosmos.

The challenge of unravelling the cosmic Gordian knot has given rise to a collection of ordering approaches, each with different goals and perspectives. Accordingly, their levels have different names, such as epochs (e.g. Chaisson, 2006), eras or regimes (e.g. Spier, 2015) or dimensions (Henriques, 2003). The following examples show how individual scholars have arrived at their own thresholds and levels.

An early Big History approach is that of Jantsch (1980). He essentially divided all cosmic systems into two large groups, the microstructures, such as atoms and cells, and the macrostructures, such as stars and planets. For each group he offered a timeline of construction steps (summarised in Table 1).

Microstructures	**Macrostructures**
Photons	Superclusters
Leptons	Clusters of galaxies
Baryons	Galaxies
Light nuclei	Stellar clusters
Light atoms	Stars
Heavy atoms	Planets
Molecules	Rock formations
Crystals	Planetary chemo-dynamics
Dissipative structures	Gaia system
Prokaryotes	Heterotrophic ecosystems
Eukaryotes	Societies with division of labour
Multicellular organisms	Groups, families
Complex animals	

Table 1: A timeline of the emergence of increasingly complex systems in the universe. The types of systems are divided into so-called micro- and macro-structures (Jantsch, 1980, Figures 24 (p 94) and 28 (p 132)). Time/complexity increases from top to bottom.

Another Big History classification is that of Chaisson (2001, 2006). He divides the history of the universe into seven epochs, called (1) particle, (2) galactic, (3) stellar, (4) planetary, (5) chemical, (6) biological, (7) and cultural. Around this time, Henriques (2003) introduced the 'Tree of Knowledge System', which developed a progression and ranking in four abstract dimensions of existence: matter, life, mind, and culture. More recently, he and colleagues discussed how the model relates to the aims of the big history community (Henriques et al., 2019). David Christian and William McNiell (2004) wrote the book 'Maps of Time, an introduction to Big History'. Later, David Christian et al. (2014) proposed the use of eight so-called major thresholds of Big History. These thresholds are: (1) origins of big bang cosmology, (2) first stars and galaxies, (3) formation of chemical elements, (4) earth and solar system, (5) life, (6) what makes humans different? (7) agriculture, (8) the modern revolution. This ranking also inspired the book Big History by the Macquarie University Big History Institute (2016). More recently, and using the logic of 'combogenesis', defined as: 'the birth of new types of entities by the coming together and integration of previous things', Volk constructs a so-called Grand Sequence (Volk 2017, p. 1). This consists of twelve fundamental levels, ranging from (1) fundamental quanta, (2) nucleons (protons and neutrons), (3) atomic nuclei, (4) atoms, (5) molecules, (6) prokaryotic cells, (7) eukaryotic cells, (8) complex multicellular organisms, (9) animal social groups, (10) tribal metagroups, (11) agro-villages, and (12) geopolitical states (Volk, 2017, p. 22). Volk also groups the above levels into three dynamic realms: one of physical laws, one of biological evolution, and one of cultural evolution (Volk, 2017; 2020).

These examples show that authors often look for 'macro-level frames and perspectives … to effectively organize their fields and to situate disciplinary findings in a larger picture of understanding' (Henriques et al., 2019). To reach these goals it has been suggested that a 'convergence model of emergence' may well offer a 'comprehensive map of the time-by-complexity relationship' (Henriques & Volk, this issue).

While working along these lines, authors have used different general logics. This explains why there are different rankings with different numbers of levels, while the types of entities may differ between levels. In this context, the identification of a general logic that would link successive levels would be of great help to integrate different rankings, to discuss the consistency of a ranking, to know if there is a gap in a ranking or to extend a ranking with the aim of predicting systems at future levels. Therefore, from the point of view of the empirical cycle, there is an urgent need to find ways to reconcile differences while seeking integration.

Above all, you need a logic if you want to extrapolate a ranking. But not all rankings lend themselves to extrapolation. In order to extend a ranking in the most probable way, taking into account Ockham's rule, it is best to use the simplest logic. If a ranking has the form I, II, III, IIII, IIIII, one can imagine many ways to continue the ranking, for example by repeating it, but the simplest logic is to assume that you get this ranking by 'adding a bar at each step'. Meanwhile, the systems involved are always 'groups of bars'. Focusing on the simplest explanation, the most likely next levels are IIIIII, IIIIIII, etcetera. A logical ranking with these properties can be considered consistent and can be used in a predictive way.

Of course, a ranking can be consistent without being predictive. An example is the following: ..., 1, *, happiness, K, a picture of a stone, green, ... This example follows the logic that the next object can be anything that a person can think of or observe in the world. However, the resulting sequence provides no information about a particular next object, nor about its properties. In this case, the logical ranking criterion has been made too abstract (in the sense of undefined) for extrapolation. In this case, generality gets in the way of making precise scientific predictions, as Popper urged researchers to do. This suggests that researchers should prefer rankings with a kind of logic that is precise enough to allow extrapolation.

Between 1992 and 1993, during a desktop study, the author's attention was drawn to the challenges of creating rankings in ecology that allow extrapolation (Jagers op Akkerhuis, 2010, pp. 13-17). When analysing complexity in ecology, different authors used different numbers of levels, used levels based on different criteria, even within the same ranking, and placed different types of systems at these levels. The desire to organise things in what might be called a meta-approach inspired the search for a common framework for hierarchy in ecology. In the winter of 1993-1994 the idea was born that a particular framework could provide a consistent ranking with fixed thresholds and levels that could be used in a predictive way. The elaboration of this idea led to the first publication about the subject (Jagers op Akkerhuis & van Straalen, 1999). Since then, more and more new insights have been integrated into the theoretical framework now known as O-theory (the abbreviation O-theory is used to distinguish it from, for example, operator theory in mathematics). The principles of O-theory extend beyond ecology and can therefore be of use to Big History.

Before going into detail, it is important to note that in constructing O-theory it has been necessary to overcome three common prejudices about hierarchy in nature, which can be seen as obstacles to the further development and general acceptance of innovations in hierarchy theory. It is considered relevant to discuss here these prejudices that have been encountered in ecology, as they may also affect the way in which big historians think about hierarchy theory.

Prejudice 1: 'Hierarchy in nature is linear'.

The first prejudice is the idea that complexity in nature follows a linear hierarchy. Linearity here refers to a ranking that has only one dimension. This idea of linearity is closely associated with the part-whole analysis of systems. A focus on parts and wholes implies that if you look at a system from the top down, it is made up of parts, whereas if you look from the bottom up, the parts interact to create a large system. This way of working is sometimes presented as a practical one-size-fits-all solution. But the downside is that this logic leads to rankings that freely mix different types of systems and ranking rules. An example is the ranking from fundamental particles to atoms, molecules, stars and planets, people, families and society. At the lower levels of this ranking, small physical particles combine to form more complex physical particles. For example, atoms combine to form molecules. But at the higher levels, interactions lead to groups. For example, when individual people interact, they form families or societies. The people involved take on a new role as members of a family or society. But a family or society is not a physical entity. The members are not attached. They can go their own way, join other groups and even participate in different groups simultaneously. A family, like other groups, is a mental abstraction. Not a physical particle. These examples show that ranking on the basis of parts and wholes runs the risk of confusing physical particles and groups. To use a popular metaphor, they are mixing apples and oranges.

Would it be possible to untangle the mixed hierarchies and create a consistent ranking in which the systems at each successive level are always of the same overarching type? O-theory suggests that to achieve this goal, one must first consciously separate the apples from the oranges (Jagers op Akkerhuis & van Straalen, 1999; Jagers op Akkerhuis, 2010). To explain how this can be done, the following example takes an organism, say a horse, as a starting point. From there, three general hierarchies can be imagined, each with its own rules for identifying levels.

The first hierarchy begins with the horse and extends into its interior. Inside the horse you will find smaller and smaller parts of the body, from the abdomen, to the organs, to the tissues, to the cells, to the membranes, to the molecules, and so on. The levels of this classification can be based on conceptual (fiat) thresholds, such as the horse's abdomen, as well as natural (bona fide) thresholds, such as a cell in a tissue. Interestingly, each time you take a different perspective, such as a metabolic, hormonal or developmental perspective, what you see as parts can change, as can their level. In O-Theory, the many possible rankings within a horse are seen as extending along the 'internal dimension'. There is no preferred order along this dimension.

The second type of hierarchy extends from a single horse to the things it interacts with. Here you can create different groupings, each resulting from specific interactions. For example, a focus on mating leads to groupings called herds or species. Other interactions lead to broader groups such as communities, or ecosystems. You can also create hierarchies based on who eats what. These are called food chains. Each time you choose different interactions to determine the groupings, it affects which elements participate in a group. In O-theory, all the different rankings of groupings are considered part of the 'outward dimension'. There is no preferred order along this dimension.

Third, in addition to the inward and outward dimensions, one can imagine another dimension that organises the differences in the major body plans of organisms. Put simply, this runs from simple bacteria to eukaryotic cells, plants and animals. The basic idea of this dimension is that successive processes of integration lead to increasingly complex types of systems. This idea can be found, for example, in the work of Teilhard de Chardin (1946), Oppenheim and Putnam (1958), and the grand sequence of Volk (2017), and is also central to O-theory. It is associated with what is called the 'upward dimension'.

Just as the size of a wardrobe is defined by three independent parameters, length, width and depth, the above examples span three independent dimensions for ranking hierarchies in the organisation of nature. These insights into three dimensions go beyond the assumption of a single linear hierarchy in nature.

There is a caveat here because the steps along the upward dimension do not come out of nowhere. They depend on developments along the outward or inward dimension. For example, the bacterial ancestors of the mitochondria in eukaryotic cells could not just walk into any bacterial host and live there. Instead, it is thought that their current obligate endosymbiotic lifestyle was preceded by a symbiotic aggregate lifestyle. This aggregate is classified as a grouping along the outer dimension. By analogy, the cells of a multicellular organism, such as a plant or fungus, would probably have lived as a group of attached cells before plasma connections were formed between the cells to fuse them into a single unit. But developments need not always and only use the outward dimension. In the course of evolution, complexifying developments can also take place along the inward dimension. For example, special cells will first have developed extensions that allow them to act as neurons. Then, within a multicellular organism, neurons could evolve over many generations to form large networks that, together with sensors such as eyes and ears and activators such as muscles, could eventually form a next-level entity with its proper position along the upward dimension.

With the above argumentation it is possible to let go of the prejudice that there is a single hierarchical, linear natural hierarchy. Instead, three independent dimensions of hierarchy have been discovered.

Prejudice 2: 'Because hierarchy is always context dependent there exists no preferred hierarchy for organizing nature'.

It is widely accepted in philosophy that the construction of any hierarchy depends on the context of its use. The result is that one can imagine as many hierarchies as there are contexts for their use. For this reason, it seems counterintuitive for O-theory to advocate the use of a preferred complexity hierarchy in nature, especially one with fixed levels. How can this paradox be resolved? One solution is to consider that O-theory is a context-dependent theory. The specific context of O-theory is the identification of a fixed ranking of levels of organisation in nature, which shows a logically consistent sequence of levels and types of systems in such a way as to provide a basis for extrapolation. O-theory thus deliberately aims to identify a hierarchy that is appropriate to this very specific context. Recognising this, it is no longer problematic if the approach results in a single ranking with fixed levels. It is a matter of context.

Prejudice 3: 'Hierarchies suggest that complexity can only increase'

As Spier (2022) has pointed out, processes in the universe can lead to complex systems, but they can also lead to destruction and chaos. For example, all complex life on Earth will one day be destroyed when our Sun becomes a red giant and explodes. This shows that not all processes in the universe lead to complexity. Instead, thermodynamic chaos may eventually prevail. In this respect, one must be careful not to interpret a ranking of complexity as a necessary direction of development. A complexity ranking is a logical ordering of organisational types. Systems can gain or lose a level in the ranking. By the same token, a causal ranking of the emergence of increasingly complex types of systems should not be equated with the logic of a timeline. In general, however, the emergence of more complex systems also demands more time.

Introducing O-theory

The development of O-theory occurred in the context of trying to make sense of the many frameworks used to analyse levels of organisation in ecology. To reduce the complexity of the task, it was decided to focus initially on small systems such as atoms, molecules or cells. The visionary work of Teilhard de Chardin (1946), Oppenheim and Putnam (1958) and, more recently, Jantsch (1980) had already suggested a distinction between small and large systems. As a criterion for small systems, Teilhard de Chardin used their 'formedness' and 'centredness'. Formedness is about having a surrounding layer. Centredness depends on a unifying internal organisation. The large objects did not have these qualities. Teilhard de Chardin (1946) said: 'The atom, the molecule, the cell and the living organism are true units because they are both formed and centred, whereas a drop of water, a pile of sand, the earth, the sun, the stars in general, however complex or elaborate their structure, seem to possess no organisation, no 'centricity'. However imposing their extent, they are false units, aggregates arranged more or less in order of density'. These new discoveries allowed him to group together atoms, molecules, cells and multicellular organisms and to arrange them according to the order of their formation.

Oppenheim and Putnam's approach was based on functional reduction and aimed to provide a framework that would unite all the different branches of science. They described their approach as follows "We offer, therefore, a system of reductive levels chosen so that a branch with the things of a given level as its universe of discourse will always be a potential micro-reducer of any branch with the things of the next higher level (if there is one) as its universe of discourse" (Oppenheim & Putnam, 1958). In order of progressive reduction, Oppenheim and Putnam distinguished the following levels in their model: social groups, (multicellular) living things, cells, molecules, atoms and finally fundamental particles. Because in later years people have associated the levels of organisation in Oppenheim and Putnam's model with the layers of a cake, their model has also become known as the 'layer cake model'.

The works of Teilhard de Chardin and Oppenheim and Putnam were concerned with systems science and preceded the theory of Big History by several decades. Perhaps this is why these works are rarely referred to by big historians. For example, when Jantsch (1980) divided systems into two groups, the microstructures and the macrostructures, and ranked the systems in these groups separately, this shows a marked similarity to these historical publications.

A challenge when working with so-called small systems is the identification and definition of their causal sequence of emergence. This is also recognised by Volk, who proposes as a solution the use of combogenesis, which he defines as 'the birth of new types of entities by the coming together and integration of previous things' (Volk, 2017, p. 1). O-theory suggests an equivalent approach, based on a logic called 'dual closure', originally referred to as 'hypercycle formation' and 'compartmentation' respectively (Jagers op Akkerhuis & van Straalen, 1999) and elaborated in e.g. Jagers op Akkerhuis (2010, 2016). In O-theory, the systems resulting from dual closure are called operators. We can now define O-theory as follows: with dual closures as the basic processes and operators as the basic elements produced by the dual closures, O-theory describes in an abstract causal way how a series of operators of increasingly complex types has emerged in nature. This series is named the operator hierarchy. The levels of complexity resulting from dual closure can also be used as a classification. But this use is only secondary.

In O-theory the construction sequence starts from quarks. Quarks are regarded as fundamental objects that do not themselves exhibit dual closure. For this reason, a quark is not an operator. Volk uses similar reasoning to deduce that quarks precede his grand sequence (Volk 2017, p. 34). With quarks as the basis, every dual closure involves the first possible combination of two closures, a so-called new process cycle and an associated spatial envelope. Both the new process cycle and the spatial envelope have their own definitions.

The new process cycle can be defined as: The first possible, new type of circular process in which the objects change each other's states through an advanced type of dynamic interaction. It is through the advanced interaction that existing entities create the new type of process cycle.

	Dual closure			
Complex property that allows process closure	**Creation of new type of process closure based on transformations**	**Addition of new type of spatial closure causes physical unity**	**Operator type resulting from dual closure:**	**Level**
Quarks emit and absorb gluons	Cycle of mutual transformation through the exchange of gluons between quarks (causes the strong force)	Confinement surrounds the quarks (induced by sufficient space)	**Hadron** (e.g. a proton, neutron or pion)	1 (the first operator)
Hadrons emit and absorb light mesons called pions	Cycle of mutual transformation through the exchange of pions between hadrons (causes the nucleus)	Electron shell surrounds the nucleus	**Atom** (e.g. Helium)	2
'Vacant' positions in electron shells allow for the exchange of electrons	Cycle of mutual transformation through the exchange of electron pairs (molecules) or as a sea (metals) between the atoms	Shared electron shell or electron sea surrounds the atoms	**Multi-atom** (e.g. molecules, metals)	3
Special molecules allow for catalytic reactions	Cycle of mutual transformation through catalytic reactions between molecules	Cell membrane surrounds the plasma with autocatalytic set	**Cell** (e.g. bacteria and archaea)	4
Clonal cells develop plasma connections	Cycle of mutual transformation through plasma exchange between neighbouring cells	Shared membrane surrounds the connected plasma	**Multicellular** organism (e.g. blue-green algae)	5.a
Some cells develop physiological symbiosis.	Cycle of mutual transformation through (obligate) physiological interactions between hostcell and guestcells	Cell membrane of the hostcell surrounds both cells	**Endosymbiont cell** In O-theory: **hostcell** (e.g. protozoa)	5.b
Clonal hostcells develop plasma connections	Cycle of mutual transformation through plasma exchange between neighbouring hostcells	Shared membrane surrounds the connected plasma	**Multihostcellular** organism (e.g. plants, algae, fungi)	6
Some cells develop signal transduction to other cells	Cycle of mutual transformation through information exchange between groups of neurons.	Shared interface consisting of sensors and activators surrounds the neural network	**Neuronmemon** (e.g. horses, humans)	7

Table 2: Overview of how a sequence of dual closures can be seen as causal for the emergence of increasingly complex operators. First, there are lower level entities (quarks or operators) some of which show or develop an advanced interactive property (column 1). Second, this property is causal to the emergence of a new process closure (column 2). Next, the process closure is contained by an associated spatial closure (column 3). The combination results in an operator of a new type (column 4). The last column shows the binary code given to each operator type (modified from Table 2.1 of Jagers op Akkerhuis, 2016, p. 37).

New means that the specific interactions have never occurred before in cosmic history.

The new interactive process is caused first by quarks and then by increasingly complex operators. Because nature can only build more complexity out of what already exists, low-level operators first became part of the next operator. However, because dual closure is an abstraction, becoming a part is not essential. High-level operators can also enable the new process closure in other ways.

The associated spatial envelope can be defined in more detail as: The first possible new type of boundary layer enveloping the elements of a process closure. A cell's spatial closure, for example, specifically mediates the process closure, i.e. the autocatalytic set of molecules that sustain a cell through their concerted activity. The spatial closure should not be considered as impermeable. For example, the ability of food to enter a cell and waste molecules to leave a cell is obligatory for its activity.

At low levels of complexity, spatial closure may not seem very 'material'. For example, a plasma of freely moving quarks exchanging gluons would drift apart as space expands. However, a very strong force, called the colour force, confines groups of quarks to small volumes. In this process, spatial closure is little more than a local force field that did not already exist in the quark plasma, but took shape as space expanded. At higher levels, the spatial closure increasingly takes on a material form. An example of this is the membrane of a cell. As a distinct material layer, the membrane is the interface of the catalytic processes of the cell's process closure.

All the process closures and spatial closures involved in O-theory, as well as the operators they create, are listed in Table 2 (previous page).

Since nature can only build with what is already there, subsequent dual closures up to level six are brought about by the physical integration of objects of the highest possible preceding level, either fundamental particles or operators. The common dual closure logic of all these steps can be explained using the example of the atom.

The process cycle of the nucleus can form because the protons and neutrons have a complex, new property. They can emit and absorb particles called pions, which are themselves hadrons made up of two light quarks. The exchange of pions creates a strong force that binds the protons and neutrons involved, quantum-mechanically linking their states. The resulting process closure stabilises the neutrons, which would otherwise decay with a half-life of about fifteen minutes. The new process that adds the spatial closure is the following. At temperatures below 3000^{o}K, the positive charge of the proton(s) can attract and bind low energy electrons. Due to their particle/wave duality, the electrons settle into a probability space around the nucleus, known as the electron shell.

In combination, the process cycle of the nucleus and the associated spatial envelope of the electron-shell define the atom. The example of the atom is also chosen to illustrate why the definition of dual closure speaks about the 'highest possible' preceding level(s). When a nucleus attracts electrons, these are fundamental particles. This implies that the immediately preceding level of hadrons is skipped. In principle the highest preceding level is the cause of the next dual closure. However, since a spatial envelope of hadrons is physically impossible, the remaining option is that of the next lower preceding level of fundamental particles.

Successive dual closures define a subset of systems which - through their history of emergence - are all members of a large family, the family of operators. Since dual closure is present or not present, the ranking of successive types of operators has fixed levels. The sequence of dual closures results in the following types of operators at the following levels: hadrons (level 1), atoms (level 2), molecules (level 3), cells, such as bacteria and archaea (level 4), multicellular forms, such as the bacterial blue-green algae (level 5a) followed by hostcells, such as protozoa (level 5b) and multi-hostcellular organisms, such as plants, fungi and algae (level 6). The final category is that of the so called neuronmemon (level 7).

What is a neuronmemon? A neuronmemon is a multi-hostcellular organism with a neural network of sufficient complexity to exhibit dual closure. Such organisms are conventionally placed in the taxon Animalia, the animals. However, the term animal in biology also includes the sponges and placozoans, which lack neurons, as well as early evolutionary forms and/or developmental stages that may have a neural network without dual closure. In relation to the focus on dual closure, the new term neuronmemon is introduced to allow a specific focus on organisms with neural dual closure (see also Table 2). The term memon is chosen to honour the meme concept introduced by Dawkins (1976). He discussed the evolutionary dynamics of (mentally) copyable elements of thought, the ideas or, as Dawkins called them, memes, in analogy to the dynamics of genes. Such dynamics are typical of organisms with neural networks or analogous constructions. The shorter term 'memon' is used in O-theory to refer generically to all possible types of memons, neuronmemons being a special subset.

Because the neural network of a neuronmemon develops from within a multi-cellular organism, it may seem that this dual closure does not follow the logic of previous dual closures, where operators of the highest preceding level are physically integrated to produce the next dual closure. For example, atoms integrated to form molecules and molecules integrated to form cells. In contrast, whole plants or fungi did not integrate to form a neuronmemon. That the neuronmemon does not deviate from the overall logic is because, as explained above, dual closure always refers to an organisational state. It is an abstraction. Therefore, the new state of dual closure does not have to develop through the cooperation of whole operators, i.e. through integration along the outward dimension. Instead, the dual closure of the neuron-memon evolved like a new organ in an existing multicellular organism. Integration in this case took place along the inward dimension. This was possible because some of the cells in a multi-hostcell organism developed extensions that could send signals to other cells, allowing a neural network with a new process closure to form. At the edges of the neural network, sensors and activators developed to form the spatial closure. The body of a multi-cellular organism simply provided the most efficient scaffold for innovation.

When O-theory speaks about an operator, the focus is on dual closure. For example, O-theory views the living host-cells connected by plasmodesmata as the most important aspect of the organisation of a tree. Strictly speaking, only these connected cells are the operator. This means that the heartwood and bark, which are made up of dead cells, are not included. In biology, however, the focus is generally on the whole phenotype of the tree. It is of practical importance that these two views can be reconciled. Theoretically, O-theory makes a distinction between the operator and its extensions. The living cells of a tree are the operator, and the heartwood and bark are the extensions. The phenotype studied by biologists thus combines the operator and its extensions. And when the neural network and sensors in a multi-hostcellular embryo develop into a neuronmemon, the rest of the tissues change status to become extensions. But in practice, the term operator is also used to denote the operator with its extensions. Whether a text refers to a phenotype, an organism or an operator (with or without extensions) will be easy to understand in most contexts. If

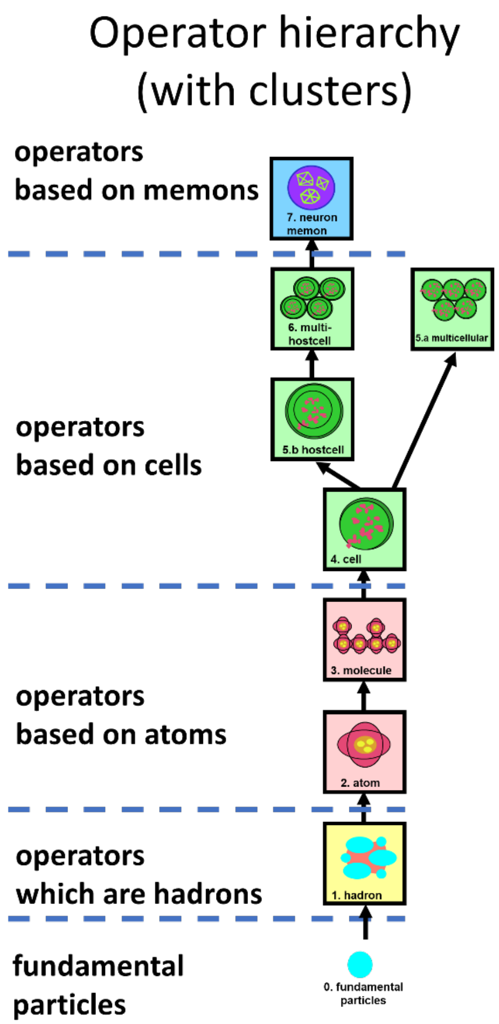

Figure 1: A simple representation of the operator hierarchy. Complexity increases from bottom to top, one dual closure at a time. Dashed blue lines and colour differences separate operators in clusters. All operators in a cluster are combinations or elaborations of the basic operator of the cluster (the first in the cluster). A new term is introduced for the most complex operator: neuronmemon. Simply put, this term refers to an animal with a neural network with dual closure.

necessary, the exact status can be clarified in a short explanation..

A basic graph of the emergence of all types of operators is shown in Figure 1.

A unique result of the logic of dual closure is that the ranking it produces shows a branching pattern, because after the level of the cell (e.g. bacteria and archaea) there are two options to continue the hierarchy. One option is to go towards multicellular forms of bacteria (such as cyanobacteria). The other option is to continue in the direction of cell-in-cell construction of the eukaryotic cell. O-theory prefers to use the term hostcell rather than eukaryotic cell. This is because in many cases the nucleus of the cell, the 'karyos', is lost during cell division, only to be rebuilt later in each daughter cell. However, the cells that are part of the obligatory endosymbiotic relationship, such as mitochondria and chloroplasts, always remain present during cell division. This makes them better candidates as criteria for use in O-theory.

