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JBH, the journal of the International Big History Association (IBHA), is published online and is accessible to members of the IBHA. The IBHA also publishes its bulletin, *Origins* and *Emergence.* The bulletin contains members' essays on Big History. *Emergence* presents accounts of their activities and views, announcements of conferences and meetings of interest, and other communication of interest to IBHA members.

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From the Editor

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When thinking about big history, I am often conflicted as to how to refer to it. Is it an academic discipline or a research field? Are these even different things? Perhaps it is a branch or system of knowledge. Then the mind reels: a theory, a structuring principle, a scientific creation myth, an origin story? What is this imaginative vision that we have got hold of? Collectively, the contributors to this edition suggest that I am asking the wrong question altogether.

On one level, the essays here presented are markedly diverse. There is a historiographical piece by Barry Rodrigue wherein he narrates and documents the history of big history and reflects upon its significance. Ken Solis makes the case for the ways in which a carefully laid out theory of ethics, what he calls "complex-information ethics," could provide a broad framework for making judgments about right and wrong at scales well beyond the human, aiding big historians to think more clearly about changes to the biosphere, artificial intelligence, transhumanism, and possible encounters with extraterrestrial intelligence. For his part, Fred Spier is interested in re-examining the threshold approach. Barry Wood shares the latest research on the Chicxulub impact and connects it to the history of the IBHA itself. Ken Baskin draws on complexity theory, especially in regard to the principle of emergence, as a way of reexamining the history of religious forms and systems. But what these authors have in common is an ongoing interest in thinking *within* big history, that is, in entering into a conversation about the paradigms of our—What shall we call it?—our *perscrutation*.

Many of us see big history as a paradigm for history in general. It fits perfectly the definition Thomas Kuhn provided in *The Structure of Scientific Revolutions* (1962): "a universally recognized scientific achievement that for a time provides model problems and solutions to a community of practitioners."[1] According to Kuhn, such paradigms are often laid out in seminal texts, or, rather, we can think of those seminal texts *as* paradigms, which is arguably what we have in David Christian's *Maps of Time* (2004), which would make collective learning a paradigm for big history.[2] Such paradigms, according to Kuhn, share two essential characteristics: (1) their achievement is "sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity," and (2) they are "sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve."[3]

> —Which is precisely what our contributors are trying to do.

Kuhn also noted, though, that finding paradigms in the social sciences is difficult, that there is far more disagreement among social scientists about the nature of legitimate scientific problems and methods than in the natural sciences.[4] How much more so, one hastens to add, in history and philosophy.

> —Which is made clear in our current edition (and arguably in the pages of the *Journal* in general).

But perhaps big history is a different sort of ecosystem. Perhaps this just *is* our paradigm. Perhaps being "sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve" is who we are. The crux of the matter is that the historical sciences are more complex than the physical sciences. Big history requires some form of scientific pluralism. It is supradisciplinary—and the different systems of knowledge that it makes use of—astrophysics, geology, biology, *all* the social sciences, history, philosophy—have different problems and different methods and look at the world from different perspectives.

The English philosopher, Mary Midgley, proposed the aquarium as an apt metaphor in such cases. If we think of the world as a huge aquarium, we cannot see it as a whole from above. We must peer into it through a great number of small windows. Inside, the lighting is dim. There are rocks and weeds and all manner of tricky places where the inhabitants might hide themselves. What is that over there? Is it a fish? Is it the same fish we saw a moment ago? Is it a rock glittering in the shadows? Or some yet unidentified creature? The only thing to do for understanding it is to run around to another window and see whether we can get a better view. The only way we will be able to make sense of the world is to look at it from as many different angles as possible. It simply won't do to suggest that our window is the only one worth looking through.[5]

Notes

1. Otto Neurath, ed., *International Encyclopedia of Unified Science*, 3rd ed., enlarged, Vol. 2, No. 2 (Chicago: University of Chicago, 1970), viii.
2. David Christian, "Bridging the Two Cultures: History, Big History, and Science," *Historically Speaking* 6, no. 5 (2005): 21-26.
3. Thomas Kuhn, *Structure of Scientific Revolutions* (Chicago: University of Chicago Press), 10.
4. Kuhn, viii.
5. Mary Midgley, *The Myths We Live By* (London: Routledge, 2011), 40. First published in 2004.

Big History—A Study of All Existence

Part 1: A World Connected

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PROLOGUE

This is a brief overview of the field of big history and my personal reflection on its significance. Like others, I developed a macro-perspective of existence from the 1950s onward, as a natural way of thinking, without label or rubric. It was only in 2003 that I heard of big history and realized this concept expressed much of what I had been doing.[1]

This realization mirrored the experience of many others around the world in the second-half of the 20th century—interdisciplinary and macro-historical studies had emerged independently around the planet in a global conjuncture. It was a general human expression, representing an impulse of humanity.

For my part, I had engaged in ethnographic studies in various locations, with a focus on human adaptation. I therefore saw cosmic evolution, big history, and universal studies as a component of humanity's survival strategy—a concept especially understood by our post-Soviet and Asian colleagues. As a result, my focus in this two-part article is on how macro-historical studies relate to the theme of human survival in this modern era of climate crisis.

Others will have a different focus and have been effected by different concepts and authors. Their views are just as valid, and I encourage them to share them. Big history is a house with many rooms.

This article is done in collaboration with and is jointly published with the *Journal of Globalization Studies*.

究天人之际，通古今之变，成一家之言。
To inquire into the relationship between heaven and human, to comprehend the vicissitudes of past and present, and to form a single narrative of it all.

— 司馬遷 Sima Qian, 100 BCE

Like Sima Qian, our ancestors wondered about their existence as they looked up at the stars, watched red lava flow down volcanic slopes, heard waves roll softly along a beach, and felt the breath of other life on their skin. However, this creative process was not just a poetic legacy—it took root in brutal shifts on the landscape three-million years ago, when such questions were a serious strategy for human survival.

As ice sheets absorbed the world's moisture, the global climate cooled and dried. In East Africa, forests retreated, forcing our ancestors onto arid grasslands. They had to find a new way of life, searching out wetlands and new foods to harvest. Their repertoire of skills grew to match the shifting climate and biome—from stone tools, fire, and clothing to shelters and snares, along with increasingly complex languages. Those who could not adapt, perished.[2]

Additional shifts in the glacial period forced our ancient families farther afield, but our surviving kin prospered and migrated into new landscapes, adding to their collective knowledge as they went. Family bands grew and used their keen observations to craft complex worldviews. We get glimpses of these new understandings in calendars built by early foragers and farmers.

In these early times, gaps in understanding were filled in by fables and magic. Although the instructions for making a stone hand axe differed from explaining

Image 1: The markings on the Ishango bone have been interpreted as a lunar calendar by some scholars. At its top is a quartz tool for incisions. Dated to 20,000 years, it was crafted by a fishing community along the Semliki River in today's Democratic Republic of Congo. Courtesy of the Royal Belgian Institute of Natural Sciences. For more information, see Royal Belgian Institute of Natural Sciences 2018.

bright objects in the night sky, all explanations involved intangible meanings, which often served as memory devices flavoured with fantasy. Stones were thought to have hidden qualities as much as constellations. Myth and science coexisted with a rich use of metaphor and narrative.[3]

As the last glacial advance began to wind down twenty millennia ago, sea levels and fresh water tables rose, which contributed to new abundances along with the development of horticulture and pastoralism. Then another period of aridification began 8000 years ago—the Great Drying. In North Africa, wetlands evaporated as grazing herds compounded the climate problem. Prairies degraded into Sahara dunes. Some adapted to desert life, such as the Bedouin, but others relocated to new areas of water: the Mediterranean, Lake Chad, and the Niger and Nile rivers. One of these transitional sites was Nabta in southern Egypt, where cattle remains and climate change are seen in archaeological sites, including celestial-oriented stones. Their later migration to the Nile is thought to have contributed to the Egyptian cult of the sky-goddess, Hathor.[4]

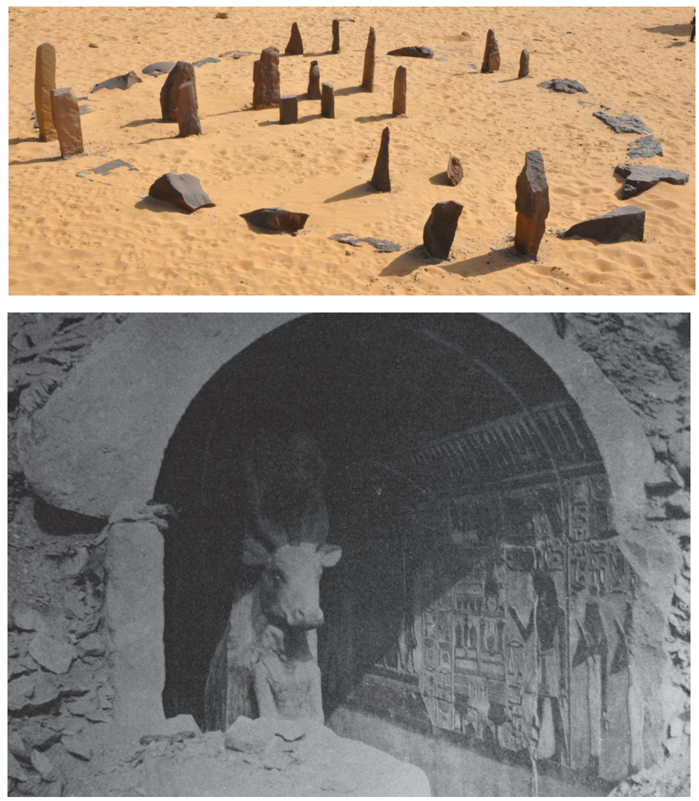


Image 2a: Upper – Reconstruction of the Nabta calendar circle of c. 7000 BP at the International Museum of Nubia, Aswan, Egypt. Photograph by Raymond Betz, 2009, *Wikimedia Commons*. 2b: Lower – Hathor shrine, Deir el-Bahari, Egypt, c. 1500 BCE. Photograph by Henri Édouard Naville, 1907, *Wikimedia Commons*. The cult of the sky-goddess, Hathor, represented as a cow, is considered an artefact of Saharan pastoralist integration into what would become Egyptian civilization. For more information see Brass 2017.

Image 3: Artefacts of the Indus Valley Civilization, c. 2400 BCE. Harappan script on a stone seal (above) at Lothal and water reservoir (below) at Dholavira, in Gujarat, India. Photographs by Barry Rodrigue.

Other peoples around the world moved to the Tigris and Euphrates, Indus and Ganges, Yellow and Yangtze, Norte Chico and Barka, as well as smaller wetlands.[5] This inter-ethnic clustering required them to share resources and led to new social dynamics. Complex agriculture arose, along with centralized religions, new craft specializations, wider communication skills (writing in a dominant language), and stratified society. Today, we call this survival strategy: *civilization*.

Such links between climate, resources, and civil society were noted by Islamic scholar Abū Zayd Ibn Khaldun in his نودلخ نبا ةمّدقم [Muqaddimah / Prologue] almost 800 years ago.

> This [lack of water] can be observed in countries where springs existed in the days of their civilization. Then, they fell into ruins, and the water of the springs disappeared completely in the ground, as if it had never existed.[6]

While we think in terms of the steady advance of civilization, its establishment and spread were a fractured process. Many societies continued traditional foraging lifestyles, while others adopted a few attributes of civilization but not others. Some abandoned civil life when circumstances changed, while others took it on when events suited them. An example is the Oxus Civilization in the Aral Sea watershed, which shifted with climatic changes 4000 years ago, before finally succumbing to aridification and its people taking on the nomadic and farming lifestyle of the surrounding steppe peoples.[7] Civil society was a mixed global pattern of human adaptation.

With these adaptations, worldviews also changed, as seen when Yorùbá Babalawo in West Africa, pre-Socratic philosophers in the Eastern Mediterranean, Mauryan sages in South Asia, Zhou scholars in East Asia, and Mayan astronomer-priests in Central America codified holistic cosmologies. Rational answers slowly replaced myth to become fact-based understandings. This process accelerated as peoples began more and more to connect via trade routes. Besides an exchange of precious commodities, they shared ideas.

In these early stages of global networking, scholars knit together larger ideas about humanity and nature and, in the process, began to transcend imperial, religious, linguistic, and ethnic frontiers. In the first century BCE, Roman philosopher Lucretius expressed a material view of the Universe and a unitary sense of humanity in *De Rerum Natura* [*On the Nature of Things*]. Likewise, medieval scholar Abū Zayd Ibn Khaldun composed his vast universal history, باتك ربعلا / *Kitāb al-ʿibar* [*Book of Lessons*], which assesses human experience in a pragmatic worldview through the lens of Islamic civilization. These collective understandings of a common existence went through times of intense thought called axial, renascent, enlightened, and revolutionary.[8]

Besides holistic family-community instruction, dedicated centres for learning sprang up in places like Nalanda (India) over a thousand years ago, while Inca aristocracy along the Andes attended the *Yacha Huaci* [House of Knowledge] for lessons in reading *quipu*,

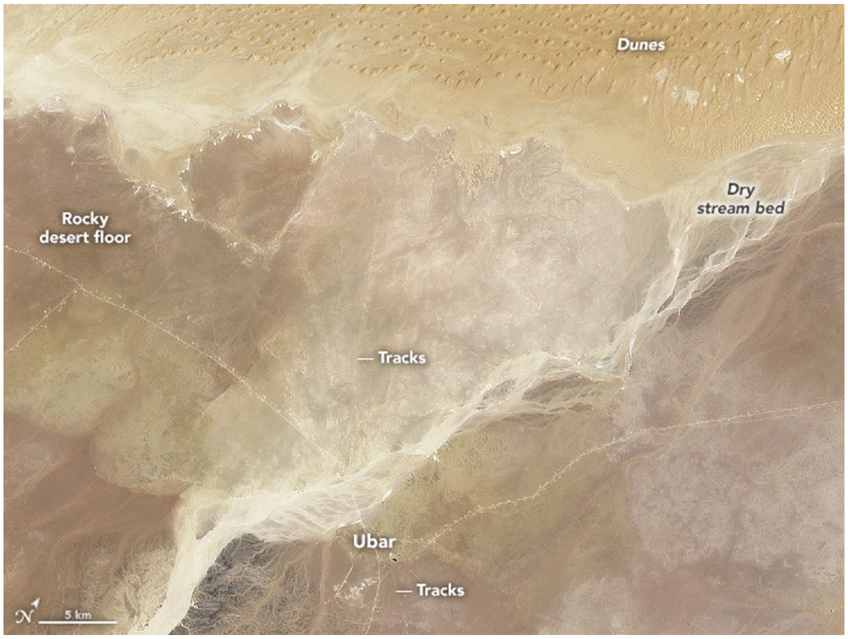
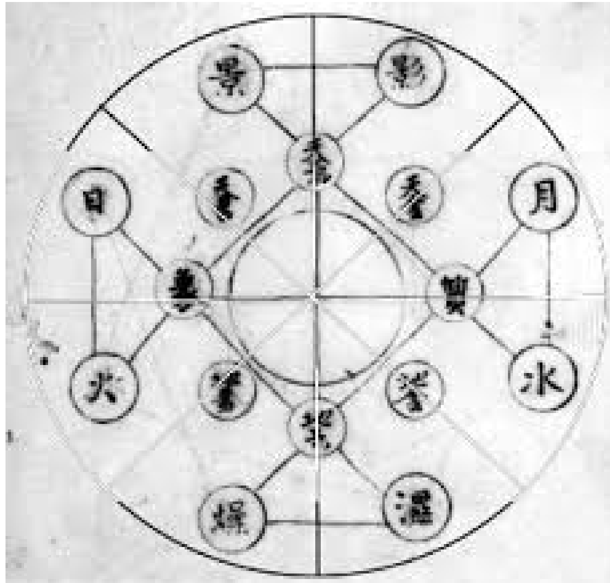


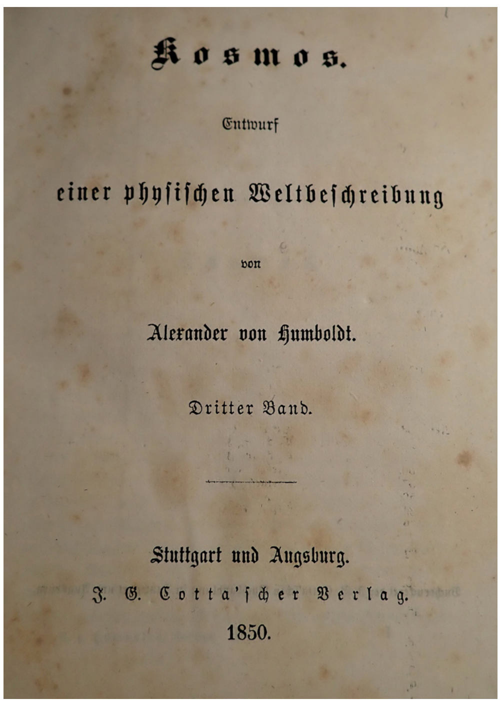
Image 4: Orbital image of routes used in the frankincense trade through the Arabian Peninsula, which flourished from about 5000 to 2000 years ago, as part of the wider Eurasian trade network (including the Silk Roads). These tracks also served for idea exchange, as at the *caravanserai* of Ubar, which fell to ancient climate change. Image from the *Landsat 5* satellite, 27 May 1994. Courtesy of NASA. For more information, see the NASA *Landsat* Gallery at https://landsat.visibleearth.nasa.gov/view.php?id=90847 and Nabataea.net / 'Ubar' https://nabataea.net/explore/cities_and_sites/ubar/. Page of a rhinoceros, bull and forest life from Zakariya al-Qazwini's *Marvels of Creatures and Strange Things Existing*, a popular collection of Eurasian cosmogeography, c. 1280; an image from an mss. painted in Shiraz, Persia, c. 1545 CE. Folio 109, Chester Beatty Library, Dublin, Ireland. Courtesy of *Wikimedia Commons*. Al-Qazwini lived in Qazvin in northern Iran. For a local big history of Qazvin, see Ravandi-Fadai and McNeer 2016.

mathematics, and public affairs. In China, Emperor Yongle ordered a vast encyclopaedia, 永樂大典 [*Yongle Dadian*] in 1403. Almost a million pages in length, it has been superseded in scope by only *Wikipedia*. Even some of the brilliant works of Leonardo da Vinci drew inspiration from Asian innovation.[9]

By our early modern period, European colonial expansion in the fifteenth century led to profound changes in understandings about humanity, but there was no metaphysical quality of north-west Eurasian society that unleashed their hegemony on the world. Far from just a European phenomenon, the new global engagement had grown from the silk-road system into a planetary sphere of interaction that is more properly designated as 'global civilization.'[10]

Neo-Confucian scholar Miura Baien (1723–1789) merged Japanese concepts with Chinese and European ideas to develop a new vision of the world and existence, as in his masterpiece, 玄語 [*Deep Words*]. Miura's work has been compared favourably with the later studies of Alexander von Humboldt (1769–1859). Anthropologist Keiji Iwata, for example, sees Miura's work as an expression of Eastern cosmology / existence, with Humboldt's studies expressing Western perspectives. Humboldt had studied at the University of Göttingen, where his professors sought to unify knowledge and deploy it so individuals, society, and nature could coexist. His five-volume study,




Kosmos.

Entwurf

einer physischen Weltbeschreibung

von

Alexander von Humboldt.

Dritter Band.

Stuttgart und Augsburg.
J. G. Cotta'scher Verlag.
1850.

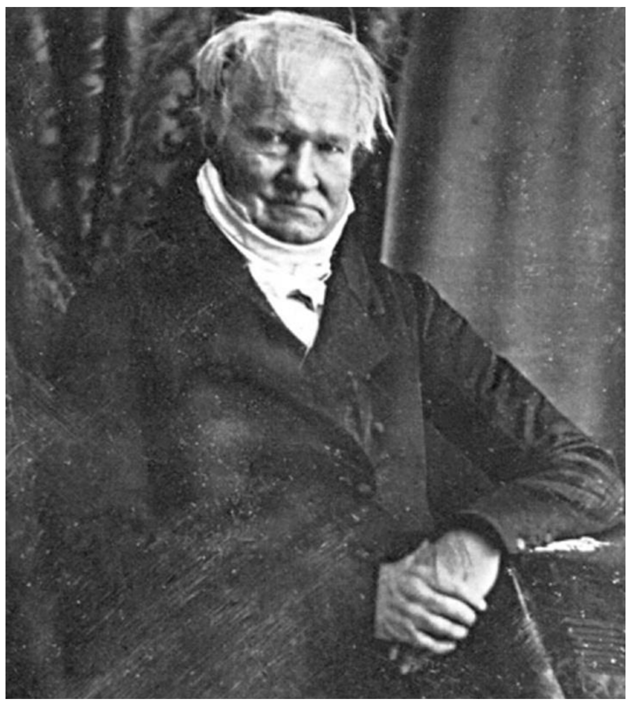


Image 5: Top – Miura Baien, c. 1785, and one of his 玄語図 [thought-diagrams] to conceptualize Earth and its place in the universe (much as Albert Einstein used *Gedankenexperiment* or thought-experiments). Alexander von Humboldt (bottom), 1847. Photograph by Hermann Biow. On the left is the jacket of Vol. III of his series *Kosmos* (1850). Images from *Wikimedia Commons*.

Kosmos (1845), is a precursor to what would come to be called big history.[11]

As historian Daniel Smail at Harvard University points out, "… all universal histories before 1859 [a revolution in historical understandings of deep time] were big histories, since they began with cosmology (as it was then understood) and subsequently linked in the human genealogy."[12] Ironically, just as such synthesis was coming together, its diffusion was interrupted by countertrends in the modern university system that led to specialization, disciplines, and departmental studies.[13] This partitioning of knowledge led to deepening insights about the world and cosmos, but it also led to silos that divided categories of thought and caused pervasive distrust of attempts to synthesize concepts into larger narratives.

In these days of the late 1800s, the new academic departments represented more general 'fields' than narrow 'disciplines,' while much of their work lay in defining intangibles—such as 'culture' in anthropology or 'consciousness' in psychology. These studies also debunked older concepts, such as 'aether,' which chemists dismissed as a relic of alchemy. Universal history participated in this process, as it built links between these fields and disciplines.[14]

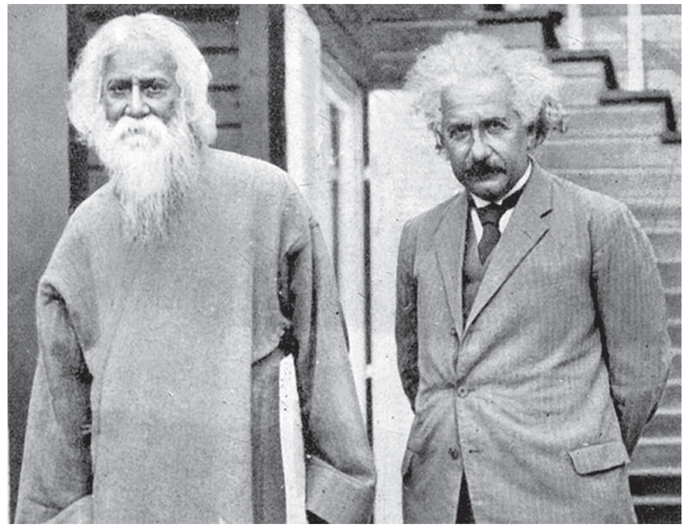
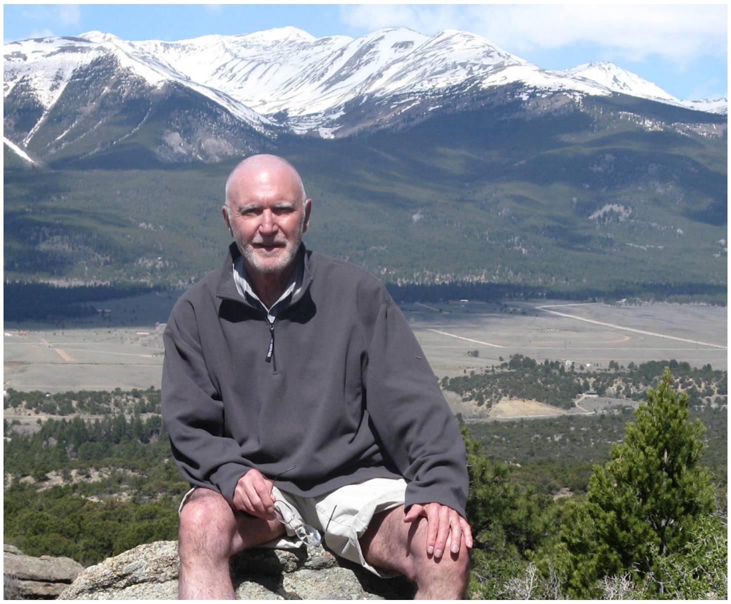


Image 6: Top left – Peter Kropotkin reading his book, *Mutual Aid*, to his friends, the animals. Sketch by Geoff Olson, writer and artist in Vancouver, British Columbia (Canada); used with artist's permission. Top right – Rabindranath Tagore and Albert Einstein in Caputh, Germany, 14 July 1930. UNESCO image. Bottom left – Maria Montessori (left-front) in India, 1939. *Wikimedia Commons*. Bottom right – Kinji Imanishi (centre) in Uganda, 1958. Matsuzawa and McGrew 2008: 588. Itani Junichiro Archives, Primate Research Institute, Kyoto University (Japan).

From Departmentalism to Cross-Disciplinary Studies

Despite growing institutional resistance to universal models of knowledge, holistic frameworks continued. Geographer Peter Kropotkin's Siberian natural history fieldwork in the 1860s and 1870s contributed to his theories of global social responsibility, as in *Mutual Aid: A Factor of Evolution* in 1902. The next year, biogeographer Alfred Wallace, co-discoverer of evolutionary theory with Charles Darwin, released his synthesis of existence, *Man's Place in the Universe*. Such macro-thinking percolated widely through popular



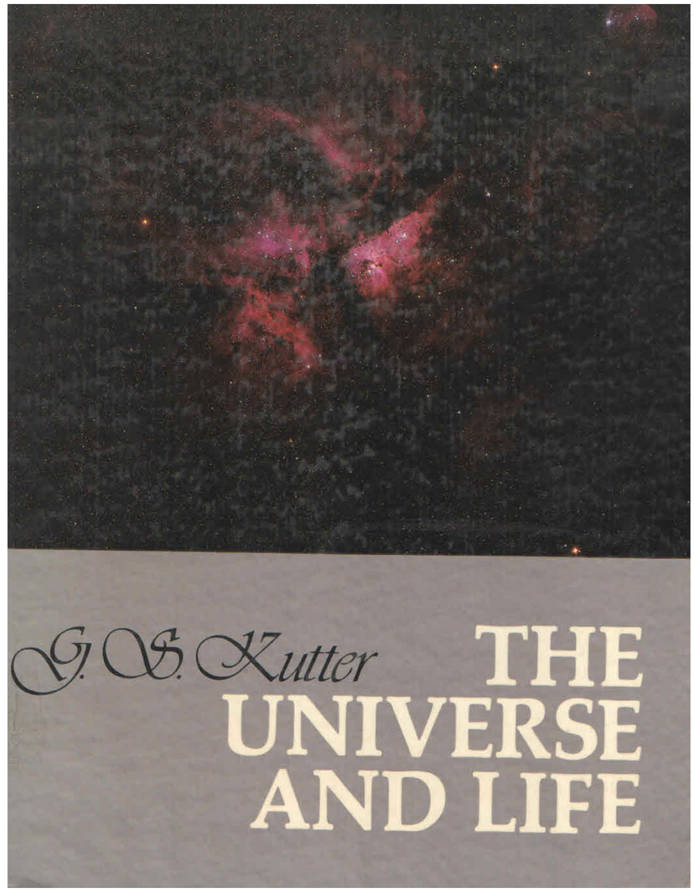


Image 7: G. Siegfried Kutter (left) in the Rocky Mountains above Breckenridge, Colorado (USA), May 2010. Photograph courtesy of Sheryl Kutter. His book, *The Universe and Life* (1987). Author's collection.

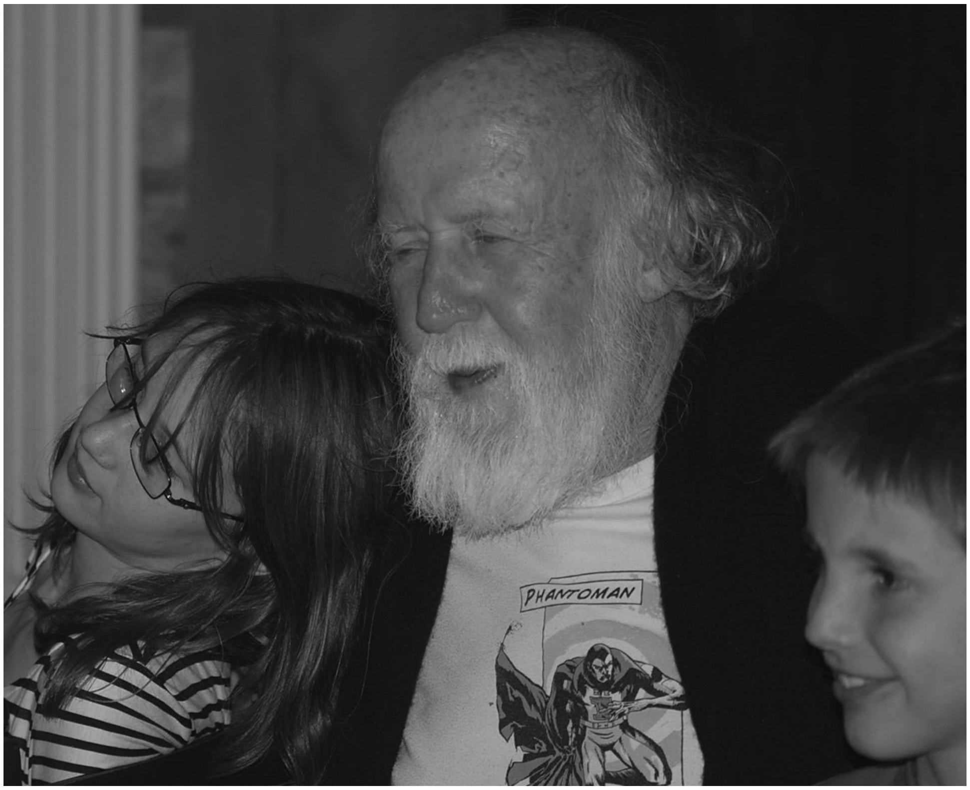
and ecumenical culture.

Author H. G. Wells's *Outline of History* (1920) was updated with new scientific breakthroughs over the next fifty years. Engineer Hiram Maxim composed *Life's Place in the Cosmos* (1933), which considered the existence of life beyond Earth, based on the latest scientific knowledge. Scholar, artist, and Nobelist Rabindranath Tagore encouraged the global-networking of science and philosophy, ideas that he collated in Bengali essays as वशि्व परचिय ह [*Our Universe*] in 1937. Christian scholars like palaeontologist Pierre Teilhard de Chardin and astronomer Georges Lemaître advanced science and how it related to the human condition.[15]

By the 1940s, universal notions entered primary education, as in Maria Montessori's pedagogy of *cosmic education*, adopted from an English model and developed while she was interned in India during the Second World War.[16] Similarly, ecologist Kinji Imanishi composed his thoughts of life's commonalities in 生物の世界 [*The World of Living Things*] in 1941, on the eve of his military deployment. He survived the war and expanded on his concept of 自然学 *shizengaku* or 'deep nature thought' as an integrated view of existence.[17]

Each rendition incorporated the latest discoveries of science and considered how they could be applied to society. In industry, cross-disciplines arose in new fields like astro/physics and bio/chemistry. The scientific and technological ferment of the World War and Cold War eras led to new data, which required ever-larger frames of reference, from aerospace and oceanography to medicine and computer science. It was a time of new frontiers.

In 1949, the United Nations Educational, Scientific & Cultural Organization (UNESCO) set up a commission to assemble a history of all humankind, producing a multilingual, multi-volume series: *The History of Humanity* (1966, 2009).[18] The Space Race also galvanized efforts for new interdisciplinary discoveries, while socio-historical scholarship struggled to understand the post- colonial world through its many disciplinary and



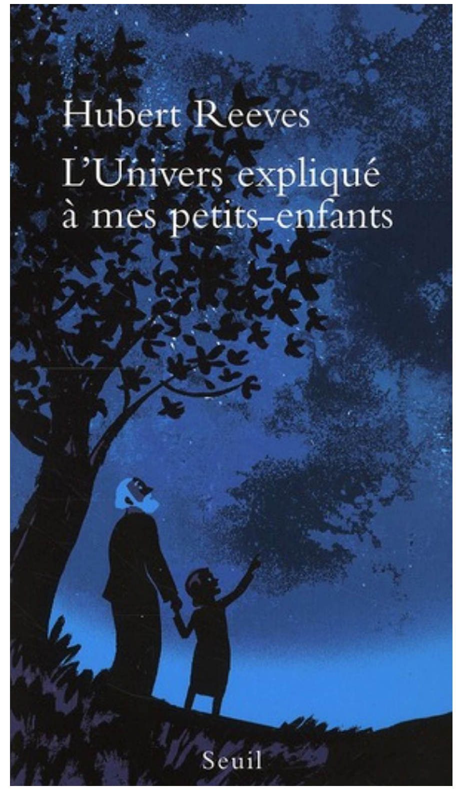


Image 8: Left – Hubert Reeves with his grandchildren, Elsa and Cyprien Reeves-Coutand, in Italy, 2011. Photograph by Benoit-Reeves; from Hubert Reeves. Right – His 2011 book, *L'univers expliqué à mes petits-enfants* [*The Universe Explained to My Grand-Children*]. Author's collection.

social lenses.

Soviet scholars developed an integrated pedagogy that spanned the natural and social sciences.[19] Astrophysicist Josif Shklovsky wrote an early book of this new view of existence: Вселенная. Жизнь. Разум. [*Universe, Life, Intelligence*] in 1962. Four years later, an expanded English adaptation was produced with US astrophysicist Carl Sagan as *Intelligent Life in the Universe*.

This international co-operation was not accidental as a similar macro-study had developed in the United States. From the 1920s through the 1950s, Harlow Shapley had promoted cosmography, a study that examined the interlinked nature of stars, the Earth, life, and humanity at the Harvard College Observatory. In the 1960s, Carl Sagan offered his rendition, and, in 1974, astrophysicists George Field and Eric Chaisson began a course on cosmic evolution.[20]

Likewise, in the 1970s, astrophysicist G. Siegfried Kutter integrated celestial studies with studies of life and society as part of the cutting-edge, interdisciplinary course structure at Evergreen State College. His synthesis appeared as *Universe and Life: Origins and Evolution*.[21] Astronomer Tom Bania taught Cosmic Evolution: Search for Extraterrestrial Life at Boston University, while Earth scientist Michael Rampino had organized The History of the Universe from the Big Bang to the Big Brain at New York University.[22]

This wide thinking reflected the high-stakes competition going on among the respective allies of the Soviet Union and the US in the second half of the twentieth century. Many of these scholars began to move beyond the technological rivalry of the times in order to look at the possibilities of peaceful coexistence, not

Image 9: Aerospace engineer Qian Xuesen (left) worked on complexity studies in the 1980s, which led to a meta- synthesis of scientific knowledge: 开放的复杂巨系统 [The Open Complex Giant System]. From Xinhua News Agency, 2009. Evolutionary biologist Lynn Margulis (centre 2005) participated in the synthesis of knowledge through the lens of microbiology in her 1986 study, *Microcosmos*. Photo from *Wikimedia Commons*. Mathematician Antonio Vélez (with his daughter and collaborator, Ana Cristina Vélez Caicedo) began his trilogy on universal history in 1984. Photograph from the Vélez family, 2019.

just with other humans but with our habitat and other lifeforms. This progress toward assembling a big picture of our place in the vast scheme of things emerged in other parts of the world as well.

Hubert Reeves studied physics with developers of the atomic bomb and became an astrophysicist at France's Centre national de la recherche scientifique. He brought his studies down to Earth in popular books like *Patience dans l'azure: l'évolution cosmique* [*Patience in the Azure: Cosmic Evolution*] in 1981, where he explained the stars, along with the significance of water, Einstein's dog, and jazz. His work has become a mainstay of the environmental movement and a youthful audience seeking to change the world.[23]

In the 1980s, Chinese scholars, including the celebrated rocket scientist, Qian Xuesen, began studies of complexity. They developed a paradigm that served as a meta-synthesis of scientific knowledge, 开放的复杂巨系统 [The Open Complex Giant System].[24] Such global awareness took place in many fields and began to produce a wealth of integrated knowledge about our existence. Other works included bio-geologist Preston Cloud's *Cosmos, Earth and Man* (1978) and astrophysicist Erich Jantsch's *The Self-Organizing Universe* (1980). Mathematician Antonio Vélez in Colombia began a trilogy on universal history with *Del Big Bang al Homo sapiens* [*From the Big Bang to Homo Sapiens*] in 1984.[25]

Evolutionary biologist Lynn Margulis developed a universal view of existence via microbiology, which led her into collaboration with chemist James Lovelock to study self-regulating global systems; Lovelock's friend and neighbour, author William Golding, helped to name this the Gaia hypothesis. [26] Some works became very popular. The television series, *Cosmos*, with Carl Sagan (1980), was viewed by over 500 million people in sixty countries, while the book, *A Brief History of Time* (1988), by astrophysicist Stephen Hawking, sold over nine million copies.[27]

This search for meaning also found expression in various faith traditions. Philosopher Jiddu Krishnamurti generated an understanding that embraced humanity, nature, and the cosmos, as in his *Beginnings of Learning* (1975). A global movement of 'Teilhard associations' sprang up, based on Teilhard de Chardin's thinking in *Le phénomène humain* (1955). One of these activists, cultural historian Thomas Berry, expounded a 'new story' that integrated a global narrative of humanity and nature, as in his *The Dream of the Earth* (1988). Both Krishnamurti and Berry set up organizations that developed education programs, multimedia productions, and converged with the new science and scholarship in the global articulation of holistic thinking.[28]

Parallel to this activity, social and economic studies coalesced with international relations in an effort

to comprehend the many faces of global development. Economic historian Andre Gunder Frank moved global studies outside Cold War frameworks to describe a one-world system, while social scientist Immanuel Wallerstein envisioned interlocking subsystems. This socio-historical work began to merge with larger paradigms, as when economist Graeme Snooks moved his Theory of Global Dynamic Systems to encompass Earth history.[29]

The Merging of Cross-Disciplinary Studies

Another manifestation of these cross-disciplinary connections appeared in calls for reform of higher education. In 1985, world historian John Mears advocated for an integrated curriculum of general education around a theme of evolutionary and universal history. Four years later, he began a course that spanned existence in the context of history at Southern Methodist University in Dallas, Texas (USA), as did David Christian at Macquarie University in Sydney (Australia).[30] As Christian explains, he began asking the question: 'When does history begin?' Receiving different answers, he realized that students were getting confused fragments about our origins:

> The astronomer talking of 'galaxy and star formation,' the geologist discussing 'plate tectonics and erosion,' and the biologist describing 'life and evolution' were all referring in different ways to what historians might describe simply as historical change or change through time.[31]

So Christian sought to erase the jagged edges between these studies and design a course that was more unified. In 1991, he coined the term *big history* in a moment of whimsy, when asked what such a perspective was called … and the name stuck—for many social scientists.[32]

Physical scientists still use the term, *cosmic evolution*, while the other designations remain in use, such as o*pen complex giant system* among cybernetic scholars in China and *the story* among progressive Christians, or under no special name whatsoever, when seen as just an extension of a discipline, as in *macro-sociology*. This holistic trajectory continued, arising elsewhere quite independently and often acquiring regional identities.

In China, some social scientists began to adapt ideas for an integrated view of history from their physical science colleagues. Historians Qi Tao (1991) and Cheng Ming (1994) each argued for interdisciplinary and holistic interpretations of ancient history. In 1996, science historians Dong Guangbi and Tian Kunyu published *The Origin of Heaven and Earth—Natural Evolution and the Birth of Life*. Three years later, historian Ma Shili, at Nankai University, extended his text on world history to include cosmic origins and the evolution of life. In 2000, historian

Image 10: From left – Eric Chaisson, John Mears, and David Christian. Photographs from Eric Chaisson, Barry Rodrigue, and David Christian.

Image 11: Akop Nazaretyan, one of the founders of modern universal history. Left – His 1991 Russian text, *Intelligence in the Universe* (in Russian). Right – At the Eurasian Center for Megahistory & Social Forecasting, Institute of Oriental Studies, Russian Academy of Sciences (Moscow), c. 2015. Photos from the author's collection and courtesy of Karina Nazaretyan.

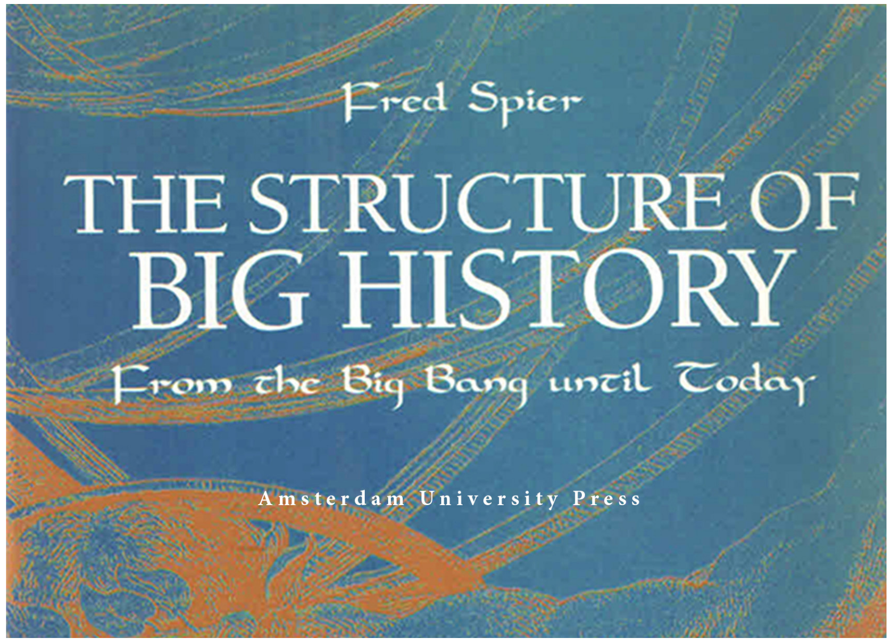
Huang Liuzhu called for uniting natural science and human histories, urging his colleagues at Northwest University (Xi'an, Shaanxi) to initiate such a program.[33]

Historical psychologist Akop Nazaretyan codified his research in the Russian Academy of Sciences under the Education Ministry's category of 'conceptions of modern sciences,' which he considered Универсальная история [universal history]. In 1991, he produced Интеллект во Вселенной: истоки, становление, перспективы [*Intelligence in the Universe: Sources, Evolution, Prospects*], a bridge between Shklovsky's research and his own work in social psychology and conflict resolution. He joined with global historians and scientists in this effort, such as biologist Alexander Markov, anthropologists Andrey Korotayev and Dmitri Bondarenko, historian Leonid Grinin, and astrophysicist Alexander Panov.[34]

Sociologist Johan Goudsblom and biochemist/social historian Fred Spier first encountered b ig history upon reading David Christian's "The Case for 'Big History'" (1991). On a visit to Australia the next year, Goudsblom met Christian and brought back a copy of his syllabus. He and Fred Spier started a course in big history at the University of Amsterdam two years later. Spier then produced *The Structure of Big History: From the Big Bang until Today* (1996), in which he outlined the parameters of the new field. He also introduced big history at several other universities, such as Eindhoven University of Technology and Amsterdam University College. These initiatives continue through the work of Esther Quaedackers, who herself contributed the important concepts of *little big history* and *local big history* to encapsulate focused studies in a big history context.[35] In this way, three generations of a dynamic academic lineage have given continuity to big history in the Netherlands and Europe.

Eric Chaisson's works serve as a standard for physical scientists, as with *Cosmic Evolution: The Rise of Complexity in Nature* (2001). Akop Nazaretyan synthesized his principles in *Civilization Crises within the Context of Universal History: Self-organization, Psychology and Forecasts* (2001). David Christian developed his *Maps of Time: An Introduction to Big History* (2004), while Cynthia Stokes Brown produced *Big History: From the Big Bang to the Present* (2007), which she worked into a continuum of world history. Fred Spier produced his own overview in *Big History*

Image 12: Fred Spier (left) and Johan Goudsblom, 1995. Photograph by Witho Worms. Spier's text, *The Structure of Big History* (1996), was the first to codify the new field. Photograph from author's collection.



and the Future of Humanity (2010).[36] These and other works have been translated into world languages and appear in new editions; thus, a solid core of literature came into service of the field. These works also drew scholars whose works had already moved in these directions. Two of them were Tom Gehrels and Walter Alvarez.

A strong pragmatic and social foundation underlay the work of astrophysicist Tom Gehrels. He had founded the celebrated Space Science Series at the University of Arizona in 1974. His text, *Hazards Due to Comets and Asteroids* (1995), brought together concepts behind his Spacewatch Project (1980), an astronomical survey at the Kitt Peak National Observatory that hunted impact threats to Earth.[37] The diversity of his thinking and its applications appeared in his memoir, *On the Glassy Sea: An Astronomer's Journey* (1989).

Adapting new scientific strategies, geologist Walter Alvarez developed deep-time sequences in the Mediterranean region, described in *The Mountains of St. Francis* (2009). From this work, he and others developed a theory of how an asteroid impact contributed to the extinction of many lifeforms 65 million years ago, including the dinosaurs, as described in *T. Rex and the Crater of Doom* (1997). In addition, he began research on other extinction episodes in Earth's history.[38]

Gehrels and Alvarez developed concerns about the survival of life on Earth and offered their visions of the field—Alvarez's Big History: Cosmos, Earth, Life, Humanity at the University of California Berkeley (2006) and Gehrels's Universe, Humanity, Origins and Future at the University of Arizona (2007). Both also established themselves at overseas centres where they offered their courses: Alvarez at the Coldigiocco Geological Observatory in Italy and Gehrels at the Physical Research Laboratory in Ahmedabad, Gujarat, India.[39]

Visual timelines have existed since petroglyph sequences in the Palaeolithic, so it is no surprise that computer technology led to new materials that articulated deep time. Eric Chaisson and his colleagues visualized their evolutionary models in *Cosmic Origins: A Logarithmic Rendering of Look-Back Time* (2001) and *Arrow of Time: A Linear Rendering of Forward Time* (2007). Designer Roland Saekow and Walter Alvarez worked to develop their own highly interactive timeline, *Chronozoom* (2010), with Microsoft Research.[40] Both remain available on the Internet, and other such electronic aids have proliferated and supplemented the scholarship.

Big history received endorsement from a wide range of public figures, from Microsoft founder Bill Gates and Nixon White House counsel John Dean to

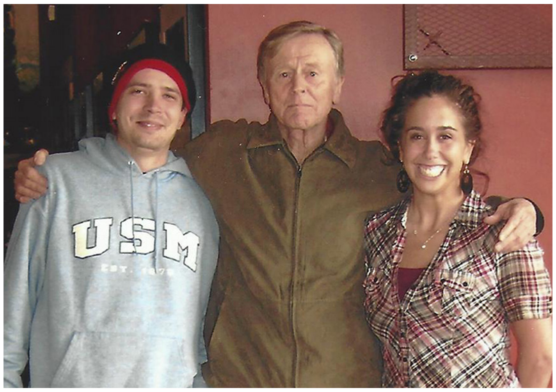


Image 13: Left – Tom Gehrels (centre) with students Luke Gizinski (left) and Dani Potvin (right) at a presentation on "Big History and the Multiverse," Brunswick, Maine, 24 March 2010. Right – Walter Alvarez guiding big historians on a geological fieldtrip at Furlo Pass, La Marche, Italy, August 2010. Photographs by Barry Rodrigue.

American Vice President Al Gore. This led to new productions, as when Gates and David Christian developed a free, web-based secondary/continuing education curriculum, which emerged as the Big History Project in 2011. As an outgrowth of this initiative, the first college-level textbook, *Big History: Between Nothing and Everything*, came out two years later.[41]

The first world conference on big history took place at the International University of Nature, Society and Humanity in the Soviet-era science city of Dubna, Russia in November 2005 on the theme of *Big History and Synergetics*. As a result of this gathering, an edition of *Social Evolution & History* was devoted to big history that year and included many of the field's innovators. In October 2009,

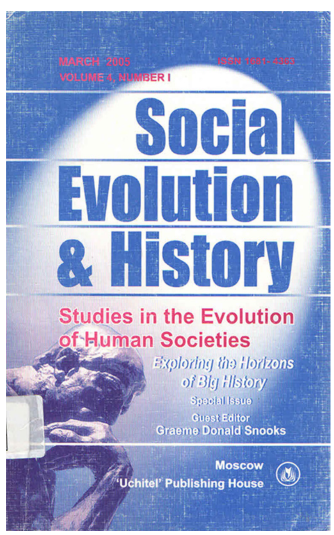


Image 14: First Big History conference, *Big History and Synergetics*, at the International University of Nature, Society & Humanity, Dubna, Russian Federation, November 2005. Left – Akop Nazaretyan, David Christian, and Fred Spier by the Volga River. Courtesy of Fred Spier. Right – Akop Nazaretyan entertaining on the piano with a singer before dinner. Courtesy of Fred Spier. Centre – *Social Evolution & History / Exploring the Horizons of Big History* (2005). From author's collection.


Image 15: Left – Panel of big historians at the Historical Society conference, *Reflections on the Current State of Historical Inquiry*, Boothbay Harbor, Maine (USA), June 2004 / (from the left) John Mears, David Christian, Tom Gehrels, Eric Chaisson, and Fred Spier. Photograph by Kim Dionne and Barry Rodrigue; courtesy of Fred Spier. Right – David Blanks (centre) with students at the founding Conference of the African Network in Universal & Global History, University of Ilorin, Nigeria, December 2009. Photograph from David Blanks.