Once the hierarchy of the operators has been constructed, it can be used as a basis for analysing the organisation of all other systems resulting from interactions between operators, which in O-theory are called interaction systems.

How the use of dual closure can contribute to Big History

A major scientific goal of Big History is not only to organise historical knowledge, but also to create predictive models of cosmic development. As a basis for prediction, one needs a consistent model of levels of complexity. Dual closure provides such a model. Because of the dual closure, the operator hierarchy has fixed levels, while the systems involved are always operators. This means that the hierarchy is consistent in terms of both rules, levels and entities. Consistency also means that different people using dual closure will in principle always arrive at the same basic hierarchy.

Now that the operator hierarchy provides a ranking with a continuous series of fixed levels, one can consider extending this ranking to future types of operators. To extend a hierarchy one always needs some kind of periodicity. The study of periodicity in the operator hierarchy is an extensive topic that has been explored in previous work by the author (Jagers op Akkerhuis & van Straalen, 1999; Jagers op Akkerhuis, 2016). O-theory starts with dual closure steps as the first-order periodicity, and from this basis recognises higher-order periodicities.

One fundamental higher order periodicity is that of clusters. Put simply, all the operators in a cluster share the same type of building block. For example, in the cluster of atoms and molecules, all systems are either atoms or made up of atoms. Similarly, in the cluster of cellular operators, all systems are cells or are derived from cells, such as multicellular organisms, hostcells and multihostcellular organisms. Finally, in the memon cluster, only the neuron-memon has evolved so far (see Table 2).

Another fundamental higher order periodicity is that of so-called closure families. Across clusters, closure families group operators that share a common property. For example, hadrons (hadron cluster), molecules (atom cluster), multicellulars, and multihostcellular organisms (cell cluster) are all recognised as members of the so-called multi-operator closure family, because they always represent groups either of quarks (in the case of hadrons) or of preceding level operators (in all other cases).

The opportunity to explore the ability of higher order regularities to predict future operator types is new. However exciting it is, the derivation of accurate predictions remains a challenging area of research. It is beyond the scope of this paper to go into detail here, as higher order regularities would first need to be properly introduced and then combined to produce accurate predictions. How this can be done has been explored in previous work by the author (e.g. Jagers op Akkerhuis, 2001; Jagers op Akkerhuis, 2016; pp. 271-275). This is all work in progress. Simply put, the results so far suggest that the memon cluster will one day house a total of eight types of memon, the more complex of which are all technical in nature.

O-theory is not a theory of everything. Dual closures restrict the theory to operators. This allows three contributions to classical problems in Big History: (1) the classification of systems into two large non-overlapping groups, one containing the operators and the other containing all systems without dual closure, the so called interaction systems, (2) the construction of a consistent hierarchy with fixed levels of increasingly complex types of operators, (3) deductions leading to predictions of future memons. With the possibility of predicting future memons, O-theory provides big historians with a methodology for complying with the empirical cycle.

With the new approach, the operators, classically called small systems, can be organised in a consistent way. The challenge that remains is to organise what are classically called large systems, such as galaxies, black holes, stars, planets, meteorites, ecosystems and societies. All these systems are made up of interacting fundamental particles and/or interacting operators and are called interaction systems for this reason.

Both the operators and the interaction systems play their part in the development of the universe. It is therefore not possible to separate these systems causally. However, a conceptual separation is possible. In the context of Big History, I have proposed in previous work to distinguish between a 'phenotypic' and a 'genotypic' perspective (Jagers op Akkerhuis, 2019 p 67). The phenotypic perspective of the universe focuses on how the world as a whole appears to us. This perspective is represented by interaction systems. Observations of phenomena of interaction systems play a leading role in many epochal approaches in Big History. First there is a universe filled with plasma. Then clouds of matter form, which contract to form galaxies. Within the galaxies, black holes, stars and planets form. And then, on the planets, you can see ecosystems forming. Finally, in some ecosystems, roads, factories and cities mark the rise of culture. It will be intuitively clear that this focus on the world as a whole is complemented by a focus on the emergence of the operators. In retrospect, the naming of a phenotypic and genotypic perspective is confusing, as it has strong associations with biology. It may therefore be better to speak simply of interaction systems and operators. This is also closer to the use of macrosystems and microsystems proposed by Jantsch (1980, see also Table 2).

Obviously, interaction systems and operators offer inseparable perspectives on universal dynamics. At the same time, each perspective triggers its own thresholds. First, when focusing on interaction systems, they go through stages of development that result from different processes and can be viewed from different perspectives. For example, a star begins its life as a cloud of cosmic dust. The cloud contains fundamental particles, hadrons, as well as hydrogen and helium nuclei and atoms. Gravity then pulls the dust together. Depending on the amount of dust, a star or a black hole is born. The processes can take different paths. Inside stars, nuclear fusion produces larger types of atoms. Over time, a 'young' star can become an 'adult' star, and eventually an 'old' star. This may become a red giant before exploding. New secondary or even tertiary stars can form from the debris. Planets can also form. Once formed, a planet remains a planet. But on the planet, new processes can lead to the emergence of bacteria, followed by eukaryotic cells and eukaryotic multicellulars. These new inhabitants change the 'type' of the planet as a whole from a chemical system to an ecological system. Within these patterns of change, many different thresholds can be identified, caused by different processes and leading to different sequences and/or cycles of events. Secondly, by focusing on dual closures, the analyses are guided into a step-by-step approach to thresholds, each associated with the next type of operator. The use of dual closure implies that there is only one perspective. Depending on the perspective chosen, either interaction systems or operators, what is seen as a threshold is different.

Combining the interaction system and operator viewpoints opens up new possibilities. For example, based on operators and their hierarchy, interaction systems can be ranked according to the most complex operator present or dominant in the system. This is also logical from a functional point of view, as the most complex operator will generally tend to drive the salient processes that characterise the system. For example, a planet may change from being a chemosystem, hosting atoms and molecules, to an ecosystem, once it has also become home to bacteria. The 'type' of planet may then change again the moment eukaryotic cells appear. In this way, the operator hierarchy provides a tool for fine-tuning the classification of the type or 'developmental stage' of celestial bodies.

Discussion

How can O-theory contribute to Big History? Two contributions can be suggested here. The first focuses on the general approach taken by Big Historians. It starts with the question of what Big History is and what are the foundations of the discipline. Big History is often described as a scientific discipline that examines history from the Big Bang to the present, is multidisciplinary, looks for universal patterns or trends, and places humanity in a universal context. Given these characteristics, Big History can be seen as a broad canvas that connects well-known academic disciplines such as quantum physics, chemistry, biology, sociology and robotics. Researchers in each of these disciplines look for empirical evidence and cause-and-effect relationships that allow them to construct models and make testable predictions. In this way they follow the empirical cycle. Each discipline already covers its own local part of the broad canvas that connects all the sciences. This means that the contributions of Big History lie in the area of integrating frameworks and overarching patterns. What is the unique contribution of Big History to achieving such goals?

In attempting to answer this question, it is relevant to mention another discipline with a broad scope called systems science. Systems scientists study abstract commonalities between systems of all kinds, extending the scope to the universe and everything in it. This overlap suggests that

Big History and systems science are natural partners. Potentially, then, collaboration with systems scientists could help big historians achieve their goals of extracting large patterns, building overarching frameworks, and using their insights to guide scientific predictions. Because O-theory is rooted in systems science, it can help connect Big History with this broad discipline.

The second contribution of O-theory is in the area of thresholds. It has been suggested that 'the concept of thresholds in Big History is fatally flawed and ought to be abandoned' (Spier, 2022). This criticism is underpinned by four claims. The first is that there is no clear definition of what a threshold is. The second is that there are no clearly defined scientific criteria for setting a threshold. The third is that the proposed thresholds cannot be used to structure the whole of Big History. The fourth is the focus on increasing complexity while ignoring its decrease.

O-theory can help big historians translate the above criticisms into an advanced view of thresholds. To illustrate how this can be done, the four points raised by Spier can serve as an example. Using O-theory, there is clarity about what a threshold is, because each threshold is defined by a dual closure that leads from operators at level X to a more complex kind of operator at level X+1 (point 1). The way in which the dual closure distinguishes thresholds is abstract, but has its basis in both physics and systems theory (point 2). It is also relevant that O-theory does not exaggerate its goals. It focuses primarily on the operators and their hierarchy of emergence as a result of dual closures. It does not aim to organise the whole of Big History. Any broader application, such as considering an analysis of Big History based on interaction systems, can always refer to the ranking of the operator hierarchy as a basis (point 3). After all, what the operator hierarchy provides is an abstract, causal ranking. This ranking classifies systems according to the number of dual closures required for their emergence. By gaining or losing a dual closure, systems can move up or down this ranking. Both the possibility of gaining and losing dual closures are natural options in O-theory (point 4). These arguments show that O-theory can solve problems with the definition and interpretation of thresholds.

In summary, O-theory analyses phenomena in the universe from a systems perspective, which means that it uses the system concept as a mental tool. However, it does not generalise to a level where all things are systems. Instead, it distinguishes between types of systems, mainly operators and interaction systems. Starting from fundamental particles, increasingly complex operators result from dual closures. By offering a singular, causal perspective based on dual closure, the operator hierarchy provides a means of solving the problem that the rankings in Big History generally differ in the number of levels of complexity, in the types of entities, and in the rules for moving from one level to the next. The proposal is therefore to add the operator hierarchy to the theoretical toolbox of Big History. Next, the operators and their ranking can be used to analyse the world of interaction systems, which can be seen as the appearance of the universe at large. Since the ranking proposed by O-theory is logically consistent because it is based on dual closures, it offers possibilities for predicting future types of operators. Given all these new possibilities, the use of O-theory could help big historians to make their discipline not only an integrative, causal and transdisciplinary science, but also a predictive one.

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The Nexus of Storytelling and Collective Learning: A Synergistic Spark for Human Emergence

John Hasse
Rowan University

Correspondence | **John Hasse** hasse@rowan.edu
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Abstract: This paper explores the implications of storytelling as an essential complimentary concept to collective learning for labeling human emergence within the Big History thresholds framework. It proposes that the distinctively human cognitive capability for communicating explanatory descriptive narration (i.e., storytelling) was a foundational adaptive behavior and central driving force that launched humans into a unique evolutionary pathway as collective learners whose increasing knowledge has transformed the world. Storytelling provides a theorem for why human language skills and brain capacity increased so dramatically since our common ancestor with chimpanzees, and how our storytelling brain models our world through narratives that undergird human belief systems and facilitate complex social coordination. The paper outlines the symbiotic role that storytelling played in turning the cultural "ratchet" of collective learning throughout prehistoric times and its corresponding influence on prehistorical milestones. It goes on to explore the benefits of teaching storytelling as a complement to Big History threshold (6) collective learning and concludes with a look at the vulnerability of the human storytelling brain regarding its ability to unite or divide people through the power of narratives, whether they are factual or fictional. The paper invites the Big History community to consider embracing the emerging transdiscipline of storytelling within the Big History tent as synergistic complement to collective learning, that pulls together many Big History threads and which can help improve the effectiveness of telling Big History as a common human origin story for navigating the precarious prospects of the Anthropocene.

Introduction

The emergence of humans in the evolutionary story of the universe is a prominent topic within the canon of Big History. But what makes homo sapiens so substantially different from other large brainy animals that it warrants designation as one of only 8 threshold events in the scale of the evolution of the universe? When can we say that humans became quintessentially "human" and how did that transformation happen in an astonishingly brief few million years since diverging from a common ancestor with chimpanzees? What can explain how we gained the superpowers of human culture to spread around the world into wildly different environments, created a vast technologically advanced global civilizations and come to dominate the entire biosphere? Can a better understanding of what makes us uniquely human help us to negotiate the turbulent predicament we have created at this moment in history through the overshooting of our global planetary boundaries?

While generations of brilliant researchers and writers have been exploring these questions of human significance from a multitude of disciplinary perspectives employing continually developing advances the sciences, the maturing transdiscipline of Big History with its all-encompassing framework of time and space also has much to contribute to the discourse. Central to Big History's treatment of human emergence is the theory of "collective learning." Collective learning is the uniquely human ability to accumulate, increase and pass on knowledge between current and future generations thus giving rise to our unprecedented population growth trajectory, prodigious cultural creativity, technological advancement, and subsequent massive impact on the ecological functioning of the planet. Big History sectionalizes the evolution of the universe into eight thresholds of increasing complexity. Human emergence is the sixth threshold and is often branded with the label collective learning. While this paper engages the framework of Big History thresholds and continues the convention of human emergence as threshold (6) to maintain continuity, it recognizes the inherent limitations and subjectivity of using a numbering system to label such evolutionary thresholds (Spier, 2022). Regardless of the label, the human species' experiment with collective learning and the modern world that it has produced is arguably consequential in the story of the evolution of the universe.

Big History joins a collection of multiple works over the past half century that have reflected on the place of humanity within the larger epic narrative of the evolution of the universe. Carl Sagan (1980) presented the story of cosmic evolution as a captivating narrative portraying the universe's journey from the Big Bang to the emergence of life and human consciousness. Jantsch (1980) presented self-organization as a fundamental principle that underlies the emergence and development of complex systems within the universe. He emphasized the interconnectedness and interdependence of systems at different levels, from subatomic particles to galaxies, and from individual organisms to social structures. Jantsch proposed that humans possess a unique capacity for conscious self-reflection and intentional action, enabling them to participate actively in the co-evolution of their societies and shape their own future. In contrast to thresholds of increasing complexity, Jantsch organizes the line of thought into four periods: Cosmos Evolution (Astronomy & Physics): Life Evolution (Biology & Earth sciences): Human Evolution (Anthropology): and Civilization (regular history). Preston Cloud's "Cosmos, Earth and man" (Cloud, 1980), explores the intricate relationship between humanity and the universe, guiding readers through a profound reflection on humanity's place in the vastness of space to contemplate humanity's role in the grand scheme of the cosmos. Swimme and Berry's "The Universe Story" (1992) narrates the history of the universe from its origins, emphasizing the interconnectedness of all phenomena and the emergence of complexity, consciousness, and ecological awareness. A central question explored across these works and many others, notwithstanding, is how to place the significance of humanity within the universe.

While my academic preparation as a land use geographer did not include training in human evolution, paleolinguistics or the cognitive development of the human brain, the deeply transdisciplinary field of Big History grants license to practitioners to step into areas outside of their expertise in order to explore broader interdisciplinary connections between often disparate fields. What my geography disciplinary preparation has given me is big picture thinking and skills in identifying the patterns that connect seemingly independent component parts into complex functional systems. I also bring to this paper more than 15 years' worth of experience teaching the fundamentals of Big History within an introductory undergraduate geography class and the spark of ideas presented herein emerged out teaching the evolution of humans within the Big History context. When the call for a special edition of the Journal of Big History with the theme of "Big History-Reexamining Fundamentals" came, I felt compelled to share insights gained through teaching Big History and especially regarding the essence and meaning of human emergence developing ideas that have connected exceedingly well with students on the significance of being a homo sapien.

Threshold (6): Collective Learning-Human Emergence

The course through which many of the insights discussed in this paper have arisen is titled *Earth, People & the Environment* (EPE). A simple formula describing the class is EPE = Big History + Maps (i.e., physical/human geography) + Anthropocene. The purpose of this general education course is to orient students in their time and place within the changing world they will be entering. I developed and began teaching EPE in 2006 by offering two sections with a combined total of 52 students. During this past academic year (2022-2023) Rowan University offered 35 sections of EPE taught by thirteen different faculty for a total of 1,256 students enrolled for the year. The full story of the success of EPE for teaching Big History will need to be saved for a different article that will focus on Big History pedagogy through a geographic lens. Notwithstanding, as EPE has evolved at Rowan over the past decade it has been a living laboratory for how students assimilate a course that places their own lives within the narrative of the larger arc of life on our remarkable planet during a time of critical urgency. What has been especially rewarding with this class is that students have contributed to the evolution of discourse over the years as they have helped to expand ideas regarding the process of human emergence and significance of homo sapiens in the grand narrative of the universe.

When the course gets to human emergence (threshold (6) in Christian's framework) it invariably generates widespread and enthusiastic engagement among students. We explore the questions of what distinguishes "us" from other species. We explore the physical changes of upright walking, opposable thumbs, brain enlargement, tool usage and fire. We examine the branching of different hominine species, brain enlargement, climate change throughout the Pleistocene and the waves of human migration out of the African motherland. We dive into language, settlements, and artifacts of artistic and ritualistic expression. We organize these ideas and lay out the theory of *collective learning* as a key concept in Big History (Baker, 2015).

Collective learning is the Big History theory originated by David Christian that provides an explanatory mechanism for cultural evolution that brings human history into a compatible framework with the increasing cosmological complexity of the emergent universe. Collective learning is the process of knowledge being shared by one member of a community with other community members and/or with succeeding generations so that it can build and accumulate more knowledge than any single individual could do on their own within a single lifetime. Christian describes collective learning as "our unique capacity for sharing and accumulating information" (2018, p.173). It is an "information ratchet" that "stores information in many minds over many generations, so that information can outlive the individual who created it" (Christian, 2015, p.30). With collective learning, "new information accumulates at the level of the community and even the species" (Christian, 2015, p.30). "The ecological knowledge contributed to that pool by each individual can survive long after his or her death. So, knowledge and skills can accumulate non-genetically from generation to generation, and each individual has access to the stored knowledge of many previous generations" (Christian, 2011, p.241). David Baker has written on collective learning as a foundational unifying theme within Big History in the context of the rise of complexity in the universe:

> "Collective learning… has allowed humans to exploit our ecological niches with increasing efficiency and allowed us to largely harness the energy flows of the planet and the Sun. Through foraging, agriculture, and heavy industry collective learning has raised the carrying capacity of the population, allowing for more potential innovators, who in turn raised the carrying capacity, thus creating even more innovation. Gradually, over 250,000 years of humanity, the population has risen and we have generated increasingly complex societies and have developed the capacity to harness an enormous amount of energy. In terms of the wider rise of complexity and in processes of Universal Darwinism, collective learning is the summit of the process (Baker, 2015, p.82).

David Christian distinguishes collective learning as analogous to a Darwinian adaptive process within human culture.

> "Humans as individuals are not that much cleverer than chimps or Neanderthals; but as a species we are vastly more creative because our knowledge is shared within and between generations. All in all, collective learning is such a powerful adaptive mechanism that one might argue it plays a role in human history analogous to that of natural selection in the histories of other organisms" (Christian, 2011, p.243).

The theory of collective learning provides a compelling mechanism for the increase in cumulative knowledge that a given social group possesses, how that knowledge accumulates and increases in pace over time, and how the technological application of that increasing knowledge resulted in homo sapiens continually finding new means of exploiting energy and other resources.

A Big Blank Spot on the Collective Learning Map

As sagacious as the collective learning thesis is, one can nevertheless be left with a sense that the idea on its own is limited as a standalone label for capturing the uniquely essential nature of humanity. While collective learning does provide a compelling framework, the theory only goes so far in capturing the full essence of the human enterprise. There are indispensable aspects human existence that are not well captured by the term 'collective learning'. Indeed, there are significant gaps in collective learning theory's ability to provide a satisfying explanatory mechanism for many essential human behaviors. Whereas the historical outcomes of collective learning have been a major focus of the Big History scholarly work to date and are thus most fully developed, an explanation for how collective learning came to be, how it functions, how it collects, processes, stores and disperses knowledge learned and how it has changed over time in lockstep with the evolving human brain, has been less explored. Christian does make reference to the antecedents to collective learning as being the result of "evolution of an exceptionally powerful form of language that allows us to exchange ideas and insights with such precision and in such volume that they can accumulate in collective memory "(Christian, 2018, p. 15). Additionally, Christian, Brown, and Benjamin describe how human symbolic language allowed "the ability to share in great detail and precision what each individual learns" (Christian et al., 2014, p.89). But there has been far less exploration in Big History discourse as to what drove the evolution of the human brain to be so highly developed, manipulative, perceptive and at such a high level of neurological capacity that symbolic language and collective learning could begin to take place? As Baker acknowledges, there is a "big blank spot on the map …[regarding]... what ability, origin, and selection pressure caused collective learning" (Baker, 2015b, p.304).

A big blank spot on the map is too enticing for a geographer to ignore and thus we dig into this blank spot by exploring what systems undergird collective learning. For collective learning to take place it must have an underlying system for collecting information, conceptualizing information into useful knowledge, distilling the information into experience and extracting the wisdom of the knowledge. There must be a system for information storage and retrieval, transfer between information keepers and a system of knowledge dissemination to the community. And for a culture to be meaningfully employing collective learning there must be a mechanism for cultural motivation for agency and action. Thus far there has been little written about the underlying mechanisms through which collective learning takes place and how it would have evolved over time.

My EPE students have picked up on the big blank spot regarding the limitations of the concept of collective learning. As powerful as collective learning theory is, students have nonetheless questioned whether collective learning on its own is adequate in providing a satisfying explanation for what makes humans uniquely human beyond their role as accumulators of knowledge. To some students, the terminology of collective learning was characterized as overly academic and insufficient for conveying complex behaviors, cultural expressions and philosophical and spiritual insights through which humans live their lives, interact with one another, and interface with the other species in which we share the biosphere. Students have pointed out that not only do humans learn collectively, but they also worship collectively, they celebrate collectively, they play collectively, they perform collectively, they laugh together, and they share emotional responses with one another. Humans also work collectively in society, they fight wars collectively, and they express art to other members of one's community. These are also defining characteristics of what distinguishes humans from other species that are not adequately captured by the Big History label as humans as the collective learning species.

Perhaps most significantly, collective learning as the label for human emergence does not convey the ability of humans to make meaning. As one EPE student postulated, collective learning theory on its own might be sufficient to describe the evolution of the purely logical (and science fiction) brains of Vulcans from Star Trek but humans have a lot more than rational logic driving our behavior that can be explained by accumulated knowledge alone. Furthermore, the explanation for how collective learning occurs is attributed to "joining individual learning to a sufficiently powerful system of communication" (Christian, 2015, p.71). Clearly collective learning can only be possible with symbolic spoken language of homo sapiens but there has been little development in the Big History literature for what takes place with human language that results in collective learning taking place compared with other language systems of other species that don't collectively learn. How is the knowledge that is collectively learned, shared, transmitted, stored, recalled, managed, assimilated, and leveraged into behaviors that sustain life and that can be passed down to benefit subsequent generations?

In exploring this discourse, I and some Rowan colleagues that also teach EPE began contemplating other themes that could complement collective learning to explain what uniquely drives many human behaviors, what motivates our actions, and how those actions have shaped the specific events of history. Bearing in mind that in an exceptionally short time span of only several million years of evolution, homo sapiens have gone through a remarkable biological development of cognitive complexification that has increased the human brain volume threefold resulting in human mind becoming vastly different in what it does and how it works and how humans behave than our closest evolutionary cousins, the chimpanzee, and bonobos. What drove the human brain to expand so rapidly, to develop symbolic language, to increase cognitive perception and to develop conscious self-reflection and awareness? To begin to fill in Baker's big blank spot in collective learning theory, we might explore the divergence of hominins from chimpanzees.

What distinguishes human language from that of other primates?

When discussing the differences between humans and chimpanzees, students will invariably say that 'chimps cannot talk like humans.' I respond, "do chimps have language"? If one takes a broad definition of language as a 'a systematic means of communicating ideas or feelings using conventionalized signs, sounds, gestures, or marks having understood meanings' (Miriam-Webster, 2023), then yes, other primates including chimps have been shown to have fairly sophisticated language. Vervet monkeys were shown to have three distinct calls for warning from danger from pythons, lions, and eagles. When recordings of the calls were replayed, members of the group responded in an appropriate way for the predator indicated in the call (Seyfarth et al., 1980). Noted primatologist Jane Goodall documented the nuanced communications of chimpanzees in the wild over five decades of her research of chimpanzees in the wild (1986, 2010). She revealed that chimps use gestures, pant-hooting grunts, and other vocalizations to communicate needs, wants, emotions, warnings, etc. demonstrating many communicative behaviors analogous with human communication. Goodall's work has pioneered chimp behavioral research in the field and inspired generations of other researchers who are developing increasing knowledge about chimp communication and behavior revealing complex language capabilities including communicative interactions and comprehension of symbol-referent relationships (Savage-RUmbaugh et al., 1986). Other researchers have explored the extensiveness of great ape gestural communication (Moore, 2015;, Townsend et al., 2017). Hobaiter and Byrne (2011, 2014), have been developing a dictionary of chimp vocabulary observing over 60 gestural indications of distinct units of communication. The dictionary demonstrated that chimps have the cognitive ability to comprehend/model systematic symbolic meanings to those communication units. Girard-Buttoz et al. (2022) documented 390 unique vocal sequences produced by chimpanzees in not only single vocal units but also in two-unit sequences (bigrams), which in turn were embedded into three-unit sequences (trigrams). Schel et al. (2013) observed that chimps, when presented with the threat of a python (a rubber model in the experiment), vocally communicated alarm calls intentionality directing their communication to arriving community members while visually monitoring of the arriving member's reaction and only stopping when the members were safe thus demonstrating goal-directed behavior. Leroux et. al. (2023) performed a similarly designed python study finding that the specific sequential combination of calls resulted in different reactions than the calls made individually or in a different sequence demonstrating that the cognitive building-blocks facilitating syntax may have been present in our last common ancestor with chimpanzees.

The Leroux study probably serves as a good example of the upper level of language complexity for combining multiple "words" together for chimp communication of ideas in the wild. A chimp can combine three words to communicate, in essence, the equivalent of "danger - python - caution". One can see the evolutionary benefit for chimps to be able to communicate this information to one another. But those three ideas clustered as a combined unit of information seem to be the limit of conceptual communication complexity that a chimp can cognitively model. Chimps do not have a need to string more than a few words together to be able to survive just fine in their social structure within their jungle habitats. Chimps arguably have functional language that they use for communicating many important purposes such as warning, grooming, soliciting sex, expressing anger, eating, etc. with no more than a trigram combination level of communication. However, with a trigram maximum, chimpanzee language is not able to explain more complex ideas or narrate actions not so much because they don't have the linguistic capabilities but because they don't have the cognitive equipment to model those ideas or make conscious sense of a sequence of more than a few words strung together. Chimp brains do not have the neural circuitry to think and visualize in explanatory narratives, remember explanatory narratives, understand someone else's explanatory narratives, or take action based on the understanding of explanatory narratives. Simply put, chimpanzees cannot tell stories and cannot understand stories told to them and thus cannot make larger symbolic meaning of explanations and narrations or have agency based on story.