World History Connected devoted an entire edition to big history topics.[42]

Other associations encouraged these developments, including the World History Association, the Historical Society (based in the US), and the African Network in Universal & Global History. In turn, big historians helped groups like the Network of Global & World History Organizations (headquartered in Leipzig, Germany). Senior historians like William McNeill provided advice and support, as did publishers like global historian Leonid Grinin at Uchitel Publishing in Russia and the Berkshire Publishing Group in the United States.[43]

The Consolidation of a Movement

It is easy to look back now and see this trend, but as recently as 2009, the leading advocates for the field were unsure how widespread the big history movement was or would become. The question was discussed by the panel for Macroevolution: Hierarchy, Structure, Laws and Self- Organization at the Russian Academy of Sciences' Fifth Conference on *Hierarchy & Power in the History of Civilizations* in Moscow in 2009. Barry Rodrigue, with other big historians, began assembling a global directory and bibliography to see who was doing such macro-studies.[44]

A shared belief was that there were only perhaps a handful of active scholars, but, to everyone's surprise, we found dozens of people teaching and researching different forms of big history. Most had independently developed their own perspective because 'it just made sense.' In other words, a global *conjuncture* had taken place over the previous fifty years.

As a result of discovering this ferment, Rodrigue proposed the formation of a global association of big history in August 2010, during a workshop at the Coldigioco Geological Observatory in the Apennine Mountains of Italy. Discussion of a professional society had gone on for years, but the documentation of big history practitioners made it apparent there was a critical mass to make it viable. The International Big History Association was launched at Coldigioco at that time.[45]

The IBHA embarked on organizing itself, as well as bringing together those active in big history around the world. This was done through what amounted to an on-going '24/7' open-ended board meeting. The approach worked well, given its spread across the global landscape. Its administrative structure was put in place, and they adopted a working definition of big bistory:

Image 16: Left – Russian Academy of Sciences' Fifth Conference on "Hierarchy & Power in the History of Civilizations," Russian State University for the Humanities, Moscow, June 2009. On the left are Fred Spier and Esther Quaedackers with Akop Nazaretyan and Barry Rodrigue in front / on the right are Leonid Grinin and Andrey Korotayev in dark jackets. Right – Founding meeting of the IBHA, Coldigioco Geological Observatory, La Marche, Italy, 23 August 2010 / Fred Spier, Pamela Benjamin, Roland Saekow, Michael Dix, Walter Alvarez, David Shimabukuro, Barry Rodrigue, David Christian, Daron Greene, Lowell Gustafson, Penelope Markle. (from back left).

> ***Big History seeks to understand the integrated history of the cosmos, Earth, life, and humanity, using the best available empirical evidence and scholarly methods***.[46]

The organization developed a website; a bulletin, *Origins*; a newsletter, *Emergence*; and the *Journal of Big History*. In 2011, the IBHA fielded six panels and two roundtables at the 20th World History Association conference in Beijing, where board member Craig Benjamin was a keynote speaker.[47] In February 2012, most of the board presented at the Global Futures 2045 conference in Moscow, which Akop Nazaretyan and Barry Rodrigue co-organized with media executive Dimitry Itskov. The inaugural conference of the IBHA was held at Grand Valley State University in Michigan in 2012 on the theme of *Teaching and Researching Big History: Exploring a New Scholarly Field*.

Independent efforts sprang up and joined with big history associations, such as Wendy Curtis's *The Biggest Picture: From the Formation of Atoms to the Emergence of Societies* (2013). Besides the IBHA, several independent regional centres formed, often with additional themes of action. In 2011, the Eurasian Center for Megahistory & System Forecasting came together in the Russian Academy of Sciences' Oriental Institute.

Image 17: The IBHA's first conference, *Teaching and Researching Big History: Exploring a New Scholarly Field*, at Grand Valley State University, Allendale, Michigan (USA), August 2012.

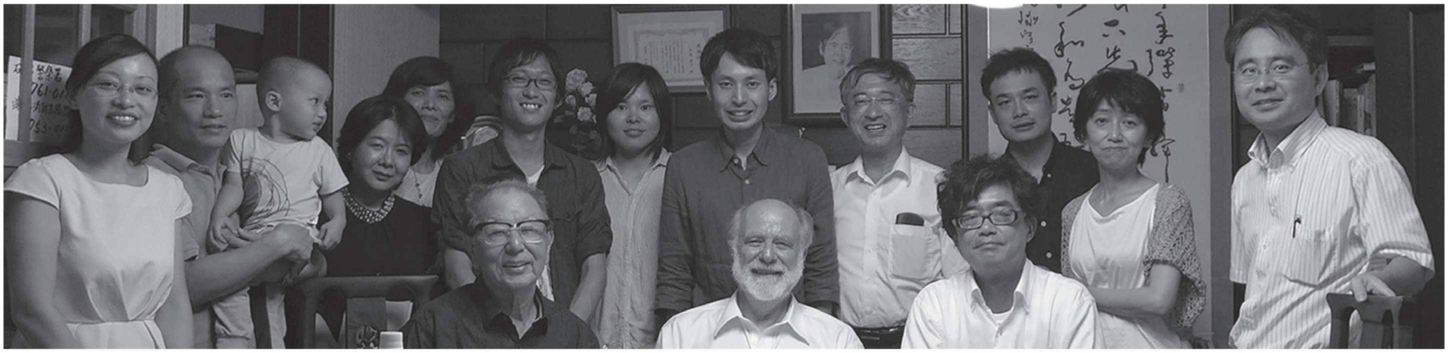


Image 18: Meeting of the Institute for Global & Cosmic Peace, 5 September 2015, Yokohama City, Kanagawa (Japan). At the centre are Osamu Nakanishi, Barry Rodrigue, Hirofumi Katayama, Nobuo Tsujimura (behind Rodrigue), and Hideki Iwaki (far right). Photograph by Kazuko Ohta.

They focused on the predictive potential of historical trends to understand human activity and avert crisis, and co-present conferences. Akop Nazaretyan, a scholar and advisor in conflict resolution, served as its first director. The Eurasian Center continued its study of macro-history with Uchitel Publishing, managed by Leonid Grinin and Andrey Korotayev. Their almanac, *Evolution*, is devoted to big history.[48]

In Japan, big history first merged with the peace movement. The Institute for Global & Cosmic Peace (IGCP) had begun in 1986 during the Cold War's Space Race through the work of historian Osamu Nakanishi. Philosopher Alexander Chumakov's holistic perspectives inspired Nakanishi, and, in 2005, his student, Nobuo Tsujimura, introduced concepts of big historian David Christian and planetary scientist Takafumi Matsui. The discussions led to a framework of宇宙学 [universal studies]. The IGCP then engaged with Barry Rodrigue and Akop Nazaretyan, leading to a series of publications about the intersection of big history and peace studies.[49]

In 2015, biochemist Martin Robert introduced big history concepts into his course on Life and Nature for international students at Tohoku University in

Image 19: Kenji Ichikawa and students at Aletheia Shonan High School, Chigasaki, Kanagawa (Japan). Courtesy of Kenji Ichikawa.

Sendai, Japan. Two years later, he and geologist Norihiro Nakamura developed a liberal arts course for Japanese students, based on big history, with archaeologist Mitsuru Haga and astrobiologist Yumiko Watanabe.[50]

In 2016, environmental economist Hirofumi Katayama, astronomer Ryosuke Miyawaki, and their advisor, Nobuo Tsujimura, established the Big History Movement and a course at J. F. Oberlin University in Tokyo. That year, world history teacher Kenji Ichikawa introduced big history at Aletheia Shonan High School in Chigasaki, Kanagawa.[51]

Big history arose in South Korea as part of a national program of *convergence education* between the sciences and humanities in 2009. David Christian introduced it with world historians Ji-Hyung Cho and Seohyung Kim at Ewha Womans University in Seoul. Cho and Kim taught the first regular courses of big history, developed programs for secondary schools, and translated big history materials into Korean, including a twenty-book series on Korean big history for teens. In 2015, Kim founded the Cho Big History Academy.[52]

China has multifaceted settings of big history. The Open Complex Giant System began to integrate scientific disciplines, while progressive world historians expanded historiography to include science and the

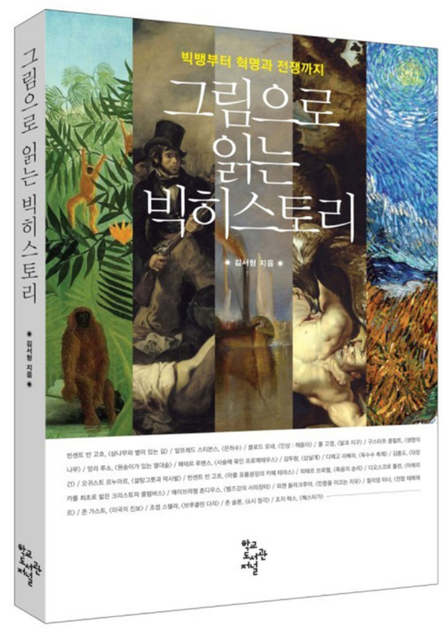


Image 20: Top left – Myung-Hyun Lee's *How the World Began* (2013) in the Korean big history series for high schools. Top right – Seohyung Kim's *Big History with Painting* (2018). Bottom – Seohyung Kim (right) and 9th grade students in a big history course in Seoul. Courtesy of Seohyung Kim.

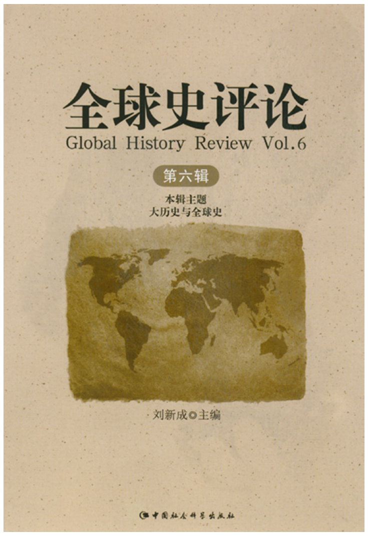


Image 21: Left – *Global History Review*, a themed issue on Big History and Global History edited by Liu Xincheng and Sun Yue in 2013. Right – Meeting of members of the Asian Big History Association and the Institute for Global & Cosmic Peace / Nobuo Tsujimura, Sun Yue and Hiroko Oh (right), Hirofumi Katayama and Osamu Nakanishi (left), Yokohama, Japan, 14 October 2017. Photo by Kazuko Ohta.

natural world. These trends continued. Women's research physician Zhao Mei assembled her thoughts of *qi* [life energy] in a big history context and approached historian Zhu Weibin at Sun Yat-sen University in Guangzhou, who saw it as a natural extension of global history. This perspective had been earlier endorsed by officials of the Shanghai Communist Party, when David Christian's book, *Maps of Time*, was vetted for publication in 2007. It was seen as compatible with Chinese historical paradigms.[53]

The Asian Big History Association came together as a result of this work in China, Japan, and Korea. Its organizational meeting was held at the second IBHA conference in San Rafael, California with Sun, Tsujimura and Kim as organizers, along with Barry Rodrigue. Their initial work forged more solid links between its members. In 2014, Rodrigue accepted an offer as visiting scholar in big history at Shandong Normal University in Jinan, Shandong Province, China. This was arranged by Sun Yue with historian Qi Tao, who had advanced big history models twenty years earlier and had become deputy governor of Shandong Province. This assignment was in preparation for the International Congress of Historical Sciences, held the next year in Jinan.[54]

In 2013, English translator and historian Sun Yue joined the IBHA board and, as editor of the *Global History Review*, produced, with his colleagues, the first issue of a journal on big history in China.[55] In Beijing, CITIC Press also began publishing a series of books on big history, which its editor, Ma Xiaoling, wrote "… gives us all a broader vision, more possibilities and more attention to our common human future."[56]

In August 2015, Rodrigue and Sun organized a panel on big history for the ICHS conference in Jinan, where they joined the board of the Network of Global & World History Organizations, along with Lowell Gustafson of the IBHA. Sun described his studies about the twin sides of humanity's perplexing search for social stability: its need for harmony and creativity that exists alongside witch hunts and conflict. He sees its resolution as a central issue of big history.[57]

Atmospheric scientist Alexis Lau 劉啟漢 taught at the Hong Kong University of Science & Technology for twenty years and served as director of its Institute for the Environment. He thought about cancelling their general education course on climate change because he saw how students became pessimistic after taking it. Then he heard about big history from his colleague, Robert Gibson, and, in 2015, merged it, along with

Image 22: Hong Kong University of Science & Technology's summer big history program, July 2019 Left – Secondary students from the Hong Kong Academy for Gifted Education. Right – Alexis Lau teaching about macroscopic sustainability. Photographs courtesy of Aidan W. H. Wong.

sustainability studies, into the climate change course. The result was dynamic. The next year, graduate student Aidan W. H. Wong 王瑋軒 joined him in this work and attended the third IBHA conference in Amsterdam. Their course, Big History, Sustainability and Climate Change, remains in the core curriculum. In 2017, they collaborated with the Hong Kong Academy for Gifted Education on a macro-sustainability course for secondary students. Two years later, Wong worked with Hong Kong scholars to publish a course book, *Big History: A Scientific Origin Story* (2019).[58]

A public advocate in Taiwan, Gavin Lee first learned of big history in 2017 while he was writing a book on *The Maritime Silk Road and World Civilization*. He found that big history provided a more holistic way to understand the world's interconnectedness. The next year, he started Worldviews Academy as a vehicle to encourage big history, beginning with a six-class sequence for the general public and for high school. After Taiwan's K-12 education reform in 2019, Ming Dao High School added this course as an official elective under the guidance of its principal, Albert Wang. Others followed.[59]

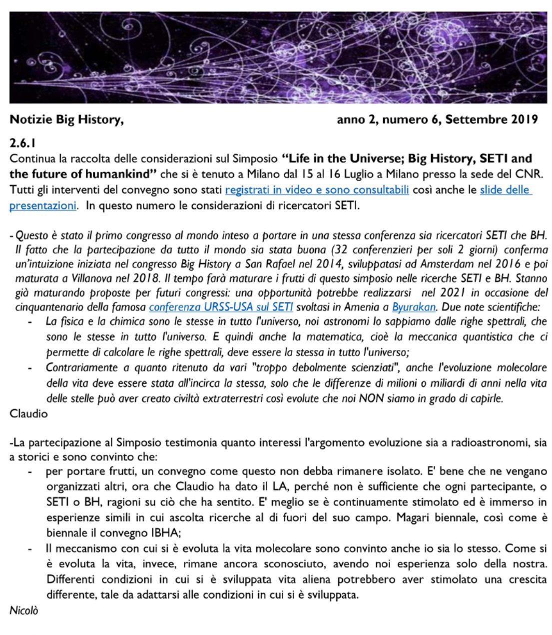
Their team expanded course content with new media tools, such as virtual and augmented reality, along with classroom experiments and digital arts. They customized big history for different sectors, such as problem-solving scenarios for life-long learners. For

Image 23: Left – Augmented reality experience in how neurons form memory, Ming Dao High School, Taiwan, 22 September 2020 / Huai-Rui Zhang, Ke-Jie Lin, Shan-Ni Liu, Amy Lin, and Cheng-En Wu (from left). Photograph by Gavin Lee. Right – Big History Lecture at National Taiwan University, 5 May 2018. Photograph by Gina Hsiao.

business leaders, they adapted big history theories, like self-organizing and emergence concepts to guide organizational change in Executive MBA programs at the National Taiwan University and Tunghai University. By 2021, over 3000 people had participated in World-views Academy's activities, while three high schools and a university adopted its curriculum. The academy is presently curating an online series of articles about big history for the general public and designing a course for experiencing each complexity threshold with a featured board game.[60]

Some of the seeds of the European Big History Network were also planted at the second IBHA conference in 2014, when Dutch big history student Maarten Oranje and Spanish geology professor Olga García-Moreno decided to reach out to scholars in Europe. García-Moreno worked with geologist Walter Alvarez, who had asked Esther Quaedackers to invite palaeontologist Jan Smit and social scientist Jesse Bos. During the Amsterdam Big History Conference (2016), the idea became concrete, and the next year, she organized the first EBHN assembly in Salas, Asturias, followed by another in 2018, with twenty scientists and teachers. The third EBHN meeting was organised in Coldigioco in 2019.[61]

As a result of these meetings, several activities were initiated in secondary and university settings. Constance van Hall and Jesse Bos (Netherlands) and Adalberto Codetta (Italy) began an exchange between big history teachers from Spanish, Italian, and Dutch secondary schools with support from the EU Erasmus Program. Esther Quaedackers (Netherlands), Olga García-Moreno (Spain), Jacob Wamberg (Denmark), and Giovanni Grieco (Italy) also brought together their universities of Amsterdam, Oviedo, Aarhus, and Milan to work on a collaborative course in local big history. Funded by the Royal Netherlands Academy of Arts and Sciences, students from their universities worked together to analyse their local histories through a big history lens. In addition, students and teachers brought out an Italian newsletter with Adalberto Codetta on big history, while Giovanni Grieco in Italy advanced the role of geoparks and eco-museums for public education about big history.[62]



Notizie Big History, **anno 2, numero 6, Settembre 2019**

2.6.1

Continua la raccolta delle considerazioni sul Simposio **"Life in the Universe; Big History, SETI and the future of humankind"** che si è tenuto a Milano dal 15 al 16 Luglio a Milano presso la sede del CNR. Tutti gli interventi del convegno sono stati registrati in video e sono consultabili così anche le slide delle presentazioni. In questo numero le considerazioni di ricercatori SETI.

- *Questo è stato il primo congresso al mondo inteso a portare in una stessa conferenza sia ricercatori SETI che BH. Il fatto che la partecipazione da tutto il mondo sia stata buona (32 conferenzieri per soli 2 giorni) conferma un'intuizione iniziata nel congresso Big History a San Rafael nel 2014, sviluppatasi ad Amsterdam nel 2016 e poi maturata a Villanova nel 2018. Il tempo farà maturare i frutti di questo simposio nelle ricerche SETI e BH. Stanno già maturando proposte per futuri congressi: una opportunità potrebbe realizzarsi nel 2021 in occasione del cinquantenario della famosa conferenza URSS-USA sul SETI svoltasi in Amenia a Byurakan. Due note scientifiche:*
  - *La fisica e la chimica sono le stesse in tutto l'universo, noi astronomi lo sappiamo dalle righe spettrali, che sono le stesse in tutto l'universo. E quindi anche la matematica, cioè la meccanica quantistica che ci permette di calcolare le righe spettrali, deve essere la stessa in tutto l'universo;*
  - *Contrariamente a quanto ritenuto da vari "troppo debolmente scienziati", anche l'evoluzione molecolare della vita deve essere stata all'incirca la stessa, solo che le differenze di milioni o miliardi di anni nella vita delle stelle può aver creato civiltà extraterrestri così evolute che noi NON siamo in grado di capirle.*

Claudio

-La partecipazione al Simposio testimonia quanto interessi l'argomento evoluzione sia a radioastronomi, sia a storici e sono convinto che:
  - per portare frutti, un convegno come questo non debba rimanere isolato. E' bene che ne vengano organizzati altri, ora che Claudio ha dato il LA, perché non è sufficiente che ogni partecipante, o SETI o BH, ragioni su ciò che ha sentito. E' meglio se è continuamente stimolato ed è immerso in esperienze simili in cui ascolta ricerche al di fuori del suo campo. Magari biennale, così come è biennale il convegno IBHA;
  - Il meccanismo con cui si è evoluta la vita molecolare sono convinto anche io sia lo stesso. Come si è evoluta la vita, invece, rimane ancora sconosciuto, avendo noi esperienza solo della nostra. Differenti condizioni in cui si è sviluppata vita aliena potrebbero aver stimolato una crescita differente, tale da adattarsi alle condizioni in cui si è sviluppata.

Nicolò

2.6.2

Image 24: Left – Activists in the Local Big History Program in Italy – Stefano Masini, Chiara Codetta, and Tobia Galimberti. Photograph from the members. Right – *Notizie Big History* 2 (6) September 2019 [Big History News], Milan, Italy, ed. Adalberto Codetta. Courtesy of Adalberto Codetta.

Image 25: The reincarnations of big history. Left – Cynthia Brown and Mojgan Behmand presenting on Dominican University's big history core curriculum at the 20th World History Association conference in Beijing, July 2011. Photograph courtesy of Mojgan Behmand. Right – Students presenting their Little Big History Final Exam Projects at Holy Angel University, March 2018. The Holy Angel big history program was derived from the Dominican program (see text), so, despite the end of Dominican's efforts, its big history initiatives continued. Photograph courtesy of Rubeth R. Hipolito.

In the midst of these successes, there were counter-trends. The first big history course had been added to a core curriculum at the University of Southern Maine (USA) in 2006 and was offered online three years later. Dominican University of California put big history into its core curriculum in 2009. In 2012, Macquarie University established its Big History Institute in Sydney (Australia), which, among other initiatives, developed an award-winning big history MOOC (massive open online course) and an elementary school level big history curriculum. Macquarie also graduated the first PhD students in big history.[63] Despite the popularity of such academic developments, especially among students, university administrators ended all three programs, reinforcing a vision of education as a profit-making business.[64] Nonetheless, new efforts continued to rise, in part, as a result of these closed programmes and their scholars.

In my own role as International Coordinator for the IBHA (2011-2021) and the Asian Big History Association (2014-2021), I engaged in a considerable amount of fieldwork and outreach, including a sabbatical at Shandong Normal University in Jinan (China) and dialogues in Beijing, Moscow, Lake Tahoe, Grozny, Boston, Hanoi, Montreal, Guangzhou, and Bombay. It also involved the six-year production of an international, comprehensive anthology of big history, *From Big Bang to Galactic Civilizations*, which appeared as a three-volume series between 2015 and 2017. It involved one hundred contributors from twenty-five nations and many mother tongues.

As a result of the anthology, the Indian Association for Big History was founded at Symbiosis International University in Pune, Maharashtra (India) in 2016. There was fertile ground for it. Orla Hazra and Prashant Olelaker had promoted a New Story program (see below) in Bombay, while macro-history studies had begun for secondary students, such as at the Sri Adwayananda Public School in Kerala under stimulus from the Big History Project.

At this point, my home university in the United States was one of the institutions (described above) that shut down its successful world and big history courses in an ill-considered move to enhance profit margins. I was invited to join the faculty at the Symbiosis School for Liberal Arts to set up a core course in big history, the first such course in a South Asian university. This led to more dynamic activism in Asia, involving the Asian Big History Association and the IBHA. In 2018, Symbiosis began an annual symposium on Big History

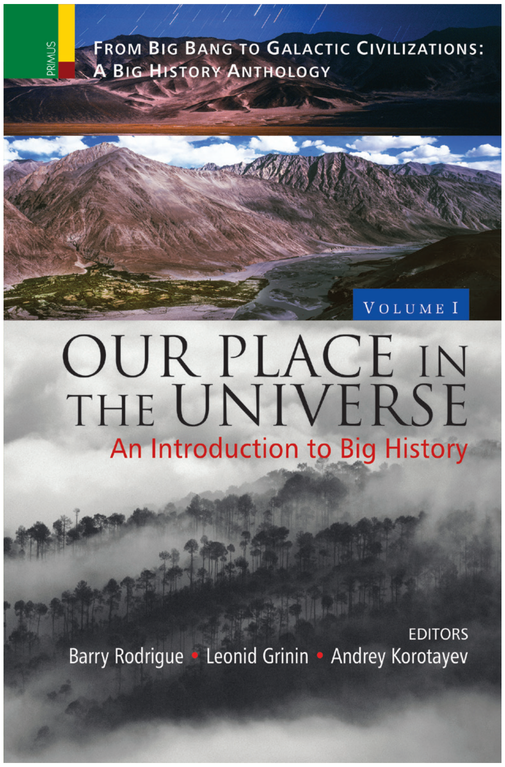


Image 26: Top-left – Front jacket of *Our Place in the Universe*, Vol. 1, *From Big Bang to Galactic Civilizations* (2015). Top-right – Editors and authors Leonid Grinin, Barry Rodrigue, and Andrey Korotayev at a Ukrainian tavern in Moscow, February 2012. Bottom – The first university class in big history, Symbiosis School for Liberal Arts, Pune, Maharashtra, (India), 2018. The course was set up by Shweta Deshpande, Afshan Majid, Priyadarshini Karve, and Barry Rodrigue (centre-front). Photograph from the Barry Rodrigue Collection.

and Interdisciplinarity with J. F. Oberlin University's Big History Movement and the ABHA. A series of webinars then began in 2020 with colleagues from Malaysia, Japan, and India that led into the 2021 Global Big History Conference (the Fifth IBHA Conference and the Third ABHA / SSLA symposium).[65]

By necessity, this conference became innovative, since it took place during the COVID pandemic. Since

it was a global event, online, with participants from all around the world, we set it up as a rolling rendezvous that ran twenty-four hours a day for four days, so that each time zone would have activities during its prime times—eighty-four hours of continuous participation. It was an ambitious but highly successful program that set a new worldwide benchmark for including people who would not otherwise attend in person.

For the first time, as a result of this online ability, friends from the newly formed African Big History Association were able to attend our 2021 Global Big History Conference. They had come together in 2018 as a result of their work with Tan Chee Keong, a big historian from Malaysia who was with his family working in Yaoundé, Cameroon.[66]

Creative, Ecumenical, and Tribal Expressions

Creative expressions have appeared inside and outside the academic community long before the field of big history was ever conceived as such. For example, geologist Alessandro Montanari is also a musician who teamed up with Gabriele Rossetti, a sound engineer, to convert geological data into music via a computer programme they designed. The resulting 'geophonic' compilation, *Balla con la Terra* [*Dances with the Earth*], made in 2001, musically represents episodes of Earth's stratigraphic history in the Umbria and Marche Apennines. They use this creativity to expand knowledge about our place in the world. The Coldigioco Geological Observatory, which Montanari and Paula Metallo co-founded with Walter and Milly Alvarez in 1992, serves as an incubator of creative arts,

Image 27: The symbol for the 2021 Global Big History Conference embodies the four-fold aspects of Big History—Cosmos, Earth, Life, Humanity—as represented by the moon and sky, tree and leaves, animal tracks and earth in a yin/yang representation of nature/harmony. In the grooves of the tree bark are the Japanese kanji for *yasumu*, which means rest and joy —an ancient and complex imagery made up of 人 *hito* [humans] and 木 *ki* [tree]. The combined symbols show the people are supporting each other beneath a tree. It reminds us that to change the world, we must acknowledge that change comes from engagement, mutualization, and symbiosis with each other and with nature, around the world and in the multiverse. Appreciation to Yoshihiro Takishita 瀧下嘉弘 of Kamakura, Japan for the ideas and to our artist, Ishikha Jain, of the Symbiosis School for Liberal Arts, Pune, Maharashtra.

Image 28: A few of the founding members of the African Big History Association / Ngaingha Eric Ngong, Patrick Penka, Mesei Ndeise Florence, Nganfon Eric Goubissih, Juliana Jala, Sabastian Ngong Ateh, Ajih Joseph Mbah, and Cassian Kochi Ngong (from left). Yaoundé, Cameroon, January 2018. Photograph by Tan Chee Keong.

as it does for science.[67]

Two big history PhD graduates from Macquarie University in Australia embarked on creative expression of their studies in 2014. David Baker wrote an eighteen-episode series on big history for *YouTube's Crash Course* and the Big History Project, with over 150,000 viewers, while Rich Blundell spun off his "Shakespeare in the Cave: A Big History of Art." As he describes it, "Our art is not only a product of cosmic creativity, but it is through our art that new drastic change can emerge."[68]

Nigel Hughes is a paleobiologist at the University of California in Riverside. He specializes in the study of trilobites and has worked in the Himalayas for

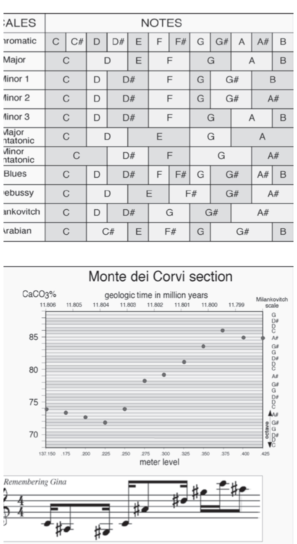


Image 29: Left – An example of the geophonic creative process from *Dances with the Earth*. Right – Paula Metallo's collage *A Flowering Mind* on Alexander von Humboldt. Centre – Paula Metallo, Milly and Walter Alvarez and Sandro Montanari in Gubbio, Umbria, c. August 2010.

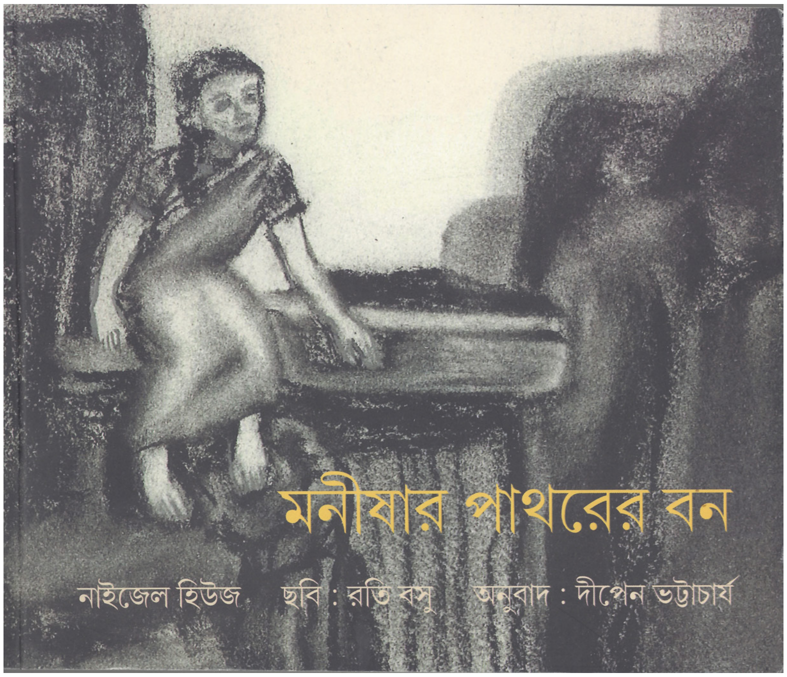


Image 30: Left – Jacket of Nigel Hughes's children's book, মনীষার পাথররর বন / *Monishar Pathorer Bon* [*Monisha's Stone Forest*], about a Bengali girl's search for answers about fossils and life. Right – Nigel Hughes in a Bengali classroom. Courtesy of Nigel Hughes.

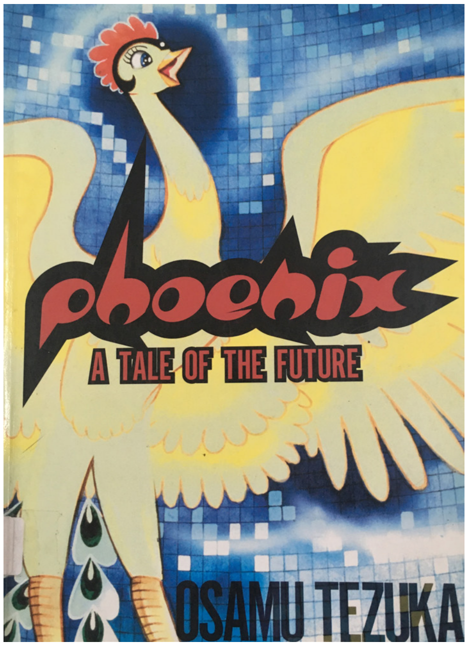
much of his career. He also works on projects in South Asia promoting public education and Earth sciences. As part of this work, he wrote the children's book, *Monishar Pathorer Bon / Monisha and the Stone Forest* (2012) in Bengali and English, which also appeared online as a multimedia event. It introduces basic principles of historical geology in a story about a curious village girl searching for a natural explanation for petrified wood, which is common throughout much of Bengal. The book sales support public education in India.[69]

The creative arts have long held big history views, outside the academy, as in the bioregional, geopoetic, eco-feminist and eco-art movements. For example, Nobuo Tsujimura attributes a big history perspective to Osamu Tezuka's manga, especially his life-work masterpiece, *Phoenix*. The "father" of Japanese animation, Tezuka's series, *Phoenix*, appeared in twelve volumes between 1967 and 1988. As Tsujimura summarizes it, "Art is not just means to explain and spread Big History, but Big History itself is art to explain humanity in the whole universal history."[70]

Based on his life in Bombay in the 1980s, novelist Greg Roberts independently assembled his vision of existence, which he called "Resolution Theory" in his novel, *Shantaram* (2003). He presciently asks, "Are we leaving a lamp of Earth Empathy in our literature, presentations or elsewhere for those who will one day see us and our conferences as history?"[71]

Shubhangi Swarup, also from Bombay, grounded the characters in her novel, *Latitudes of Longing* (2018), within the tectonics of Nature. As she wrote about her experience,

> [o]ver time, novels have evolved into a myopic enterprise, centred around singular human actions, limited by political borders, identity politics, and, even worse, a plot. The cause and effect within a plot is restricted to its characters, devoid of the appreciation and continuations within a larger universe. In an increasingly polarised and isolating world, the human imagination has been trapped in rooms of its own creation. If the reader views life from just one window, then I, as a novelist, want to tear down all the windows and walls, and bring down the roof. I want to pull the entire



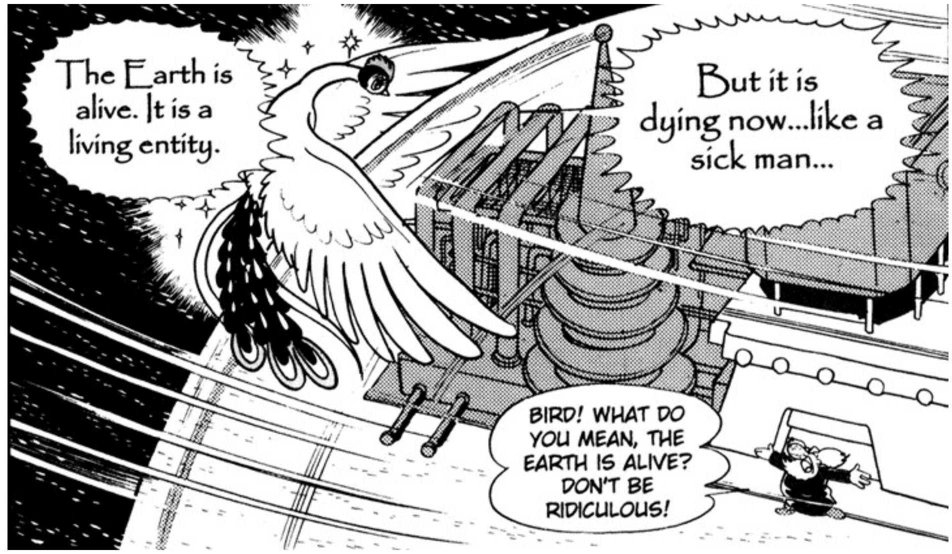


Image 31: Cover and panel in English translation of Osamu Tezuka's *Phoenix*, vol. 2, *Future*, c. 1968. Author's collection.

structure down till the reader is standing under an immense sky and looking at the infinity we call a horizon. For in that infinity, human history is only a tiny slice of the Earth's history, and the evolution of life doesn't begin with our ancestors leaving Africa but the birth of the first unicellular organism or perhaps the Big Bang. For only when we have grounded ourselves in this way can we appreciate the vastness of our own lives.[72]

While this academic and creative movement spread, a growth of interfaith exchange with new scientific discoveries occurred. David Christian prominently described his big history model as a "modern creation myth," one that formed a basis for all humanity to share globally, outside the confines of a single tradition. His sensibility was reinforced by the classroom experiences of big historian Craig Benjamin, who saw this search for meaning as a central responsibility for students: "…[T]he lack of a modern creation myth is actually harmful to our species because without it we are left only with an overwhelming sense of disorientation and purposelessness that Emile Durkheim referred to as 'anomie.'"[73]

Before C. P. Snow's discourse about a growing divide between science and the humanities, bridges were already being built. In 1954, the Institute on Religion in an Age of Science (IRAS) formed, which included astronomer Harlow Shapley, a founder of cosmography, which had led to studies in Cosmic Evolution at Harvard University. IRAS helped found *Zygon: Journal of Religion and Science* twelve years later, and its contributors included leading scholars and educators in macro-historical studies, like astrophysicist Eric Chaisson and biologist Ursula Goodenough.[74]

Archbishop Lazar Puhalo of the Orthodox Church in America had been a dynamic and early advocate for science, rationalism, and faith. His book, *On the Neurobiology of Sin* (2010), served as a bridge between the two cultures. He joined the dialogue of big history, speaking, along with other big historians, at the *Global Futures 2045* conferences in Moscow (2012) and New York (2013). He raised important moral questions about issues like immortality and artificial intelligence and participated in the IBHA conferences.[75]

Cosmologist Brian Swimme worked with Catholic philosopher Thomas Berry and began the Center for the Story of the Universe in 1989, which was affiliated with the California Institute of Integral Studies in San Francisco. This led them into deeper collaboration

Image 32: Left – Archbishop Lazar Puhalo at the fourth IBHA conference in Amsterdam, July 2016. Photograph by Barry Rodrigue. Right – Lazar Puhalo (back right) in dialogue with astrophysicist Stephen Hawking in Salt Lake City, Utah, in September 2016. Courtesy of Lazar Puhalo.

with religion scholars John Grimm and Mary Tucker, who founded the Forum on Religion and Ecology at Yale University in 2006. Their production of *The Journey of the Universe* (2011) was a multimedia synthesis of Berry's and others' views of spiritual meaning in the cosmos.[76] Parallel to this work, the Philadelphia Center for Religion and Science had grown into the Metanexus Institute by 1997 and, through its director, William Grassie, became a supporter of big history

Jennifer Morgan, a journalist and educator, also grew out of this tradition of the Universe Story. After participating in an Earth Literacy Program at Genesis Farm in Blairstown, New Jersey, she composed the *Universe Story Trilogy* for children between 2002 and 2006, consulting with noted scholars like astrophysicist Neil deGrasse Tyson and anthropologist Jane Goodall. She then developed the *Deeptime Network* (2014) with a mission to unite all faith traditions with each other and with science.[77]

Pope Francis's *Laudato Si', On Care for our Common Home* (2015) led to renewed actions by Catholics around the world to conserve the planet. Among them, in 2016, Prashant Olalekar and Orla Hazra merged these ideas with Thomas Berry's "New Story" and a big history paradigm to establish their course, Awakening to Cosmic Compassion, at the Department of Interreligious Studies, St. Xavier's College, Mumbai.[78]

Educator Luis Calingo had served as Provost of Dominican University of California when it added big history to its core curriculum. In 2015, he became

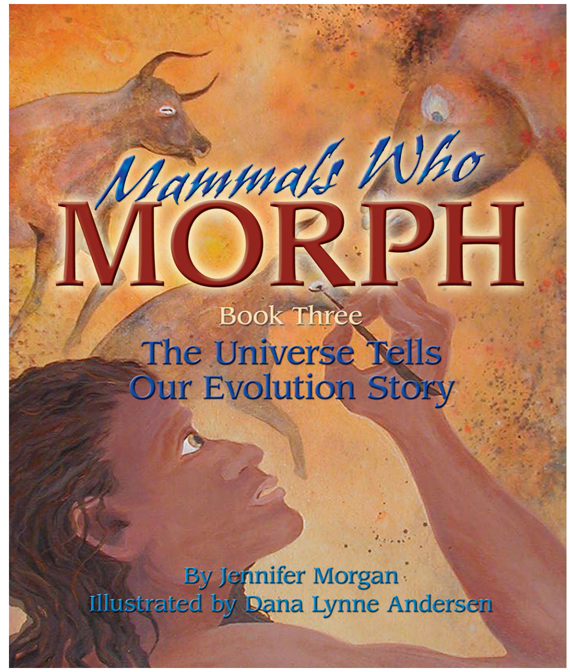


Image 33: Jennifer Morgan and her son, Morgan Martindell, on a Cosmic Walk in 1997. Courtesy of Jennifer Morgan. Cover of the *Universe Story*, Vol. III, *Mammals Who Morph* (2006). Dawn Publications. Logo of the *Deeptime Network*.

President of Holy Angel University, a major research institute in central Luzon, Philippines (his home area) and, two years later, sent professors to the Summer Institute in Big History at Dominican. Holy Angel then began a two-course big history sequence the following year. With the largest Roman Catholic population in Asia, but acknowledging the Philippines' Islamic and animistic traditions, Holy Angel promotes big history along with its many philosophical traditions.[79]

While much of the overt and well-publicized efforts at rapprochement between science and religion exist in a western context, especially among Christians, that does not mean that such efforts do not exist elsewhere. Besides helping Malaysia's farmers adapt to changing land and climate, soil scientist Shamshuddin bin Jusop also had been active in guiding Muslims to see how Islam and modern science are bound together, as in his popular text, *The Earth Story: Lessons from the Quran and Science* (2006). Similarly, physician H. Sudarshan, a Vedic scholar living among the Soliga tribal people of South India for over forty years, adapted his worldviews and medical practices in a complex weave of science and community service, as delivered by his medical/educational NGOs, the Karuna Trust, and the Vivekananda Girijana Kalyana Kendra.[80]

While big history discussions often centre on urban forms of education, it must be kept in mind that many tribal societies from which civilization grew maintain holistic and inclusive concepts of existence. It is acknowledged that their low-impact survival strategies could help correct the lifestyle of dominant societies. Far from being an exotic primitivism, or a return to nature, tribal experience encompasses Traditional Ecological Knowledge (TEK), while connecting with the scientific community, as in the 1994 founding of the Alaska Native Science Commission. Traditional societies have a major potential to re-envision our future in a big history context.[81]

Such bridges have already been opened, as in biologist Edward Wilson's *The Creation: An Appeal to Save Life on Earth* (2006) and recently led to the global anthology, *Science, Religion, and Deep Time* (2022), edited by big historians Lowell Gustafson, Barry Rodrigue, and David Blanks.

Broad Diversity and Context

If big history were just an obscure micro-discipline that a handful of specialists were advocating, it would not necessarily be of significance. Since the movement and its area of scholarship reflect a human trend

of wider, more inclusive awareness of natural phenomena, we see it as a co-operative, scientific, and scholarly endeavour that will continue to expand with exciting possibilities.

It was not the invention of one person or a small research community but instead an organic response by many independent thinkers all around the world, a global conjuncture. This is a testimony to the universal thinking of human beings to be able to arrive at similar ideas from many different backgrounds, an exercise in global intellectual ability. Big history fits within a wide variety of educational structures and is taught at many levels and in many departments and general education curriculums. Its popularity is dramatic: universities hold undergraduate classes accommodating hundreds of students and online courses draw students from around the planet.

Many scholars focus on complexity as a benchmark of evolution. While this is an important concept, philosopher Wang Dongyue reminds us of the fragility of complexity: as things become more complex, instability increases.[82] Other scholars identify other processes. Biologist E. O. Wilson refers to the cross-disciplinary unification of knowledge as *consilience*. Fred Spier breaks it down into a series of nested *regimes*, while David Christian focuses on *thresholds*. Barry Rodrigue centres his work on social implementation of universal studies, or *mutualization*. Big history also employs concepts like collective learning and concerns for the Anthropocene.[83] Being a young nexus of people and information, other new conceptualizations will appear.

This effort to understand our place in the Universe transcends big history in its institutional sense since these approaches and understandings appear elsewhere, outside the big history programmes described above. For example, geographers Georges Nicolas and Eric Waddell see a need for humanity to bridge a widening chasm between meaning and science. E. O. Wilson also addressed this concern in his book, *The Meaning of Human Existence* (2014):

Image 34: Left – Orla O'Reilly Hazra and Prashant Olalekar, Department of Interreligious Studies, St. Xavier's College, Bombay. Right – One of their symposiums on big history at Jnana Deepa Vidyapeeth (JDV), the Pontifical Athenaeum in Pune, Maharashtra, in 2016. Photographs by Barry Rodrigue.

> Human beings are not wicked by nature. We have enough intelligence, goodwill, generosity, and enterprise to turn Earth into a paradise both for ourselves and for the biosphere that gave us birth We can plausibly accomplish that goal, at least be well on the way, by the end of the present century. The problem holding everything up thus far is that *Homo sapiens* is an innately dysfunctional species.

Paleobiologists Neil Shubin and Ted Daeschler discuss these wider contexts in their disciplines, as in Shubin's book about our evolutionary lineage, *The Universe Within* (2013). Others have widely popularized such macro-concepts, as with biogeographer Jared Diamond and historian Yuval Harari.[84] So, whether big history succeeds as a field of study or morphs into something else is immaterial—the concept and the effort to comprehend our widest existence and our future (based on that understanding) is here to stay.

Existence and Survival

Questions about existence are still a serious strategy for human survival, as much as they were two million years ago at Olduvai Gorge, a process that led to our being the sole-surviving species of our lineage. We are today facing another life-changing crossroads, a crisis of our own making and of an even more rapid and intense nature. The present-day disruption of the ecosphere has been caused by our very own success.

Over-population has engulfed the planet along with stratification of resources. Entire species of life are vanishing, along with fresh water supplies. Non-renewable resources are being exhausted and resource wars are proliferating. Pollution makes swathes of the world uninhabitable. Climate change is impacting the entire planet, from the melting of the world's ice sheets and permafrost to the related rise in sea levels and greenhouse gas emissions, along with storm surges, disruption of ocean currents and wind patterns, and wildfires.

Local agriculture and business are destroyed by competition from mega-industry, resulting in the vast concentration of people in urban areas, as more and more residents are dropped to the lowest rungs of society. Many think they can escape this devastation, but that is a false illusion. More than half the world's oxygen is generated by the ocean's phytoplankton, which is being severely impacted by global warming and pollution. A decline in microalgae will not just imbalance marine life; it will impact our ability to breathe ... all species, all individuals, everywhere.

In a moderate scenario, the scale of the present-day crisis could lead to the end of civilization as we have come to know it. In a worse case, it could lead to human extinction, along with the demise of many other species and biomes. Nonetheless, we have many things in our favour. Instead of having to develop new stone tools, our present problems largely involve ways of seeing the world and social transformations. One of the tools at our disposal is big history.[85]

Perhaps the most powerful understanding to come from big history is not only to reinforce how all humans are one unified family but also how we are related to everything else, from inanimate matter to other life forms. This is not intuitive; nor is it a simple revealed process of having a general understanding and good intentions. There must be a willingness to act on this knowledge.

Society is a messy process. It began to be perfected as our species moved out of their forests. The start of the glacial age over two million years ago forced our ancestors onto the East African grasslands, where they were challenged to find new forms of sustenance by fluctuating periods of dry and wet climates. These implications will be discussed in Part Two of this essay—"The Children of Climate Change."

Acknowledgments

The author would like to thank the following people for reading this article and offering thoughtful and constructive comments: G. Siegfried Kutter, John Mears, Eric Chaisson, Sun Yue, David Christian, Fred Spier, Penelope Markle, Nobuo Tsujimura, Akop Nazaretyan, Sun Chao, Li Qingcheng, Zhao Beiping, and David Blanks.

Notes

1. My first awareness of such macro-ideas came when I was six years old and dug up what I thought to be a *Brontosaurus* femur (…in retrospect, it was probably just a cow's leg bone)! My parents and Jesuit educator Bernard Scully encouraged my learning about prehistoric life and science. In the 1970s, I studied with G. Siegfried Kutter, a founder of what later came to be called big history. My macro-consciousness intuitively manifested itself, while I did my PhD in geography at Université Laval in the 1990s, when I was assigned to write the opening chapters of a historical geography of south-central Québec. The National Institute for Scientific Research rejected my proposal to start the book with the Big Bang, but they did let it begin at Pangea! Courville and others 2003. In 2002, a colleague, Bob Schaible, told me of an article he read about big history, which began my purposeful affiliation with other big historians.

2. As an example of some of this research, see the following. Bönnen and others 2021.

3. Rodrigue 2019: 109–112; idem 2022.

4. Tierney and others 2017. Brookfield 2010. Brooks 2010. Haas and Cramer 2006. Hassan 1988.

Barnard and Duistermaat 2012. Malville, Wendorf and Mazar 1998.

5. Hritz 2010. Kathayat and others 2017. Mostern 2021. Wu and others 2021. Haas and Creamer 2006.

6. Khaldun 1958: 481.

7. Dubova 2019. Gannon 2021.

8. For big history considerations of the Axial Age, see the following. Bondarenko and Baskin 2016.

Puhalo 2016.

9. UNESCO, World Heritage Centre 1966, 2009. Vega 1609: 357–359. Christos 2010. *Encyclopædia Britannica* 2007. Broek 2018.

10. Rodrigue 2019: 112–115.

11. Miura 1789, 1982. Iwata 1989. Miura's work was hampered by foreign and domestic policies of Japan's Tokugawa shogunate and so it became lesser known than those of other scholars. Piovesana 1965. Mercer 1998. I am grateful to Nobuo Tsujimura for bringing Miura and Iwata to my attention. Christian 2010: 12. Spier 2010: 10. I am grateful to Fred Spier for bringing Alexander von Humboldt to my attention. Rodrigue 2019: 115, 122.

12. Daniel Smail, Cambridge, Massachusetts, e-mail to Barry Rodrigue, 4 August 2010. Darwin's book, *On the Origin of Species*, came out in 1859 and was part of a 'time revolution' in historical understanding, one mediated by geologists and archaeologists. Christian 2015.

13. Wallerstein 1991. Christian 2010: 13–15.

14. Waddell 2017.

15. Tagore 2006. Teilhard de Chardin 1955. Lemaître 1927. I am grateful to Alex Holowicki for his presentation on 'Big History and Big Anxieties in the Interwar Period: Rethinking Hiram Percy Maxim's *Life's Place in the Cosmos*' at the third IBHA conference in Amsterdam in 2016.

16. Montessori 1998: 15. Jos and Anne-Marie Werkhoven, Almere, Flevoland, Netherlands, private communication, 26 May 2015. Werkhoven 2016.

17. Matsuzawa and McGrew 2008. I would like to thank Nobuo Tsujimura for sharing his insights about Imanishi. Nobuo Tsujimura, personal communications (email), to Barry Rodrigue, 4 June 2017.

18. Duedahl 2011.

19. Nazaretyan 2005.

20. Eric Chaisson, 1975; idem 1977; idem 1982; idem, personal communications, to Barry Rodrigue, 29–30 June 2010; idem, to Barry Rodrigue, Joseph Voros and David Baker, 22 January 2015, 4 February 2015. Field and others 1978. Field 1980.

21. G. Siegfried Kutter 1987; idem, 2011: 102–103. As with so many other of these efforts, the course work and book came together from collaborative

efforts, notably with ecologist Burton Guttman and microbiologist Elizabeth Martin Kutter, who also wrote a synthesis of her work in relationship to big history. E. Kutter 2017.