In contrast, humans can string many hundreds of communication units together to create a much more sophisticated cognitive model of the world around them and can conceptualize the sequence of events experienced within that world into meaningful ideas. The brainpower for human communication necessitates not only the language skills for making and interpreting the sounds and gestures of speech, but more significantly, it requires the cognitive modeling of the ideas behind the communicated information. Homo sapien brains can do all those things because we've evolved the adaptive behavior of *storytelling*. We've developed the cognitive circuitry to model our complex world into narratives in which we visualize and explain what happened, transfer those cognitive models through a sequence of multiple communication units that convey those sequence of events, decode those sounds and gestures within the listener back into visual cognitive models of what happened and ultimately derive deeper meanings to the narrative sequence. As far as we know, no other species models the world through storytelling. Homo sapiens, as Jonathan Gottshall (2012) has posited, can be thought of as the *storytelling animal*. While many species could arguably be considered sapient at some level, homo sapiens might be more appropriately labeled *homo historicus*, the storytelling human.

For the rest of this paper, I use the term *storytelling* as shorthand not just for the spoken account of a narrative but for the entire package of human adaptations related to our unique narrative explanatory cognitive modeling system through which we experience the world. We are different from other primates because we think in narrative explanatory models, we share those narrative thoughts through our sophisticated largely oral language communication system, we decode the explanatory narrative model in the brain of the listener which visualizes the narration in their imagination and derives the emergent meanings encoded in the narrative.

Of course, human language has many more functions than solely facilitating storytelling. Like our primate cousins, human language is used for warning, grooming, soliciting sex, expressing anger, communicating about food and so on. Nevertheless, storytelling is arguably the main behavior that distinguishes us from other species. One can see the analogy of the evolution of the feather by Mesozoic dinosaurs which employed feathers to perform multiple functions such as to insulate, shed water and display mating information etc. But there is a strong case to be made that the most significant evolutionary application of the feather was to facilitate the adaptive behavior of self-powered flight. Paleontologists are discovering that many dinosaur species possessed feathers including velociraptors (Turner et al., 2007), but only archaeopteryx used feathers for a new adaptive behavior of self-powered flight launching a revolution in a successful adaptive behavior that has subsequently differentiated into 11,000 species of modern birds. Many animals have a form of language but only humans have evolved language into the novel behavior of storytelling which has been differentiating ever since into myriads of global cultures today. If storytelling is indeed an adaptive behavior, it would have had to emerge through an incremental process of Darwinian natural selection.

The Emergence of Storytelling: A Thought Experiment

A thought experiment can walk one through that transition from ancestral pre-human with a comparable trigram language capability of modern chimps to the storytelling hominid ancestor of modern humans. We begin our mental exercise at some point after the last common chimp human ancestors diverged into ancestral hominids and ancestral chimpanzees. What would be the outcome when one of our hominid ancestors began incrementally increasing the number of units of language communication strung together beyond three. Perhaps they were able to add a locational dimension to their communication so that "danger-python-caution" which we've established chimps essentially can communicate became "danger-python-***waterhole***-caution". No doubt many mammals have locational capabilities within their brains. Elephants can remember and return to watering holes that they have not been to in years (Moss, 2012). An elephant can lead others to the place it remembers but it can't abstractly communicate that place to another. So, adding an abstract symbolization of a specific location is a significant step in cognitive modeling of language development. One needs to first abstract the idea of a specific location, symbolize their location in the environment and then symbolically communicate that modeled geographic location to the listener in a way that they can decode the location. No small task for an evolving hominin brain.

The single addition of an abstraction of locational information to the sequence of communication units could have a beneficial outcome for the individual receiving the information, as well as their family or potentially the whole community. For example, it would be beneficial for the band if that sequence of communication "danger - python - waterhole - caution" was shared with members of the community that were not at the scene so that more community members could avoid the waterhole or it could be beneficial if a member heard it from someone other than the original observer thus increasing the number of community members that benefit by this potentially life-saving information. This is only one "word" more complex than modern chimp language but already hinting at the beginnings of proto-collective learning. Information gained by one member could benefit many other members of the community without them directly experiencing the event. But perhaps more significant than the language complexification of stringing 4 words together is the increasingly complex cognitive modeling necessary for that extra added word to be meaningful. The development of cognitive neural networks representing an abstraction of an event of significance occurring in a specific location is a big leap in complexity beyond chimp cognition and likely would have taken extensive generations of natural selection and the development of unique cognitive modules for abstracting locational comprehension in symbolic communication.

Adding the capability for a 5th word to the string of communicated information continues the complexification. Let's say the fifth word personally identifies an individual community member in the band with a unique vocal call. Now we need to cognitively model the idea of individual identity through some kind of unique symbolic representation. The idea of a personal identifying name would need to be added to the proto-human language tool kit. Let's say Fred was the one who observed the python and communicated that to others as it was happening. If a first-person listener to Fred later passed the information to another who did not observe it directly using Fred's name to identify the individual engaged in the action the communication would add a 5th word to become "Fred-danger-python-waterhole-caution." Now we need to have a way of changing the meaning to past tense to signify 'was cautious' (or was not cautious as we shall see) initiating the need for developing grammatical tenses in language. Somewhere in that ability to add a few additional words of linguistic complexity proto humans would begin to have a cognitive abstraction of the experience of the world that begins to be uniquely human. At some point human brains go from living purely in the moment like our chimpanzee cousins (e.g., communicating the immediate wants and warnings driven primarily by instinct) to a brain that begins abstracting the moment into a narrative model that can first be created in one individual's mind, then be shared with another so they can comprehend that narrative explanation, which can then be transferred to the minds of a third or fourth or 20th person without direct observation. We are beginning to see the need for distinguishing between in-the-moment communication and communicating a conceptualization of past event as the ratchet of communication complexification is increased.

Adding the capacity for clustering six words of information communication takes an even larger leap toward distinguishing human language from chimp language. In our thought experiment we can imagine abstracting the occurrence of death. Certainly, the concept of death is experienced by chimpanzees in a manner accessible to the chimp cognitive capabilities. Jane Goodall observed on a number of occasions chimpanzees exhibiting behavior that suggested that chimpanzees were mourning the death of members of the community. In one instance a chimp child was observed tending her dying mother (Goodall, 2010). In another example a chimp community that had experienced the recent death of a chimp child was observed exhibiting striking behaviors of mourning (King, 2016). These examples demonstrate that chimps emotionally respond to death and instinctively avoid dying so death is arguably a salient concept to a chimp. But chimps don't have the language capability or the cognitive ability to abstract a narrative model of the idea of death. A chimp can likely feel the emotion of loss but can't say to another "my child died I'm sad." Imagine adding to our proto human language the idea of death to our string of communicated words.

"Danger-python-waterhole-caution-Fred-dead".

With the addition of this sixth word, something larger emerges than the simple meaning of the individual six words combined at face value. There is a deeper meaning conveyed that taps into the previous experiences and emotions of the listeners so that the narrative carries not only technical information for what happened through the six-word cluster but evokes a deeper significance of what happened. It's at this stage where the ability of the human brain to abstract events through narration and then derive meaning from that cluster of words that we cross fully into the realm of storytelling.

To illustrate the point that a story carries deeper meaning than the face value of the communicated words, we can invoke the urban legend of novelist Ernest Hemmingway writing the world's shortest story. Ernest Hemmingway was challenged by friends to compose a story with the fewest number of words possible. His response was to pen the following six-word story: "For sale, baby shoes, never worn." (Gottschall, 2021, p. 62) While the story itself has been questioned as to whether it can be authentically attributable to Hemingway, the six-word tale nevertheless captures the essence of what elevates a sequence of words to the level of becoming a story. A story typically carries something greater than the technical accounting of something that takes place. The baby shoes story carries larger implications or meaning as to the significance of why the shoes are for sale implying death of an infant, the sorrow of parents who are selling the shoes and the lost potential to a life that will never be lived. The six words that make up the story say nothing about these deeper thoughts, but the listeners inject their own previous experiences and cognitive pathways to extract a larger meaning. This is a remarkable emergent property of human storytelling that becomes a narrative cognitive hologram for experiencing reality through narration. The human brain had to evolve the ability to conceptualize what's important about what happened and identify the so-what of what was communicated in the narration beyond the simple meanings of the individual words themselves. Like a star igniting from goldilocks conditions of gravity compressing hydrogen gas past the threshold of igniting thermonuclear fusion, the human brain crosses the threshold of chaining multiple words together until they animate explanatory narrative sequence of communication units into storylines that communicates a larger "so-what" of what takes place and the emotional meanings inferred.

A modern chimp cannot say "danger-python-waterhole-caution-Fred-dead". More importantly, a chimp brain cannot think "danger-python-waterhole-caution-Fred-dead" and understand the deeper significance of those sequenced words. But at one point after perhaps thousands of generations of incremental changes slowly increasing the number of words clustered into chains of ideas and the necessary cognitive architecture, one of our direct human ancestors began to express and comprehend explanatory narratives and the threshold into the new adaptive behavior of storytelling was crossed. In our thought experiment, storytelling became a central evolutionary driver explaining why our modern symbolic language developed with a capacity for vocabularies of thousands of words and our sophisticated recursive grammatical capabilities as necessary tools for communicating increasingly complex narrative models. We invented storytelling because narrative explanatory communication is an incredibly powerful behavior that models ideas and understandings of an infinitely complex world that, when symbiotically allied with collective learning, have come to transform the entire geo-biochemical functioning of the planet.

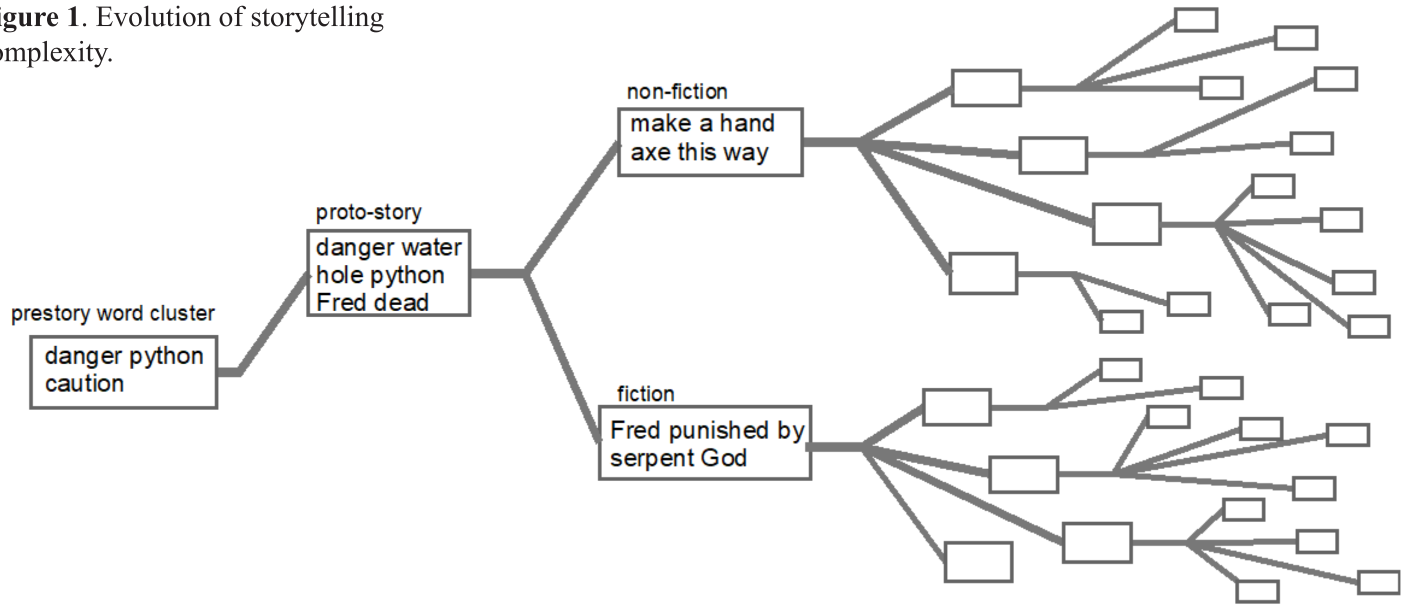
Building the Storytelling Mind

If storytelling is the adaptive niche of humans, then it would have evolved in a Darwinian fashion from the very simplest recounting of an event at the waterhole to an increasingly more sophisticated and nuanced capability for communicating more and more complex ideas through narrative. As our mind experiment continues, humans would have refined stories to be increasingly effective for avoiding danger and death or for finding or acquiring food. Telling stories would facilitate transferring learned behaviors such as the sequence in which to nap stone tools, fire making techniques and how to hunt more successfully. Each incremental variation in the usage of story for enhancing survival would potentially be passed on if it proved beneficial to the survival of the species. Perhaps natural selection of story would be amplified with sexual selection for more persuasive storytelling performances. Over the course of tens of thousands of generations, the evolution of storytelling would have resulted in stories differentiating into multiple categories or *story species* (figure 1) that served different functions within culture. Languages would have evolved in sophistication and vocabulary to better capture the nuances and timing of sequences within the narrative, who was doing the action, whether the action happened in the near past, long ago or what might happen in the future.

Along with the evolution of the vocalization capabilities of spoken speech that would be needed to convey the intricacies of story, the human brain would have had to evolve the cerebral architecture and neural pathways to perform all the functions necessary for increasingly sophisticated storytelling and story listening. The brain would have to develop the neural pathways to abstract symbolization of agents and actions in the world around them. The storytelling brain would need to develop the ability to visually imagine the narrative actions within the mind eye as well as the capacity to comprehend outcomes and consequences as cognitive models. A storytelling brain would require an extensive memory storage and retrieval system all with a highly plastic capacity for learning potentially not only thousands of words and the meanings behind them but the narrative themes and thematic meanings. The cerebral requirements for storytelling have resulted in the evolution of the human brain that has perhaps 86 billion neurons (Azevedo et al., 2009), three times the volume and number of neurons of our closest biological relative, the chimpanzee.

Comparing the relative simplicity of chimpanzee's non-storytelling cognitive modeling with that of the highly

Figure 1. Evolution of storytelling complexity.



Note: As an adaptive behavior, storytelling would have increased in complexity in a coevolutionary fashion with the increasing capacity of the brain to better model the world through a sequential cluster of words that abstracts meaningful understanding of what is communicated. Storytelling would have evolved from simple short descriptions of what recently happened to increasingly complex stories that could share more nuanced essential cultural knowledge. In this manner storytelling would have differentiated into different story categories and subcategories resulting in a spectrum of nonfictional and fictional story species.

complex cognitive sophistication of a modern story-telling human, one appreciates the massive amount of evolutionary change that occurred in only a few million years to result in a brain triple the capacity of our closest living evolutionary cousins. Figure 2 diagrams a schematic of the cognitive modeling of a modern chimp versus the cognitive modeling of a modern human brain. The Chimp brain (1) creates a cognitive model of reality from a combination of sources including (a) the direct sensory input of its five senses, (b) its personal memory of past experiences, (c) instinctual spontaneous drives, (d) social community input, and (e) the environment. This cognitive model is then provided to the module in which an individual experiences and interacts back with the world. I call this module a *personal conscious paradigm*. I have it labeled with a VR in the diagram since individuals experience the conscious modeling of reality provided by the brain as a sort of virtual reality that one may experience by putting on a VR headset. British writer Will Storr writes about the science behind storytelling describing the way the brain invokes the experience of consciousness:

> It feels as if we're looking out of our skulls, observing reality directly and without impediment. But this is not the case. The world we experience as 'out there' is actually a reconstruction of reality that is built inside our heads. It's an act of creation by the storytelling brain. This is how it works. You walk into a room. Your brain predicts what the scene should look and sound and feel like, then it generates a hallucination based on these predictions. It's this hallucination that you experience as the world around you (Storr, 2020, p. 21).

In the case of a chimp brain, that experience of its hallucination of reality is going to be based on its input of senses and its instincts. A chimp experiences life in the moment within its environment and among its community with perhaps some experiential memories, input from other community members and certainly emotions. But a chimp's brain is unable to abstract a deeper meaning about the events going on. A chimp's personal conscious paradigm (VR) is its experience of reality at any moment and that present tense hallucination will be the basis that drives that chimp's individual actions (f). A chimp's cognitive model of reality is quite complex among all mammals, but it is far simpler compared with the brain of a human.

A human cognitive model of reality (labeled (2) in figure 2) is far more complex. While humans have essentially the same inputs of: (g) senses, (h) personal memory, (i) instinct (although atrophied), and (j) environment, humans have a variation of model inputs from their community which I have depicted as (k) close personal relations and (l) larger cultural community. A human's input from close relations and larger community enters the human brain mostly through language in the form of storylines. The stories can be as small as story fragments or as large as hours-long epics. The storytelling cognitive module (labeled (3) in figure 2) is the human storytelling processing center. It takes symbolic language input (i.e., sounds and gestures) and turns it into hallucinations of what the speaker is thinking through their language communication. The story module looks for characters that manifest actions, plots, and settings. It looks for patterns of narrative that fit its internal library of archetypal characters, processes, and narrative themes. The storytelling module draws on its vast memory of experiences and stories told over their lifetime to make sense and meaning out of the inputs and projects possible consequences into the outcomes. The storytelling brain draws on emotions and even ties into the motor circuitry of the body to create the vivid hallucination of a story as an experience that can be as viscerally real as the hallucination of reality that the brain creates from its sensory input alone.

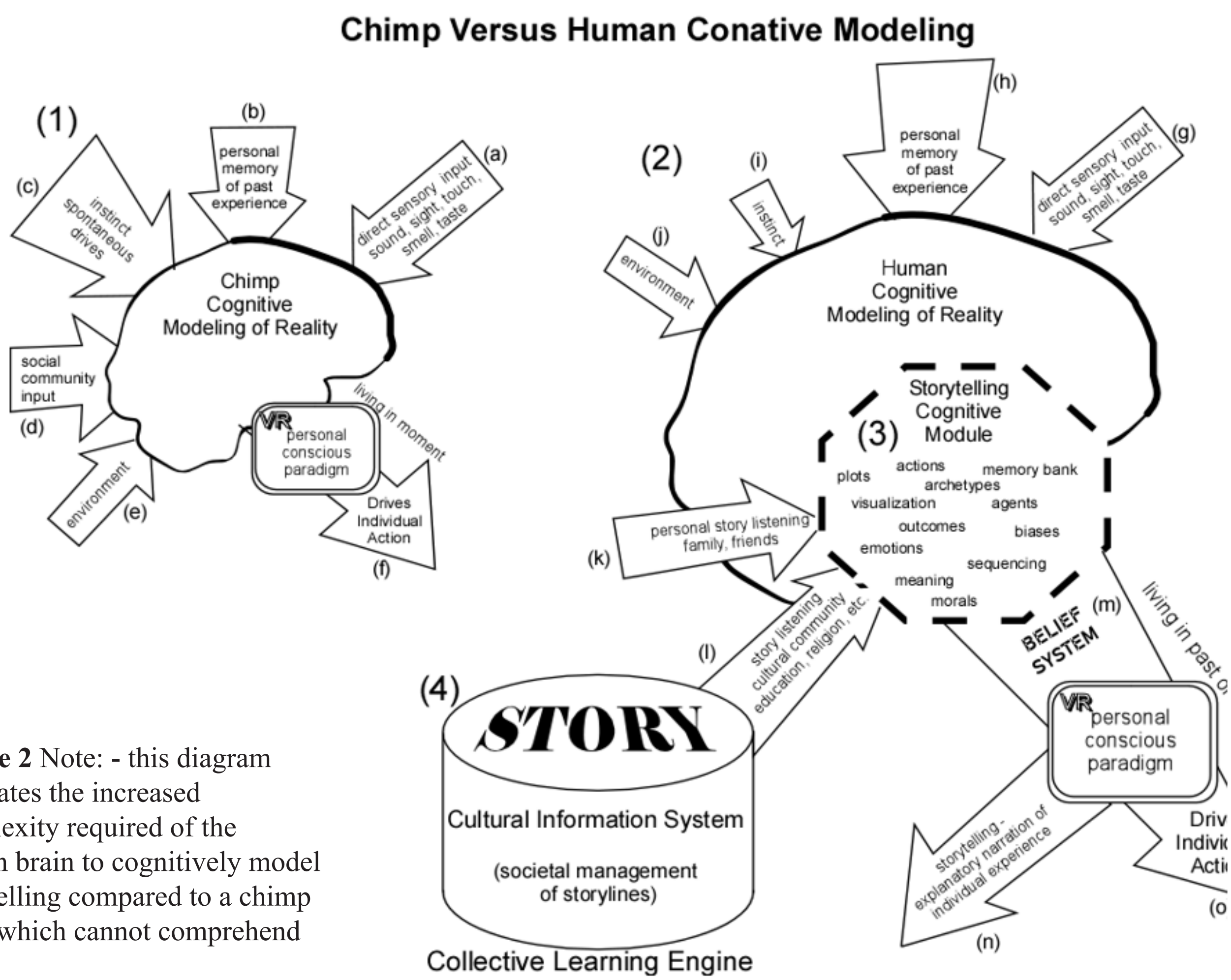


Figure 2 Note: - this diagram illustrates the increased complexity required of the human brain to cognitively model storytelling compared to a chimp brain which cannot comprehend story.

The human brain with its storytelling module takes all the story inputs, experiences, memories, and communications from other members, minimizes information and storylines that it deems least important or wrong and amplifies the storylines that it deems to be most valid through experience or provided by respective authorities and creates a living narrative belief system (m) or *meta-story* through which it experiences its personal conscious paradigm (VR). The personal conscious paradigm of a human (its hallucination of reality) is then available to send stories back to the community through their own storytelling faculties (n). Likewise, human actions (o) will be driven by an individual's personal conscious paradigm. Both chimps and humans will have their VR personal conscious paradigm experience of reality, but a human's experience is processed through its story cognitive module which will infuse narrative meaning on every conscious hallucination generated and thus will drive actions based on narrative beliefs. A human will live his whole life experiencing life in narratives and making beliefs out of narratives and acting out of those beliefs. But a chimp has no narrative experience of reality and no beliefs, living much more connected to the direct sensory input and takes action based on its instinctual response to the world around them. As historian Yuval Noah Harari writes "You could never convince a monkey to give you a banana by promising him limitless bananas after death in monkey heaven" (Harari, 2014, p.33).

The final part of the proposed human cognitive model is the community story system (labeled (4) in figure 1). Story is primarily a system of sharing information about what happened or how to understand something but is meaningless outside of the context of the community members who share the story. The human brain evolved with language and story shared through oral and gestural communication. So, the storytelling module is shaped by the spoken language of a given culture to keep the storylines in the oral memory banks of multiple community members. The information is transferred through storytelling as stories are repeated throughout years and among generations of community members. The keepers of the storylines are the keepers of a culture's knowledge. Storytelling is the cultural information system of a society and the common thread to song, music, dance, and ritual making. Stories are the mechanisms through which a society works together on larger tasks such as facilitating a tribal group's ability to hunt and forage, an agrarian society's ability to coordinate agricultural production or larger social projects of civilizations such as road making or going to war. The cultural information system of story is the engine through which collective learning is manifest. Science writer Gia Vince captures the essence of stories nicely:

> "[stories] work as collective memory banks, storing detailed cultural information encoded in narrative. Stories help cultural knowledge to linger in the collective memory long enough to accumulate and evolve, and they provide a reliable energy-efficient way of transmitting complex, context rich cultural information widely. As human cultural adaptation-our brains evolved with reflexive use of narrative as part of our cognition. Stories shaped our minds, our societies, and our interaction with the environment. Stories saved our lives." (Vince, 2020, p.82)

Once humans could cognitively model narrative explanations of our experience through storytelling, we could leverage our unique communication system to transmit complex information about phenomena and actions experienced by an individual to result in a meaningful response by others in the community who received that information. As the human storytelling/listening brain evolved in complexity it would have eventually reached a stage of awareness and understanding of characters and actions that one's own life would be experienced as a real time story where one's ego becomes the protagonist of their own life narrative as in a role-playing video game (RPG). This might suggest that human consciousness itself may be a variation of the storytelling reality modeling cognitive circuitry.

An Emerging Science of Storytelling

As far as we know, humans are the only species that has anything like this ability for cognitive narrative explanatory modeling of reality. Storytelling has emerged as something novel among the earth's species and has opened a whole new set of subsequent emergent possibilities through cultural evolution. As a thought experiment, the incremental development of storytelling as a driver of human evolution may be worthy of discourse among big historians, but what evidence is there to support the proposition that storytelling is central to what makes humans human? Over the past several decades many different lines of research from widely divergent fields have provided compelling components to what may be emerging as a transdisciplinary science of storytelling.

The study of primate communication among homo sapien's closest biological cousins as previously referenced provides a starting point since the earliest hominins would have likely had a similar cognitive capacity. While there is likely no direct archeological evidence that can trace the evolution of combining word clusters into narratives, computer simulations suggest that the ability for symbolic communication could have emerged spontaneously under natural selection (Grouchy et al., 2016). Researchers are using techniques on the modern human brain such as fMRI brain scans of subjects recreating increasingly sophisticated stone tools to suggest neural representation of action grammars of human behavior implying incremental coevolution of language and technology (Stout et al., 2021, Arbib et al., 2023).

Fisher (2006) presents a "narrative intelligence hypothesis," suggesting that storytelling and symbolic thought were key factors in human evolution, enabling the transmission of complex information and facilitating cooperation. Storytelling and imaginative abilities would have been selected for during human evolution, contributing to our cognitive and social development (Lombardo, 2008). Barham & Everett (2021) make the case for the deep evolutionary foundation for hominin symbol use concluding that symbol-based language is expressed materially in arbitrary social conventions that permeate the technologies of Homo erectus and its descendants. Deacon (1997) investigated the co-evolution of language, storytelling, and the human brain arguing that storytelling played a central role in the development of symbolic thinking and the unique cognitive abilities of humans. Salillas (2021) explored the evolutionary roots of storytelling and its adaptive functions discussing how storytelling enhances social cognition, fosters cooperation, and transmits cultural knowledge across generations. Hogan (2011) explores the universality of narrative structures and their connections to human emotions. Gottschall and Wilson (2005) delve into the evolutionary significance of storytelling, arguing that narratives have played an important role in shaping human behavior and culture.