22. Thomas Bania, personal communications to Barry Rodrigue, 12 February 2014, 31 March 2014.

Michael Rampino, entry in Rodrigue (with Stasko) 2009: 15–16.

23. Cadrin-Rossignol 2002.

24. Qian 1991. Qian, Yu, Dai 1990. Cao, Dai, Zhou 2009. Sun 2015. Lu 2004. I am grateful to Sun Yue for bringing the Open Complex Giant System to my attention.

25. Sulkin 2015.

26. It bears noting that Lynn Margulis and Carl Sagan had been married from 1957 to 1964. They evidently shared a passion for holistic views of existence, considering their subsequent work. Lovelock and Margulis 1974. Lovelock 1975. Lovelock and Epton 1975. Margulis and Sagan 1986. Margulis 1998.

27. KCET Studios and others 1980. *Wikipedia*, "Carl Sagan," accessed 13 October 2021. L. Hawing 2016. McKie 2007.

28. One of the groups dedicated to Teilhard's work is the Association des amis de Pierre Teilhard de Chardin. On some of the ongoing initiatives related to Berry's work and its links to big history, see the following: Hazra 2016; Morgan 2017.

29. Frank 1978. Wallerstein 1984. Snooks 1998; idem, Institute of Global Dynamic Systems.

30. Mears 1986; idem, personal communication to Barry Rodrigue, Western History Association, Conference, Incline Village, Nevada, 14 October 2010; idem 2016.

31. David Christian, personal communication to G. Siegfried Kutter, 2011.

32. Christian 1991. Christian and McNeill 2008.

33. Huang Liuzhu's proposal for uniting natural and human history at Northwest University was not adopted. Sun Yue, personal communications to Barry Rodrigue, 2013–2014. Sun Yue at Capitol Normal University in Beijing is a leading big historian in China and has been engaged in a study of Chinese traditions of macro-history. Sun Chao at Shandong Normal University in Jinan was a student of Ma Shili. I appreciate their insights into the development of big history in East Asia. PhD students Li Qingcheng at Sun Yat-sen University and Zhao Beiping at Beijing Normal University also assisted me greatly.

34. Bondarenko, Grinin and Korotayev 2011. Grinin, Korotayev and Markov 2017. Panov 2017.

35. Spier 2005a: 1; idem, 2017. Quaedackers 2015.

36. Some of these efforts were challenging. Cynthia Stokes Brown had planned to write her book in the 1990s, but the sabbatical committee at Dominican University of California laughed at her and refused to allow such an 'outlandish' proposal, so she was forced to defer the project for a decade. Cynthia Stokes Brown, personal conversation with Barry Rodrigue, 6 August 2014.

37. The Spacewatch Program was begun by astronomer Tom Gehrels at the Kitt Peak National Observatory in Arizona (USA) in 1980. University of Arizona, Lunar and Planetary Laboratory, Spacewatch. Gehrels 2007: 183–202; idem, personal communication to Barry Rodrigue, 24 March 2010.

38. Other team members also published, such as Smit and Hertogen 1980.

39. Gehrel's text was developed/updated with his students as *Survival through Evolution, from Multiverse to Modern Society* (2007).

40. Eric Chaisson's timelines are maintained with additional materials at the Harvard University website, *Cosmic Evolution: An Interdisciplinary Approach* 2013. Saekow 2016. Duan 2013.

41. Gates and Rose 2009. Dean 2009. Gore 2013. Sorkin 2014. Christian, Brown, and Benjamin 2013. Sorkin 2014. The Big History Project focused on organizing courses and projects in schools in the US, Europe, and Australia. Some schools in non-Western countries developed big history independently by using the *BHP* website, as well as other sources. Bob Regan, e-mail to Barry Rodrigue, 11 July 2019.

42. A playful slogan for the 2005 Dubna conference was paraphrased from the *Communist Manifesto* —"The spectre of Big History is roaming the Earth."

Spier 2005b. Akop Nazaretyan, personal conversations with Barry Rodrigue, Moscow, Russia, February 2012. *Social Evolution and History: Exploring the Horizons of Big History* 2005. *World History Connected* 2009. In this issue, a review of books by world-historian William Everdell provided an interesting overview of big history. Everdell 2009. Alexander Moddejonge also provided an early synthesis of big history in his MA thesis. Moddejonge 2012.

43. Christian and McNeill 2008.

44. Several versions of the directory and bibliography resulted, which explains variations in content and participants. They appeared online, but, as sites became defunct, some versions vanished. A few were as follow. Rodrigue with Stasko 2009; idem, 2010. Stasko and Rodrigue 2010a; idem 2010b. Rodrigue, Spier, Christian, and Chaisson 2011. Rodrigue and Sun 2017.

45. The big historians who met at Coldigioco and founded the International Big History Association on 20 August 2010 were David Christian of Macquarie University in Sydney (Australia), Walter Alvarez of the University of California at Berkeley (USA), Craig Benjamin of Grand Valley State University in Michigan (USA), Cynthia Stokes Brown of Dominican University in California (USA), Fred Spier of the University of Amsterdam (Netherlands), Lowell Gustafson of Villanova University in Pennsylvania (USA), and Barry Rodrigue of the University of Southern Maine (USA). Other participants who were instrumental at this session were Alessando Montanari and Paula Metallo (directors of the Coldigioco Geological Observatory), Milly Alvarez, Pamela Benjamin, Gina Giandomenico, Penelope Markle, Daron Green, and Michael Dix. Barry Rodrigue chaired this first meeting.

46. The IBHA statement was based on a definition of big history used by Walter Alvarez.

47. The big history panels and roundtables were organized by Barry Rodrigue and Craig Benjamin. Rodrigue 2013.

48. Barry Rodrigue began as Secretary for the IBHA, but, in 2011, he became International Coordinator. The IBHA discussed how to encourage such worldwide growth at its first board meeting in Grand Rapids, Michigan in 2011. Part of Rodrigue's duties involved encouragement of local and regional initiatives, including that of the Eurasian Center, which he had proposed to Akop Nazaretyan and Andrey Korotayev. In 2015, he was appointed Research Professor in the Euarasian Center, Russian Academy of Sciences, Institute of Oriental Studies. Social Studies c. 2017.

49. Nakinishi and others 2014; idem, 2016; idem, 2017. Nakanishi and Tsujimura 2015; idem, 2016. Rodrigue 2013.

50. Martin Robert had learned of big history through David Christian's TED Talk and then consulted Big History Project materials. Martin Robert, Kyoto, e-mails to Barry Rodrigue, 20–22 December 2018. Christian 2011.

51. I appreciate the background details of these efforts in Japan from Nobuo Tsujimura, who participated in much of the formative work.

52 Kim 2015.

53. Zhao 2016. Zhu 2016. Christian 2007. Rodrigue 2013. News of the debate in Shanghai about David Christian's *Maps of Time* came from Osamu Nakanishi, who had learned of it from colleagues in the Chinese Communist Party. Nobuo Tsujimura, Tokyo, e-mail to Barry Rodrigue, 29 June 2015. Osamu Nakanishi, private conversation with Barry Rodrigue and others, Yokohama, 5 September 2015.

54. Rodrigue 2013.

55. Liu and Sun 2013.

56. Ma Xiaoling, Beijing, e-mail to Barry Rodrigue, 6 June 2017.

57. Network of Global & World History Organizations 2021.

58. Aidan Wong, Hong Kong, e-mails to Barry Rodrigue, 17–20 October 2021.

59. Lee Chiata, Taipei, e-mail to Barry Rodrigue, 16 October 2021.

60. Lee Chiata, Taipei, e-mail to Barry Rodrigue, 16–20 October 2021.

61. During the COVID pandemic, the European Big History Network met bi-monthly online. Esther Quaedackers, Amsterdam, e-mails to Barry Rodrigue,

20 October–24 November 2021. Jesse Bos, Amsterdam, e-mail to Barry Rodrigue, 28 October 2021.

62. The Italian newsletter editors are Adalberto Codetta, Giovanni Grieco, Renza Cambini, Silvia Morlotti, Davide Tonet. Jesse Bos, Amsterdam, e-mail to Barry Rodrigue, Pune, 28 October 2021. Adalberto Codetta, Milan, e-mails to Barry Rodrigue, 28 October–16 November 2021. Esther Quaedackers, Amsterdam, e-mails to Barry Rodrigue, 20 October–24 November 2021.

63. Rodrigue 2010. The students to first graduate with doctorates in big bistory were David Baker and Rich Blundell at Macquarie University. David Christian, Sydney, e-mail to Barry Rodrigue, 26 October 2021.

64. Likewise, some opposition arose from traditionalist academics who saw big history to be an attack against 'human agency' or religion. Furedi 2013.

65. The programme and the recording for the 2021 Global Big History Conference Symbiosis School for Liberal Arts and others 2021.

66. African Big History Association 2018. Nganfon Eric 2018. Tan 2019.

67. Rossetti and Montanari 2001. Paula Metallo is a creative artist and co-director of the Coldigioco Geological Observatory. Metallo 2016.

68. Baker 2014–2017. Blundell 2014.

69. Hughes 2012; idem, 2016. Hughes, Basu, Bipattaran, and Ensemble 2012.

70. Tsujimura 2014.

71. Roberts 2003: 705–709; idem, Geneva, emails to Barry Rodrigue, 4 April 2012, 23 January 2019; idem, Symbiosis School for Liberal Arts and others 2021, pp. 70–72. A version of the contents of second e-mail appeared in the programme of the 2021 Global Big History Conference for which it was sent. I would like to thank Michael Dix for noting this connection between Greg Roberts's work and big history.

72. Shubhangi Swarup, Bombay, email to Barry Rodrigue and Oishika Neogi, 10 March 2020. A version of the contents of this e-mail appeared in the programme of the 2021 Global Big History Conference.

73. Christian 2004: Introduction. Benjamin 2009. Not everyone agreed with the characterization of big history as a modern creation myth, including John Mears and Barry Rodrigue. A concern was the implied association of science with myth. Mears, conversation with Barry Rodrigue, Western History Association Conference, Incline Village, Nevada, 14 October 2010.

74. Institute on Religion in an Age of Science. Zygon: *Journal of Religion and Science*. Shapley 1966.Chaisson 1999. Goodenough 2003.

75. Puhalo 2010; idem 2016. Orthodoxy in Dialogue. Roderick 1977.

76. Brian Swimme 2016.

77. Morgan 2002; idem 2003; idem 2006; idem 2017.

78. Hazra 2016; idem 2017/2022. Olelaker 2017.

79. Espartinez, Maniago, and Gonzales 2018. Holy Angel University 2018a; idem, 2018b. Nobuo Tsujimura, Tokyo, email to Barry Rodrigue, 6 October 2021. Santa Cruz Sentinel 2021.

80. Jusop and Tan 2022. Sudarshan 2022. Shamshuddin, Tan and Sudarshan engage with big history to encompass their ideas of existence at global venues with the IBHA and ABHA.

81. Shtyrbul 2006. Rodrigue 2014.

82. Chaisson 2010; idem 2011. Bondarenko and Baskin 2016. Wang 2020. Bridge-Minds 2021.

83. Moddejonge 2012. Wilson 1998. Spier 1996. Christian, Brown, Benjamin 2013. Rodrigue 2017b. Baker 2016. Chaisson 2010; idem, 2011.

84. Nicolas 1989. Waddell 2017. Wilson 2014: 176. Diamond 1998. Harari 2015. Edward O. Wilson, Cambridge, emails to Barry Rodrigue, 4 May 2012.

85. Rodrigue 2021; idem 2017b.

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Author's note: Some difficult-to-access items appear on my web-portal, *Rodrigue Global* <http://www.rodrigue-global.org/>. The box is simply titled "Archive" or can be accessed via *Universal Studies—Big History Center II: Papers, Lectures, Tools and Links*: <http://www.rodrigue-global.org/universal-studies--archives.html>.
—Barry Rodrigue

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Thresholds of Increasing Complexity in Big History: A Critical Review

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ABSTRACT

In this article, the concept of Thresholds of Big History is critically examined. It should be abandoned because it is fundamentally flawed.[1]

Introduction

The idea of thresholds of increasing complexity as the principal organizing principle for big history contains important flaws, and should be abandoned. A proper understanding of this controversial theoretical issue is vitally important not only for a good understanding of academic big history but also for teaching it both within academia and in secondary schools.

Over the past ten years I have offered earlier versions of this criticism many times in private but expand on them here in public for the first time. While I differ on this issue with David Christian, who is the originator and principal advocate of the Thresholds Approach, I continue to respect and highly value his pioneering work in big history.

To understand the issues involved, first a history of the Thresholds Approach will be sketched. This will be followed by a critical examination of this concept.

When and how did the concept of thresholds of big history emerge?

On March 2, 2011, David Christian gave a TED talk summarizing all of big history called "The History of World in 18 Minutes." This was part of a session with the title *Knowledge Revolution* that was guest-curated by Microsoft cofounder Bill Gates. This TED talk was intended to launch their joint initiative, called the *Big History Project* (BHP), to create a secondary school project for teaching big history by providing online all the needed materials.

In this talk, Christian suggested a structure for big history based on what he called thresholds of complexity, with each threshold indicating a further rise of complexity within big history. A total of eight thresholds were chosen. In his TED talk these thresholds were 1. Big Bang; 2. The stars light up; 3. New chemical elements; 4. Earth and the solar system; 5. Life on Earth; 6. The appearance of our species; 7. Agriculture; and 8. The Modern Revolution.

In his book *Origin Story: Big History of Everything* (2018) these thresholds became 1. The Big Bang; 2. The emergence of stars; 3. The emergence of the first heavy elements forged in large stars; 4. The emergence of our solar system; 5. The emergence of life on Earth; 6. The emergence of *Homo sapiens*; 7. The emergence of agriculture; 8. The emergence of the Anthropocene (starting in the 20th century); and 9. A future sustainable world order? In the time line of the same book, Threshold 8 is also mentioned as the 'emergence of the fossil fuel revolution.'

In his TED talk, Christian announced the Thresholds Approach as follows:

> Each stage [of rising complexity in big history] is magical. They create the impression of something utterly new, appearing from almost nowhere in the Universe. We refer in big history to these moments as thresholds moments.

It was in January of 2011, after having received a request to comment on the first BHP course draft, that I became aware of the fact that David had begun structuring big history along those lines. Immediately, I sent some of my objections to the Thresholds Approach in an e-mail message dated January 20, 2011 (still in my possession)—a little more than a month before Christian's TED talk. However, I did not receive a reply; after that, I was no longer consulted by the BHP.

Unknown to me, Christian had already begun promoting his Thresholds Approach at least four years earlier, namely in the audio version of his book *Maps of Time: An Introduction to Big History* (2004) that was released by *The Great Courses*.[2] On its website, the release date of that audio course is not mentioned. I may be wrong, but to the best of my knowledge, it was released early in 2008 (cf. Christian 2008). It was this course that Bill Gates had listened to—while working out on his home trainer, as the story goes—and that had stimulated him to initiate and support an online course for teaching big history in secondary schools.

However, in Christian's earlier book, *Maps of Time*, these thresholds do not appear. I had not listened to—or even looked at—that audio course because David Christian had told me that it was an audio version of *Maps of Time*. He had never mentioned to me that in this audio version, the concept of thresholds was introduced as a structuring principle for big history. It was only in December of 2020, while investigating the history of the Thresholds Approach, that I became aware of this.

In this audio course (as it appeared on *The Great Courses* website in December of 2020), the Thresholds Approach is explained as follows:

> To tell this epic, Professor Christian organizes the history of creation into eight "thresholds." Each threshold marks a point in history when something truly new appeared and forms never before seen began to arise.
>
> Starting with the first threshold, the creation of the Universe, Professor Christian traces the developments of new, more complex entities, including the creation of the
>
> first stars (threshold 2);
> the origin of life (threshold 5);
> the development of the human species (threshold 6); and
> the moment of modernity (threshold 8).

To the best of my knowledge, by March of 2011 David Christian was still one of the few academics, if not the only one, who was teaching big history while using this Thresholds Approach. That makes his TED talk claim, "We refer in big history to these moments as threshold moments," an over-generalization. In reality, there was no such consensus at all within the small but growing field of academic big history, of which I was one of its early pioneers. Within this context it may be important to mention that as of 1995, while co-organizing the University of Amsterdam big history course, David Christian and I had intensively collaborated in shaping this new field.

Over the past ten years I have raised in private my questions and doubts about the Thresholds Approach many times, most notably with David Christian but also with other big historians who advocated the Thresholds Approach. The standard answer was that, indeed, the thresholds were chosen arbitrarily and other choices could have been made, but they had proven to be good pedagogical devices.

If these thresholds are, indeed, arbitrary, why make them central to the narrative of big history? Yet, according to those advocating the Thresholds Approach, while mentioning the Emergence of Life, for instance, we should instead be talking about The Fifth Threshold: The Emergence of Life. It was capitalized as such as a chapter title in both the original online of the BHP course and the textbook *Big History: Between Nothing and Everything* (2014), authored by David Christian, Cynthia Stokes Brown, and Craig Benjamin.

How warranted and convincing is that, given the arbitrary character of the thresholds? This question became especially urgent after many adherents of this approach began to talk, for example, about Threshold Five, without even further mentioning what it was about. Apparently, all of us engaged in big history were supposed to know what that meant. In doing so, a group of big history 'thresholds insiders' was taking shape, while those big historians who thought that the Thresholds Approach was, perhaps, not such a good idea suddenly became outsiders.

In David Christian's book of 2018, these sequences within the chapter titles have been reverted, at least partially under pressure of my persistent criticism, or so I suspect. In that book it became Life: Threshold 5. Yet, for David Christian and his followers, the Thresholds Approach has remained central to big history although at least one of those thresholds was slightly altered over time, as noted above. My criticism in private may also have led to changes in the BHP, in the most recent version of which the Thresholds Approach has become considerably less dominant although it has not yet disappeared.[3]

What does the word 'threshold' mean in English?

In critically examining the Thresholds Approach, let us first examine the meanings the word 'threshold' in English as well as Christian's use of it as a general scheme for big history. According to the Merriam-Webster online dictionary a 'threshold' holds several possible meanings.[4]

1 : the plank, stone, or piece of timber that lies under a door: sill
2a : gate, door
b(1) : end, boundary specifically: the end of a runway
(2) : the place or point of entering or beginning: outset on the threshold of a new age
3a : the point at which a physiological or psychological effect begins to be produced has a high threshold for pain
b : a level, point, or value above which something is true or will take place and below which it is not or will not

The meanings mentioned under 2b (2) as well as under 3a and b do apply to David's use of the term, but the other meanings do not, or apply only insufficiently. What about Threshold One: The Big Bang? Can we define any clear circumstances that allowed this to happen, or that held back the emergence of our Universe? To my knowledge, we do not know anything about what may have happened before the Big Bang.

By contrast, the emergence of more complex chemical elements within stars does require certain clearly-defined high temperatures and pressures within those stellar cores. As a result, that situation can indeed be described as a threshold. Can we similarly precisely define threshold circumstances for the emergence of life, of humans, or of agriculture? That does not appear to be the case, not least because in those latter situations, cause and effect are still at best only partially understood, while a considerable degree of chance effects would also have played a role in those transitions to greater complexity.

Let us pursue the meaning of thresholds in big history a little further, first of all the question: can all those thresholds of big history empirically be observed, such as stars for instance? For most of them there appears to be no way of doing so. What we can observe are changing processes that may include the rise of complexity within certain favorable circumstances but no observable barriers that were holding back the rise of them.

If most of these thresholds of big history cannot be observed empirically, they must be interpretations of that history. By itself, that is not a problem. All our scientific concepts are interpretations of reality. Let us take as an example the term *gravity* as defined by Sir Isaac Newton. This concept did not exist before the great scientist coined it, and it cannot be observed as such in nature; but its effects can empirically be observed and are thought to have existed almost as long as the history of the Universe. Yet according to

Einstein's interpretation, these effects—the mutual attraction of ordinary matter—are not caused by gravity at all, but instead by the warping of space-time by the mass of such bodies. In other words, Einstein's theory of relativity offers a different interpretation of the same observations.

What are my major objections to the Thresholds Approach as a valid general interpretative scheme for big history?

The question now becomes this: how valid is the Thresholds Approach as an interpretative scheme for big history? This problem becomes pressing as soon as one realizes that there have been a great many processes leading to greater complexity, far more than only the eight thresholds mentioned by Christian. This is not only the case within the history of the Universe as a whole, but also—and perhaps most notably—within Earth's developing biosphere, in which a great many processes leading to greater complexity occurred between the emergence of life and that of anatomically modern humans. More about that below —

This raises the fundamental question: when does a transition leading to greater complexity qualify as a threshold, and when not? In other words, what are the academic criteria for defining thresholds? To the best of my knowledge, this question has not yet systematically been addressed by those who have adopted the Thresholds Approach. As a result, it appears as though such clearly defined criteria do not yet exist. Instead, it appears as though those eight thresholds of rising complexity have sprung forth from Christian's imagination without any further attempt at academically systematizing them, for instance by wondering what the academic criteria are for a rise in complexity to qualify as a threshold.

By itself, it is not at all bad that scientific concepts spring forth from an academic's imagination. They all do. However, in order to be used in academia, they must first be submitted to rigorous scrutiny. That has as yet not happened. This is another major flaw of the Thresholds Approach.

As soon as we start doing so, we find ourselves in considerable trouble. First of all, Thresholds 1, 2, and 3 apply to all of big history. Yet, Thresholds 4 to 8 do not do so at all. Threshold 4 is about the emergence of our solar system. Surely, in the entire Universe a great many solar systems must have emerged, many of them much earlier than ours. This makes one wonder how accurate it is to focus the story for Threshold 4 almost exclusively on our solar system. Clearly, by doing so, as mentioned above, Threshold 4 is no longer valid for big history as a whole, but instead only for a very tiny portion of it.

One may argue that the emergence of stars with rocky planets such as Earth was a major step in the rise of complexity within the Universe as a whole. That may well have been the case, but because we know so very little of the entire observable Universe at those relatively small scales, how can we be sure that what happened within our solar system is valid for all of big history? There may well have been other forms of greater complexity in big history that we may not even be able to imagine right now.

Like all empirical science, big history is based on the best available observational evidence. Because today we can observe so little of those relatively small yet potentially very complex objects within the Universe as a whole, in that very important aspect we are currently staring into a big unknown. This unknown should be recognized as such. It should not be swept under the carpet by suddenly concentrating the attention solely on our cosmic neighborhood and our own planet without mentioning this enormous change of focus, while continuing to employ the Universe-wide concept of thresholds, which is from that period onward in time, applicable to only solar system and Earth history.

This situation signals, therefore, a major systematic and methodological flaw in terms of the Thresholds Approach presented as being a general big history scheme, which it is not. Over the course of cosmic time, it turned instead into a solar system-centric scheme, yet implicitly (and perhaps unintendedly) presented as part of the measure of all things during all times.

It gets worse. Because Threshold 5 is about the emergence of life on Earth, while using this general big history concept, we suddenly find ourselves focusing exclusively on our own planet. One could argue, of course, that we do not know any life elsewhere within our solar system, let alone in the rest of the Universe. Even so, this lack of knowledge should not lead us to imposing this supposedly universal concept 'thresholds of big history' solely on one single planet, as though from that moment onward Earth history would be the measure of all things during all times.

Similar arguments apply to Thresholds 6, 7, and 8: the emergence of humans, of agriculture, and of modernity, all of which are anthropocentric. The change in 2018 of Threshold 8 into 'the emergence of the Anthropocene' makes it a little less anthropocentric. However, it is still far from being applicable to the entire Universe, of which we know hardly anything on this relatively small scale.

Furthermore, one may wonder whether, during the long period between the emergence of life and humanity, there may have been other major transitions toward greater complexity within our biosphere that might qualify as thresholds. What about the emergence of plate tectonics; the emergence of life capturing sunlight; the emergence of complex life; or of life moving on land, to name a few? What about the established geological epochs? Why would they not qualify as thresholds of some sort, and on which grounds, not even as 'mini thresholds' (a term later used by Christian to characterize the emergence of states)?

What about human history? Why would, for instance, tool use and the domestication of fire, both with enormous effects on humans and the biosphere, not qualify as thresholds? What about the 'mini threshold' of the emergence of states? What are the academic criteria for determining that? What about the first wave of globalization after Columbus's encounter with what soon would be called the Americas, with enormous worldwide social and ecological effects? What about the current wave of informatization using ever more complex computers connected to each other by rather complex electronic networks, all with huge social and ecological consequences? Why would these spectacular changes not be thresholds of some sort? These examples are only some more obvious ones.

In this respect, a calculation that I made while writing a book about the biosphere's history may be helpful (Spier 2022). Human history (defined here as starting seven million years ago) forms only 0.175 percent of the biosphere's history (defined here as about 4 billion years). The period after humans began to use fire represents 0.038 percent; the period of agriculture 0.0003 percent; the period of states 0.00015 percent; the past 530 years since Columbus and his crew first stepped ashore on a Caribbean island 0.000013 percent; the period of the industrial revolution 0.0000067 percent; and the proposed Anthropocene (defined as the geological period in which nuclear traces resulting from human action began to appear in the biosphere) as little as 0.0000016 percent of the biosphere's history.

These numbers provide a first indication of the extraordinarily fast acceleration of human history, including its similarly growing influence within the biosphere. They do not inform us at all about anything that has been happening in the rest of the Universe during that period, with the exception of spacecraft circling Earth and traveling through our solar system, some of them carrying humans into space, as well as electromagnetic radiation generated by humans moving out into the cosmos. All of that is almost negligible given the size of the Universe. Yet in the Thresholds Approach, human history, which represents at most 0.175 percent of the biosphere's history and only 0.05 percent of big history, contains four out of a total of eight thresholds of big history.

What about the future?

What about the future, of which we do not know anything, empirically speaking? Is Threshold 9, the transition to a 'sustainable world order,' indeed the only important new phase to be expected in big history? Isn't that a little anthropocentric as well? What about, for instance, Earth's biosphere after humans; the end of the solar system after the Sun burns out; and the future

of the Universe as a whole?

In the book *Big History: Between Nothing and Everything* (2014), such longer-term questions about the future were discussed in chapter 13 with the question, "More thresholds?" on its title page, while no specific thresholds were attached to any aspect of the big future. At the end of the book *Origin Story: Big History of Everything* (2018), while trying to look further into the future, David Christian also discussed a few of these longer-term trends, such as the end of plate tectonics and the Sun nearing the end of its existence, while the rest of the future Universe received some attention as well, again without mentioning any further thresholds. Apparently, the Thresholds Approach does not work very well for the future Universe. It is too much tied to human history to be applicable to a universe within which humans no longer exist.

What about the decline and disappearance of complexity in big history?

Are there other reasons why the Thresholds Approach would not work well for considering the future? Is that because in our expected big future, no further rise of complexity would take place but, instead, only the decline and disappearance of greater complexity would occur? Even if that were the case, this raises the profound question of whether the Thresholds Approach perhaps mostly, if not exclusively, focuses on the rise of complexity while neglecting its decay. Here we see another important defect of the Thresholds Approach.

This bias toward rising complexity is more generally present in Christian's work, most notably perhaps in his term 'collective learning.'[5] While employing this term in 2010, I suggested also systematically including 'collective forgetting.' In terms of the Thresholds Approach, the notion of 'collective forgetting' offers a great many situations in which thresholds were crossed downward as part of declining or completely disappearing complexity.

In fact, big history as a whole can be characterized by the interplay of processes of emerging, rising, declining, and disappearing complexity, as I argued in my article about this subject (2005), including its title "How Big History Works: Energy Flows and the Rise and Demise of Complexity." Today, such a decline in complexity would include the biological simplification of the biosphere over the past 12,000 years through human action. While considering these rather profound questions, this additional major weakness of the Thresholds Approach becomes clear, namely, that it mainly, if not exclusively, focuses the attention on rising complexity while neglecting its decline and disappearance.

Which circumstances may have contributed to this erroneous interpretation of big history?

Which more general aspects may have contributed to the adoption of the Thresholds Approach? Within this context it is important to mention that at the beginning of his TED talk, Christian raised what he saw as the great puzzle of big history: "How does the Universe make complexity?" This quotation exhibits a certain degree of anthropomorphic language. Seen from an academic perspective, the Universe does not make complex things. With the exception of the artificial complexity created by animals including humans, all the rest has emerged all by itself.

This criticism may appear trifling, but I think it is not. This type anthropomorphic or otherwise dramatic language is rather common in David Christian's big history accounts. To be sure, many terms in the natural sciences were coined while using daily language. The 'attraction' by gravity offers such an example. Yet while explaining big history, one should be careful to follow the established scientific language and avoid adding more anthropomorphic terms, especially when they are not correct.

David Christian's answer to the question of how the Universe makes complexity was "With great difficulty," while subsequently mentioning as an explanation the idea of Goldilocks circumstances—favorable circumstances that allow the emergence of greater complexity—while correctly crediting me for that approach.[6]

Physically speaking, however, Christian's answer is only part of the answer. In his groundbreaking book

Cosmic Evolution: The Rise of Complexity in Nature (2001), the US astrophysicist Eric Chaisson had already given an excellent explanation of the rise of complexity in all of cosmic history in terms of what is known in physics as non-equilibrium thermodynamics. Within this context it is important to note that Chaisson is a true pioneer of teaching and researching what he calls "cosmic evolution," which is, in essence, the same as big history, but in Chaisson's approach with a much larger emphasis on cosmic history.

In a very short summary of Chaisson's explanation of the rise of cosmic complexity, energy flows through matter are required for greater complexity to emerge, including the need to dissipate the inevitable larger chaos (entropy) into the rest of the Universe in the form of low-energy radiation. This is possible thanks to the expansion of the cosmos, which has turned it into ever-increasing, mostly empty, and very cold space. Seen from a thermodynamic point of view, this cosmic expansion has, therefore, turned the Universe into an ever-increasing space for entropy.

However, while describing this general process, Chaisson did not systematically explore the important role of Goldilocks circumstances. While *Cosmic Evolution* can be a difficult read for those who have not studied physics, my explanation of Chaisson's seminal work in *Big History and the Future of Humanity* (2010) was clearly made.

Why, then, was Chaisson's approach in terms of energy flows through matter as a major requirement for the emergence of greater complexity in cosmic evolution not even mentioned in David Christian's TED talk while seeking to answer this fundamental question, or adopted in his further work, including the BHP course? It is exactly this approach to cosmic evolution/big history that ties every moment of Earth history, including human history, inextricably to the history of the Universe.

What about the lack of an 'Earth at a distance' view?

What may further have caused the uncritical adoption of the Thresholds Approach? Although at first sight this subject may again appear trifling, advocates of the Thresholds Approach rarely, if ever, use images of 'Earth at a distance' as exemplified by the famous *Earthrise* photo, which was taken in December of 1968 by the astronauts of Apollo 8 as well as the similarly famous *Full Earth* photographed in 1972 by the Apollo 17 crew.[7]

This lack of attention to 'Earth at a distance' views can, for instance, be observed in David Christian's choices for pictures to illustrate big history, which are almost always Earthbound scenes looking out into the sky. There are a few exceptions. Within the textbook of 2014 (but not its cover) and on the *BHP* website, there are a few pictures of our planet seen from low Earth orbit. Yet these photos do not show our entire planet surrounded by black space. To the best of my knowledge, also among other adherents of the Thresholds Approach, photos of 'Earth at a distance' are rarely used, if at all, to illustrate big history. The only exception known to me is offered by the *Great Courses* website as viewed in February of 2022, which sports a *Full Earth* picture, as well as the cover of their *Course Guidebook* (Christian 2008).

Within this context it may be worthwhile to pay some attention to what Apollo 8 astronaut William Anders had to say about this subject. In December of 1968 while in lunar orbit, Anders took the famous photo of the Earth above the stark lunar surface that soon became known as *Earthrise*. In 2009, Anders formulated his change of view as follows:

> The biggest philosophy, foundation-shaking impression was seeing the smallness of the Earth.… Even the pictures don't do it justice, because they always have this frame around them. But when you…put your eyeball to the window of the spacecraft, you can see essentially half of the universe.… That's a lot more black and a lot more universe than ever comes through a framed picture.… It's not how small the Earth was, it's just how big everything else was.[8]

Within this context, my article "On the Social Impact of the Apollo 8 *Earthrise* Photo, or the Lack of It?" published in 2019 in the *Journal of Big History* may also be relevant. The lack of such pictures among adherents of the Thresholds Approach makes one wonder whether they perhaps missed that profound change of view.

This lack of an 'Earth at a distance' view may also be visible in the design of David Christian's first big history course. Its 1992 study guide bore the title, *HIST 112: An Introduction to World History*.[9] This is the study guide, still in my possession, that we used as a model for our first big history course at the University of Amsterdam. The 1995 study guide offered essentially the same course, while both study guides do not mention the term 'big history.' Yet in his article "The Case for Big History" (1991), David Christian had already launched this term publicly for characterizing his revolutionary course.

Why would that be? This more conservative course title may have been part of a political move to get and keep this revolutionary course accepted within Macquarie University's School of History, Politics & Philosophy, but it may go deeper than that. In 1992 this course consisted of Introduction: A Sense of Time (2 lectures); Part 1: Before Humanity (six lectures); Part 2: The First Human Societies (four lectures); Part 3: Agriculture and Tributary Societies (six lectures); and Part 4: Capitalism and the Modern World (7 lectures); by 1995 its lecture content had hardly changed.

This understandable focus on human history, given its place within the School of History, Politics & Philosophy is, however, also found in David Christian's TED talk of 2011, which had the title "The History of Our World in 18 Minutes." Why not "The History of Our Universe in 18 Minutes"? In following this approach, cosmic history is presented as an introduction to world history, and not as a vastly larger entity within which Earth and human history have evolved.

To be sure, David Christian's pioneering attempt to look so much farther into the past than only human history was revolutionary. Still big historians need to take further mental and theoretical steps to put Earth and human history in their proper place within the scheme of cosmic history.

Concluding Remarks

All of this leads to the following conclusions. Because of its lack of precision in defining what a threshold is; the lack of clearly defined academic criteria to establish them; its erroneous use as a concept for structuring all of big history; and its focus on rising complexity while ignoring its decline, the concept of thresholds of big history is fatally flawed and ought to be abandoned.

I am not alone in my criticism. Also, Eric Chaisson (2014) and the UK astrophysicist Michael Garrett (in Crawford 2019; Garrett 2021) have independently criticized the anthropocentric character of the Thresholds Approach. Yet because of the Thresholds Approach's simple, rhetorically seductive, and at first sight persuasive character, it has rather uncritically been embraced by a great many people, none of whom has apparently taken the time and mental distance to scrutinize this scheme carefully. Some of them may simply have been too busy to do so, while perhaps lacking sufficient experience in this field. Others may not have done so because they may have assumed that this scheme must be good since it is promoted within a project supported by one of the wealthiest men in the world, with the expectation that it had been carefully peer reviewed.

From my point of view, it is great that Bill Gates chose to support big history in this way. Regrettably, however, his pioneering initiative did not lead to a BHP course that was set up according to sufficiently rigorous academic standards. As a result of this situation, a new myth clothed in academic attire has been going around the world. It is promoted with the support of Bill Gates's money and prestige as part of a secondary school project for teaching big history to young people worldwide in a way that is not sufficiently in accordance with carefully-amassed empirical evidence and academic interpretations. Furthermore, by taking this erroneous track, any further theoretical progress in big history has become virtually impossible.

The approach advocated in my book *Big History*

and the Future of Humanity (2010, 2015) still works considerably better, or so it seems to me. In that book I argue along the lines of transitions to greater complexity while not prioritizing any of them according to a fixed and numbered scheme that was claimed to be valid for all of big history but while also paying considerable attention to the decline and disappearance of complexity.

Regarding the place of Earth and human history within big history, at the beginning of Chapter Four: Our Cosmic Neighborhood: The Emergence of Greater Complexity, I wrote the following (2010, 62-3):

> We do not know whether life and culture as we know them are unique, or whether they have also emerged elsewhere in the universe. [. . .] If there is life elsewhere in the universe, it may well have preceded life on Earth. The first heavier chemical elements needed for life probably emerged as early as 10 billion years ago. Given the enormous numbers of galaxies—perhaps 100 billion in the known universe, each harboring perhaps as many as 100 billion stars—the chances appear considerable that life and culture would have emerged in other places also, quite possibly much earlier than on our home planet. Moreover, seen on a cosmic scale we do not even know whether life is, in fact, the next step toward greater complexity. Perhaps other forms of greater complexity exist out there that we are currently unable to detect or even imagine. As a result, while discussing the emergence of life and culture on Earth, our big history account by necessity becomes solar-system focused and Earth-centered.

To me all of this still appears reasonably correct, uncontroversial, and considerably more precise than the Thresholds Approach. Yet as I keep emphasizing, no current big history account should be seen as mature. We still find ourselves at the beginning of summarizing big history, and great progress seems still possible.

"We have a choice," the US planetary scientist Carl Sagan (1934-1996) said within a different context. His public program in the 1980s called *Cosmos* served as a great inspiration for David Christian to think of big history and start his revolutionary course. Yet to my knowledge Carl Sagan's rhetoric never compromised any serious science that he sought to popularize.[10] I very much hope that all of us will follow his great example, each of us in our own ways.

Notes

1. I owe many thanks to Gijs Kalsbeek, whose careful commentary—as so often during the past 40 years—has helped me to say what I think and recognize what I needed to think of. The editorial skills of Lowell Gustafson, another good friend, as well as his many excellent suggestions very much improved this article as well. Another great friend, Armando Menéndez Viso, provided great commentary that has added further clarity and structure to the text, while also Olga García Moreno, another highly-valued friend and colleague from Asturias, Spain, offered her stimulating comments. Also, my colleague and great friend Esther Quaedackers helped to improve this text. As an external reviewer, Tyler Volk contributed useful suggestions for further improvement. As always, I remain solely responsible for the final text.

2. Course title: *Big History: The Big Bang, Life on Earth, and the Rise of Humanity*. Course No. 8050. Last accessed February 20, 2022. https://www.thegreatcourses.com/courses/big-history-the-big-bang-life-on-earth-and-the-rise-of-humanity.

3. *BHP*. Last accessed February 20, 2022. https://www.bighistoryproject.com and https://www.oerproject.com/Big-History.

4. *Merriam-Webster.com*. s v "threshold." Last accessed February 20, 2022. https://www.merriam-webster.com/dictionary/threshold.

5. Christian first introduced the term 'collective learning' in his book *Maps of Time* (2004). It essentially

means the same as the term 'culture' as defined by the British anthropologist Sir Edward Burnett Tylor (1832-1917), by many considered as the father of cultural anthropology. On page 1 of his famous book *Primitive Culture* (1871) he defined 'culture' as follows: "Culture or Civilization, taken in its wide ethnographic sense, is that complex whole which includes knowledge, belief, art, morals, law, custom, and any other capabilities and habits acquired by man as a member of society." My notion of cultural forgetting: Spier 2010, p.114; 2015, 182-3.

6. The idea of such favorable circumstances as conditioning the rise and demise of complexity within big history was first presented in my article about this subject of 2005. It was later elaborated in my book *Big History and the Future of Humanity* (2010; 2015).

7. For the impact of the *Earthrise* photo or the lack of it, see Poole 2008 and Spier 2019. Also, during unmanned space flights, high-impact pictures of Earth at a distance were taken, most notably perhaps the *Pale Blue Dot* photo of Earth taken by Voyager 1 in 1990 from 3.7 billion miles away and the Cassini mission's picture taken in 2017 of Earth from under the rings of Saturn.

8. Chaikin and Kohl (2009, 158).

9. Macquarie University, 1992 Study Guide HIST 112: An Introduction to World History, School of History, Politics & Philosophy. Among Anglo-Saxon historians, 'world history' usually means 'human history.'

10. For instance: Carl Sagan's *Cosmos* series, now on *YouTube*, and his lecture "The Age of Exploration" (1994). https://youtu.be/6_-jtyhAVTc.

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The Chicxulub File
Discovering the K-Pg Mass Extinction: A Four Decade Perspective

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KEY WORDS

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ABSTRACT

In 1979 geologists Luis and Walter Alvarez discovered a layer of iridium-rich rock in the Apennine Mountains dating from 66 to 65 million years BP, the time when dinosaurs went extinct. Their theory that an asteroid strike had caused this massive extinction remained speculative and controversial until the 1991 discovery of a telltale crater from a synchronous asteroid impact. The effects of this impact, centered at Chicxulub on the Yucatan Peninsula, were worldwide. Over the years, impact spherules were found at numerous sites, along with evidence of a massive tsunami throughout the Gulf of Mexico and adjacent coasts. From accumulating evidence, the theory was ratified in 2012, though many details remained unknown. However, a series of dramatic discoveries reported from 2019 to 2022 have led to a chronology of events both during and subsequent to the impact. Evidence for the rapid recovery and development of mammals has been found in the fossil record and, thus, the biological foundations of our own emergence. The final 2019 issue of Science (20 December) named this a "superyear" for studies of the Cretaceous-Paleogene (K-Pg) extinction as the runner-up science "breakthrough of the year." Through these separate discoveries, a coherent hour-by-hour narrative has emerged, marking the onset of the Cenozoic era and providing a foundation for the emergence of *Homo sapiens*.

Introduction

When scholars gather, they sometimes choose to memorialize their common interests, fields of specialization, or new perspectives on existing knowledge. In 1743, Benjamin Franklin and prominent leaders in and around Philadelphia founded the American Philosophical Society whose membership eventually included most of the founding fathers. Today it remains the grandfather of all such intellectual societies. In 1783, the philosopher-economist Adam Smith, the chemist Joseph Black, and geologist James Hutton formed the Oyster Club at Edinburgh, which became the intellectual center of the Scottish Enlightenment, with David Hume, John Playfair, and Sir James Hall among its early members. In 1892, the naturalist and intrepid explorer of the American wilderness, John Muir, founded the Sierra Club which, among many environmental groups, remains the most influential today. To these assemblies we could add hundreds more. In 2010, geologist Walter Alvarez led a small, multidisciplinary group of scholar-teachers to a place in the Apennine Mountains in Italy where, in 1979, he and his father had noticed a revealing iridium-rich layer at the Cretaceous-Paleogene (K-Pg) boundary, leading them to theorize that a massive asteroid had struck the Earth 66 to 65 million years ago, bringing such massive changes to the environment that the ruling dinosaurs were driven to extinction. This was an event that opened up a new chapter in the history of life.

The Alvarez theory, published in *Science* (Alvarez et al. 1980), followed by a search for evidence and the discovery of the Chicxulub crater a decade later (Hildebrand et al. 1991), blended cosmic, terrestrial, biological, and anthropological history into a single narrative.

Big Historians at K-T Boundary in Gubio, Italy: David Christian, Walter Alvarez, Craig Benjamin, Barry Rodrigue, Cynthia Brown, Fred Spier, Louis Spier, Lowell Guistafson

Figure 1. August 20, 2010: International scholars stand before the K-T (K-Pg) Boundary in Gubbio, Italy. Here, in 1989, geologists Luis and Walter Alvarez discovered a mysterious layer of iridium-rich debris signifying an asteroid impact 66 to 65 million years ago that corresponded with the disappearance of dinosaurs in the fossil record. Following this visit, they formed the International Big History Association (IBHA). Source: IBHA archives.

The theory and its verification became a paradigm for how the best science should work. The Alvarezes became the iconic scientist-explorers; Chicxulub became the symbolic center of a group of scholars who banded together to form the International Big History Association (IBHA). A decade later, the organization has scores of members, several associated big history organizations, its own scholarly journal, and has completed its fifth biennial conference.

I. Iridium

The disappearance of dinosaurs from the fossil record may seem unimportant, like the demise of trilobites or extinction of the dodo bird. Much less recognized except by biologists and anthropologists is the corollary emphasized by Alvarez (2017) that we live in a contingent universe. Had this event never occurred, all subsequent life on Earth would have been indescribably different, and humanity in its present form would never have evolved.

No matter how far we stretch imaginations, it is almost impossible to find an event that touches all four chapters of Big History: Cosmos, Earth, Life, and Humanity. As such, it provides a narrative bridge across C. P. Snow's "two cultures"—the sciences and humanities (Snow 1959; Wood 2013). This event impinges on so many dimensions of the grand narrative as well as being high drama in its own right that the dinosaur story has devolved into entertainment. Over three decades, Michael Crichton's *Jurassic Park* (1990) and five movie sequels have recreated the hazardous past of life on Earth, and dinosaurs have overtaken erector sets, Legos, Hot Wheels, and skateboards to become the most popular of children's collectibles, rivaled only by Barbie dolls and Beanie Babies. The Alvarez theory is now the assumed correct and unrivaled explanation for dinosaur extinction among the general public. We might easily conclude the case was closed thirty years later when forty-one scientists writing for *Science* declared the evidence sufficient to end all doubt and speculation (Schulte 2010), but we now know that Chicxulub is much more than an asteroid strike, a crater, and a catastrophic extinction. During the 1980s when the theory had not yet been verified, secondary evidence began accumulating, and this continues today.

The initial entry in the Chicxulub File was an assumption that the event was local or regional.

Figure 2. In 1979 Walter Alvarez and his father discovered an iridium-rich layer at the K-Pg Boundary in the Apennines dated at 65 million years BP. They initially assumed it was caused by a local asteroid impact. The subsequent discovery of the same layer around the world confirmed that this was a global rather than local event. He theorized that an asteroid impact was responsible for the extinction of the dinosaurs and upward of ninety percent of all life on Earth. The crater was discovered in 1991. Source: http://ircamera.as.arizona.edu/NatSci102/NatSci102/lectures/massext.htm

Accordingly, Europe became the area of interest; however, no known asteroid strikes in the region could account for the plenitude of debris found in the Apennines. Exploration widened when geology colleagues discovered the same iridium-rich layer at distant locations around the world. Convinced that the theory was correct, Luis and Walter Alvarez published their findings in *Science* (1980) while assuming that the crater would eventually be found. Meanwhile, its debris circling the planet for months or years in the upper atmosphere and thus blocking out the sun was the assumed cause of dinosaur extinction. Their initial attempts to establish dates, along with early speculations and explorations, are recounted in Walter Alvarez's book, *T-Rex and the Crater of Doom* (1994).

II. Doubts

Despite its simplicity and clarity, the Alvarez theory gained little traction through the 1980s. Without a crater, the theory was easily dismissed. The well-preserved, 4,000-foot diameter Meteor Crater near Flagstaff, Arizona, marks the impact of a 150-foot diameter meteor approximately 50,000 years ago, but meteoric debris is limited to a radius of thirteen kilometers, or eight miles (Rinehart 1958). An asteroid explosion large enough to blanket the Earth with a relatively even dispersal of debris challenged the geological imagination. Almost immediately, a rival explanation surfaced. The Deccan Traps that cover 200,000 square miles of west central India and were originally, before erosion reduced the footprint, six times as extensive, were put forth as an alternate explanation (Courtillot 1980). Spewing volcanic debris and noxious gases both before and after the K-Pg Boundary, perhaps over thirty to one hundred thousand years, the Deccan Traps were considered climate-altering enough to bring on a mass extinction. This alternate explanation earned equal time through the 1980s (Beardsley 1988). For some, this seemed an equally tenable conclusion, especially given the extent of the Deccan Traps as the largest volcanic event on the planet. A single catastrophic event like an asteroid strike with power enough to do such extensive damage seemed beyond imagining, whereas a sustained alteration of Earth's atmosphere and climate over thousands of years seemed to provide a more reasonable explanation. The Achilles heel of the Alvarez theory remained the absence of an identifiable impact crater. This left the theory stranded for a decade.

That all changed in 1991 when satellite photography with ground-penetrating radar located a 110-mile-wide impact crater centered at Chicxulub, an ancient Mayan village near the northwest coast of the Yucatan Peninsula (Hildebrand 1991). Half the crater was situated on land; the other half lay under sea bottom sediment in the Gulf of Mexico, but the impact had occurred at a time when both the Yucatan Peninsula and the adjacent gulf were part of the same shallow

prehistoric sea. Dating of materials from the crater rim became the arbiter; sea-bottom cores confirmed what Alvarez suspected: a massive asteroid had struck Earth 66 to 65 million years ago, after which dinosaur fossils disappear from the geologic record. The Chicxulub crater thus became the smoking gun for the last great mass extinction of prehistoric times.

This recognition opened up geology as a field of fascination. An old-style emphasis on catastrophic events as shapers of Earth history had seemingly been cleared from the table decades earlier; with few exceptions, the geologists were committed to gradualism—a view that said geological change occurred slowly and uniformly. This view had been woven into geological theory by James Hutton's *Theory of the Earth* (1788) and the eminent nineteenth-century geologist, Charles Lyell, who managed to set out a three-volume, thousand-page tome, *Principles of Geology* (1830-1832), with no mention of earthquakes and little on volcanoes other than his exploration of Mount Etna (1832, III). However, the discovery of the Chicxulub impact and its effect on life planetwide blew the lid off gradualism. Catastrophism moved to center stage.

Summarizing its importance, Richard Leakey (1995, 58) referred to this as "a new catastrophism" and summarized its importance. "This represents the second major revolution in the science of geology in this century. The first was the realization that the Earth's crust is fragmented as a series of plates whose gradual movement through the eons moves continents around the globe." However, extinction by asteroid opened up new questions. What other events of the past might have been triggered by catastrophes? Were earlier extinctions caused by catastrophic events? What lay behind ancient periods of global warming? Were eras of worldwide glaciation a result of gradual change or were they perhaps triggered by catastrophic events—nearby supernovas, stellar collisions, or sudden quakes within the Earth itself? Earlier mass extinctions were reexamined with the idea that cataclysmic cosmic events might provide explanations for what had hitherto remained a mystery. As Michael R. Rampino (2017) has shown, a whole new emphasis on cataclysms as primal shapers of a "new geology" began to gel, leading scientists to expanded explorations of extinction events.

III. Spherules

Meanwhile the hard work of sifting evidence went on. Experience gained from the study of more recent asteroid impacts such as Meteor Crater in Arizona had identified certain crystalline and mineral formations unique to such events—shocked quartz, tektites, and glassy spherules as small as or smaller than a grain of rice. Almost immediately, long-recognized deposits of such oddities along Caribbean shores gained relevant interpretation. What kind of local disruption would attend an asteroid impact?