Stephen Pinker (1997) in his influential book explored various aspects of human cognition, including language and storytelling, from an evolutionary perspective, offering insights into the adaptive functions of narrative. Boyd and Richerson (1985) explore the role of cultural evolution in human adaptation, shedding light on how storytelling could have contributed to the transmission of cultural knowledge and cooperation within groups. They refined their concepts (Richerson & Boyd, 2005) by exploring the interplay between genes and culture in human evolution, emphasizing the importance of cultural transmission, including storytelling, in shaping human behavior and societies. Boyd (2009) expanded on the evolutionary significance of storytelling and argued that narratives have played a crucial role in human cognitive development, social cohesion, and cultural transmission. McAdams (2018) discusses the role of narrative identity in human development, connecting it to the evolution of storytelling as a mechanism for constructing and transmitting personal and collective narratives.

Robin Dunbar (2004, 1996) explored the role of gossip, which often takes the form of storytelling, focusing on its prominence in human social interactions and its evolutionary functions in building social networks, enforcing norms, and sharing information. He argues that storytelling and gossip have contributed to the cohesiveness of human groups and the development of social bonds (Dunbar, 2014). In a similar vein, historian Yuval Noah Harari, has emphasized that storytelling is an intrinsic part of human nature and a driving force in the development of civilizations. Harari explores how humans have used shared myths, narratives, and stories to create cohesive societies, coordinate in large groups, and construct complex belief systems. Harari suggests that our ability to create and believe in fictional narratives has enabled the formation of imagined orders, such as religions, nations, and economic systems, which have had a profound impact on human history (Harari, 2014).

The psychological investigation of the narrative representations in the modern human psyche was first explored by the Swiss psychologist Carl Jung. Jung established the concepts of archetypes as the instinctual psychic models of images, character roles, behaviors, and personalities that are universal, innate, and symbolic patterns or images and underlie the unconscious of all people and influence human behavior (Jung, 1968). To Jung, archetypes undergird an individual's psyche conceptualization of the world, structure conscious as well as unconscious behaviors and are manifest in individual dreams as well as the social building blocks of cultural mythologies that are fundamental to bond all societies. As such archetypes play a deep role in the narrative cognitive modeling of the brain. Examples of archetypes include the hero and the hero's journey, the villain, the mother, the warrior, the idea of death etc. Jung described these instinctual archetypal characters and plots as universal to all people and living within not only the individual human psyche but also within a shared collective unconscious which he believed was a reservoir of inherited experiences and wisdom accumulated over the course of human evolution (Jung, 1969; Neumann, 1974). Likewise, for the theory of mind (Premack & Woodruff, 1978) who identified the unique aptitudes of one individual to understand and put themselves in the place what another is thinking may be another extension of the storytelling/listening cognitive modeling circuitry. As such, theory of mind would be the ability for one's own internal narrative model to mirror and comprehend the narrative experience of another.

Joseph Campbell (Campbell, 2008; Campbell & Campbell, 1969) expanded on Jung's ideas of archetypes within mythology through comparative study of mythologies of world cultures. Campbell revealed the universal themes of the hero's journey and the monomyth themes that run through all cultures. Campbell theorized four functions of myths to ground members of a society in mystical, cosmological, sociological and/or pedagogical/psychological orders of humankind. Campbell's work influenced a whole generation of contemporary storytellers and was most notably George Lucas' inspiration for the Star Wars epic.

Since storytelling requires a community of story listeners, the most significant level for a story to be relevant is at the social level of the community with which one shares the stories. For the vast majority of time that homo sapiens have been around, that group of shared stories would be the local tribal community. All the story themes, plots and characters and meanings would have been shared among the tribal group. When narrative archetypes are shared it is the most profound social bond. Storytelling among a society creates a shared connection of individuals to their community and their ancestors. Shared cultural stories create a sense of shared reality, meaning and purpose.

Over most of the time that humans have been in existence we have been a tribal, mythological oral storytelling-based species. Today's brain is still biologically rooted in the archetypal tribal oral storytelling/listening process. Modern cognitive science is providing a lot of insight into the storytelling processes upon which our brains still are based. The fascinating phenomenon of speaker-listener neural coupling (Stephens et al., 2010) underscores the deep neural connection established between storytellers and their audience, shedding light on the intricate mechanisms behind effective communication and the shared understanding of narratives. Other research exploring the neural mechanisms underlying social interactions is revealing a coupled dynamics framework for understanding how shared neural patterns contribute to communication and empathy (Hasson & Frith, 2016, Nummenmaa et al., 2008).

Other researchers have leveraged fMRI and PET brain scans to unravel the neural underpinnings of language processing and storytelling. Price (2012) reviews two decades of brain scan studies on language processing covering a range of methodologies and providing a valuable context of research in mapping the brain's language functions. Huth et al. (2016) identified distinct brain regions responsible for various language components, including semantics, syntax, and phonology. Their research used fMRI to create an atlas of where the brain stores words by mapping the cerebral blood flow across the brain while test subjects were listening to a storytelling podcast called the "Moth Radio Hour". The work revealed the distributed nature of language processing, illustrating the coordinated activity of multiple brain areas to enable our complex linguistic abilities. What was most striking about this study was that while each of the thousands of individual words were mapped to a relatively small but unique spatial patterns of brain activity, the entire brain was essentially engaged at some point during the storytelling episode suggesting that the cognitive circuitry for storytelling requires a brain as large and complex as the modern human brain to tell stories at the modern level of complexity.

Other areas in which the storytelling nature of humanity is prominent includes the humanities, communications and performing arts suggesting that storytelling is more central to defining the human species than has been generally emphasized to date. Like the transdisciplinary nature of Big History which makes large scale connections between many different disciplines across the natural sciences, social sciences and humanities, the transdisciplinary nature of storytelling science also draws from widely divergent fields from cognitive sciences to anthropology to social sciences to humanities and performing arts. In fact, there does not appear, as of yet, to be an organized coordination of storytelling sciences at the larger scale which might suggest, considering the deep synergies, that Big History could be an academic home for storytelling science.

The Synergistic Nexus of Storytelling and Collective Learning

If storytelling is so central to how the human brain conceptualizes the world and storytelling provides the mechanisms through which societies collectively work together then what is the relationship of storytelling to collective learning in the Big History framework and how does storytelling begin to fill in the "big blank spot on the collective learning map" (Baker, 2015b, p.304)? As discussed early in the paper, collective learning happens when information, knowledge and wisdom accumulates and disperses among members of a society and/or between generations. But collective learning cannot occur without an underlying apparatus to allow the information to be captured, stored and disseminated. A successful collective learning system would by design necessitate a mechanism for:

- information collection
- information conceptualization into useful knowledge
- Information distillation into experience
- information storage and retrieval
- generation of wisdom
- development of meaning
- transfer between information keepers
- knowledge dissemination to the community
- cultural motivation for agency and action.

All these functions are performed by storytelling, which provides the cultural human information system that facilitates collective learning to take place. David Christian describes how collective learning can be understood as a variant of a learning machine that has emerged as a manifestation of the universal Darwinism of information. "Universal Darwinism builds complexity by accumulating, storing and disseminating information about how to make things that work" (Christian, 2015, p.67). Christian goes on to describe how collective learning is the third informational variant to emerge nested on top of 'individual learning' of an organism in which knowledge is accumulated in an individual from direct experience which in turn is nested on top of the 'genetic learning and natural selection' information acquisition coded in the DNA of all living organisms.

Storytelling folds into this as the information engine underlying collective learning in its role as a third information machine variant. Figure 3 illustrates how storytelling provides the information subsystems that undergirds the collective learning process. For each improvement of the storytelling brain and/or each improvement in effectiveness of a storyline for collecting, conceptualizing, transmitting, making meaning and acting on the narration, the potential for collective learning would increase. As collective learning increases a society's understanding of how their world works or how to better coordinate among members, a community can leverage that knowledge for new emergent cultural expressions. In this manner cultures evolve and diversify with story as the glue holding a society together. This in turn results in cultures differentiating as their histories unfold from the pallet of historic possibilities provided by the synergistic nexus of storytelling and collective learning.

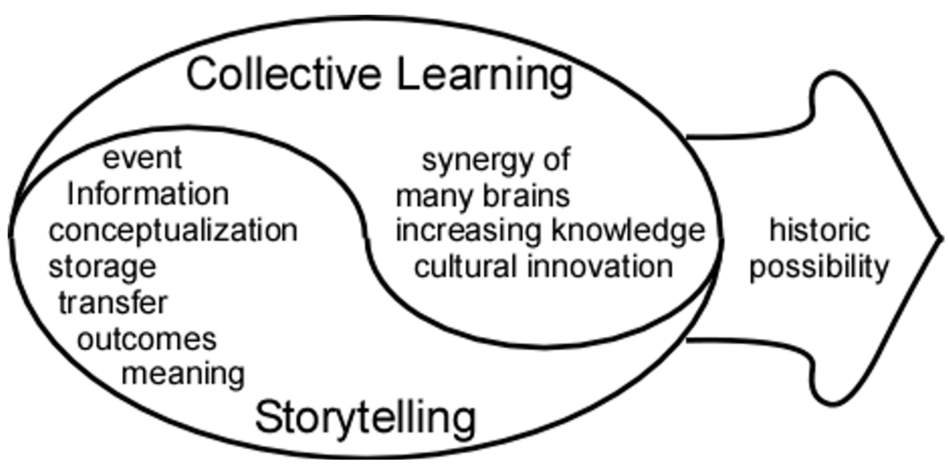


Figure 3. The synergistic nexus of storytelling and collective learning.

Note: Storytelling provides the information system by which collective learning can be manifest. In turn the state of collective knowledge of a society drives the possibilities of cultural evolution (i.e., history).

To illustrate, all living organisms respond to the events and stimuli with biological information. A human child may skin their knee and the body's biological information system immediately clicks into gear with a healing response. This is the first information machine variant is based on genetic information. The child will remember their direct experience of the event to avoid repeating the circumstance that led to the injury. This personal learning within the memory of the child would represent a second level information machine. A chimp child would have the same two levels of information machine at play. But non-present members of the chimp group would not have access to the event or be able to benefit from learned experience of the event. In contrast, when the little human child tells the story of what took place that resulted in the knee scrape to another member of the community, the occurrence can be shared with and understood by non-present members and the beginnings of collective learning take hold. With the telling of stories, events are explained and processed and made meaningful. If the storyline is successful at conceptualizing and making useful knowledge out of the event that is subsequently shared with others, the process of collective learning takes place. Storytelling is the mechanism that facilitates collective learning rising to a level 3 Darwinian information machine. For the vast majority of time that humans have had the capacity to tell and listen to stories, cultural information would be manifest within storylines orally passed between generations serving as memetic code for cultural evolution. Since the information system is oral based, each time a story is told some details may be lost while others may be embellished. In this Darwinian manner, the most universally relevant aspects of the story would be propagated, and least significant details would eventually drop out.

The evolution of storytelling and thus its corresponding level of collective learning would have occurred very slowly at first since it required the physical development of the storytelling brain to model the world in narrative thought. The brain would have to develop neural pathways and cognitive models to represent agents, settings, events, outcomes as well as enhanced memory and image processing of not just what one sees but the mental visualization of imagery generated by story. One can only speculate about the exact sequence of the evolution and pace of the storytelling capacity in any given hominin ancestor. Perhaps it would have an analog in the development of the storytelling capacity of a modern-day child. During its first few years, a human child progresses through multiple stages of language development going from pre-linguistic coos and cries to full grammatical fluency in which they become articulate storytellers/listeners. For example, a child begins to understand simple baby stories in their first year, begins to talk in their second year, begins to acquire the ability to understand the mental states of others (i.e., theory of mind (Leslie, 1987)) at about four years followed by an increasing ability to understand false beliefs between the ages of 4-6 years old. When each of these stages would have been first manifest in hominin development is difficult to say but must have happened sequentially. As such human storytelling capabilities throughout hominin evolution would have had to go through a similar set of storytelling capacity advances.

The stage of storytelling capacity and corresponding level of collective learning could perhaps be inferred by the size and morphology of the brain, the sophistication of tool making, the advancing ability to scavenge and hunt, the degree of migration into different environments, the mastery of fire etc. These are all prehistorical outcomes of collective learning in the story of humanity that would be rooted in the storytelling information system that underlies collective learning. In addition, throughout prehistory the evolutionary drive for better storytelling that could transfer increasingly complex knowledge more efficiently probably resulted in the brain's architecture employing many heuristics, or mental shortcuts, to simplify the many complex cognitive storytelling tasks. While there have been dozens of these cognitive biases identified such as confirmation bias and overconfidence bias (Tversky & Kahneman, 1974) that may or may not be associated with the evolution of storytelling neurological functionality, these cognitive biases must have been relatively benign and may have even had some pro-positive outcomes (e.g. faster decision making) in the context of the prehistoric storytelling capabilities lest they would have been evolved out of the system for their negative impact. Once storytelling capabilities become driven more by rapidly changing cultural factors than biological factors, we can see that cognitive biases do not have time to evolve out of the system and may become potential liabilities for being manipulated in pending cultural stages of storytelling evolution.

Nevertheless, over the early paleolithic, as more complex and refined storytelling capabilities emerged through the biological evolution of the underlying cognitive pathways, the ratchet of collective learning and cultural evolution would have incrementally notched higher. In the later paleolithic, cultural innovations and progression would have eclipsed biological factors in influencing storytelling capabilities. Cultural factors influencing storytelling would have included increased migration and trade, development of song and dance, graphic abstractions of story in art on cave walls and pottery etc. Such cultural factors would all have amplified the pace of the evolving sophistication of storytelling and the corresponding level of collective learning. Increasing levels of collective learning would have resulted in further accumulation of knowledge and subsequent cultural complexification as well as more efficient exploitation of the environment for survival. Refined hunting technologies and strategies probably gave advantage to homo sapiens over Neanderthals and Denisovans as well as factored in megafauna extinctions. Eventually population pressures and changing climates required new levels of storytelling and corresponding collective learning resulting in the development of agriculture (BH Threshold 7) in the neolithic revolution. As population subsequently increased and concentrated in settlements, the ratchet of cultural evolution would have continued to notch yet tighter leading to the mini-threshold of civilization with the advent of the bronze age and the invention of writing.

Throughout the paleolithic, storytelling would have been an organic, life-enhancing, and symbiotic part of human behavior. Storytelling that was out of step with the knowledge needed to survive in a given ecosystem would not last long. Storytelling that transferred pro-positive behaviors that fostered survival within the environments in which a society lived would have had the highest chances for survival, stories replicated, and the collective knowledge passed down through successive generations. The paleolithic storytelling brain functioned brilliantly considering the multiple climatic changes it endured with successive ice ages and global migration throughout all corners of the world. The modern human storytelling brain has probably had very little biological change since the paleolithic.

With the advent of agriculture in the neolithic, storytelling would have had a major transformation. Instead of stories that taught how to survive within the carrying capacity of the wild ecosystem, neolithic storytelling would have shifted to teach how to domesticate and exploit resources to a much higher level than was possible with foraging. Storytelling itself would have transformed from a symbiotic process of individual personal relationship to a community and the natural world to a domesticated form of storytelling where stories were used to exploit the resources of the natural world as well as exploit the collective labor needed for the work-intensive labor of agriculture.

A phase change in storytelling was reached with the advent of civilization and the onset of writing in the bronze age. Storytelling would leap from being primarily orally-based within small groups that organically evolved from one generation to the next to being something captured permanently in written script and controlled by a relatively small group of elites. Writing was the first transformational technology that created a foundational transition in storytelling processes with equally transformational impacts on collective learning. Writing, however, was only a precursor to many additional changes in communication technology that will prove to impact storytelling capabilities and have consequences for collective learning outcomes including innovations such as the printing press, radio, TV, internet, etc. However, we will stay focused on the prehistoric period of storytelling/collective learning for the remainder of this paper and save post civilization for future writing.

The Prehistory Collective Learning Bathtub

David Christian (2015) evoked the image of a bathtub for conceptualizing the incrementally rising level of collective learning. The drain at the bottom of the tub would be left unplugged representing the fact that some cultural knowledge is continually lost over time within any given culture. However, as the flow of new cultural information increased faster than it drained, the level of collective learning would rise to new levels until it eventually overflowed the tub. I have expanded on the Christian collective learning bathtub by integrating the role of storytelling as a synergistic compliment necessary for the rising level of collective learning to occur. For the framework of this paper, I focus on the prehistoric period since storytelling capacity is largely determined by the biological development of the brain whereas post-historical storytelling capacity shifts to be primarily culturally driven and warrants a separate treatment. As our human ancestors evolved the cognitive capacity of the brain to tell increasingly nuanced and complex stories, the collective knowledge in those stories could result in beneficial outcomes that would tighten the ratchet of cultural evolution.

In Figure 4 and Table 1, I've adapted Christian's bathtub idea to illustrate the process of the coevolution of storytelling and collective learning and the subsequent historical outcomes during the prehistoric. Throughout the paleolithic period, the storytelling stage and the subsequent level of collective learning would be primarily determined biologically by the functional state of our symbolic language system and the cognitive capacity of the brain to model explanatory narration. In this manner the level of collective learning would be determined by the sophistication of the storytelling capability throughout the span of hominin lineage. Stage 0 Storytelling would precede the beginnings of what we would consider functional storytelling and therefore would not yet have reached a minimum level of collected learning. The common ancestor of chimps and humans would be considered Stage 0 storytelling as would modern chimps today.

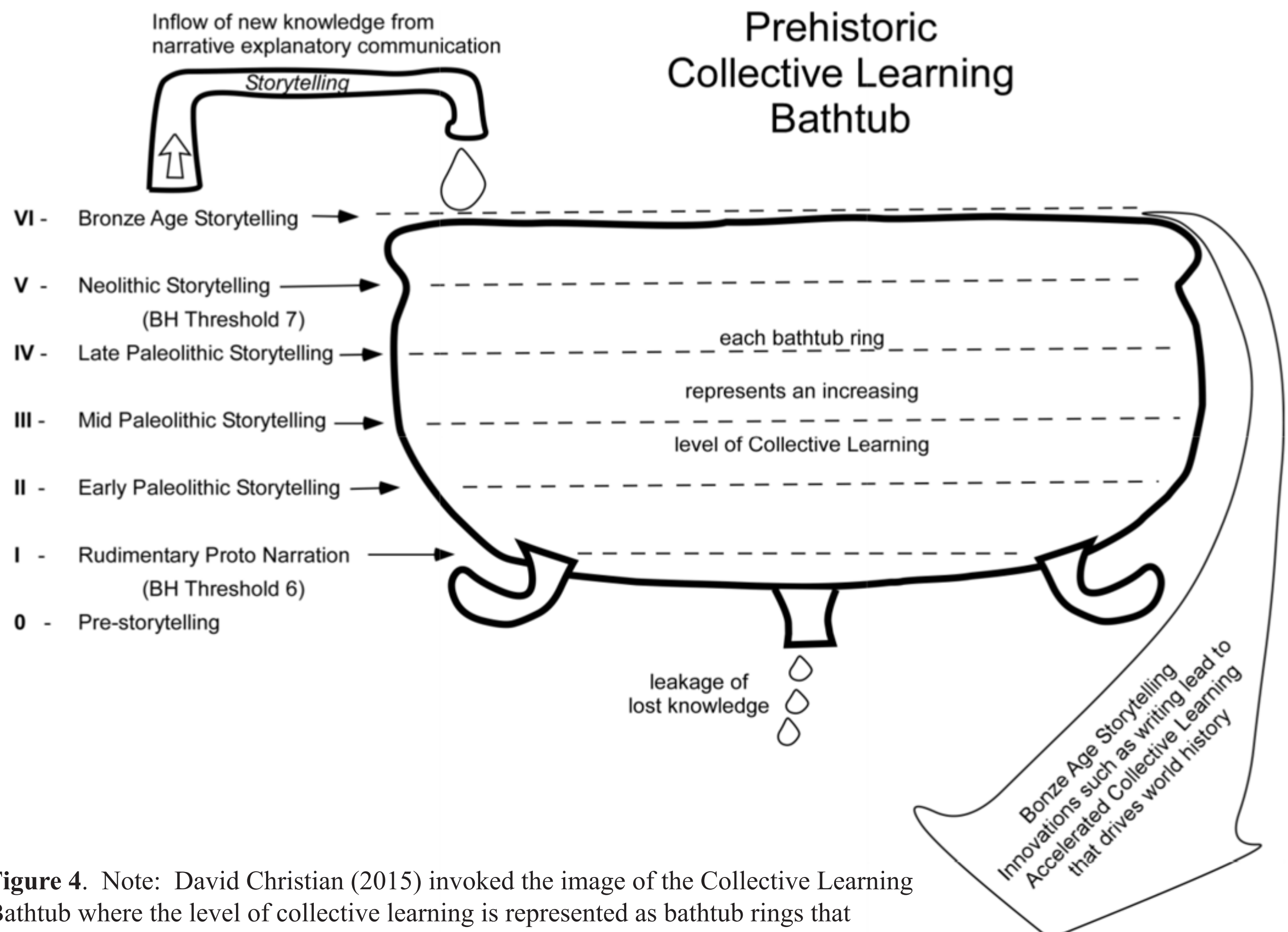


Figure 4. Note: David Christian (2015) invoked the image of the Collective Learning Bathtub where the level of collective learning is represented as bathtub rings that increase incrementally through the cultural ratchet. The graphic depicts each storytelling stage and its corresponding collective learning level in the tub. While some collective knowledge would leak out of the drain as there is an inevitable degree of cultural loss, the speed of the flow of new information would increase each time there was a shift in the storytelling capabilities that would allow better understanding, better retention, or more effective outcomes in using the knowledge for better surviving a changing environment. With the advent of the Bronze Age innovations in storytelling such as writing increase the pace of collective learning spilling over the tub into a different phase and driving world history.

Table 1. Stages of Prehistoric Storytelling-Collective Learning Coevolution			
Storytelling Stage	**Storytelling Capability/ Milestone**	**Collective Learning Outcome**	**Selected Historical Consequence**
VI - Bronze Age Storytelling	writing trade networks social stratification money	civilization coercive power axial age social stratification bronze	City-states Uruk, Ur Thebes and Memphis Tyre Athens, Sparta
V - Neolithic Storytelling (BH Threshold 7)	narrative dissemination of agricultural practices agrarian mythology polytheistic religions concentrated village populations unify larger groups with common stories	farming knowledge lifestyle cultivation domestication permanent settlements loss of foraging cultural knowledge, beginnings of social specialization consensual power	Agricultural hearths Fertile Crescent Nile valley Indus Valley Huang He Valley Meso American and Andean Sub-Saharan Pacific Islands
IV - Late Paleolithic Storytelling	G3 grammar sophisticated story capabilities, theory of mind, deception animistic religions, tribal mythology	increasing pace of innovation - tools, art, hunting technique facilitate survival in changing climate	Sapiens displace Neanderthals and Denisovans - sapiens migrate around the globe. megafauna extinctions
III - Mid Paleolithic Storytelling	G2 grammar more nuanced abilities for explanatory narration	clothing, improving tool usage, scrappers, awls ornamentation, ritual burial, ice age survival	Neanderthals and Denisovans survive glacial fluctuations
II-Early Paleolithic Storytelling	G1 grammar common language shared among group	able to explain narrate important behaviors to group - fire usage, migration skills, raft building	Homo erectus migrates out of Africa into Asia develops fire usage hunting and cooking
I-Rudimentary Proto-narration (BH Threshold 6)	multi-word combinations can share info to third person	some info shared beyond observer allowing simple knowledge buildup	Homo habilis uses Oldowan stone tools, meat eating increases
O- Pre-storytelling (common ancestor w chimps)	none	none	behavior driven primarily by instinct

Note: This table presents a sketch of the Darwinian coevolution of storytelling and collective learning throughout the paleolithic period. Storytelling provides the information subsystems that facilitate collective learning in a synergistic relationship. As storytelling capabilities are incrementally improved through cognitive/cultural complexification, it facilitates the collective learning outcome resulting in possible influences on history. The table is not intended to be comprehensive but rather conceptual with many likely omissions and/or inaccuracies.

Once one of our human ancestors evolved the cognitive capacity for stringing enough words together to achieve the simplest of narrative communication Stage I Rudimentary Storytelling would have been reached and the most basic level of collective learning would have begun. One might speculate that it occurred with homo habilis since the first stone tool usage would imply a level of cognitive complexity that might be related to primitive proto-storytelling capability. I propose that the onset of Stage I Rudimentary Proto-Narration is where Big History Threshold (6) Human Emergence is located albeit would have been a subtle form of collective learning. Stage II Early Paleolithic Storytelling would have occurred when spoken language had reached a full spoken language with G1 grammar indicating some significant storytelling capability and thus a corresponding higher level of collective learning. I speculate that this would have occurred with homo erectus considering the feat of migrating out of Africa and into Asia, stone tool usage, and larger brain capacity are all indications that H. erectus had a reasonably sophisticated language (Everett, 2016) for functional storytelling.

In going from Stage II to Stage III - Mid Paleolithic Storytelling, grammatical complexity would have increased going from G1 to G2 grammar with Neanderthal and Denisovans. In this scenario, Neanderthals and Denisovans would have had at least a moderately well-developed storytelling capacity which would have resulted in a measurable increase in collective learning allowing learned behaviors for clothes making, complex hunting practices and possibly art and ritual burial (Pike et al., 2012; Rendu et al., 2014). In Stage IV - Late Paleolithic Storytelling, homo sapiens would have eventually had the most well-developed storytelling/collective learning capacity with full recursion of G3 grammar which in turn may have afforded them advantage in cultural knowledge that allowed them to displace Neanderthals in Europe (Villa & Roebroeks, 2014) and Denisovans in Asia (Higman, 2021). Stage IV storytelling would have been significantly more sophisticated enabling the development of collectively learned knowledge to guide homo sapiens to culturally evolve at a more rapid rate than any previous hominin and migrate to all major world zones.

Once homo sapiens spread throughout the globe and population began to reach the foraging carrying capacity of much of the world and assisted by the warming and stabilizing Holocene climate, the Paleolithic storytelling/listening brain was able to retool for Stage V - Neolithic Storytelling. Neolithic storytelling would have constituted a major mythological and cosmological phase change. Agriculture is a big deal in the story of the planet and is considered a major threshold (7) in Big History. Cosmology and mythology shifted from nature-based egalitarian community and animistic to seasonal farming and herding-based tribal stories where the divine plays the role of tending and overseeing people and the source of the harvest. The mythological stories of early agrarian period would have created a social identity of larger groups than previous paleolithic tribal societies. Neolithic stories would have had themes regarding the cycles of sowing and reaping, floods and famines and life in permanent settlements, social classes emerged with domesticated animals playing a significant role in the stories.