Maurrasse and Sen (1991) drew attention to the Cretaceous-Paleogene (K-Pg) marker bed of the Belloc Formation on southern Haiti where a proliferation of tektites and shocked quartz had been discovered some years earlier. Attention began to focus on scattered impact materials and the so-far unimaginable effects of a colossal tsunami. With the location of the asteroid strike established at Chicxulub, the search for evidence by Alvarez, his colleague Jan Smit, and others now focused on the Gulf of Mexico and adjacent lands where ejected material from the impact would most logically be found. Evidence of a massive tsunami were found in

Figure 3. Glassy spherules measuring less than a millimeter in diameter, ejected skyward from the Chicxulub impact, are dated to 66 to 65 million years ago. Hundreds have been recovered from sites around the world. These spherules were recovered at the Tanis site, North Dakota. Photo source: See Sanders (2019).

the Brazos River Valley in Texas; some of these searches are narrated in Alvarez's later book, *A Most Improbable Journey* (2018). Since the age of the crater had been established from sea-floor cores drilled decades earlier during the 1957-1958 International Geophysical Year (IGY), attention turned to more extensive core analysis. From cores at Sites 536 and 540, Alvarez et al. (1992) found considerable disruption of Upper Cretaceous layers topped with iridium-laced impact materials, tektites, and tiny glassy spherules. Jan Smit et al. (1992) reported on a rock outcrop at Arroyo el Mimbral in northeastern Mexico nine meters (28 feet) thick interrupting a much thicker sequence originally deposited at a depth of four hundred meters (1250 feet). Dates linked these precisely to the K-Pg Boundary 66 to 65 million years ago. Moreover, they showed prominent ripples in sediment, evidence of turbulent wave action typical of seiches—oscillating waves that combine the motion of two wave systems sloshing in opposite directions. It appeared that some reaches of the Caribbean had been subjected to massive tsunamis and wave action rare in normal climate situations.

While Chicxulub gained credence as the cause of dinosaur extinction, attention thus turned to environmental disruption attending the event. One recognition after another dawned; the Chicxulub File swelled with theory and speculation sufficient to answer evidence. At the moment of impact, heat would have momentarily soared to the levels of a nuclear explosion releasing one hundred million times the energy of the largest thermonuclear bomb ever detonated. Debris launched into the sky would necessarily have spread fire over much of the planet; the resulting atmospheric perturbations would have caused extended planet-wide warming sufficient to bring on ecological collapse. The impact may well have jolted crustal faults enough to cause earthquakes and volcanic eruptions. It was clear that much of the telltale layer at the K-Pg Boundary was fallout from the fire and fury of a planet ablaze.

Sorting out the evidence was first a task of reconstruction. During the first seconds and minutes, the expanding crater would have bulldozed rock, sea-bottom sediment, and seething water to the extent of the eventual crater. Debris comprised of shattered asteroid materials, Earth crust dust, and regional rocks would have been ground together, the result being a chaotic scene of tumbled and tangled impact materials. Debris ejected above ground, parallel or close to parallel with the surround terrain, could be expected to leave a circle of evidence thinning with distance, like the debris left following denotation of a bomb. Yet millions of tiny tektites and glassy spherules had appeared far beyond such a circle, falling into distant valleys, watersheds, and alluvial plains, blanketing the planet, often encased in sediment turned to rock over the past 65 million years.

How all this distant debris had been scattered so far called for mathematical calculation. Even the smallest fragments of shocked quartz or tektites have mass; they are subject to physical laws; they have trajectories. As the study of debris dispersal expanded, the Chicxulub File grew far beyond the initial discoveries along the K-Pg Boundary.

It was soon clear that identifiable debris could arrive at a particular destination by many routes. As Bermudez et al. (2015) have shown, spherule deposits on Gorgonilla Island of the southwest coast of Columbia indicate that impact debris was launched into the upper atmosphere high enough to follow a trajectory above Central America and come to Earth hundreds of miles away in the eastern Pacific region. This, in miniature, is the archetype of trajectories. Taking into consideration the mass, ejection velocity, and angle of launch, Kring and Durda (2002) provide simulations for a range of material at varying velocities. The mass of ejected material was too variable for definitive conclusions.

In general, particulate debris of higher velocity will travel farther. Increasing the angle of launch beyond forty-five degrees may launch debris higher but not necessarily farther. Ejection velocity and angle of launch were the primary determinants. Maximum velocity and a near-vertical trajectory may propel material halfway to the Moon before gravity returns it to Earth while some would be launched into outsized

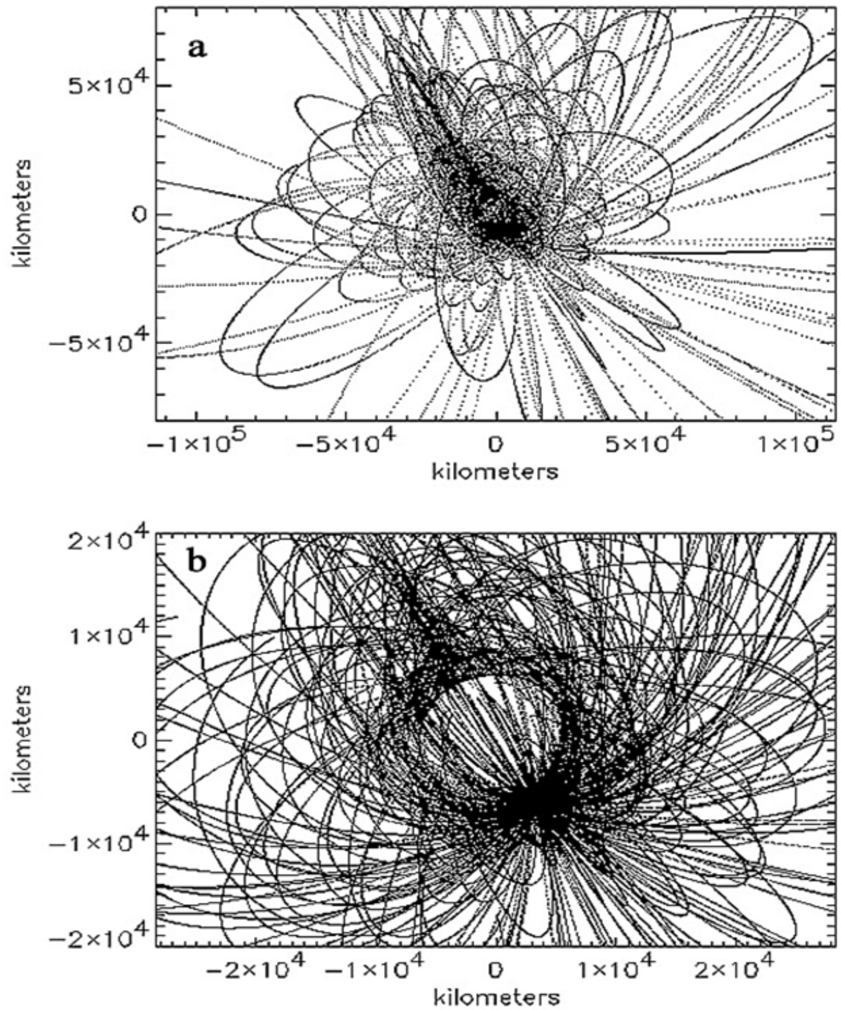

Figure 4a**.** The scale shows ejection trajectories out to 100,000 km (60,000 miles). Most high-speed ejecta came back to Earth with impact locations concentrated along an orbital line extended by the rotation of the Earth. Dotted trajectories indicate elongated orbits taking months or years to complete, with some propelled at escape velocity such that ejected material was destined to soar beyond the control of Earth's gravity.

Figure 4b**.** A smaller scale shows near-Earth ejection trajectories out to 20,000 km. Here variable but lower-than-escape velocities keep ejected material within the control of Earth's gravity, resulting in planet-wide distribution with a tendency toward concentration at the antipodes—the point directly opposite the original impact; in this case, such concentration lies at the bottom of the Indian Ocean to the southwest of India. Source: Kring and Durda (2002), Figure 5.

orbits, joining the ranks of near-Earth Objects (NEO) within the inner Solar System. Still other ejecta might well attain escape velocity such that they are now soaring like Voyagers I and II along trajectories that will lead them among the stars.

The sheer volume of asteroid debris at hundreds of identifiable sites indicates that unimaginable amounts of material were blasted skyward; an inventory of sites now runs to hundreds. Assemblies of tektites, microtektites, shocked quartz, and mineral spherules at hundreds of locations challenges imagination, though this is not surprising once the dimensions of the catastrophe come into focus. Calculations from the diameter of the crater (165 kilometers; 110 miles) and estimated impact velocity (30,000 to 45,000 mph) indicate kinetic energy from an asteroid eight to twelve miles in diameter. Working with a compromise diameter of ten miles, simple math indicates an asteroid of 520 cubic miles would lead to an enormous amount of material ejected into the atmosphere as superheated dust and gas. The resulting crater penetrating miles into the Earth's crust indicates several times this volume of Earth material was blown skyward—25 trillion tons according to one estimate—a mass close to the recent 30 trillion ton estimate of the mass of the technosphere—the entire human-made world of cities and civilization (Zalasiewicz 2014).

As impact debris was hurled outward, it cooled and blanketed the planet. Earthquakes and perhaps volcanic activity accompanied the impact, though evidence has long since been obscured. Undoubtedly, there is evidence so deftly hidden that it may remain forever beyond discovery. The history of the world is told in rocks, as Walter Alvarez is fond of noting. That is true, but some history is also written in tsunamis. Their impressions may last a long time, but these, too, may eventually disappear.

The progress of discovery over several decades has led to a more expansive analysis of the Chicxulub

impact. One line of inquiry looked far beyond the Earth in search of a plausible origin. Was this impact a unique event? As E. M. Shoemaker (1998) has shown, asteroid craters preserved on stable cratons in North America, Africa, and Australia indicate a marked increase in Near Earth Objects (NEO) and an approximate doubling of one kilometer-plus asteroid collisions over the past 100 million years. While the full implications are still debated, William Bottke et al. (2007) have argued that breakup of a 180-kilometer asteroid 160 million years ago may have been the precipitating event. Such a "catastrophic disruption" is evidenced today by orbiting debris: the 40-kilometer diameter Baptistina asteroid surrounded by numerous smaller bodies that make up the Baptistina Asteroid Family (BAF). This cluster orbits on the innermost region of the main asteroid belt. Identified by unique but similar inclinations and eccentricities, "the BAF's location, age and fragment size distribution are remarkably well suited to generate a 100-myr-long surge in the multi-kilometer NEO population . . . [and] provides the most probable source for the projectile that produced the K/T impact on Earth." Philosophically, this analysis extends the whole discussion of contingency (Wood 2019) far beyond the Chicxulub impact to distant astronomical events—precisely the kind of multiple domain causation that distinguishes the inquiries of big history.

Originally regarded as a European occurrence, the discovery at Chicxulub has turned it into a global event: no other cataclysm has left such widespread evidence, from rippled sea bottoms and chaotic debris to shocked mineral and glass spherules on supersonic trajectories that took them to sea bottoms and mountain tops. Even so, this catastrophic event was not exhausted by the tracking of its spherules or its connection to the extinction of the dinosaurs. We could naturally expect that much was still hidden, like the crater itself, buried beneath half a mile of sea bottom sediment. We should, therefore, not be surprised that new discoveries are emerging—several, in fact, in 2019 and since.

IV. Crater

Asteroid craters on the Moon remain visible for millions or billions of years, but those on Earth disappear or blend into the landscape after a few million years from the steady forces of erosion. The Chicxulub crater is an exception. Buried under hundreds of feet of sediment, much of it has been preserved, thus providing a laboratory for the study of asteroid impacts**.**

In 2016, Sean Gulick, a research professor at the University of Texas Institute for Geophysics (UIG), led a study of the crater by drilling into the peak ring formed within the crater. Recovered cores revealed a sequence of sedimentation that told the story of the

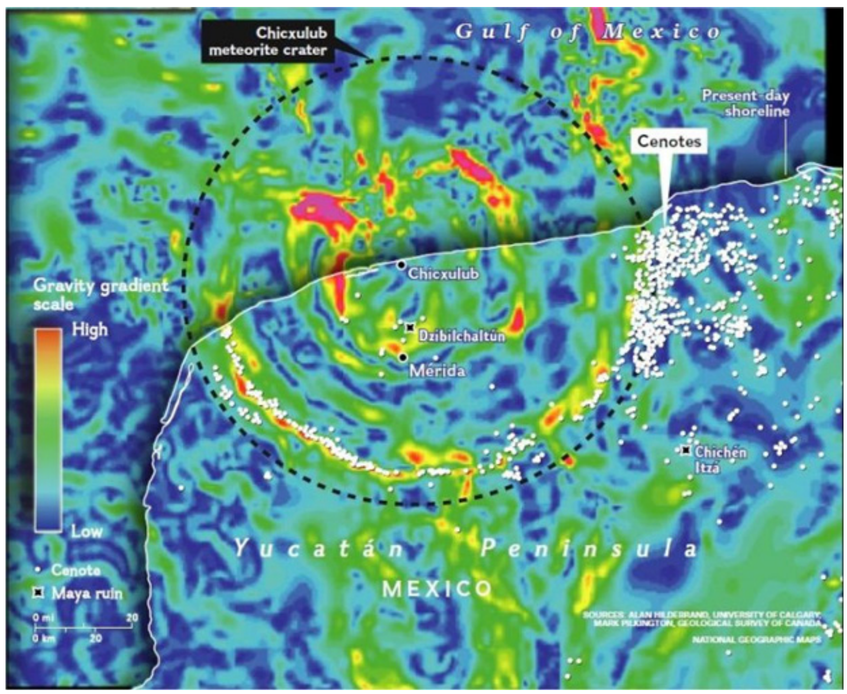

Figure 5. The original impact occurred at sea but changes in sea level have raised the point of impact at Chicxulub above water. However, before this uplift the entire crater was buried under half a mile of sediment. The southern ring of the crater on the Yucatan Peninsula is marked by numerous cenotes, probably because of the collapse of limestone piled up around the edge of the crater at impact. The peak ring halfway between Chicxulub and the outer crater is visible in patches of red indicating gravity anomalies, which initially revealed the location of the crater. The drill core extracted by Gulick et al. (2019) was recovered from the peak ring. Source: *Wikimedia Commons*. See also Hildebrand et al.

first few hours after the impact. The study, enticingly called "The First Day of the Cenozoic," was published in the *Proceedings of the National Academy of Sciences* (PNAS) in September 2019. We are thus able to visualize a detailed timeline of what happened in the minutes and hours on the day of the impact (Black 2019).

At the instant of the leading-edge touchdown, the trailing edge of the ten-mile diameter asteroid would hardly have entered the atmosphere. Traveling at ten or more miles per second with a volume of more than 500 cubic miles, it struck Earth with the power of ten billion Hiroshima bombs. A rereading of John Hersey's *Hiroshima* (1946) reminds us of how people hundreds of yards away were instantly incinerated by heat from the blast. Forests near asteroid impacts are vulnerable to a violent wave of radiation. "For Chicxulub, the plume was considered to emit sufficient thermal radiation to ignite flora up to 1,000 to 1,500 km from the impact site." At greater distances, it is argued, "High-velocity ejecta reentering the Earth's atmosphere emits thermal radiation that is sufficient to ignite dry plant matter and char living flora at sites within a few thousand kilometers from the crater and may directly ignite living flora at more distant locations" (Gulick et al. 2019).

Interpretation of impact energy indicates that the disintegration of the asteroid and its conversion to molten rock began instantaneously, with the Earth's crust in its path turned into a molten brew within microseconds. The ultimate cavity is 20 km (12 miles) deep with a deeper crush cavity to a depth of 20 to 30 miles—almost to the foundational levels of the Earth's crust. "Within tens of seconds of the impact, a ~40 to 50-km radius [60-mile diameter] transient cavity was formed and lined with impact melt" (Gulick et al. 2019). Material from this explosion consisting of 500 cubic miles of asteroidal material plus ten times that amount of crustal material that was excavated and blown skyward by "ballistic ejection," resulting in the iridium-rich layer discovered in the Apennines and spherules recovered at hundreds of sites around the world. The volume of molten material created could well have been ten to twenty times the original volume of the asteroid; that is, 2,500 to 5,000 cubic miles.

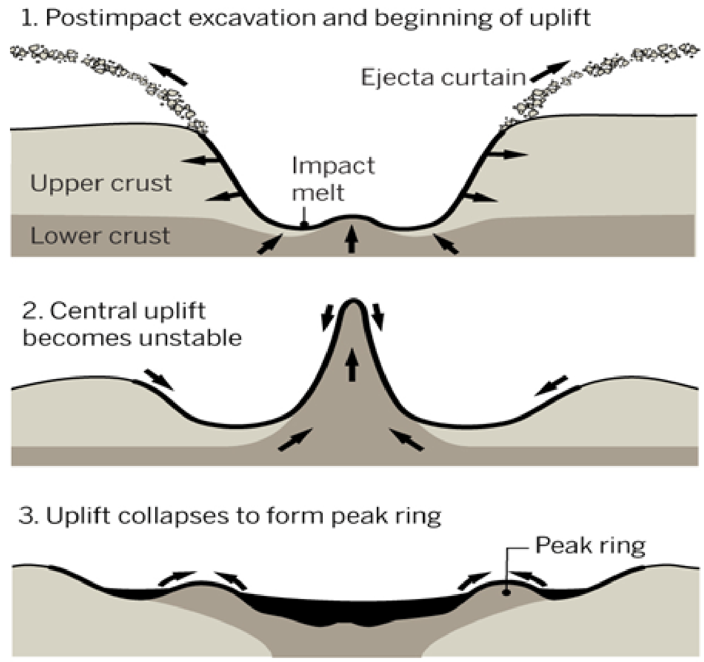

Figure 6 (1). A Minute After Impact. The asteroid has penetrated deep into the upper crust, producing a crater cavity up to 20 kilometers (12 miles) deep at the impact site, extending outward for an overall diameter of 160 kilometers (100 miles). Seawater towered into a tsunami hundreds of feet in height. Limestone sea bottom plowed outward formed the crater rim. The mass of the asteroid and much of the crater interior was ejected skyward at supersonic velocities by the force of an explosion estimated at 100 million times the largest thermonuclear explosion ever detonated.

Figure 6 (2). Liquified granitoid material from the lower crust surged upward as a central "splash" of molten rock, momentarily forming a tower of lava-like material up to 10 km (6 miles) above sea level, then collapsing and surging down and out in all directions.

Figure 6 (3). Deep crustal material, now brought to the surface, flowed out to form a peak ring with a diameter of perhaps 60 miles. Over the next hour, melt rock poured over the peak ring and into the crater to a depth of hundreds of meters. Within hours a tsunami resurge poured in sand, gravel, and charred forest debris from Gulf of Mexico coasts. Source: See Altounian.

Gulick's geological team was able to drill to a depth of 750 meters. The Chicxulub crater floor is now 600 to 1000 meters (1800 to 3000 feet) below sea level, but their drilling position over the peak ring was optimal for analyzing the sequence of events. The drill core brought

Figure 7. Drill Core from the Chicxulub Peak Ring. Seen here is a visible transition at a depth of ~700 meters. The pink and white composite granite on the right, originating in basement levels of the Earth's crust, was splashed up as liquified rock, then washed outward to form the foundational material of the peak ring. During rebound, molten rock washed back over the peak ring, burying it under 40 meters of breccia and suevite, seen to the left. More then poured into the crater. Subsequently, tsunami backwash added layers of sand, gravel, and charred floral remains that were swept into the crater from distant beaches and burning forests. Source: See Smith.

up composite granite from 700+ meters that originated as "fluidized basement rock" from much deeper in the Earth's crust. This was brought to the surface by rebound issuing in a vertical splash momentarily towering to the height of Mount Everest. Immediately, it began to collapse, carrying melt rock downward and outward to form the primarily granitoid peak ring.

The sequence from the ring core shows 130-meters of impact melt rock covered by fluidized basement rocks that form the peak ring, covered over with 40 meters of brecciated melt rock and suevite—a composite of rock, crystals, and glass typical of impact events. As is known from deposits in Mexico and Texas, the impact created a massive tsunami that may have towered hundreds of feet, virtually driving Gulf of Mexico water miles away from the crater. Within hours, melt rock rebound surged over the peak ring and poured into the crater, adding 90 meters of breccia. Within a day the resurge added hundreds of feet of debris from surrounding sea bottom and coasts, including sand, stone, and gravel—material brought hundreds of miles from distant beaches around the gulf. The team concluded that an abundance of charcoal in the top layers likely "originated from impact-related combustion of forested landscapes surrounding the Gulf of Mexico, as the impact site was entirely marine" (Gulick et al. 2019). Compared to the explosions of sudden volcanic eruptions, earthquakes, and landslides, the infilling of the Chicxulub crater is thought to be the most massive rapid transport and deposition of Earth material in geological history.

A corollary of this study is the absence of sulphates in the impact region. The evidence suggests that the impact hurled most sulfur compounds skyward. "In the atmosphere, sulfate combines with water vapor to form sulfate aerosols that impede solar insolation." The cause of floral and faunal die-off is clear: an almost total interruption of photosynthesis in plants with a domino effect through the entire faunal food chain. "Global surface temperatures would have declined by >20° C, and that disruption of the Earth's climate could have lasted ~30 years" (Gulick et al. 2019).

Another recent study has added to the extinction record. Michael Henehan et al. (2019) have analyzed the chalky sea bottom remains from foraminifera, single-celled planktonic animals whose shells settle into thick ocean-floor sediments. Boron isotope measurements in layers of ancient foraminifera indicate a rapid drop in pH levels in ocean-surface waters immediately following the Chicxulub impact. This increased ocean surface acidification, the result of which was extensive extinction of marine life. Additional measurement shows that former pH levels returned within a few tens of thousands of years, leading to the emergence of a new generation of marine creatures.

The significance of the Chicxulub event for the emergence of mammals and primates is now well known (Alvarez 1994); the importance of this event for the emergence of human life has been explored (Alvarez 2017); the obvious contingency as a dimension of human existence forms a multi-episode chapter of big history.

In a recent study, G. S. Collins et al. (2020) remark

that theoretical studies of impact kinetic energy have usually been calculated "under the simplifying assumption of a vertical trajectory" though this is statistically less common. Modeling various angles of impact and velocities, this team combined calculations with onsite geological evidence to work out the most likely trajectory of the Chicxulub asteroid. As a target, Earth presents an area of 100 million square miles with the bullseye for a near-vertical strike limited to one or two million square miles. The off-center target area is thus many multiples of the bullseye area. Statistically, the majority of trajectories will occur at an angle; thus "a near-vertical impact is unlikely. Only one quarter of impacts occur at angles between 60º and 90º and only one in fifteen impacts is steeper than 75º (Collins et al. 2020). Variations in a three-dimensional profile of the Chicxulub crater suggest an angular strike. Offsets between the positions of central uplift, the peak-ring center, and maximum mantle uplift along a northeast-southwest line suggest that the asteroid struck from the northeast at an angle between 60º and 75º. Prior to these calculations, imaginative illustrations of the asteroid arrival varied: in *Fantasia* (1997) Walt Disney pictures the asteroid speeding across the sky at a shallow angle as small as 30º, whereas William K. Hartmann's painting in Alvarez's *T-Tex and the Crater of Doom* depicts a near vertical trajectory.

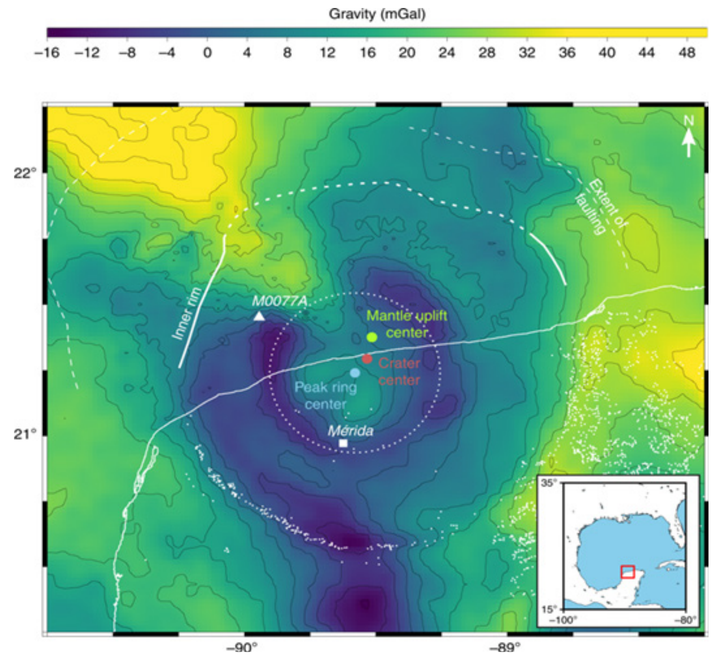

Figure 8. The white line marks the emergent Yucatan Peninsula coast from seafloor uplift subsequent to the Chicxulub impact. Separation between the maximum uplift center (green), crater center (red) and peak-ring center (blue), indicates an angled trajectory estimated at 60º to 75º from the northeast to southwest. Source: Collins et al. (2020. Figure 1. Adapted from Gulick, S., et al. 2013. "Geophysical Characterization of the Chicxulub Impact Crater." *Reviews of Geophysics* 51: 31–52).