Stage VI Bronze Age Storytelling represents the beginning of civilization and an even larger phase change. Storytelling in this stage becomes primarily driven by cultural innovations rather than biological adaptation. The pace of collective learning becomes accelerated by cultural developments that impact the state of storytelling such as writing, money, social stratification, trade networks, and shared information. From this point on cultural change further accelerates and the prehistoric collective learning bathtub overflows. A completely different post-historical collective learning bathtub will have to be tackled in a future paper.

Students Storytellers in Teaching Big History

As the paper winds down, I'd like to circle back around to my Big History classroom where the seeds of this essay were planted. While the theorem sketched out in the pages above for a storytelling/collective learning nexus may or may not be found creditable historically or anthropologically, as a pedagogical framework for engaging students in the classroom, my colleagues and I have found that storytelling as a key concept for human emergence (BH Threshold 6) to compliment collective learning powerfully engages students on a personal level. I often ask my students if they can see examples of humans as a storytelling species reflected in the world as well as in their own lives and behaviors today. The discussion is usually revelatory and a eureka moment. Typically, students will start reflecting on how humans are storyteller by offering examples of the more traditional definition of storytelling such as "people love to watch movies and other performing arts which are stories" or "people read or watch news stories to figure out what's happening in the world", "many religious beliefs are based on scriptural stories" or "people tell their daily personal stories on social media".

When I ask students to think about storytelling in the broader sense of 'explanatory narrative information sharing' students begin to see storytelling in many other places. Education is a form of storytelling; advertising is a form of storytelling. In a court of law lawyers tell stories about plaintiffs and defendants to convince a story-listening jury of guilt or innocence. Politicians are storytellers aiming to persuade story-listening voters of the benefits of their ideas or the flaws of their opponents. Science is a type of storytelling with specific rules that only allow empirical evidence, factual data, logic, and reason to be used to explain the nature of the natural world. Historians are storytellers of what happened in the past and geologists are storytellers of the earth's physical processes. Memoirs and biographies are stories of people's lives and obituaries are stories that capture who we were after we are gone. Students find storytelling in social media posts, the lyrics of their songs, in podcasts and in their video games. Gossip is one particular topic that students home in on explaining how prevalent it is for people to talk about other people behind their backs.

Some students have mentioned that the idea of seeing people as having storytelling minds has helped them put ideological polarization into a broader perspective explaining how different people can see the same event through completely unintelligible different narrative models. Students talk about how story gives meaning and makes one look deeper into our role as the storytelling species helping them to feel personally connected to the Big History of our planet. Students identify with the power of their own storytelling mind to keep them binge watching streaming serial videos from one episode to the next because their storytelling brain just has to know how the cliffhanger turned out.

One of the most consequential assignments for the course is an essay where students narrate their own life events and identify their own thresholds of complexity that have shaped them into who they are today. They become storytellers of their own little Big History and capture the essence of their own story placed within the framework of the Anthropocene. The assignment has been very popular and creates a sense of personal participation in the Anthropocene.

The past few paragraphs give a glimpse into how fruitful the theme of storytelling/story listening as a defining characteristic of humanity in the Big History has been in the classroom. While there is much more of a story to tell about this experience, this paper would be remiss without giving an indication about the remarkably positive pedagogical experience the storytelling/collective learning theme has been to myself and several colleagues. Storytelling powerfully engages students to relate their own life story to the narrative of Big History and tap David Christian's challenge for today's generation to embark on their own quest to navigate through a complex future into the Anthropocene.

Discussion - The Big So What

This paper has explored the idea of how the storytelling nature of humanity might contribute to the Big History concept of collective learning throughout prehistory as well as the pedagogical benefits of integrating storytelling into the Big History classroom. But does a storytelling framework have larger relevance for our current moment in time? If the human mind has evolved, in essence, to be a storytelling machine then understanding how that machine works and how storytelling motivates action and human agency is essential for humanity to figure out and Big History can play a major role in developing and disseminating that knowledge.

As of the writing of this paper, the world stands at a precarious set of social and environmental predicaments the outcomes of which could go in many directions and storytelling will be a central agent in how the future will unfold. Storytelling has the power to inspire courage, invoke creativity, and encourage perseverance by drawing on the archetypal hero's journey and the ability of stories to unify people to work toward common goals. At the same time, storytelling is vulnerable to being weaponized for nefarious purposes, to instill fear, exploit vulnerabilities and subjugate disenfranchised people. The Dark Art of Storytelling as Jonathan Gottschall calls it (2021) underlies the recent resurgence of authoritarianism through demagoguery, scapegoating, gas-lighting and political polarization, or outright historical erasure. Storytelling is used to generate false narratives and indoctrinate unfounded beliefs. Tiananmen Square never happened for young Chinese. The special military operation in Ukraine is not a war but an exercise to expunge Nazis and liberate the country. A certified secure election was unjustly stolen. Climate change is a hoax. New viral species of storytelling enabled by the internet and accelerated through social media are allowing malignant storylines to spread around the world at the speed of light repeated over and over until the stories are burned into belief. State and corporate controlled media blast highly charged storylines into our vulnerable cognitively biased story brains that are biologically wired for a long past much simpler paleolithic reality to create insatiable demand for consumer goods or generate indignant anger for political engagement.

If storytelling is central to human cognition and the cultural engine through which humans collectively learn, coordinate collective social agency and drive history, then documenting the narratives, story lines, myths and the legends that underlie historical as well as current events is an essential task that the discipline of Big History is uniquely situated to perform. Big History can embrace storytelling across multiple disciplines over the longue durée of history and prehistory and provide a science-based perspective to chronicle how story has been used to coordinate, motivate, and coerce social behavior and how storytelling might reinvigorate its pro-social role. It's impossible for humanity to have a future void of story. Big History has a unique transdisciplinary vantage point to understand of the social implications of storytelling and can play an essential role in providing a storytelling theory that can possibly help provide an objective context for story to refill its symbiotic purpose.

If we are indeed at a Big History 9th Threshold of the Anthropocene, the directions that this threshold will take will be inextricably guided by the stories that we tell ourselves. If the Dark Storytelling holds the greatest sway, then the coming Anthropocene will likely be further socially and environmentally degraded. Conversely, if humanity can navigate through the turmoil, reject stories of fear, exploitation, hatred, over-consumption, and greed and embrace stories that promote truth telling, science, compassion, courage, stewardship, imagination and wisdom then the coming Anthropocene has much to be hopeful for. Big History has much to contribute to working toward the latter by offering the essential common origin story for unifying all of humanity to be able to manifest the most pro-future vision of a Good Anthropocene.

Finally circling back to the question of the significance of humanity as the storytelling species in the grand narrative of universal evolution, the invention of storytelling within the universe through the emergence of the human is on a similar magnitude of significance as to the invention of the first eye. 500 million years ago trilobites evolved a complex eye and for the first time the universe could begin to see what the universe looked like. Pre trilobite organisms could not imagine that light-based vision could exist let alone what the experience would be like. But with the trilobite eye a whole new level of experience was possible. Once storytelling is invented in the human, conscious awareness emerges within the universe allowing it to be conscious of what is happening and understand through symbolic thinking, comprehend knowledge, and employ wisdom. With storytelling, the universe has been able to document itself, tell its own story, understand its origin, and the Big History of how it got to be the way that it is today. The storytelling species is the first to celebrate existence, ponder its future prospects and make meaning. Through the imagination embodied within the storytelling human brain the universe is able to dream up entire new universes that never existed before and recreate from the residue of evidence worlds that have long since passed. That seems like a pretty big deal even on the scale of the whole universe. Even if other advanced forms of intelligent life are out there (and it seems to be statistically inevitable), it is unlikely that they will have an exact duplicate of the human narration-based consciousness that emanates out of our unique ability to tell stories. We are likely unique in all the universe and the potential for what is possible in the future of planet earth through the storytelling species should we successfully navigate our current predicaments are as unknowable, awesome and transformational to us now as was vision to sightless pre-trilobite organisms.

Conclusion

This paper has provided a sketch of an idea that has arisen through over a decade of teaching Big History at Rowan University that explores how collective learning is related to the storytelling nature of homo sapiens. It is an idea that is still under formation and this paper is a first attempt to share it more broadly with the Big History community as part of the re-examining fundamentals special edition of the Journal of Big History. The paper has attempted to make the case that storytelling is an essential emergent property of the human species and that it is a foundation of the collective learning engine that has driven history. If the idea merits further interest, there is much more work to be done fleshing out details, filling in gaps and testing the inherent speculations. The paper invites the Big History community to consider the role of storytelling science as a uniquely transdisciplinary area of exploration that can find a home within the Big History tent, pull together many diverse Big History threads and help to tell Big History more effectively as a common human origin story for navigating the precarious prospects of the Anthropocene that lie ahead.

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Cosmic Humanism:
A Vision of Humanism from Big History

Hirofumi Katayama
J.F. Oberlin University, Tokyo, Japan

Correspondence | **Hirofumi Katayama** katayama@obirin.ac.jp
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1. Introduction

In this paper I pick up humanism, and try to show a vision of humanism based on Big History. Of course, the concept of humanism has its own long history, and it has various meanings. To examine them in detail is out of my scope. American Humanist Association defines humanism as: "Humanism is a progressive philosophy of life that, without theism or other supernatural beliefs, affirms our ability and responsibility to lead ethical lives of personal fulfillment that aspire to the greater good." [1] Here, for the time being, I simply define it as an idea to admit human dignity and oppose those which oppress human beings, and discuss how Big History deals with this idea.

What vision of humanism can Big History show us? Due to the nature of Big History, its humanism must have several characteristics. First of all, it should be integrative rather than divisive. As David Christian pointed out, Big History is not a story of a tribe or nation, but for the whole humankind. So, humanism of Big History should be also at least for all human beings on the Earth as global citizens. In this respect, the humanisms of the past were not necessarily the humanism of humanity as a whole. The root of humanism is "humanitas" in the Ancient Roma, which was used for making distinction between Romans (homo humanus) and their surrounding peoples (homo barbarous). Since then, humanism seems to have had a divisive character. Big Historian's humanism should overcome it and show the integrative vision of humanity.

In addition, humanism of Big History should be suitable for the era of the Anthropocene. In the first place, the idea of humanism arose against the overwhelming powers of God, Nature, and feudalistic institutions. Humanists have tried to deny the control of God or nature, and show human beings have the ability to recognize, deny, alter, and control nature's powers in the process of modernity. In this sense, humanism is a world-view which has a very anthropocentric character. In the era of the Anthropocene when scientific technologies and industrial power of humankind have grown to the point that we can alter the geologic structure of the Earth and as a result we are now confronting many global problems such as climate change and biodiversity loss, we have to reconsider modernity and to re-examine its anthropocentric attitude towards nature. However, this should not lead to a total denial of humanity. We must reflect on the anthropocentrism of humanism, and at the same time, must continue to preserve the spirit of respect for human beings and the individual that it originally had. Therefore, paradoxically speaking, humanism in the Anthropocene is both anthropocentric and anti-anthropocentric.[2] I will examine three possible humanisms that might be suitable for Big History: Enlightenment humanism, evolutionary humanism, and cosmic humanism.

2. Enlightenment Humanism

The most important proponent of Enlightenment humanism in recent years is Steven Pinker. In *Enlightenment Now* he stressed that we should refocus on the ideas and principles of Enlightenment at the situation where irrational and inhuman political trends such as populism, extreme right, and Islamic fundamentalism have arisen in Europe, the US, and all over the world. He said he hopes Enlightenment ideas will become more deeply entrenched in the public at large. In his view, Enlightenment consists of four ideas: reason, science, progress, and humanism, and he referred to Enlightenment humanism as an indispensable component of Enlightenment. Pinker defined Enlightenment humanism in two ways. Firstly, it is a secular foundation for morality "which promotes a non-supernatural basis for meaning and ethics." It puts more stress on individual than groups or God. The humanism "privileges the well-being of individual men, women, and children over the glory of tribe, race, nation, or religion." Secondly, it is a movement to achieve prosperity of humankind. "The goal of maximizing human flourishing—life, health, happiness, freedom, knowledge, love, richness of experience—may be called humanism." (Pinker, 2018)

Humanism is in its origin closely related with the Enlightenment. The components of the Enlightenment Pinker raised are in common with Big History, and we can learn a lot from his discussion. There are at least three features that can be incorporated into our humanism. First is a leading role of humanism in Enlightenment. As mentioned above, the Enlightenment has four ideas or components (reason, science, humanism, and progress) and Pinker considers that humanism plays a guiding role among them. For example, he said "progress" unguided by humanism is not progress (Pinker, 2018:12). This means that humanism is the only bearer of value, whereas reason, science, and progress are value-neutral. "It is humanism that identifies *what* we should try to achieve with our knowledge. It provides the *ought* that supplements the *is*" (Pinker, 2018, 410, italics as in original). This clear role-sharing among the components enables us to avoid falling into anti-rationalism, anti-science, and anti-progress, when we examine the problems of modernity such as environmental degradation. Whether we can overcome the problems of modernity and the Anthropocene depends on the guide of humanism which determines how we use reason and science, and to what direction we make progress.

Second, Pinker's humanism is based on human beings' universal and natural feelings. He argued that human nature prepares us a universal capacity that calls on our moral concern, that is, the sentiment of sympathy, which are also called benevolence, pity, and commiseration (Pinker, 2018:11). What is important in his discussion, in my view, is his emphasis on the simplicity of the idea. He stressed that the philosophical system of human rights should be "thin" and said, "A viable moral philosophy for a cosmopolitan world cannot be constructed from layers of intricate argumentation or rest on deep metaphysical or religious convictions. It must draw on simple, transparent principles that everyone can understand and agree upon. The idea of human flourishing—that it's good for people to lead long, healthy, happy, rich, and stimulating lives—is just such a principle. Since it is based on nothing more (and nothing less) than our common humanity" (Pinker, 2018:418). By stressing that cosmopolitan morals should be simple, he avoids falling into intellectual elitism.[3]

Third, Pinker established the foundation of humanism with two scientific concepts, entropy and evolution. In the entropic point of view, we are "incarnate beings" which struggle with the Law of Entropy. This fact requires us to avoid violence. "We are all catastrophically vulnerable to violence—but at the same time we can enjoy a fantastic benefit if we agree to refrain from violence." Even egoistic sociopaths, he argued, eventually re-enter the roundtable of morality because of their impossibility of eternal invulnerability. Evolution can explain another foundation of secular morality: our capacity for sympathy. Evolutionary psychology explains how it comes from the emotions that make us social animals. It developed from kinship of animals who shared the same genetic makeup. Our moral sentiments such as sympathy, trust, gratitude, guilt, shame, forgiveness, and righteous anger developed in evolution (Pinker, 2018, 414-415). This evolutionary viewpoint is in common with the approach of Big History.

As discussed above, Enlightenment humanism has excellent advantages which we can incorporate into our humanism. However, it also has some disadvantages from the viewpoint of our humanist vision. First is its rejection of religion. Pinker argued that religion clashes with humanism because religion elevates some moral good above the well-being of humans, and because religion values souls above lives. (Pinker, 2018:30) He pointed out theistic morality has two fatal flaws. The first is that there is no good reason to believe that God exists. Theistic beliefs have been replaced by science. And even if there were a God, his divine decrees cannot be the source of morality because there are many moral codes in the Bible which are not compatible with today's morality. As evidence of this, people today reinterpret the Bible from a humanistic point of view, ignoring its outdated descriptions. People "read the Bible through the lens of Enlightenment humanism" (Pinker, 2018:421-429).

European modern humanism emerged from the struggle with God, so it is no wonder humanism is critical of religion. However, Pinker's argument is overly critical and one-sidedly emphasizes the flaws of religion. For example, he severely criticized Islam, but Islamic doctrines are relatively more rational and tolerant than Christianity (Iwaki, 2022, 316-317). On the other hand, he paid little attention to non-monotheistic religions such as Hindu and Buddhism. In addition, religions have functioned as bearers of humanistic morals and values, and they continue to function today. As Pinker himself admitted, "positive contributions of religions in education, charity, medical care, counseling, conflict resolution, and other social services…Religious organizations also provide a sense of communal solidarity and mutual support" (Pinker, 2018:431).

Thus, Pinker's Enlightenment humanism is inappropriate for humanism of all humankind. Pinker's attitude is so critical of religion that it brings more division than unity to humanity. Enlightenment humanism should be more tolerant, respectful, and dialogical to "non-enlightened" people in the world.

The second disadvantage of Enlightenment humanism is its excessive optimism on global environmental problems. Pinker evaluated that existing environmentalism is anti-humanistic, defining it as "movement that subordinates human interests to a transcendent entity, the ecosystem," and called it various calumnious names such as Romantic reverence for nature, quasi-religious ideology, and "misanthropic environmentalism" (Pinker, 2018:154). On the contrary, he considered ecomodernism or ecopragmatism as humanistic and Enlightenment-oriented environmentalism. He summarized the trails of ecomodernism: 1) the realization that some degree of pollution is an inescapable consequence of the Second Law of Thermodynamics, 2) industrialization has been good for humanity, and 3) the tradeoff that pits human well-being against environmental damage can be renegotiated by technology. (Pinker, 2018, 123-124) In addition, he offered opposition against degrowth or climate justice movement and insisted on the necessity of continuing economic growth.

As ecological economist Herman Daly pointed out, the problem of "scale" is important in the era of global ecological crisis, but ecomodernists wouldn't admit the problem, and try to shift attention away from the problem of scale (for example, total emission amount) by focusing upon efficiency (emission per GDP). Why does Enlightenment environmentalism stick to economic growth, industrialization, or technology? The reason is that the Enlightenment has been built on the foundation of economic growth, and admitting the limit to growth leads to the limit to Enlightenment. In *an Essay on the Principle of Population*, Thomas Malthus criticized the optimism of the Enlightenment thinker such as William Godwin and Nicolas de Condorcet over endless production and population growth, and argued that the slower growth rate of food production over population growth sets limitation to the Enlightenment of humanity. He said, "This natural inequality of the two powers of population and of production in the earth, and the great law of our nature which must constantly keep their efforts equal, form the great difficulty that to me appears insurmountable in the way to the perfectibility of society" (Malthus, 1798, 5). That is to say, for Enlightenment environmentalism to admit planetary boundaries means the denial of the Enlightenment itself. Although Pinker referred to Malthus, he carefully avoided mentioning the problem of planetary boundary. Enlightenment environmentalism calumniates that ecology movements' criticism against anthropocentrism of the Enlightenment is "misanthropy" (Pinker, 2018, 122). However, if we admit the limits of growth and the existence of planetary boundaries, we have no choice but to question the Enlightenment's optimistic and anthropocentric view of humanity.

3. Evolutionary Humanism

Evolutionary Humanism was advocated by famous biologist Julian Huxley. He is de facto Big Historian who argued the evolutionary vision of the universe in the earlier stage. He proposed to view the universe *sub specie evolutionis*, and generalized the evolutionary concept in the fullest measure. He recognized that the expansion of evolution theory provides a new vision of the cosmos and of our human destiny, and that evolution is a natural process of irreversible change, which generates novelty, variety, and increase of organization. According to him, the evolution of the universe has three phases: inorganic or cosmic phase, biological phase, and psychosocial phase. Each phase has its own characteristic method of operation. As for the mechanism of change, that of inorganic phase is random interaction, that of biological phase is natural selection, and that of psychosocial phase is "psychosocial selection." In psychosocial selection, the evolution process is mainly cultural, and changes occur not in human bodies or gene-complexes but in human cultures. This process has very different features from that of biological evolution. He pointed out, "man's truly unique and most important characteristic—cumulative tradition, the capacity for transmitting experience and the fruits of experience from one generation to the next." This was achieved through the development of symbolic language (Huxley, 1992, 27-33, 49). As described, Huxley's understanding of cosmic evolution is almost identical to that of Big History, sharing many ideas such as complexity, emergence, threshold or regime, and collective learning.

Huxley's uniqueness is shown in his idea on the evolution of mind. He considered the universe has evolved from "world stuff," which has both material and mental aspects. Human beings are both matter and mind because we are organizations of the universal world stuff. In addition, not only human beings but also other lives have a potentially mental aspect. He called this source of subjective awareness "mentoid." He said, "There must be at least a potentiality of mind in the fertilized ovum…In both ovum and amoeba we must postulate some mind-like quality, a mentoid…some dim beginnings of subjectivity." Brains are "mechanisms for intensifying, amplifying, and organizing life's original dim subjectivity to a point where it can properly be called *mind*, and becomes significant in the animal's life" (Huxley, 1992, 40-41, 55, italics as in original). From this unique idea, he derived an integrative vision, evolutionary humanism, which unifying mind and body, science and religion, human beings and other living things, and all humankind. "Such an Evolutionary Humanism is necessarily unitary instead of dualistic, affirming the unity of mind and body; universal instead of particularist, affirming the continuity of man with rest of life, and of life with the rest of the universe; naturalistic instead of supernaturalist, affirming the unity of the spiritual and the material; and global instead of divisive, affirming the unity of all mankind" (Huxley, 1992, 73).

This is the outline of Huxley's evolutionary humanism. It has many excellent advantages for Big History's humanism. First, evolutionary humanism tried to provide a universal framework for humankind as a whole. We can see it in his efforts to establish UNESCO. As you know, UNESCO is a specialized agency of the United Nations aimed at promoting world peace through international cooperation in education, arts, sciences and cultures. Huxley engaged in establishing UNESCO to realize his idea of evolutionary humanism, and became its first director.

In his pamphlet on UNESCO issued in 1947, Huxley examined what philosophy is appropriate for UNESCO. He argued as below. Any philosophy which is sectarian is contrary to UNESCO's aims, because it pursues the values for humanity as a whole. UNESCO cannot lay a foundation on a particular religion, social ideology, race, nation, or ethnic groups. UNESCO also cannot adopt the view that the State is a higher end than the individual because it stresses on democracy and the principle of human dignity, equality and mutual respect. So, it's general philosophy should be a kind of humanism. And that humanism must be a world humanism, treating all peoples and all individuals as equals in terms of human dignity and mutual respect. It must also be a scientific humanism; however, it cannot be materialistic. It must embrace the spiritual and mental as well as the material aspects of existence, and must attempt to do so on a truly monistic, unitary philosophic basis. In addition, it must be an evolutionary, instead of a static or ideal humanism. Recently a general theory of evolution has developed. It not only shows us man's place in nature, but allows us to demonstrate the existence of progress in the cosmos. In this respect, he proposed the concept of evolutionary humanism as the basic philosophy of UNESCO. He said, "Thus the general philosophy of UNESCO should, it seems, be a scientific world humanism, global in extent and evolutionary in background" (Huxley, 2010, 6-8). Based on the philosophy, he proposed that UNESCO should construct a unified pool of tradition for the human species as a whole, which must include "the unity-in-variety" of the world's art and culture as well as the promotion of one single pool of scientific knowledge (Huxley, 2010:17). The time was the beginning of the cold war. In a situation where the world was divided by ideologies, Huxley hoped that evolutionary humanism would contribute to overcome the divisions.

The second advantage is, evolutionary humanism has some kind of cosmology. It was shown his unique philosophical concept of world stuff. Although it is speculative, the concept enabled him to grasp mind and body, human beings and other living things, and humanity as a whole in a unified way. We could say his concept was handed down by Carl Sagan's famous phrase, "we are made of star-stuff." His cosmology is related to his evaluation of religion. Unlike the case of Pinker, Huxley admitted the significance of religion for humans to enjoy "divinity" of the universe. He defined divinity as "what man finds worth of adoration, that which compels his awe" (Huxley, 1992, 223). He said: "Science have removed the obscuring veil of mystery from many phenomena…but it confronts us with a basic and universal mystery—the mystery of existence in general, and of the existence of mind in particular. Why does the world exist? Why is the world stuff what it is? Why does it have mental or subjective aspects as well as material or objective ones? We do not know. All we can do is to admit the facts" (Huxley, 1992, 107). He also called religion as "applied spiritual ecology," which deals with the relations of humankind with the rest of the external nature, the relation of an individual with the rest of their internal nature, and the relation of an individual with other individuals and with their community (Huxley, 1992, 108).

Third advantage of evolutionary humanism is its anti-anthropocentric nature. It is derived from the unitary nature of evolutionary humanism. Human beings have a kinship with other lives. He said, "Animals, plants and micro-organisms, they are all his cousins or remoter kin, all parts of one single branching and evolving flow of metabolizing protoplasm" (Huxley 1992, 79). Evolutionary humanism helps to restore our unity with nature and tells us that we have the collective duty of preserving nature (Huxley, 1960, 272-273). He protested against human's overexploitation of nature. He said, "man must remember that he is a part of nature, and must learn to live in harmonious symbiosis with the environment provided by his planet, relations of responsible partnership instead of irresponsible exploitation. If he is to make a success of his job as guiding agent for evolution, he must abandon the arrogant idea of conquering and exploiting nature; he must co-operate and conserve" (Huxley, 1992, 121-122). In addition, he criticized human being's population increase. It is already destroying and eroding the world's resources, so we have to realize an immediate decrease in the rate of population growth, and in the long run, decrease the absolute number of people in the world (Huxley, 1992, 85-86).

These are the main advantages of evolutionary humanism. When compared with Pinker's Enlightenment humanism, Huxley's evolutionary humanism is more universal and non-anthropocentric. Evolutionary humanism overcomes the shortcomings of Pinker's Enlightenment humanism as Big History humanism. We can say evolutionary humanism is the best achievement of "applying Big History" in the era of cold war.

However, Huxley's evolutionary humanism also has a serious problem. He actively advocated eugenics as a consequence of evolutionary humanism. Huxley stresses human's responsibility to nature because of human's leading position in evolution. On the one hand, this is reflected in his anti-anthropocentric standpoint. He didn't advocate the control or mastery of nature which Bacon had proposed in the scientific revolution. However, on the other hand, he directed the power of modern technologies to humans themselves—eugenics and transhumanism. This stems from his idea on human being's special position in the planet's evolution. "Man's true destiny…is to be the chief agent for the future of evolution on this planet" (Huxley, 1992, 32). Human beings are the latest dominant type produced by the evolution, and its sole active agent on the Earth. So, humankind is responsible for the whole future of the evolutionary process on the planet. Human's duty is to understand its mechanism and direct it in the right direction and along the best possible course (Huxley, 1992,121). He coined the term "transhumanism," which he defined "man remaining man, but transcending himself, by realizing new possibilities of and for his human nature" (Huxley, 1960, 17). He proposed to plan a society which will favor the increase of human's desirable genetic capacities for intelligence and imagination, empathy and cooperation, and a sense of discipline and duty. And he argued that the construction of his ideal society requires negative and positive eugenics. Negative eugenics aims at preventing the spread and increase of defective or undesirable human genes, and positive eugenics aims at securing the reproduction and the increase of favorable and desirable ones (Huxley, 1992, 268).[4]

Eugenics and transhumanism aim at transcending or overcoming the constraints of nature and believe in the scientific ability of human beings to do it. How did Huxley justify these ideas? The logic he relied on is the difference of time-scale among three evolutionary phases of the universe. He argued that the tempo of the inorganic phase is measured by 1000-million-year periods. The tempo of the biological phase is measured by 100-million-year periods. On the contrary, the tempo of psychosocial phase is much faster than that of biological phase, and in addition, it manifests a marked acceleration (Huxley, 1992, 30-31).[5] He claimed that the time-scale of stellar evolution is 10,000 times as extensive as that of the evolution of life, and this is 100,000 times as extensive as that of human civilization. From this point of view, he argued that artificial selection is superior to natural selection. "To be effective, such 'non-natural' selection must be conscious, purposeful and planned. And since the tempo of cultural evolution is many thousands of times faster than that of biological transformation, it must operate at a far higher speed than natural selection" (Huxley, 1964: 263)

Thus, Huxley's transhumanism rests on a kind of accelerationist thinking. In recent years, an idea called accelerationism has emerged. Behind this idea is the development of an acceleration phenomenon called "great acceleration." Accelerationism is a series of ideas that positively view this phenomenon. In accelerationism there are two currents, the left and the right. Left accelerationism tries to find a way to liberate from capitalism through the acceleration of capitalist technology development, putting them under collective self-control and use them for liberating humans from labor with social institution such as basic income.[6] Right Accelerationism, which is more problematic, has the orientation of libertarianism and transhumanism. They try to realize new evolution beyond singularity through technologies brought about by capitalism, such as artificial intelligence, nanotechnology, genetic engineering.

Accelerationism is one of the most important ideological currents in the Anthropocene, and the attitude of Big Historians to this is being questioned. I take acceleration negatively as a human crisis caused by modernism; therefore, I am also against accelerationism. Cosmic Humanism is what I believe is necessary to deal with the crisis.

4. Cosmic Humanism

Acceleration causes two negative effects on us. First is, it makes our scope very narrow. In general, modernity's space-time consciousness has a tendency to become very narrow and shallow because of its short-termism.[7] David Hervey called it "time space compression" in his book *the Condition of Postmodernity*. Paul Virilio considered how the modern narrow perspective shows itself under acceleration phenomena. He calls his study dromology. The name was coined by him from the Greek word dromos, which means race or speed. According to him, acceleration has deprived us of our sense of proper distance, so we have fallen into a state of "gray ecology" due to "distance pollution." Virilio's image of the Anthropocene is a bunker. A bunker is an enclosed space covered with concrete, which has manifested itself concretely as an air-raid shelter, the Auschwitz gas chamber, or a nuclear shelter. And we fall into "claustrophobia," as if we were trapped in a "time bunker." He said: "We are confronted with the phenomenon of confinement…People will suffer from claustrophobia on the Earth, in the immensity of the planet." "I feel like saying that the world, the planet, is becoming a blockhouse, a closed house, foreclosed" (Virilio & Lotringer, 2002: 64, 88). Virilio depicted the dangers of modern accelerated society through impressive military metaphors. Today we are attacked by three bombs: the atomic bomb, the cyber bomb, and the genetic bomb. He pointed out "the definitive crime against humanity is the possibility that the genetic bomb would take us beyond humanity, that is, snuff it out" (Virilio & Lotringer, 2002: 135, 144).

The second problem of acceleration is the loss of our identity, which was pointed out by Hartmut Rosa (2013). He made very detailed analysis of modern acceleration phenomena. arguing that social acceleration has three dimensions: technical, social change, and the pace of life. These three reinforce each other to form what he calls the circle of acceleration. The most serious impact of the accelerated process, he believes, is the transformation of our identity. He calls this "situational identity." That is, identity becomes ephemeral, and any definition of identity is no longer stable in itself. This ephemeralization of identity is brought about by a rapid increase in choice and contingency due to "the temporalization of complexity." People lose autonomy and direction, and long-term thinking becomes impossible. The result is the experience of detemporalization, or "frenetic standstill," such as depression, stagnant time, and futurelessness. Rosa shows five brakes or decelerators. 1) Human's natural or biological limit to follow the speed of acceleration, 2) islands or oasis of deceleration, such as a religious group that keeps a distance from modern society, 3) Slowdown as dysfunctional side effect, for example traffic jam or depression, 4) Intentional deceleration, such as deep ecology, slow food or voluntary simplicity movement, and 5) structural and cultural rigidity, frenetic standstill. But, according to him, all of these are consequences or complements of accelerationism (Rosa, 2013: chap.3, 11).

Claustrophobia and the loss of identity are two main pathological phenomena in humans caused by acceleration. The point is that these are the results anthropocentrism. Trying to fit the world into the narrow framework of modernity creates claustrophobia. Also, trying to deal with the resulting loss of identity has brought about an orientation towards eugenics. In his book *the Dark Enlightenment*, Nick Land discussed how to overcome race problem. He believes that race problems stem from human beings' biodiversity, so he proposes realizing unified biological human identity through biotechnology. It means that we redefine ourselves as technoplastic beings. We go towards formation of new species. He said also it is "euvolution." This is a coined word combining "evolution" with prefix "eu" which means "good" or "excellent." It will enable us to emerge as Homo Autocatalyticus, that is, production of humans by humans through technology.

Accelerationism is a prominent ideology of anthropocentrism in the Anthropocene. Perhaps the history of "centrism" begins at the emergence of life 3.8 billion years ago. From a Buddhist point of view, the history of life is "the karma of centrism" in the universe. Anthropocentrism is considered to be the continuation and evolutionary development of this life-centrism. The history of centrism in humankind has followed: Laurasian Mythology (Witzel) in the hunter-gatherer era, the Axial Age in agricultural civilization, the scientific revolution in the early modernity, and the accelerationism in the late modernity or the Anthropocene. These correspond, respectively, to the increase and qualitative change in man's productivity and power over nature. Accelerationism is the latest form of anthropocentrism.

I believe Big History is useful in such a case. Big History's perspective is the broadest in terms of space and time that humankind has ever obtained. I call this widest scope "cosmic perspective." Cosmic perspective consists of deep space and deep time, that is, astronomical and geological space-time scales which are almost infinite for human beings. Big History is a special way to recognize the world in the broadest space and time scope.[8] I specifically call this approach of Big History "Buddhist Big History." The central concept of mainstream Big History is evolution and complexity, whereas Buddhist Big History focuses on cosmic perspective and anthropocentrism. Buddhist Big History is an approach that recognizes modern anthropocentrism as the root cause of various problems in the Anthropocene, and tries to overcome it through a cosmic perspective and "cosmic humanism."

Buddhist Big History believes humans already have abilities to solve problems. As we saw in our analysis on Enlightenment/evolutionary humanism, they have many advantages for us to realize world peace and ecological symbiosis. However, it is hindered to demonstrate such abilities by a modern anthropocentric narrow perspective. We limit our own abilities by ourselves. At first, we must break this narrow anthropocentric thinking by the infinity of the cosmic perspective—deep space and deep time. Then you will realize that we have such capabilities or possibilities of humanity.

Hartmut Rosa pointed out two layers of identity, situational and social/historical. The loss of identity means that our social/historical identity has been destroyed by the social acceleration. So, he desperately managed to reconstruct the 'oasis of deceleration' in the accelerated world as a resistance. However, Rosa doesn't notice that there is a deeper layer of identity because he doesn't know Big History. Big History considers that a human being has four identities, that is, situational, social/historical, biological, and cosmic. Cosmic humanism reconstructs "deep time identity" based on the deeper layers, the cosmic/biological.

We can point out two approaches to ethics from the perspective of big history: evolutionary approach and complexity approach. Evolutionary approach considers that ethics have evolved and developed according to the psychological and social stages of human development. Representative examples include C. W. Graves/E. Beck's color spiral dynamics theory and Ken Wilber's Integral theory. Complexity approaches find intrinsic value of a thing in its complexity, such as Ken Solis's complex-information ethics theory (Solis, 2022) and C. Vidal/J.-P. Delahaye's organizing complexity (Vidal & Delahaye, 2019). Although these approaches overlap each other, we could hypothetically divide them into two such approaches, depending on whether they emphasize evolution or complexity. However, cosmic humanism's approach differs from them. Cosmic humanism also pays attention to evolution and complexity, but they are not the most important values. This is because emphasizing evolution and complexity brings hierarchy and order into the world of existence, and it is easy to fall into the trap of anthropocentrism. Instead, the strategy of cosmic humanism is to create a symbiotic network from the deep, shared identity of all things.

Perhaps the closest to the vision of cosmic humanism is Mircea Eliade's "homo religiosis." The existential situation of homo religiosis is "open existence with an additional dimension." He said: "Clearly, his life has an additional dimension: it is not merely human, it is at the same time cosmic, since it has a transhuman structure. It could be termed an open existence, for it is not strictly confined to man's mode of being" (Eliade, 1957:166). Of course, the word "transhuman" in the sentence is not the same as transhumanism of right accelerationism. It means that, in our context, the identity of homo religiosis is not restricted in that of narrow modernity. We are open to the world as a relational and mutualized existence. It is deep time identity that gives us the additional dimension.

In the following, I would like to describe the attitudes of cosmic humanism toward reality based on the examples of the practices of two Japanese persons. Firstly, cosmic humanism seeks to find something in common rather than difference between the self and everything. It is an attitude that tries to find the same humanity in humans, the same life in other living things, and the same roots as 'star-stuff' in other substances.

中村哲Tetsu Nakamura (1946-2019) was a Japanese physician who headed Peace Japan Medical Services

(PMS), an aid group known as Peshawar-kai in Japan. In 1984, he was posted to Peshawar, Pakistan, as a doctor, and was involved in the treatment of the poor, with a focus on leprosy. In 1986, he started a medical service for Afghan refugees. Since 2000, Nakamura has been engaged in a project to secure water sources as a countermeasure against the severe drought that hit Afghanistan. In addition, in 2002, he started the long-term reconstruction plan 'Afghanistan Green Land Plan' in a mountain village in eastern Afghanistan, and an irrigation water use plan. In 2019, unfortunately he was killed in Jalalabad, Afghanistan.

Although he was a Christian, he actively continued his medical and environmental activities in the oldest Islamic society. He spent his efforts on "how to find common ground as a human being in everyday life in the midst of different religions and cultures." He said that his beliefs were reflected in his quest for "something in common as humans" rather than criticizing the beliefs and customs of other peoples. He argued that what is required of all religions is an effort to find common ground in their practices beyond their cultural husks. People in Afghanistan put their faith only in what appears as a result of actions. He therefore confidently said: "The discovery of common God is the discovery of common human." Its universality connects all people at the deepest of their existence (Nakamura, 2003:113). Although I cannot precisely understand what he meant by "common human," perhaps it is something like the sentiment of sympathy of Enlightenment humanism and deep time identity of cosmic humanism (And in addition, it is never something transhuman!)

Secondly, cosmic humanism aims at 'deepening' rather than 'evolving.' What is "human"? As long as we consider evolution and complexity to be the sole foundation of humanity, we cannot counteract their anti-humanistic effects, that is, acceleration phenomena as a result of the temporalization of complexity. I believe Big History is not futurism but 'originism.' It means that we acquire our identity, or vision, not by accelerating into the future, but by going back to our origins in the past.

We can regard washoku (Japanese cuisine) as an example of originism in Japanese culture. Culinary researcher 土井善晴Yoshiharu Doi (1957-) describes the importance of Ichiju-issai. Ichiju-issai literary means "one soup, one dish," or simple meal. He pointed out that French cuisine was born out of anthropocentrism. In French cuisine chef's creativity is emphasized, because the foundation of the French philosophy is anthropocentrism, which believes that human beings have meanings only when they continue to create something. Because it is based on a human-centered philosophy that humans make imperfect nature perfect, cooking has become an art and has also developed scientifically (Doi 2022:76). On the contrary, washoku is based on the idea that 'the best thing is to do nothing.' It means making the most of the materials and eating what you have now in season. That's why it's important not to devise in cooking Japanese meals. He said: "We have always been told to 'evolve' by trying new things and doing things that no one else has done… So, what is 'evolution'? It is the value of human existence born from the Western view of nature. In Japanese cuisine, the creation of human existence is 'deepening.' 'Evolution' is based on religions and philosophies that tell people to live that way. What we Japanese are good at is deepening" (Seikyo Shimbun, May 13, 2023). I see here the potential of Big History based not on evolution and complexity but on cosmic perspective and deep time identity.

5. Conclusion

In this paper, I have examined the vision of humanism based on Big History, starting with the two concepts of humanism, Enlightenment humanism and evolutionary humanism. The most basic reason I consider these humanisms to be big historical is that they seek the grounds of their humanism in human deep time identities. That is, Enlightenment humanism seeks a human moral basis in the feeling of empathy, which perhaps can be traced back at least to the human being as a mammal. Evolutionary humanism went further, trying to derive the equivalence of human beings and their cultures from the identity of human origins, and the symbiosis between humans and other life from the identity of origins of life.

Therefore, both of the concepts have excellent features that serve as Big History's humanism, but it has also become clear that they also have anthropocentric problems stemming from modernity. Enlightenment humanism has anti-religious and anti-ecological characters, and evolutionary humanism has accelerationist and transhumanist characters. In this sense, it should be noted that Pinker's Enlightenment humanism has no transhumanistic factors at all. So, it is not easy to summarize these approaches in the form of periodization. However, according to the periodization of "anthropocentrism" which I mentioned above, Enlightenment humanism has the traits of early modernity, and evolutionary humanism has the traits of late modernity or the Anthropocene. Humanism itself is a product of modernity, so we can distinguish them according to what characteristics of modernity they possess. Of course, these characteristics of modernity (anti-religion and productivism in Enlightenment humanism and accelerationism in evolutionary humanism) are considered to be overcome from the viewpoint of Buddhist Big History.

Then, what is the periodization of cosmic humanism? It is humanism in the coming "altermodern" future. It is a humanism that inherits the modern achievements of Enlightenment/evolutionary humanism, but overcomes the shortcomings of modern anthropocentrism. Cosmic Humanism enables true human dignity, independence, and coexistence with other living things. Although I was not able to clearly discuss the concrete vision, I think I showed its outline and direction. Cosmic perspective of Big History is important now to break the narrow framework of modernity.

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Notes

1. American Humanist Association's website. See its "Definition of Humanism" (https://americanhumanist.org/what-is-humanism/definition-of-humanism/).
2. Heidegger expressed the dilemma of modern humanism in his *Letter on Humanism*: "Should we still keep the name 'humanism' for a 'humanism' that contradicts all previous humanism-although it in no way advocates the inhuman?" His answer to the dilemma was "Man is not the lord of beings. Man is the shepherd of Being" or "Man is the neighbor of Being" (Heidegger, 1977, 221, 225). In my view, Heidegger properly raised the question, but his answer is not so good, because although he tried to alter the hierarchical/instrumental relationship between humans and other things, humans in his philosophical framework still are located outside of beings. Perhaps this alienating situation is related to the fact that Heidegger's beings, including humans, lack their own narrative of cosmic evolution.

3. Pinker's moral position, which focuses on human nature's possibility for the foundation of moral philosophy, is almost equal to that of Chinese Confucian philosopher 孟子 [Mencius]. Mencius is famous for his 性善説 [the theory of innate Goodness]. He argued that human beings are by nature good, and we can construct moral principles based on four human natural sentiments as 四端 [four starting points]: 仁 [benevolence] based on the feeling of 惻隠 [commiseration], 義 [righteousness] based on the feeling of 羞悪 [shame and dislike], 礼 [propriety] based on the feeling of 辞譲 [modesty and complaisance], and 智 [wisdom] based on the feeling of 是非 [approving and disapproving]. Pinker's practical common-sense approach to morality resonates with one of the ancient, original humanistic philosophies in the East. The translation is from the Chinese Text Project. (https://ctext.org/mengzi)
4. Perhaps his assertion of eugenics and transhumanism is related with his view on religion. As I mentioned above, he admitted the significance of religion for human beings to feel divinity, but he was critical of theism. He argued that all theistic religions based on the God hypothesis has a number of consequences which humanists find undesirable, such as petitionary prayer and all kinds of propitiatory practice, a lack of concern for life in this world and its possible improvement, the cruel doctrines of Original Sin and Damnation for unbelievers, a regrettable dogmatism and to the rejection on playing down of secular knowledge and scientific method. (Huxley, 1992:103-104) Instead, he proposed a new religion which he called 'religion without revelation.' It will be brought about through drastic reorganization of our pattern of religious thought "from a god-centered to an evolution-centered pattern." "A humanist evolution-centered religion too needs divinity, but divinity without God." (Huxley, 1992:220) We find two meanings in his evolution-centredness. One is a respect for nature which is a product of evolution, and the other is transhumanism which relies on the ability of human beings to reform their own living organism.
5. Huxley demonstrated that natural selection operates blindly without conscious purpose or aim, whereas psychosocial selection involves awareness of an aim, purpose and goal-selecting mechanism. (Huxley, 1992:33) However, Darwin took an opposite viewpoint. Darwin knew deep time, which he got from Charles Lyell's *Principles of Geology*. Getting a hint from artificial selection, Darwin constructed the theory of natural selection. However, he considered that natural selection is more creative than artificial selection because natural selection is based on deep time. He argued in *On the Origin of Species*: "How fleeting are the wishes and efforts of man! how short his time! and consequently how poor will his products be, compared with those accumulated by nature during whole geological periods. Can we wonder, then, that nature's productions should be far "truer" in character than man's productions; that they should be infinitely better adapted to the most complex conditions of life, and should plainly bear the stamp of far higher workmanship?" (Darwin, 1859: Chapter 4)
6. Important writings of left accelerationism include Williams and Srnicek (2013), Mackay and Avanessian (2014).
7. Short-termism is also the characteristic of Christianity. We can see it in the description of the Bible: the world began 6000 years ago, and the lifetime of Adam is 930 years, that of Noah is 950 years. I advocate Buddhist Big History—a type of Big History whose most essential feature is its cosmic perspective. Buddhism has its original notions of deep space and deep time, trichiliocosm (三千大三世界) and particle kalpa (塵点劫). Trichilocosm is a world system which includes one billion worlds. Particle kalpa is a timespan in grounding trichiliocosm into particles, and setting down one particle when passing through a thousand land until the particles are depleted. Thus, Buddhist Big History's cosmic perspective see the world 'sub species infinitatis,' which provides us an entirely different space-time recognition from that of modernity and Christianity. Japanese famous SF writer, Sakyo Komatsu, once said: "Space-time scale of Christian cosmology is desperately small…Buddhism built an image of space-time enormousness long ago, and in addition has explored the way for human beings to endure and overcome the nihility it delivers." (Komatsu, 1990:125)
8. Giordano Bruno's *on the Infinite, the Universe, and the Worlds* shows us a good example of cosmic perspective. He was inspired by the Copernican theory, but broadened his horizon beyond the theory. Copernicus put the sun in the center of the solar system. But his universe still has the celestial sphere. By contrast, Bruno broke the narrow wall of the universe and seized it as the infinite, and by doing so, he got a worldview which is completely free from centrism, not only geocentrism, but also heliocen-

trism. He wrote: “We recall that there is no difference to be found in flight to heaven, or from heaven to here; no difference ascending from here to there, or from there to here; no difference in descending from one place to the other. We are not more circumferential to any other place than they are to us, neither are we more central to them than they are to us: just as we walk upon our own star in our own heaven, so too do they.” (Bruno, 2014, 26) His free viewpoint is like that of astronauts in outer space. Thus, Bruno’s cosmic perspective enabled him to break narrow cosmic images of Christianity of the age, and get away from anthropocentric attitudes toward other human beings and living things on the Earth. The fact that he was burnt alive indicates how his concept of the infinite universe was not compatible with the anthropocentrism of Christianity.

The Trajectory of Human History

David Christian *
Professor Emeritus, Macquarie University Sydney, Australia

Correspondence | **David Christian** david.christian@mq.edu.au
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Abstract: Is it possible to identify a clear shape or trajectory to human history as a whole and what significance or meaning could we attach to such a trajectory? The argument here is that modern historical research within many different disciplines does indeed allow us to identify some striking shapes to the history of our species. It includes that those shapes are full of meaning for understanding the nature and significance of our strange species. Finally, it ends with some speculative ideas about how human history may evolve in the distant future in an attempt to see if we can perhaps glimpse what human history will look like when the human story has ended.

1. Preface

The late Johan Goudsblom thought about sociology on a grand scale and over vast periods of time. This paper is written in a similar spirit by a historian who admired and learned much from Goudsblom's scholarship over many years. As a professional historian, one of the big questions that always nagged at me was this: in what ways is my discipline significant? Is there meaning in history? Does it tell us something about existence? Or about what it means to be human?

Of course, there is meaning in history: meaning of many different kinds. Why else would most universities and schools in today's world have history departments? History contains so many exemplars of behaviours, social trends, and divergent historical outcomes. And so much food for thought about the rich and complex story of our strange species.

But here I have in mind a different type of meaning that historians explore much less often. That sort of meaning resides not in the details but in the overall shape or trajectory of human history when it is seen as the history of a species. What can human history as a whole tell us about our own species, Homo sapiens? In asking these questions, I have in mind the sort of meaning we find when we view a landscape, not from ground level, but from a plane flying at 40,000 feet. From that height you can see shapes that are invisible from close up. A similar sort of meaning can be found in the biographies of people, including ourselves. I have spent much of the last year with a grand-daughter in the first year of her life. Sophia's life already has a shape, but her life as a whole will have a shape that cannot yet be discerned. It is just starting. I, on the other hand, am nearer to the end than to the beginning of my life, so when I look back over my life, I can see a shape and a trajectory. They give a sort of meaning to my life by tracing the journey it has taken me on, with its many twists and turns. Can we identify analogous shapes in the history of humanity? And what can they tell us about the strange species of which we are all members? Such questions are becoming increasingly salient in an era in which the 8 billion members of our species are becoming so intermeshed so fast that we are turning into a single, globally interdependent community.

Similar questions also interested Johan Goudsblom, though he might have phrased them differently. He spent a lot of time thinking about long-term change in human history. Like me, Goudsblom was convinced that there is a lot to be learned by studying very large-scale processes. Indeed, that is why he introduced a big history course at Amsterdam, similar to the courses I taught for many years at Macquarie University in Sydney.[1] Both courses explored long-term historical processes from the largest possible scales, those of the Universe as a whole.

Today, curiously, few historians are interested in questions of meaning at these very large scales, so the questions I am asking are not part of the conceptual repertoire of most historians. The dominant role of disciplines and sub-disciplines in modern scholarship, each with its own well-policed borders, means that most historians stick to slices of human history and avoid discussing, learning about,

* David Christian, Professor Emeritus, Macquarie University Sydney, Australia; david.christian@mq.edu.au; Scopus identifier 7102447776; ORCID iD: 0000-0001-6545-3017. This article was originally published in: Johan Heilbron and Nico Wilterdink (eds.), Long-Term Processes in Human History. Special issue of *Historical Social Research*, 48, 1 (2023), pp. 62-83. doi: 10.12759/hsr.48.2023.04.

or thinking about human history as a whole, let alone the histories of other species (they leave that to biologists) or of planet Earth (the domain of geologists) or the Universe (the domain of astronomers and cosmologists). Even most world historians focus on recent centuries, as a brief survey of the contents pages of most world history journals will show. Careers and reputations are made within the institutional structures of disciplines and sub-disciplines, and it is risky to stray far beyond those borders. Resistance to large-scale, multi-disciplinary accounts of the past also reflects the fact that, in retrospect, so many earlier attempts to see the shape of human history look contrived, self-interested, and self-serving. As Stephen Mennell (1996, 3) writes,

Sociologists and historians have long been haunted by the ghosts of Herbert Spencer and other Victorian social evolutionists who, in attempting to put their own society and its recent transformation in the perspective of the history of humanity as a whole, actually succeeded only in putting the whole history of humanity in the perspective of their own society.

Today, though, we should be able to describe the overall trajectory of human history with more evidence and more scientific objectivity than in the past because since 1900, our understanding of the past has expanded hugely "both in space and in time," as Goudsblom (1996, 15-7) writes. There has been a vast amount of new research in many different historical disciplines, from cosmology and astronomy to geology and genetics, from palaeontology to anthropology and history. We also live in a more interconnected world in which the idea that world history is European history – an idea that once dominated large scale approaches to the past – now looks bizarre. And, though the ghost of Eurocentrism still hovers over much historical writing today, fields such as world history now make it possible, in principle, to write histories that try to make sense of human societies from all parts of the world. Finally, since the 1950s, new ways of dating past events give modern historical writing for the first time a stable chronometric framework reaching over vast spans of time (Christian 2009).

This multi-disciplinary boom in historical research now allows us to see the history of humanity as one part of a much larger historical story – as that of a distinct, and very strange biological species. That is the approach I will adopt here.

I will ask two main questions about the trajectory of human history. First, can we identify a clear trajectory or shape to human history? That question explains why all the illustrations in this paper have shapes. They take the form of graphs of real or imagined changes at large scales. My second question is this: what meanings do these shapes hint at for the history of our strange species? I will end with some highly speculative ideas about how human history may evolve in the future, and how it may end, because at present we can see just the early parts of the trajectory of human history.

2. The Shape of Human History So Far

Can we identify a clear shape or trajectory to human history so far, a pattern that might hint at the larger significance and perhaps even the deeper meaning of human history?

The idea of a shape to human history is not new. Many ancient traditions have imagined such shapes. Different historiographical traditions have conceived of those shapes in different ways. Some have portrayed stable, largely unchanging pasts. Some have seen history as a story of cyclical rises and falls, or a story of slow decline from a primordial Golden Age. Since the Enlightenment, it has become increasingly common to see history as a long ascent, a story of progress leading to a better future. Finally, many traditions have seen history as a story, either tragic or triumphant, written by the gods but with a limited role for human volition. What trajectories are suggested by the best historical knowledge available today?

To answer that question, we must begin by asking when human history begins and identifying some of the most important changes since then. We need a notional starting point and some clear ideas about the most important changes up to the present day.

Despite vast increases in the available evidence about human evolution, there is as yet no consensus about precisely when human history really begins. That is partly because it is difficult to pin down exactly what we mean when we talk of "human beings" or even "Homo sapiens." Goudsblom (1992) argued for an early starting point to human history, more than half a million years ago, even before human-like creatures first learnt how to control fire. Most scholars would argue for a more recent starting point within the last few hundred thousand years, and some argue that "fully modern" humans, creatures essentially the same as you and me, evolved within the last 70,000 years.[2]

Like all biological species, we evolved within a particular niche, probably in the savanna lands of southern and eastern Africa. But, unlike all other species, we now exploit environments across the entire planet and have even begun to create entirely artificial environments, from ploughed fields to modern cities. The result is that we have transformed much of the surface of planet Earth and altered the historical trajectories of millions of other species of plants and animals. In fact, in an era that many now describe as the "Anthropocene Epoch," we have become the first species in the Earth's history to dominate change on planetary scales.[3] Quite suddenly, it has become apparent that we are a planet-changing species. Though we remain learner-drivers, with uncertain skills, we are beginning to manage the fate of an entire planet. That is extraordinary enough to mark a new phase not just of human history, but of planetary history. Something quite exceptional happened in the course of human history.

Drawing a line between the earliest human societies and those of today suggests a clear large shape or pattern to many aspects of human history. That shape takes the form not of a straight line, but of a long accelerating growth curve. At local scales and short time scales there are, of course, plenty of fluctuations and reversals, rises and falls, but here it is the larger, rising trends that interest us. Though details vary, we find the same long, slowly accelerating curves if we study growth in human populations, changes in human consumption of planetary resources and energy, the increasing ecological and technological knowledge and power of our species, and human impacts on landscapes, the oceans, and the atmosphere and on other species. In

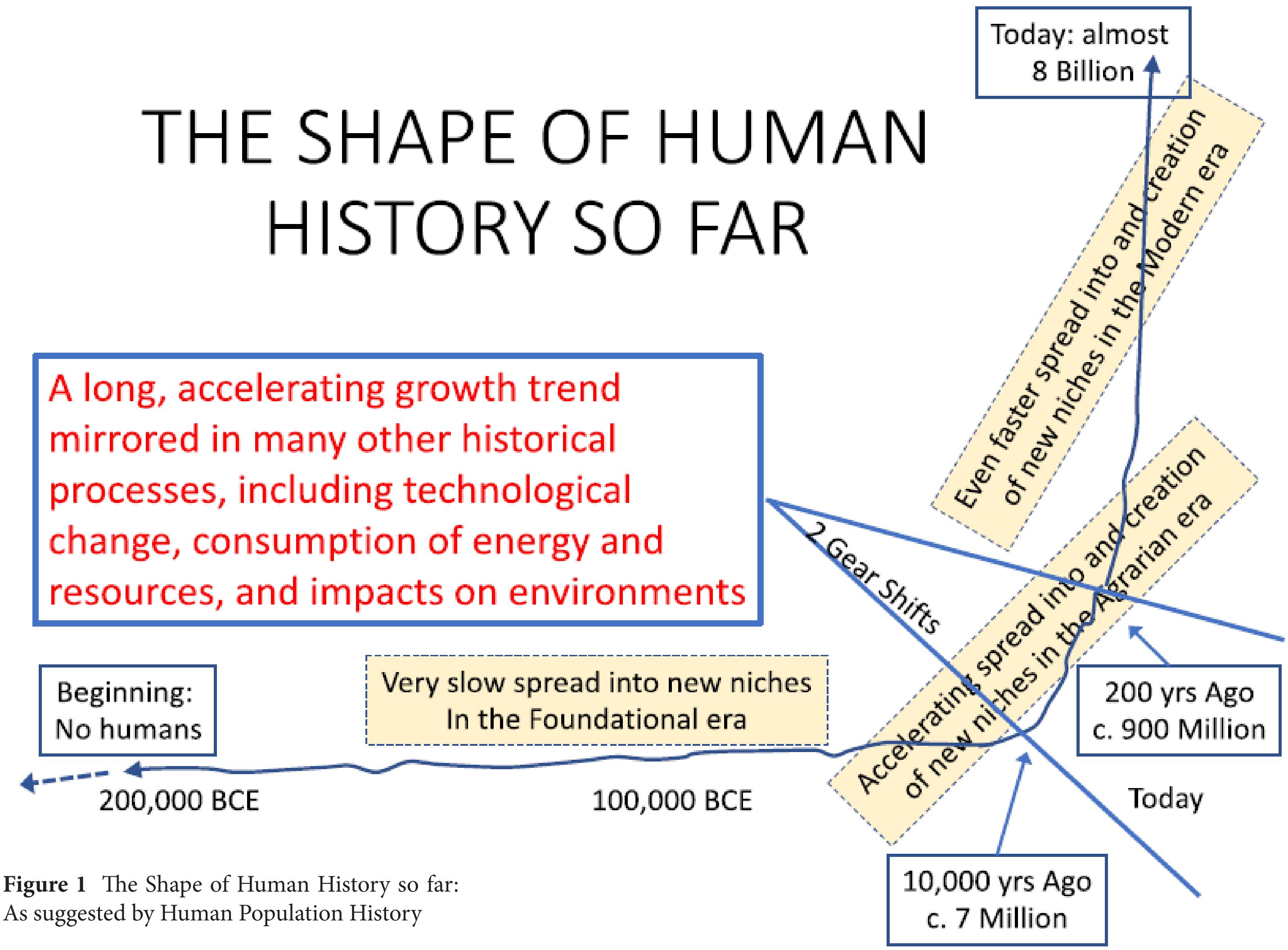


Figure 1 The Shape of Human History so far: As suggested by Human Population History

many domains of human history, the curve has two main inflection points at which the pace of change accelerated sharply. One, dating from about ten thousand years ago, is linked to the emergence of agricultural technologies. The second, dating to just the last few centuries, is associated with the emergence of today's modern, globally connected world, powered by fossil fuel energy. I will use graphs of human population growth and energy consumption to illustrate this shape, but I could also illustrate it from many other long trends. The two graphs that follow both indicate our species' increasing and accelerating control over planetary resources.

The long-term demographic history of our species illustrates this trajectory more clearly than any other long trend.

Whenever we date the beginnings of human history, we can be sure human populations were small when our species first evolved. And, despite a slow expansion in the human range, they remained small for most of human

history during what I like to call the "Foundational Era," the time period before the advent of agriculture. There is some evidence that, as late as 70,000 years ago, the number of humans on Earth may have fallen to perhaps just a few tens of thousands, perhaps as a result of the massive volcanic eruption of Mount Toba in Indonesia. But then, as group after group learned new ways of exploiting surrounding environments, humans began to spread around the world into an increasing variety of niches, and we can be sure that that meant a slow increase in the number of humans on Earth. From 60,000 years ago, and perhaps earlier, humans, a species that had evolved in Africa and Eurasia, entered for the first time the southern continent of Sahul (modern Papua New Guinea and Australia), and perhaps 20,000 years ago, they entered the Americas. Ten thousand years ago, at the end of the Foundational Era, there were perhaps six or seven million humans on Earth (Livi-Bacci 1992, 28-32). They could be found all the way from southern Africa to Siberia, throughout the Americas from Alaska to Tierra del Fuego, and also in what is today Australia. In the new lands they entered, our ancestors soon began to transform the local flora and fauna. This is particularly clear in regions such as Sahul, Siberia, Australia, and North America where their immigration into new regions of the planet coincided with a wave of extinctions of other large species from giant kangaroos to mastodon. By 20,000 years ago, the strangeness of our species' historical trajectory was already manifest.

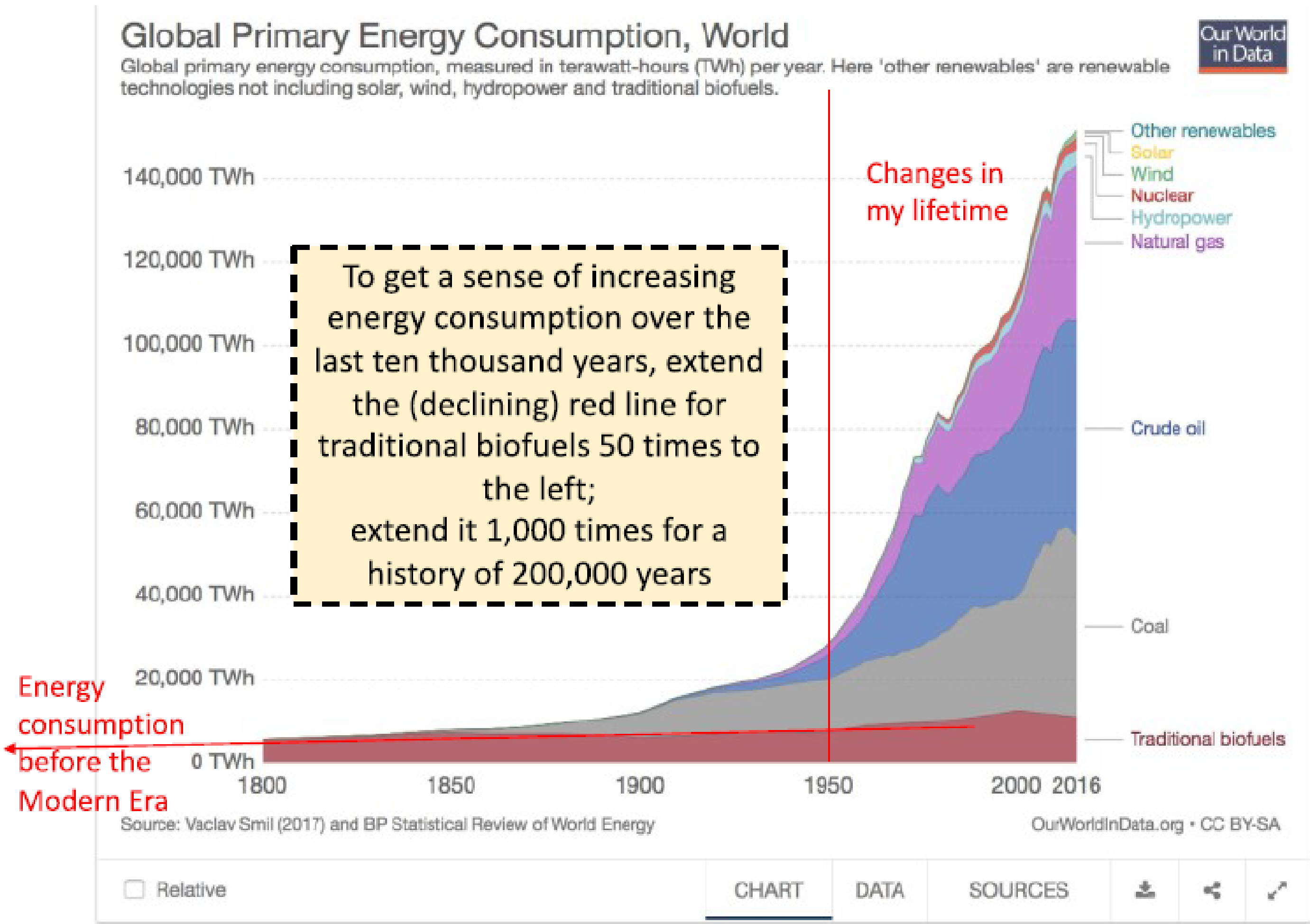
For most of the Foundational Era – by far the longest era of human history – growth of all kinds was very slow by today's standards, so slow as to be imperceptible at the scale of a human lifetime. That is why it is so easy to think, falsely, that the Foundational Era was an era of stasis. No. At scales of thousands of years – the time scales that interest paleontologists and evolutionary biologists – the spread of humans into more and more different environments was a remarkable change, even if those migrations seem glacially slow when compared to the hectic pace of modern history.

The Agrarian Era begins after the end of the last ice age, from about 11,000 years ago, with the introduction of a cluster of powerful new technologies that we commonly describe as "agriculture." These new technologies required increasing manipulation of surrounding environments, but greatly enhanced human control over landscapes (through deforestation and activities such as hoeing, ploughing, or irrigation) and species (through domestication). Increased control over surrounding resources made it possible to produce more of the food and other products humans want and need, and that drove population growth, which allowed more humans to farm more land. Feedback cycles such as this explain why the long curves of human history tend to accelerate at large scales.

If we take 200,000 BCE as the start of human history, the Agrarian Era counts for less than one-twentieth of human history. But agriculture marks a gear-shift in the pace of change because farmers could produce so much more food from a given area than foragers. That is why human populations grew faster than ever before, from perhaps seven million at the end of the last ice age to about nine hundred million by 1800 CE, at an average growth rate of almost 1.5 percent per annum. As transport and communications technologies improved, human societies also became more interconnected so that by 1500, most communities were networked on continental scales. That meant that both goods and ideas were being exchanged over larger and larger areas by more and more people. By 1800, those links were global.

As human numbers increased, so did human consumption of the planet's energy and resources. But what is striking is that production of food, energy, and resources grew even faster than populations, though until recent times only a small minority of humans benefited from growing surpluses. Graphs of energy consumption show the same, slowly accelerating growth trajectory that we have seen in graphs of human populations. In the ten thousand or so

Figure 2 Increasing Energy Consumption



years before 1800 CE, total human consumption of energy increased from approximately fifteen million gigajoules per year to more than twenty thousand million gigajoules per year, while energy consumption per person rose by more than seven times, from about three gigajoules per year to about twenty-three.[4]

In the two centuries or so of the Modern Era – about one-thousandth of the time since 200,000 BCE – increases in populations and energy consumption and in many other measures of human history have been even more spectacular. The most remarkable transformations have occurred since 1800. Technological and scientific innovation soared as cheap energy from fossil fuels drove cascades of experimentation; new transport and communication technologies from steamships to trains and airliners, from the telegraph to the telephone and internet, brought more and more people within a single global network of intellectual and economic exchanges; and change occurred faster than ever before. In just 220 years, between 1800 and 2020, the number of humans on Earth multiplied by almost nine times, rising from about nine hundred million to almost eight thousand million.[5] That is an average growth rate of about 3.6 percent per annum, or more than twice the rate during the Agrarian Era. Remarkably, most people are well-fed, thanks to an increase in the amount of land being irrigated and farmed, and to technological innovations such as genetic engineering and the manufacture of artificial fertilizers that have increased food production fast enough to keep up with soaring populations. Rising productivity in other areas made it possible (in principle) to house, clothe, and equip increasing numbers of people to higher standards than ever before. Total human consumption of energy increased by about twenty-five times, from just over twenty thousand million gigajoules per year to roughly five hundred thousand million gigajoules. Energy use per person tripled, rising from almost twenty-five gigajoules per year to about seventy-five. There is one more remarkable statistic: the span of human lives increased. For most of human history, average life expectancy was below thirty years, though by 1800 more food and better healthcare had raised it to about thirty-five years. Between 1800 and 2020 the expected life span of each baby born on Earth doubled to seventy years.

3. Making Sense of the Shape of Human History

How we assess these sustained and accelerating "growth" trajectories? We should resist the temptation to call this "progress." It is important to try to describe this shape without letting normative judgements warp our thinking. As the wars being fought today in different parts of the planet remind us, our growing powers as a species can destroy as well as create. And, as Goudsblom (1996, 24-6) pointed out, they can also create new forms of dependency, above all growing dependency on the technologies and social institutions that have given us such astonishing power over planetary resources and other species. We may have escaped the dependency on particular niches that constrain the possibilities for all other species, but a world of 8 billion people cannot possibly survive without the technological and social structures of modernity. As a recent (and controversial) survey of human history by Graeber and Wengrow (2021) concludes, the trajectory of human history can easily be seen as a story of human self-enslavement as humans have created new forms of dependence:

> Jean-Jacques Rousseau left us a story about the origins of social inequality that continues to be told and retold, in endless variations, to this day. It is the story of humanity's original innocence, and unwitting departure from a state of pristine simplicity on a voyage of technological discovery that would ultimately guarantee both our "complexity" and our enslavement. (Graeber and Wengrow 2021, 27)

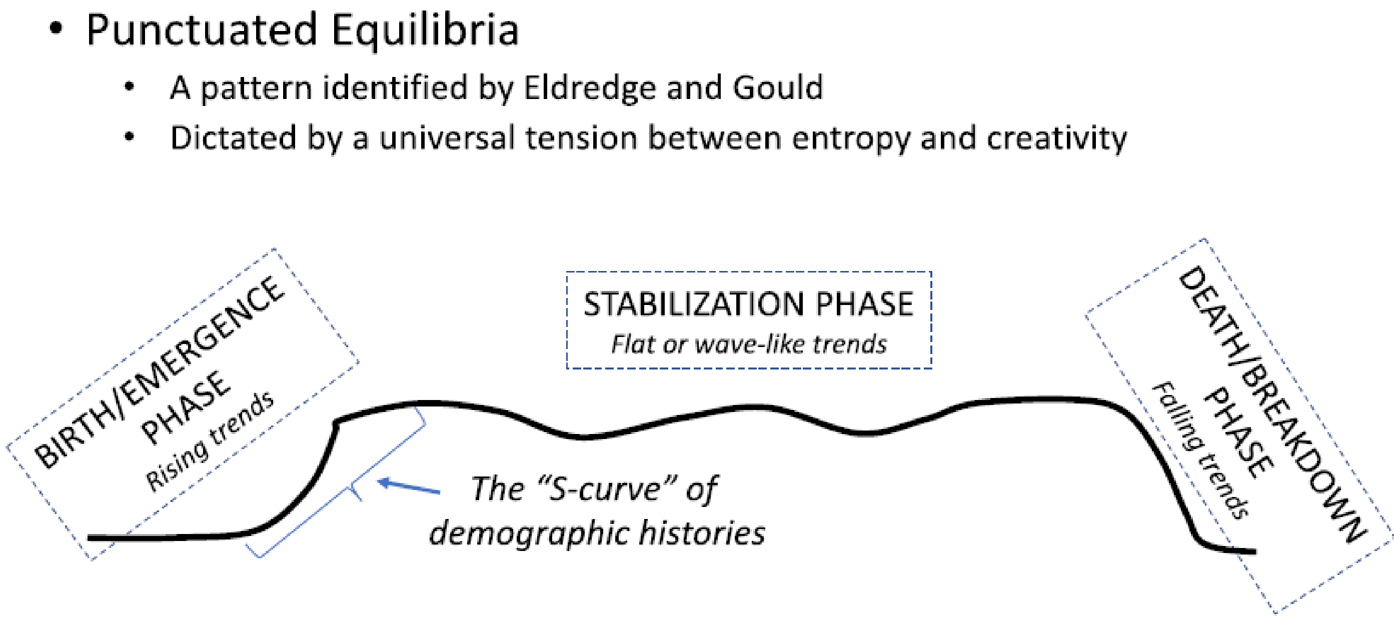
We can see the distinctiveness of our species' historical trajectory most clearly if we compare it to the historical trajectories of other species. New species can flourish when small changes give them some slight advantage within a particular environment or "niche." Koalas, for example, are specialist eaters of the leaves of particular species of trees. That is their niche. The niche both empowers and limits the new species. It creates opportunities but also new forms of dependency on a particular niche. When a new species appears, its numbers and range can increase until members of the new species, now divided into multiple local populations, have spread to wherever they can find the niche they are best at exploiting. Once a niche is fully exploited, populations stop growing and stabilize, and the new species reaches a sort of demographic plateau that may be interrupted by minor, sometimes by major fluctuations, caused by climatic or ecological change, diseases, or other natural disasters. These processes give rise to the familiar S-shaped curve at the start of the population histories of new species. Eventually, though, towards the end of the species' history, the curves will reverse and the species will go extinct because its niche vanishes, or new and more successful competitors evolve and squeeze it out, or the species itself evolves. Those processes create a chronological shape a bit like a table-mountain, with a rise, a phase of stabilization, and an eventual fall.

This trajectory, it turns out, can be found well beyond the realm of biology.

We find it in the histories of many (perhaps all) complex entities. This became apparent to me through my work on big history, which explores the past at multiple scales from those of human history to those of geology and even cosmology. At all these scales you see a similar shape, as complex entities emerge, then stabilize for a period, then vanish. All their histories conform to a standard template or shape that is universal, though the details and scales vary over many orders of magnitude. Stars may last billions of year; species for millennia or even millions of years; while individual organisms can survive for as little as a few hours and as long as a few centuries. And each stage of the template can vary, often in unexpected ways. It is in these variations that we can find a sort of meaning and significance that differs for each type of complex entity.

This template trajectory for the histories of complex entities is similar in its shape to the pattern that Niles Eldredge and Stephen Jay Gould (1972, 84) called "punctuated equilibria." "The history of evolution," they wrote, "is not one of stately unfolding, but a story of homeostatic equilibria, disturbed only 'rarely' (i.e. rather often in the fullness of time) by rapid and episodic events of speciation." All complex entities seem

Figure 3 A Standard Template for the Historical Trajectories of Complex Things



to live through the three stages we have seen in the histories of biological species: birth, stabilization, and death. In the emergence stage you see growth in population numbers and range, in energy consumption, and in impacts on surroundings. There follows a stage of relative stabilization and equilibrium, as the new entity matures and takes its place within its local eco-system. This stage is never completely stable, and a lot may change during this phase. There may even be eras of rapid change, near collapse, and sudden new growth as well as long phases of slow evolutionary change. But the middle phase is generally less abrupt than the first and third stages. Finally, there is one more punctuation, or period of rapid change during a third era of breakdown, collapse, and death. Our Sun emerged over hundreds of millions of years; its stable period will last for about 9 billion years; and it will collapse and die over several hundred million years. The history of biological species has a similar shape though a different scale, because very few species remain unchanged for more than a few million years.

4. Explaining the Distinctive Shape of Human History

How does the historical trajectory of our own species, Homo sapiens, compare to this universal template?

It actually looks very different, because so many of the trends in populations, technological power, use of resources, and so on in the human historical arc lie on exceptionally long rising trends. Of course, that is probably because we are seeing just part of a larger trajectory. Indeed, it makes sense to say that human history so far consists of a prolonged emergence phase.

Still, the trajectory is odd because for most other biological species the emergence phase does not last that long or take so many twists and turns. All organisms display some ecological creativity as they try to survive in their niches, but human history displays an entirely new level of sustained creativity. Instead of exploring a new niche and settling comfortably into it, our species has explored a steadily increasing number of different niches before eventually beginning to transform its environments, thus creating new niches that had never existed before.

Such a prolonged emergence phase is off the charts. We know of no other species in the four-billion-year history of life on Earth that has shown such sustained creativity or transformed environments so profoundly.[6] Groups of organisms, such as the first oxygen-using bacteria, show immense creativity because each species explores its own specialist niche, and together they can explore many niches and sometimes transform them. And they have left plenty of evidence of their collective creativity for modern palaeontologists to study. But a single species exploring millions of niches is something new in biological history.

Human history offers a paradigm example of Hegel's "quantity turning into quality." We have become "dragon-kings" in the lovely metaphor of Didier Sornette (2009): known creatures that have suddenly started behaving in fabulous new ways. What we see is not just one emergence or birth phase, but a series of new starts, so the whole of human history looks like an extended, step-like phase of multiple "emergences."

How can we explain this remarkable historical trajectory? If we can explain it, we can perhaps get closer to defining what makes humans different, so this is a fundamental question about human history and the species to which we belong.

Here is the explanation I find most plausible, and it is one that overlaps with many other attempts to explain the strange historical path of our species. All species nibble experimentally at the edges of their niches, but with limited success. In contrast, our species has moved well beyond each niche it has occupied, until eventually it has started reshaping its surroundings to create entirely new niches. So, what we need to explain is our species' remarkable technological and scientific creativity, our ability to learn more and more about our environments so that we can manage and manipulate our surroundings with increasing power. Behind the sustained growth trends that give shape to human history, and driving them all, is the most fundamental of all trends in human history: a steady increase in our knowledge of our surroundings, which allowed our ancestors to control more resources, more energy, more niches and, by doing so, to support increasing populations. Our "ecological power" or control over our surroundings has increased, following the same accelerating pathway as so many other trends in human history. And that has eventually given us control over much of planet Earth.

What explains this extraordinary scientific and technological creativity? I have argued for many years that the driver of this species-defining creativity is what I call "collective learning": our unique ability to share information with such precision and in such volume that information and ideas accumulate faster than they are lost, so that the total amount of information available to human communities tends to increase across generations. The idea of collective learning overlaps with ideas such as "cultural evolution" that other scholars have used to explain our exceptional technological creativity, and it may be that these differences in terminology are not that significant. For example, Alex Mesoudi (2011, 203), a specialist in cultural evolution, describes the accumulation of knowledge over many generations as "the defining characteristic of human culture." Note that our creativity is collective rather than individual – more an aspect of human groups than of human individuals – because new insights, even if they are contributed by individuals, acquire significance only when shared and stored within the collective memory of many humans linked through exchanges of information.

If this argument is on track, it means that collective learning is a defining

feature – perhaps the defining feature – of our species. It is what makes us so different. It explains our odd historical trajectory and why we have become a force for change on planetary scales.

It is important to discriminate between what I call "collective learning" and other types of learning, because many different species are capable of learning from others. Learning is a cultural attribute, so we are talking about collective rather than individual learning. Culture depends on the sharing of learned knowledge between many individuals. Such sharing, and some level of "culture," can be found in many intelligent species that have languages and can share information and ideas. Populations of chimps, for example, have different ways of hunting or cracking nuts.[7] But humans are unique in sharing information so precisely and on such a scale that collective stores of knowledge grow and evolve across generations. We know of no other species that can exchange information so precisely and in such volume that, in the long run, collective gains in knowledge begin to outweigh losses. Only in our own species do we have clear evidence for the long-term accumulation of information across many generations. That is the phenomenon I describe as "collective learning," not the more tenuous and evanescent forms of learnt knowledge that we find in some other cultural species. Something like a threshold was crossed by the first humans, a small change that made a colossal difference. The difference is, in the Hegelian language, quantitative, but it is also large enough to create an entirely new phenomenon, as "quantity turns into quality." The crossing of this threshold in our ability to share information explains why our species has become increasingly powerful, and at an accelerating rate, as more and more ideas have accumulated and been exchanged by millions of individuals and communities within expanding networks of collective learning over many millennia, giving humans increasing power over the landscapes and organisms all around us.[8]

Collective learning and cultural evolution were made possible by the evolution of human language, an exceptionally powerful medium of communication. Human language connects humans within what linguist Steven Pinker (2007, 115) calls "an information-sharing network with formidable collective powers." We do not fully understand how human language evolved, though there are many promising hypotheses. It is surely no accident that it emerged within a highly social species whose members had powerful reasons for wanting to communicate with other members of their communities.[9] No wonder all social species, including birds, whales, and primates, have some form of language. But human language is exceptionally powerful. With more space in their frontal cortex, humans had the neurological room for exceptionally large stores of names, words, and concepts, and also for the grammatical workbenches and lathes on which words and concepts can be turned into elaborate stories about real and hypothetical worlds (Roth 2013, 260).

Whatever its origins, human language led our species across a fundamental threshold opening up possibilities that had existed for no earlier species on Earth. Human language allowed each human individual to dip into and contribute to the vast and growing pool of knowledge accumulated from generation to generation in all human communities. Shared stores of well-tested knowledge gave humans exceptional and increasing power over their surroundings and over other species of animals and plants. That is why, whereas Goudsblom argued that learning how to master fire was the critical turning point in early human history, I will argue that control of fire was enabled by an early, and perhaps rudimentary, form of collective learning. It was merely one of the earliest products of that trans-generational intellectual creativity made possible by collective learning.

Collective learning also helps explain the slow acceleration we see in so many of the larger trends in human history. For most of human history, knowledge accumulated very slowly within tens of thousands of small communities. Though some information was exchanged between neighboring groups, sometimes over large distances, it was local knowledge that mattered most, which is why the societies of the Foundational Era were extremely diverse and technological knowledge diffused slowly by modern standards. Knowledge accumulated at local scales. And that helps explain why the larger process of accumulation was largely invisible to contemporaries. What stood out in the lives of individuals were cyclical patterns – the rise and fall of individual families or communities or empires.

But looking back from today, armed with much more knowledge of the past, it is easier to see the long trends of accumulation and the way they have accelerated, particularly in recent human history. Trends of collective learning accelerated because collective learning generated positive feedback loops as innovations encouraged other innovations. Thus, improved communications, whether through the domestication of horses or improvements in sailing ships or in modern innovations such as the telegraph and internet all increased the scale and speed at which humans could share and store information within networks of exchange that now span the entire planet. These feedback loops accelerated many forms of historical change until they became increasingly hard to ignore within recent centuries. "In the past," wrote the philosopher Alfred North Whitehead (1933, 93, in a chapter on "foresight"), "the time-span of important change was considerably longer than that of a single human life. Thus, mankind was trained to adapt itself to fixed conditions. Today this time-span is considerably shorter than that of human life, and accordingly our training must prepare individuals to face a novelty of conditions."

5. Where Is It All Going? Speculations about the Final Shape of Human History

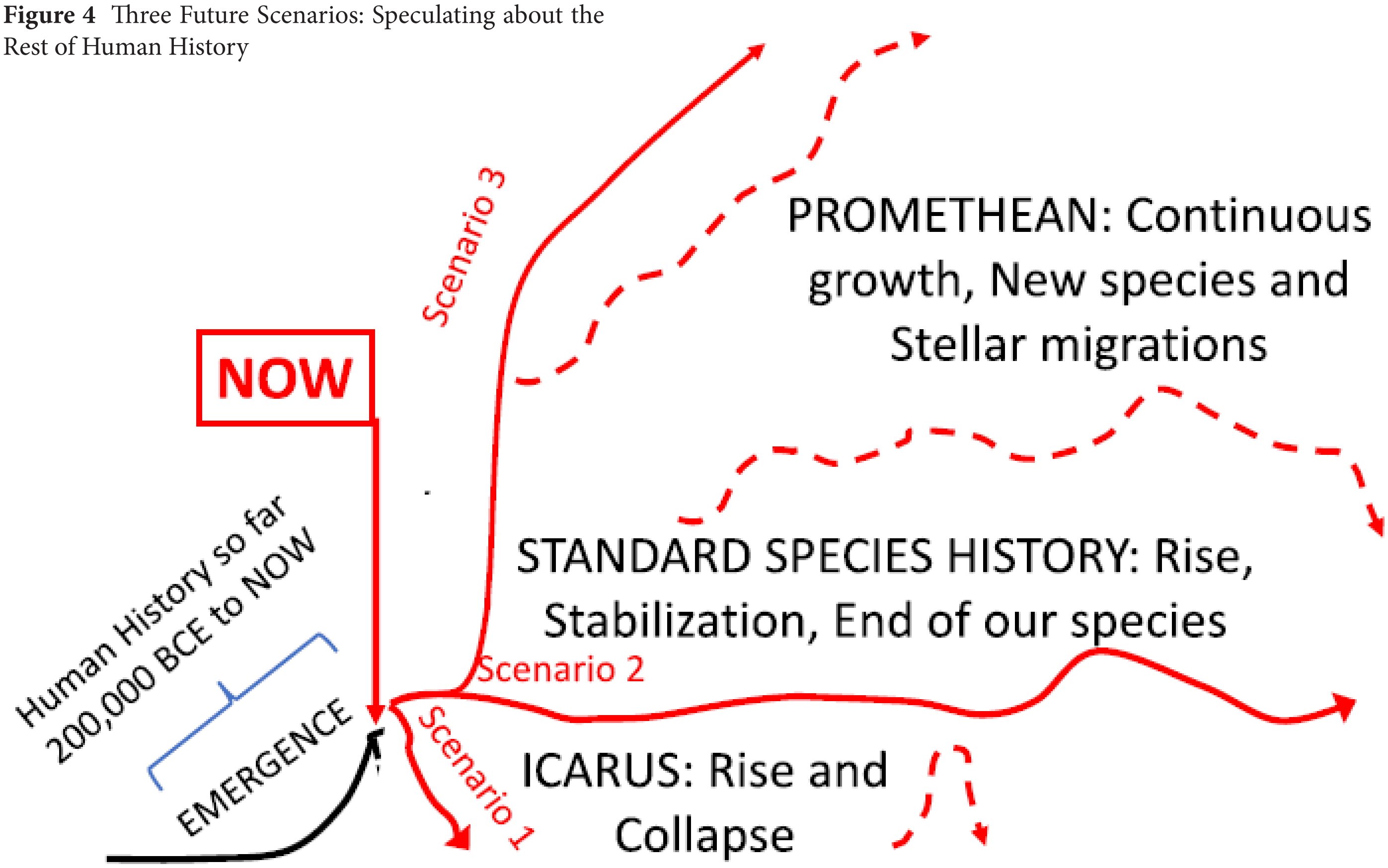
So far, we have seen just part of the larger arc of human history. This is like seeing the biography of a child, which is why the trajectories we have seen so far look like an unusually extended "emergence" phase. Can we take the next step and speculate about what it is that is emerging and what shape human history will have assumed when, eventually, the whole story can be told? I have just completed a book on the future, so such questions are very much on my mind and I will not resist the temptation to speculate (Christian 2022).

Historians generally avoid questions about the future. Indeed, the historiographer, R.G. Collingwood once thundered (1994, 54) that "The historian's business is to know the past not to know the future; and whenever historians claim to be able to determine the future in advance of its happening, we may know with certainty that something has gone wrong with their fundamental conception of history." I disagree. I will argue that careful speculation about possible futures is an important form of heuristic for historians because it can suggest new ways of thinking about and assessing the past, those parts of human history that we can see from the present moment. Speculating about possible futures is particularly helpful as we try to identify a shape or trajectory to human history and to tease out possible meanings from that trajectory. Above all, it is worth asking what the trajectory of human history may look like when that history has ended, so that we (or some imaginary future historian of another species) can imagine the whole trajectory as, today, we can describe the evolutionary history of extinct species such as the Dodo or Tyrannosaurus rex.

Such speculations are, of course, not evidence-based in the way that our

discussions of the past are evidence-based. We have no documents from the future, as Collingwood pointed out (1994, 120). So, the discussion that follows is much more speculative than the preceding sections of this paper. That is in the very nature of all types of future thinking. Nevertheless, we can never avoid trying to think seriously about likely futures, and past trends do give us some hints about the type of stories that may be told about our species when our collective story is over. Indeed, studying the more regular trends in the past is the foundation of all serious efforts at forecasting, whether in meteorology, the study of long-term change, or economics. And that means that thinking speculatively about the future has great historiographic significance because it may hint at the long-term significance of trends and tendencies of which we can only see the early phases. For these reasons, the final part of this paper will consider a number of possible future scenarios for human history and ask what sort of meanings might lurk within these different stories. I will explore three broad types of future scenarios for human history. They are based loosely on four scenarios familiar within the world of Futures Studies, and pioneered by the futurist, Jim Dator

Figure 4 Three Future Scenarios: Speculating about the Rest of Human History



(2019, "The Four Generic Futures," chap. 5, pt. 4). Though described here as distinct scenarios for the sake of clarity, the real future will surely blend elements from each of these scenarios to create futures as complex and contradictory as the past that is visible to us today.

All three scenarios make two fundamental assumptions. First, they assume the importance of collective learning as a defining feature of our species, one of the oldest and most persistent of trends in human history. They assume, in other words, that humans will keep finding out more about their environments and finding new ways of managing and making use of those environments. That implies that humans will always have a dynamic and changeable relationship with their surroundings. Second, all these scenarios assume that human history so far consists of a prolonged and unusually extended "emergence" phase. And that raises the profound question: what is emerging? What has human history so far been leading to?

5.1 Scenario 1: Collapse: The Icarus Scenario

The first scenario assumes that we humans are near to the end of the emergence phase of our history and may be entering a phase of rapid reversal and collapse driven by collective learning, by a creativity that generates dangerous technologies that we fail to control. Nuclear weapons are an example of the sort of forces I have in mind. But engineered or uncontrollable pandemics or a failure to come to grips with climate change could also lead to the destruction of much of our species and much of our environment. Under this scenario, if something new was emerging in human history, it will be still- born. We will crash, like Icarus, whose wax wings melted as he flew too close to the Sun.

What stands out in this scenario is the instability and dynamism of human history that could deny our species a prolonged stabilization phase. We may be entering a period of extreme vulnerability, a dangerous bottleneck in human history. In a careful recent study of existential dangers to our species, Toby Ord (2020, 167) puts the likelihood of a profound collapse over the next century at about 1 in 6. Of course, we should not take such estimates too seriously, but they do offer food for thought. Under most of Ord's scenarios, collapse is self-inflicted, the product of our over-reaching technological creativity. That makes collective learning both the most distinctive feature of our species and its fatal flaw. Some scholars in the SETI community have speculated that any species as creative as ours, wherever it may appear in the Universe, is likely eventually to build technologies so dangerous and uncontrollable that they will lead to destruction and collapse. That idea might help explain why we have failed so far to make contact with any other technologically creative species; none survived long enough to make contact.

A collapse scenario would mean that we are now close to the end of human history. It would mean that the trajectory of human history consists of a long emergence phase, followed almost immediately by a sudden collapse, with no significant phase of stabilization in the middle. However, it is also possible to envisage a collapse that is not total. That would be similar in shape, though much larger in scale, to the local or regional collapses that have already been seen many times in human history, such as the collapse of the Roman and Han empires early in the 1st millennium CE. Scenarios like that could eventually morph into our second or third future scenarios.

5.2 Scenario 2: Stabilization and Sustainability

Our second scenario also assumes that we may be near the end of an unusually prolonged emergence phase. But under this scenario, humans will enter a stabilization phase in which many (but not all) of the growth trends of the past will slow or be checked. This scenario looks like the standard trajectory for complex entities as they reach maturity. Many trends today already hint at the start of a slow-down in some of the most important growth trends of the past. This is most evident in the slowing of global population growth since the 1960s. In addition, there is a growing realization that some recent growth curves, such as in the emission of greenhouse gases must be slowed and perhaps even halted.

Under this second scenario, many of the growth trends of the past will slow because we have reached "planetary limits." But the scenario also presumes that humans will have learnt how to live within planetary limits, and how to collaborate on global scales. Innovation and even growth of many kinds will continue under such scenarios, and there will be no slowing of our technological creativity as we search for more sustainable technologies and ways of coping with or even repairing the damage we have already done to the biosphere and more effective ways of collaborating at global scales. But we will learn to avoid those forms of growth that pose intolerable burdens on the global ecosystem and endanger the future of humanity.

Under this scenario, we will eventually identify what it is that has been emerging in the course of human history, because the stabilization phase will mark the arrival of something new: a conscious planet. It will become apparent that human history so far has been building up to the emergence of an entirely new type of complex entity: an entire planet whose future will be shaped by the conscious collective decisions of a single species. That will mark a new phase in the 4.5-billion-year history of planet Earth. Our planet will have become conscious in the same way that our bodies are conscious; while most decisions about the day-to-day operations of the planet will continue to be taken as in the past by local processes – geological, biological, climatological, and even astronomical – the very large executive decisions about planetary futures will now be taken after conscious collective decisions by groups of humans. What we do not know is whether our planet will be the first conscious planet in the history of the Universe, or whether, perhaps, many other conscious planets exist that we have not yet detected. Either way, the emergence of a conscious planet will make human history significant on galactic scales.

Though this scenario envisages a sort of "stabilization" phase to human history, there are good reasons for thinking that the stabilization phase will not last long, no longer than a few centuries or perhaps a millennium or two. That is because, even under this scenario, we may be near the end of our history as a single species. Collective learning is already generating technologies that allow us to modify humans genetically and mechanically, and because these changes will be largely under human control, our species will begin to diversify much faster than it might have under the ancient rules of natural selection. We already know how to change our DNA and we already deploy diverse prosthetics and implants (Kaku 2018, Ch. 11). So, this scenario may be pointing towards the end of "human history" in the strict sense, as our species evolves and diversifies through conscious decisions rather than natural selection, into a range of artificially engineered "post humans." Human history conceived as the history of a single species will end as we start to engineer our own "trans-human" replacements, which will have their own history and their own, distinctive historical trajectories. They may be organisms quite like ourselves, or even very clever machines, or a complex intertwining of humans and machines. Human history will end through a sort of transcendence as we transform ourselves, deliberately and consciously, into new species.

5.3 Scenario 3: Sustained Growth and Migration Beyond Earth: Promethean Scenarios

Our third, Promethean scenario, builds on the second scenario and looks like an extension of it. Under Promethean scenarios, there will be a short stabilization phase lasting a few centuries or at most a few millennia. This will be followed by a new phase of innovation and growth that takes our human and post-human ancestors beyond planet Earth and beyond today's understandings of what it means to be human.

The first reason for taking such a scenario seriously is that we have no reason to think that the restless process of collective learning will stop. Though planetary limits will surely check many forms of growth for centuries, human science and technology will push against those limits, looking for new ways of generating energy (fusion, perhaps) and for ways of migrating beyond planet Earth. Humans have already travelled to the moon and human-made robots have already explored much of our solar system. So, the idea of humans slowly colonizing other parts of the solar system is no fantasy. Eventually, but many centuries in the future, such processes may lead to the colonization of other star systems or the building of artificial worlds. Such migrations will end the bottleneck phase of human history in which we occupy only one planetary habitat whose destruction would entail the end of human history. Instead, humans and post-humans will overflow planet Earth and begin spreading through nearby parts of our galaxy. Such a scenario would continue the sustained migrations into new environments, powered by collective learning, that have shaped much of human history (Finney 1992). This scenario also envisages the emergent "conscious planet" of the previous scenario undergoing a sort of replication, as humans and post-humans travel to and begin to manage other worlds. Indeed, this, it seems, is how conscious planets will reproduce and spread through many different niches on galactic scales.

This third scenario looks like science fiction, of course, but there are good reasons for taking it seriously. If we interpret the word "human" loosely, to include many post-human lineages whose activities are powered by increasingly dynamic forms of collective learning, then human history could be just beginning. The history of our lineage could last at least as long as its past and possibly for millions of years. Could humans still be around in 200,000 years, presumably scattered over several star systems as in the space operas of science fiction such as Isaac Asimov's Foundation series? If so, human history will turn out to be of interest and significance not just on a single planet, but on galactic scales. The "human" future will take the form of slow migrations to nearby parts of the galaxy, combined with a diversification of lifeways and even of biologies on different planets and around different star systems. If this is indeed the shape of our future histories, then we will eventually have to see human history so far as just the emergence phase of brand new entities and processes that will prove significant at cosmological scales. This is perhaps the strangest scenario we can imagine for the history of our species.

The real future will surely be messier than these neat scenarios suggest; it will be a mashup of many different scenarios. There will be regional collapses, but they may not prove fatal and may be followed by periods of stabilization and further growth and, eventually, by a slow and stuttering colonization of other worlds, accompanied by mechanical and biological diversification of our species over thousands, perhaps millions of years.

6. Meanings: What do these Speculations Suggest about the Meaning of Human History?

In the concluding part of this paper, I try to tease out four types of meaning implicit in the preceding discussion.

6.1 What Makes Us Distinctive?

Even without speculating about possible futures, the human history that we can see today shows that our species has a unique creative dynamism, based on collective learning. And that dynamism has lent planetary significance to human history as we observe it now. We are different from other species, and the trajectory of human history is different from theirs. Tiny differences in our species have turned us into something entirely new, into "dragon-kings." And that means that we live at a turning point in planetary history and perhaps in the history of our part of the galaxy. Our speculative future scenarios remind us that the creativity of our species could prove a curse, or it could drive a very long history that will take our descendants far beyond planet Earth, a history of which today's historians have seen merely the earliest, emergent stages.

6.2 The Dangers We Face

These scenarios also highlight the dangers that could arise from our astonishing creativity, dangers that are particularly threatening at the present bottle-neck moment in human history. There is a real possibility of collapse in coming centuries. But our creativity is such that we should be optimistic about the chances of collectively finding pathways through the dangers we are facing.

6.4 What Human History Has Been Building Towards

In the more optimistic of these scenarios, human history is leading to the emergence of phenomena that are entirely new on planetary scales and perhaps significant on galactic scales. Human history so far has been pregnant with a new type of complex entity: a conscious planet. And if we add to this story the likelihood of human migrations beyond planet Earth, then we can envisage futures in which the human trajectory on Earth may be repeated on nearby planets and even nearby star-systems. Under this scenario, the trajectory of human history will have galactic significance.

6.5 The End of Human History: When and How?

But there are also reasonable grounds for speculating that, except in extreme collapse scenarios, the end of human history will arise as a result of collective learning applied to our own genomes and bodies, as new technologies start generating new sub-species of humans, many of them genetically, biologically, or even mechanically enhanced. In that sense, the trajectory of human history will end with the evolution of new species whose histories will follow trajectories similar to but perhaps even more dynamic and spectacular than those of Homo sapiens.

I hope the ideas explored in this essay can justify my claim that thinking carefully about the overall shape of human history is worth doing despite the speculative nature of much of the exercise. Asking the sort of questions I have asked can suggest new ways of thinking about meanings and forms of significance that lurk within human history and within our strange species. They should surely be of interest to all scholars in the humanities.

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Endnotes

1. On big history, introductions include Christian (2018), and Benjamin, Quaedackers, and Baker (2020); see also the website of the "International Big History Association" at https://bighis- tory.org/ (Accessed March 14, 2023).

2. For recent discussions of our species' origins, see Ehret (2015); Hiscock (2015); and Gamble (2019). Gamble and Ehret argue for sustained demographic and technological change beginning about 60,000 years ago; but there are scholars who see good evidence for important technological innovation and accumulation as early as 200,000 BCE, including McBrearty and Brooks (2000).

3. Zalasiewicz and Waters (2015); for an overview of the Anthropocene as a phase of world history, see Christian (2019).

4. Based on Smil (2015), as summarized in Christian (2018, 312).

5. Data in this paragraph from Our World in Data website (https://ourworldindata.org/ [Accessed March 14, 2023]) and from Christian (2018, 312), which draws largely on Smil (2015).

6. What the evidence for such a species might look like is explored well in Zalasiewicz (2009).

7. See Safina (2020) for insight into the richness of the cultures of brainy mammals and birds.

8. For a very fine history of human technology which sees it not as a series of great inventions, but rather as the slow accumulation of tiny changes and insights made by millions of individuals, see Arthur (2009).

9. The role of cooperation is stressed in work by Tomasello (such as 2009).

Contributors

David Christian began his career as a historian and scholar of Russian history; since then he has been one of the founders of the emerging discipline of Big History. In 1989 he began teaching the first course on the topic, examining history from the Big Bang to the present using a multidisciplinary approach with the assistance of scholars in diverse specializations from the sciences, social sciences, and humanities. He served as founding president of the International Big History Association. His best-selling Teaching Company course entitled Big History caught the attention of philanthropist Bill Gates, who is funding Christian's efforts to develop a program to bring the course to secondary-school students worldwide. He retired in 2021 and is now an Emeritus Professor of Macquarie University. His publications include: *Maps of Time: An Introduction to Big History, 2005; Big History: Between Nothing and Everything, 2014; Origin Story: A Big History of Everything, 2018; and Future Stories: What's Next, 2022.*

Anton L. Grinin is a research fellow at Moscow State University and National Research University Higher School of Economics in Moscow, Russia. With a Ph.D. in biology, his academic interests include bioethics, evolutionary and future studies, the history and philosophy of technology, and globalization. He specializes in the technological revolution unfolding in the 21st century, especially in cybernetics. These events will result in the profound transformation of the economy and society, posing ethical-legal and other risks. Anton also investigates correlations between the Cybernetic Revolution, Kondratieff waves, and issues of global aging. The author of more than fifty publications in Russian and English, including two monographs, he has won the Gold Kondratieff Young Scholars Medal and the Alexander Belyaev Literature Award.

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.

John Hasse, Ph.D. AICP is a professor of geography and Director of the Geospatial Research Lab in the Department of Geography, Planning & Sustainability at Rowan University where he teaches various courses in geography, GIS and planning. Hasse's research interest focuses on land use geography and the interface of land use, environmental planning and spatial analysis. Hasse has taught courses in geography, planning and GIS where he integrates the big picture perspectives of geography and Big History with the applied tools of planning for designing a more resilient future land system. Professor Hasse integrates these same interests in his research where he has been conducting an on-going multi-decade analysis of urbanization and open space loss in New Jersey and studies the environmental impacts of future development buildout. Hasse has established the NJ MAP project, an award-winning online interactive atlas of New Jersey's environmental data. For the past decade Hasse has been teaching a course that tells the story of planet earth that integrates the time dimensions of Big History with the spatial dimensions of geography. Central to this work is the perspective of humans as the storytelling species.

Gregg Henriques is Professor of Graduate Psychology at James Madison University in the Combined Doctoral Program in Clinical and School Psychology. He received his Ph.D. in Clinical Psychology from the University of Vermont and did his post-doctoral training at the University of Pennsylvania. He is a theoretical psychologist and has developed the "Unified Theory of Knowledge," which is a consilient scientific humanistic worldview to unify psychology. He is the author of *A New Unified Theory of Psychology* (Springer, 2011), and *A New Synthesis for Solving the Problem of Psychology: Addressing the Enlightenment Gap* (Palgrave McMillian, November 2022). His scholarly work has been published in the field's best journals, and he has developed a popular blog on Psychology Today, *Theory of Knowledge*, which has received over nine million views. He is a fellow of the American Psychological Association, the 2022 President of the Society for the Exploration of Psychotherapy Integration, and founded the Unified Theory of Knowledge academic society, which hosted the 2023 UTOK Conference, *Consilience: Unifying Knowledge and Orienting Toward a Wisdom Commons*.

Gerard Jagers Op Akkerhuis. Evolutionist and system scientist. Driven by a lifelong passion for evolution and complexity, Gerard studies the past, present and the future of the universe. A unique aspect of Gerard's work is the use of a modern, scientific version of the classical 'Scala

Naturae' called the 'Operator Hierarchy'. This hierarchy offers a fundamental mechanistic basis for the classification of objects in the world, connects the evolution of the abiotic world with that of the biotic world, and suggests extrapolations beyond the current horizon of evolution. This hierarchy also serves as a basis for defining the concepts of 'organism' and of 'life'.

Gerard received his masters in Wageningen (1986, Cum Laude), received his first PhD in Ecotoxicology (Wageningen, 1993) and, seventeen years later, his second PhD in philosophy (Nijmegen, 2010). Gerard has written over 100 publications and several books: "The operator hierarchy", "The pursuit of complexity", "Evolution and transitions in complexity" and "ScienceBites". He has been interviewed by a national newspaper in the series about "Controversial thinkers whose ideas can change our vision of the world". His work has been discussed on radio and television.

Hirofumi Katayama 片山博文 is professor at J.F. Oberlin University, Tokyo, where he specializes in environmental economics. He organized and teaches one of the first big history courses in Japan <http://obhp.org>. In 2019, he and Nobuo Tsujimura organized the first Japanese Big History symposium, Big History and Liberal Arts, hosted by J.F. Oberlin University. Hiro's goal is to construct a 'Buddhist Big History,' which is based on the respect for all life and existence. His publications include Politics of Climate Change over the Arctic: Preliminary Thoughts on the Global Commons (Bunshindo 2014) and Free Market and the Commons: An Introduction to Environmental Finance (Jichosha 2008). His e-mail address is <katayama@obirin.ac.jp>.

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 modeling. His research includes Big History synergistic trends among energy, environment, organization, and information.

Ken Solis is a retired internist and ER physician with a master's degree in bioethics. His long trips to and from work over the years also gave him many hours to listen to lectures on other fields in the sciences, philosophy, and history. By coincidence, he was teaching "A Brief History of the Universe" to adults before he encountered David Christian's big history lectures for "The Great Courses." His special interest in big history is what thermodynamics, information theory, and complexity science might reveal about how systems have, depending on the circumstance, progressed, regressed, and diversified over time. He has also applied these disciplines to the formulation of an information-centric ethical theory that was published in *JBH*.

Tyler Volk, Professor of Biology and Environmental Studies, New York University. At the scale of 4 billion years, the scale of life on Earth, he looks for new models and draws links across various disciplines. Author of *Quarks to Culture: How We Came to Be* (2017) and *Metapatterns: Across, Space, Time, and Mind* (1995), here Volk, a self-described "patternologist," compares his tripartite system of dynamic realms with the working conceptual structures currently deployed in the field of big history.