V. Seaway

Most of exploration of the Chicxulub impact was undertaken without consideration of geographical constraints other than the marine location of the impact. However, the depth of the Gulf of Mexico 66 to 65 million years BP and thus the dimensions of the resulting tsunami have been difficult to determine with any certainty. Tsunami heights of 300 feet to a mile have been suggested, clear indication that here we are in the realm of speculation. Tsunami impact points around the Caribbean and the coast of the gulf can be surmised from a map of the region, but North America today is geographically quite different from what it was then. During the mid-Cretaceous Era 100 million years ago, North America was divided by what has been called the Western Interior Seaway that ran through the Great Plains from the Gulf of Mexico to the Canadian Arctic (see Figure 8). At its greatest extent it covered most of the Midwestern Prairie, a vast landmass between the Western Mountains and the Appalachians, to a depth of 2500 to 3000 feet.

In recent times this region has been memorialized in myth and movie as the land of big ranches and cattle drives. One hundred million years ago, North America had separated from Pangea and was drifting north a few millimeters a year, but it still lay several hundred miles south of its present location. Thus, the Western Interior Seaway was a tropical ecosystem of jungle and wetland with abundant flora and fauna—one of the richest of habitats anywhere on the planet for amphibian and reptilian life, including dinosaurs, whose fossilized remains are found in great numbers today along the former seaway shores in the Great Plains. By

Figure 9. The Western Interior Seaway at its greatest extent joined the Gulf of Mexico to the Arctic Ocean, originally presenting unobstructed passage north. By the time of the Chicxulub impact, the northern seaway region through Canada had begun to close and the American Great Plains had devolved into a series of linked lakes and wetlands. A tsunami originating at Chicxulub had an unobstructed 2,000-mile, sea-level route into the northern prairies, though how long it could sustain momentum was dependent on factors so far unknown. Effects through the waning seaway were likely more dependent on seismic disruptions and seiches on bounded lakes. Source: See Sampson et al. (2010).

the end of the Cretaceous, the seaway was somewhat diminished due to sea level change and orogenic uplift associated with the rising of the Rocky Mountains, but what remained nevertheless provided a straight-line unobstructed riverine valley system from the mid-Texas coast north to Montana and the Dakotas.

Given the 800-kilometer/500-mile distance traveled upstream by the *Pororoca* (tidal bore) on the Amazon River, it seems likely that an asteroid-impact-driven tsunami would roar northward through the center of North America. A tsunami of gargantuan proportions would easily override all obstructions, though its dimensions remain one of the great unknowns.

Apart from variable waterways, forces of erosion were formative in the northern prairie region. Over millions of years following the end of the Cretaceous, a widespread layer of buff-colored sandstone and drab-green shale 90 to 600 meters (300 to 2000 feet) in thickness built up as outwash from eroding mountains along the edge of the seaway. Known today as the Lance Formation, it is visible at the surface by the drab, gray-green of sterile badlands typical of the region. Atop this formation, along a region adjacent to Fort Peck Lake, Hell Creek State Park protects part of an unusually rich fossil-laden formation that extends well beyond Montana to Wyoming and the Dakotas. Here the first specimen of *Tyrannosaurus rex* was discovered in 1902. Fossils from all eight of the most common dinosaur families have since been located in the Hell Creek Formation; thousands are now housed in the Museum of the Rockies in Bozeman, Montana. The story has been amply told by Lowell Dingus in *Hell Creek, Montana: America's Key to the Prehistoric Past* (2004).

VI. Tanis

Across the state line from Montana in North Dakota, Robert DePalma, then a graduate student at University of Kansas, discovered an area of the Hell Creek Formation that looked particularly promising. In 2010, he commenced informal excavation until his discoveries turned from informal to serious and systematic. Returning summer after summer, keeping his discovery as secret as possible, he chose his own private name for the site: Tanis, the name of a relatively unknown city in Lower Egypt made famous in the film, *Raiders of the Lost Ark*. For DePalma's purposes, the name is appropriate: the real Tanis remains in ruins. An article on satellite archaeology of the original Tanis in *National Geographic* (February 2013) indicates that scores of ruined dwellings are hidden beneath the sand. Symbolically, the Tanis of the film was buried

Figure 10. Fossilized fish piled one on top of one another, crowded together with limbs, logs, and insects suggests that they were flung ashore and died soon afterward, stranded and trapped together on a sand bar after a seiche withdrew, then covered and sealed in with several feet of debris by a final tsunami. Photo source: See Sanders (2019).

by a catastrophic storm, while the real Tanis, once the capital of Ancient Egypt, has achieved mythic status as the holder of untold treasures comparable to the tomb of King Tut. DePalma's choice of name now seems prophetic.

Over the years, DePalma has gathered hundreds of fossils and made plaster casts of many more, spending winters in a Florida lab identifying and classifying a collection that includes remarkable numbers of fish of all sizes. Some tektites, he discovered, were drawn into the gills and were caught on gill rakers of fish taking their last gasp (Figure 10). The presence of tektites at this precise time when beached fish were dying indicates he was not studying an era: he was looking at the story of an hour. What DePalma had discovered was an unusually dramatic assemblage of flora and fauna jumbled together, with fresh-water fish crowded together with salt-water reptiles, three-dimensional fossils preserved in hardened clay with marine creatures intermixed with logs and branches, cones and seeds, mollusks mingled with tiny mammals, amphibians tangled with sturgeon—the whole a massive killing field of creatures caught in a cataclysm in their final hour.

DePalma's central discovery was glass-and-clay tektites caught in fish gill rakers that date to 66 to 65 million years ago. The find was more than any other assemblage of fossils where sedimentary layers signify the passage of time—where a few inches above or below could be the measure of thousands or millions of years. Here, fish had died while asteroid-impact spherules were raining down and churning through the water in their gills. Time was suddenly telescoped. A new vision of the Chicxulub impact swam into view. DePalma called in the original formulator of the theory, Walter Alvarez, and his long-term colleague, Jan Smit, an expert on mass extinctions who had studied tektites at dozens of sites. Over the previous quarter century, Alvarez and Smit had done much of the spade work of discovery associated with Chicxulub (See Figure 11).

As they studied the evidence, observations coalesced into a refined narrative. It was likely that seismic activity generated by the Chicxulub impact had caused earthquake reverberations spreading out over thousands of miles. This, they reasoned, would have reached the region of Hell Creek within a quarter hour. The result, which they had already explored in sites

Figure 11. Walter Alvarez and Robert DePalma on site at the K-Pg Boundary in South Dakota forty years after Alvarez's discovery of the K-Pg Boundary marker in the Apennines. Over several years, DePalma has excavated the site he calls Tanis in South Dakota, bringing to light a remarkable story: the final moments of the great extinction 66 to 65 million years after the fact. Photo source: See Sanders (2019).

around the Gulf of Mexico, was the creation of seiches—chaotic water sloshing. This could have occurred on numerous inland waterways along the Western Interior Seaway, sending waves into multiple rivulets and valleys with fish and other creatures caught in tempestuous waters, then beached and crowded together in a tangle of branches and vegetation. Then, minutes later, vaporized rock blasted into the stratosphere at Chicxulub 2,000 miles away would begin to arrive, falling from the sky among beached sea life trapped in a tangle of uprooted flora and fauna. Here, as elsewhere, fiery fragments from the asteroid explosion had already set fire to forests, blanketing the Earth with smoke and dust. Meanwhile, tektites falling at Tanis were drawn into the gills of dying fish. Evidence of this fall of debris was ubiquitous; it was a geologist's dreamscape. Some tektites that had landed on branches or trunks of trees in sticky sap were now encased and preserved in amber. Others landing on sand created a tiny impact crater two or three inches in diameter and a penetration cone where, at its base, the spherule came to rest, with a single fossil preserving the crater, cone, and spherule—a unique case of petrotemporality (Wood 2015).

Since 2019, the discovery at Tanis of fossilized fish with tektites lodged in their gills along with tiny impact craters and tektites preserved in amber have provided evidence for a mass extinction caused by the Chicxulub asteroid (Hadingham and Wu 2019). The impact has always been associated with the extinction of the dinosaurs. However, the dramatic discovery at the Tanis site of a fossilized dinosaur leg, with flesh and muscle preserved, has reconnected the asteroid impact with dinosaur extinction. While the evidence has not yet established an absolute chronicity, the majority opinion, based on its location and proximity to other debris, places the death of this dinosaur within a few hours of the Chicxulub impact (Martin 2022). The dramatic importance of the Tanis discoveries has attracted the British Broadcasting Company, which has been filming at Tanis for an 87-minute documentary to be aired on April 15, 2022, with later release through NOVA (Thompson 2022).

Identifying events of the last day of the Cretaceous down to the final hour is testimony to a remarkable reconstruction of a time long past. However, a question remains: can more be discovered about that final day? A team led by Melanie During has provided an answer through osteohistology of bones from fossilized fish at Tanis. Although North America had been drifting north since the breakup of Pangea, by 66 million years ago Tanis was located at a latitude subject to a seasonal cycle. Like tree rings that preserve annual growth, Tanis bone fossils preserve a seasonal record. Microscopic examination of fossilized bones from several species of fish reveals that seasonal rings uniformly terminate at a time of active growth, thus demonstrating that "the impact that caused the Cretaceous–Palaeogene mass extinction took place during boreal spring" (During et al. 2022).

Fossils convey structure, rarely process. Those at Tanis break all expectations in the narrative they tell. In the next act of this drama, a mix of tsunami and seiches through the Seaway covered everything with several feet of sand and clay, sealing in a whole ecosystem of evidence to be discovered 65 million years later. Finally, over the next few weeks, months, or perhaps years, smoke from burning forests, charred debris, and iridium-laden asteroid dust slowly settled, blanketing the land, sealing in the last chaotic times of the Cretaceous in a wrapping that spanned the globe.

Thus understood, the debris-laden assemblage takes on new meaning, Here recorded in stone was the final springtime instant of a cataclysm, a combination of impact, earthquake, seiche, and tsunami—a drama as complex as anything Sophocles or Shakespeare could have written with acts and scenes assembled from what at first looked like little more than land life, sea life, wasted wetlands, and fragmented forests strewn across an ancient beach. Here, for the first time, we could actually see the moment of the great dying.

VII. Biosystem Effects

Given the destructive power of this gargantuan impact, it is surprising that anything could survive, but survive they did. The avian dinosaurs survived to morph into modern birds. Despite acidification of the oceans, much of the deepest marine life survived, protected from atmospheric climate change. On land, small mammals survived by hiding, burrowing,

and scavenging—behavior that had served them well through millions of years of dinosaur dominance. The primary benefit of the asteroid impact for mammals, however, was the removal of predators. Here, the effects were dramatic. Summarized in reportage in *Science* in 2019, the Chicxulub superyear, Corral Bluffs, near Colorado Springs, has yielded a rich assemblage of post-impact fossils that indicate both floral and faunal rebound (Pennisi et al. 2019; Lyson et al. 2019). Mammal skulls, hundreds of vertebrate remains, and thousands of fossilized leaves and pollen grains tell the story. Within 300,000 years of the mass extinction, mammalian species had doubled their taxonomic richness with a tripling of body mass, aided by parallel increases in megaflora, including protein-rich beans and other legumes.

The extinction of non-avian dinosaurs and rise to prominence of mammalian life are the best known biosystem effects of the Chicxulub event. However, extensive study of plant fossils before and after this event have clarified effects on vegetation, particularly in rainforests. Carvalho et al. (2021) have examined plant material from Columbia showing that pre-Chicxulub forests were characterized by gymnosperms (cone-bearing plants) and tree-size ferns, resulting in an open canopy and abundant light available at lower levels. However, over a period of ~ six million years following the Chicxulub event, fossilized leaves from more than eighty species of angiosperms (flowering plants) indicate a new dominance in forest communities. The result was the highly stratified, multi-layered canopy of today's neotropical rainforests. Fifteen hundred kilometers south of the asteroid impact, Columbia exhibits a greater shift to angiosperm dominance than Patagonia, 8,000 km away where less severe consequences preserved gymnosperm dominance. Changes in forest composition in New Zealand, 12,000 km away, show minimal change from pre-impact forest composition. The mass extinction produced a "different world," but "the consequences depended on proximity to the crater" (Jacobs and Currano 2021, 29).

Carvalho et al. suggest that the pre-Chicxulub open canopy may have been the result of ground level "disturbance . . . sustained trampling by and extensive feeding by large herbivores, mostly dinosaurs" that curtailed proliferation of low-level flowering plants (2021, 67). The extent of dinosaur impact on vegetation is suggested by a recent study of *Tyrannosaurus rex* population (Marshall et al. 2021). Through careful study of fossil sequences and abundance along with probable animal density, they estimate that *Tyrannosaurus rex* persisted for ~ 127,000 generations with a worldwide population of ~ 20,000 individuals at any one time. Assuming an equal distribution over six continents, we could conclude that some 3,500 individuals may have occupied each continent. The effect of forest-floor trampling and herbivore feeding is multiplied when we add multiple species of sauropods—brontosaurus, spinosaurus, titanosaurus, argentinosaurus, and dozens more—that roamed in equally large numbers. Tens of thousands of dinosaurs, many of them larger and heavier than today's largest mammals, render the theory of dinosaur trampling a viable explanation for suppression of angiosperms and the open canopy of pre-Chicxulub forests. The diversity of the lower canopy in today's forest communities is thus a relevant ecological effect of dinosaur extinction from the Chicxulub event.

Conclusion

The link between the Chicxulub impact and the formation of IBHA is a simple one: Walter Alvarez's decision to lead others to the site in the Apennines and share what he must have felt that day of discovery in 1989 turned individual experience into collective learning. In a very real way, IBHA is the unexpected heir of his discovery. More than a decade later, the organization is focused on understanding, describing, and presenting the integrated narrative of Cosmos, Earth, Life, Humanity, and Culture using the best scholarly methods available, emphasizing its relevance to the human situation.

Now, more than forty years after Alvarez's reasoned guess that an asteroid strike had driven the dinosaurs to extinction, Sean Gulick et al. (2019) have provided a geological timeline for "the first day of the Cenozoic"

while Robert DePalma (2019) has published a simultaneous scenario of "the day the dinosaurs died." Both transcend anything we could have imagined. DePalma's discoveries leave open the question of the precise time when dinosaurs went extinct, though the charred remains of burning forests swept into the Chicxulub crater and the likely decline of global temperature leave little doubt about what happened in the aftermath. Added to this are studies documenting massive sulphate pollution of the atmosphere, acidification of the oceans, rapid floral and faunal recovery, and new flowering-plant diversity in the forest understory that laid the groundwork for subsequent mammalian dominance.

Meanwhile, a compromise has emerged: the eruptions that gave rise to the Deccan Traps undoubtedly added to the poisoning of the atmosphere, thus intensifying the great extinction (Schoene 2015). What DePalma's excavations have shown is a much more precise connection between Chicxulub and the demise of an entire ecosystem, a scenario that could easily be fitted into an hour-long news program: *Sixty Minutes*, *A Special Report*, a cold case reopened 65 million years after the fact. It is appropriate that DePalma, Alvarez, and Smit are coauthors of the article where this is unfolded in *Proceedings of the Natural Academy of Sciences* (April 23, 2019), forty years after the initial discovery. Few scientific discoveries keep yielding evidence for so long, but this one has and likely will.

As I completed a first draft of this article, an e-mail message from Walter Alvarez, "from Coldigioco, where IBHA had its start!" indicates that he and his wife Milly "[were] in Italy for intense fieldwork." Consequently, it is clear that the Chicxulub File will continue to grow because there is evidence to be found around the world and its discoverers are still hunting down its effects. Those who have seen the DePalma excavation site say there is enough in and around Tanis to keep geologists busy for half a century. Undoubtedly, too, there are discoveries yet to be made at Corral Bluffs. We can thus expect an even fuller story to unfold through the years, with each new piece of evidence adding to one of the most remarkable discoveries of our time.

DePalma's story has been told in *The New Yorker* (29 April 2019), where novelist Douglas Preston spells out his lifelong fascination with bones while witnessing and describing his excavation and recovery work in South Dakota and his winter lab in Florida—a lively piece of journalism. Unhappily, though, DePalma's discovery and the wealth of detail he has uncovered casts us as witnesses to the death of an entire ecosystem—a warning today as forest fires leave behind blackened stumps and the unplanned consequences of the human enterprise come to rest on species extinction and oil-soaked seabirds. Meanwhile, Tyler Lyson's similar fascination with bones and his discovery of ecosystem rebound at Corral Bluffs has been the subject of a *NOVA* documentary narrated by Keith David (30 October 2019). Although the demise of an entire ecosystem is an environmental tragedy, it is remarkable that we could ever witness the final hours of life gasping for a final breath following a catastrophe that happened 65 million years ago. Balancing this catastrophe, the subsequent ecosystem recovery reveals the tenacity of life on Earth that lies behind the subsequent emergence of *Homo sapiens*.

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Big History and the Principle of Emergence

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self-transcending construction

ABSTRACT

Life is a raucous carnival, full of "games" and "rides" whose ongoing interactions continually surprise us. Yet thinkers are too often tempted to treat it as a machine that spits out linear time lines of events, one leading deterministically to another. By its interdisciplinary nature, big history is inclined to treat the world as a carnival; yet the temptation to treat it in the more linear way sometimes prevails. This essay treats one key dynamic that governs life's carnival—the principle of emergence. Emergence is the process by which a relatively simple entity interacts with its environment to become structurally complex, often in ways that seem impossible to anticipate. In this way, a seed becomes a fruit tree, a small community becomes a vast city, or a shamanic religion in a hunter-gatherer band evolves into a system of belief and practice shared by a billion people. By defining emergence and exploring religion as an extended illustration, this paper makes the case for more fully incorporating the principle of emergence into the study of big history.

Plant an apple seed, and, if the soil and weather conditions are right, an apple tree will grow. The apple tree, in turn, will produce apples, which just happen to contain more seeds capable of resulting in more trees. A single tiny seed can, over time, produce an orchard with a rich harvest of delicious fruit and all the shifts in the local ecosystem that an orchard invites. This is the process of emergence, by which a relatively simple coherent entity (the seed) can result in new structures, patterns, or behaviors through the interaction of its component systems and its environment. Emergence is not a new idea, especially in philosophy, where it can be traced to Aristotle's *Metaphysics*. In modern philosophy, interest in emergence goes back to John Stuart Mill, who called it "heteropathic" causation ("Emergence" 2020).

What makes emergence so fascinating is how different it is from the linear causality that had largely dominated scientific thought since the seventeenth century. With linear causality, a single action or set of actions will produce a specific effect: for instance, heat water to 100 degrees Fahrenheit at sea level, and it will boil. But a phenomenon such as the growth of an apple orchard, or language, or a city cannot be traced to a single cause; rather, these phenomena depend on a range of causes interacting to produce new states. Rather than *linear causality*, emergence demonstrates *systemic causation*. That is, as Nobel Prize Laureate in Physics Robert Laughlin points out, where a linear approach demands that we understand nature by "breaking it down into ever smaller parts," an approach grounded in emergence requires that we understand "how nature organizes itself" (2005, 76).[1]

What I will be calling the principle of emergence sits at the heart of big history. Consider the big bang cosmology that forms the context for everything else that is treated in our discipline: an almost unimaginably tiny homogeneous mass of matter/energy seems to have unfolded into an equally difficult-to-imagine universe of hundreds of billions of galaxies, including the almost equally unthinkable diversity of life forms on our planet. I want to discuss this principle and how big history can profit from incorporating it more fully into our studies. Big history already acknowledges emergence in its multi-disciplinary approach and awareness of the many causes that interact to create, say, a new species or a thriving city, both of which are emergent phenomena. On the other hand, the way people write and talk about big history sometimes seems far more certain than emergence suggests. In this

way, the cosmological narrative is often discussed as a fact, from the Big Bang thirteen and a half billion years ago to the heat death of our universe billions of years in the future. As we will see, one of the key elements of the principle of emergence is the realization that the dynamics of our universe can be so complex that it is near-impossible to be certain what the outcome of many emergent processes will be. I believe that a look into what scientific studies of emergence are beginning to uncover may give us a more effective way to think about our studies in big history.

My purpose is not to criticize the current state of big history. Rather, I want to suggest a direction that might enable thinkers in the field to re-view their approach to the subject in a way that expands our vision and ties our methodologies more tightly into what is being done today in the physical sciences. To that end, I draw on work that has been done in complexity theory, especially its take on emergence. The first part of this essay will, therefore, examine what complexity theory has uncovered in its scientific exploration of emergence.

In the second part of this essay, I offer an extended example of what can be uncovered as we integrate the principle of emergence into a topic of interest in big history—religion. To that end, I examine several of the many evolutionary changes over the last four million years that allowed religion to emerge. Those changes range from shifts in climate to changes in body type and social structure. Once religion became part of being human, its nature continued to unfold as a key strategy in the social evolution that allowed our species to adapt from living in bands of thirty people using stone tools to cities of thirty million using electronics.

Finally, I discuss the benefits of more thoroughly incorporating the principle of emergence into big history. One such benefit is what may seem a subtle shift in the way we think about history. Consider my friend Carl, who received his bachelor's degree from MIT, is well read in quantum mechanics, and eventually went back to school to become a chiropractor. Because of the depth and breadth of his knowledge, I was surprised to learn that he disliked history in high school. When I asked why, he said it seemed to be mostly a matter of memorizing timelines, one event leading inevitably into another. I, on the other hand, have always thought of history as a carnival—groups of people interacting raucously as they play "games" and take "rides." Emergence, I have become convinced, gives us the tools for exploring history as this sort of carnival. With that in mind, let us turn to the understanding of emergence that complexity theory has developed.

Complexity Theory and the Principle of Emergence

While emergence first drew attention from philosophers, over the last forty years or so, it has become the object of scientific attention, especially with the rise of cybernetics, systems thinking, and complexity theory. This paper will draw predominantly on complexity theory. This discipline itself emerged in the 1970s, as desktop computers made it possible for scientists in fields from fluid dynamics to ecosystem studies to model the systems they studied with non-linear mathematics.[2] These scientists discovered that complex adaptive systems (CASs), as they are often called—systems with a variety of different components, whose interaction determines their behavior—produced remarkably similar patterns over time, one of which is emergence.[3] Such systems exist as nested networks on a variety of scales, from sub-atomic particles, atoms, and molecules to cells, organisms, and ecosystems, culminating with planets, solar systems, galaxies, and the universe. Each CAS is an integrated network composed of less extensive networks and is also embedded as a component in a larger CAS network.

At each increasingly larger scale, CASs generally become more complex—that is, they have an increasing number of different components and scales of networks, whose interaction determines their behavior. Up to the scale of molecules, these systems appear simple enough to operate through cause-and-effect, where behavior can be explained with simple rules, as with the example of boiling water. At the scale

of macro-molecules, such as DNA, they develop the ability to learn (e.g., Gell-Mann 1994). With that ability, they seem to acquire *agency*, the ability to participate in the carnival of emergence, in which they are continually responding to shifts in their environments and, in this way, helping to shape the responses of other agents. For example, the human brain contains about 85 billion neurons, all of which can become connected to any other. Learning occurs as a person's experience is stored in networks of neurons; each such network acts as an agent, a living entity whose purpose is to help us survive. The field of perception each of us experiences during waking hours depends largely on the interaction of these neural networks with information from our sense organs (Laughlin et al. 1990). In this case, individual nerve cells, our sense organs, and neural networks all function as agents within the brain.

As psychologist and electrical engineer John Holland explains in his book, *Emergence*, "We are everywhere confronted with emergence in complex adaptive systems—ant colonies, networks of neurons, the immune system, the Internet, and the global economy, to name a few—where the behavior of the whole is much more complex than the behavior of the parts" (1998, 2). As an example, Holland asks us to consider the complex systems that cities develop to feed, clothe, house, and entertain people who live in them. New York City, for example, grew from a community of a thousand in 1650 to sixty thousand by 1800 and a million by 1872. Yet, there was no central authority that planned where restaurants and department stores, apartment buildings and theaters should open. All these resources *emerged* as people interacted where needs created opportunities in a specific social environment.

From this perspective, the key qualities of any emergent phenomenon include these:

> Radical novelty—new things emerge that are unpredictable from knowledge of their components;
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> Coherence—these new phenomena arise in the behavior of a system, an integrated network as a whole, whether the body of a living thing, a community, or a philosophy;
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> Dynamics—the systems where emergence occurs are evolving so that both their components and the whole are continually adapting to changes in their environments; and
>
> Self-transcending construction—as emergent CASs unfold, their component systems change to meet new conditions in their environments and then recombine with other component systems to produce radically new behaviors in the whole.[4]

One other principle of complexity theory will be helpful for this discussion—the way evolving systems go back and forth between relatively long periods of stability (the *stable state*) and shorter periods of rapid change (*phase transition*). This principle is important because emergence occurs much more rapidly during phase transition, and examining why innovations emerge more rapidly there may offer suggestions for understanding how the process works.

This oscillation between stable states and phase transitions is an extension of the concept of an "attractor." In mathematics, an attractor creates the characteristic pattern of behavior, the "habits," to which any phenomenon is drawn under specific conditions (Cohen and Stewart 1994; Salthe 1993). Take a simple example: Put a chunk of ice in a pot on a hot stove. It will remain solid until it approaches its melting point, then enters a turbulent phase transition, and transforms into liquid. It will remain liquid until it approaches its boiling point, becomes turbulent again, and transforms into gas. The resulting alternation between turbulent phase transitions, in which their agents explore the environment for behaviors that enable them to survive, and the stable states in which their behavior conforms to established habits, can be represented in the "back-of-the-cocktail-napkin" Figure 1(Baskin 2008).

While the figure depicts a wide variety of phenomena of interest in big history, the most familiar may be punctuated equilibrium in biological

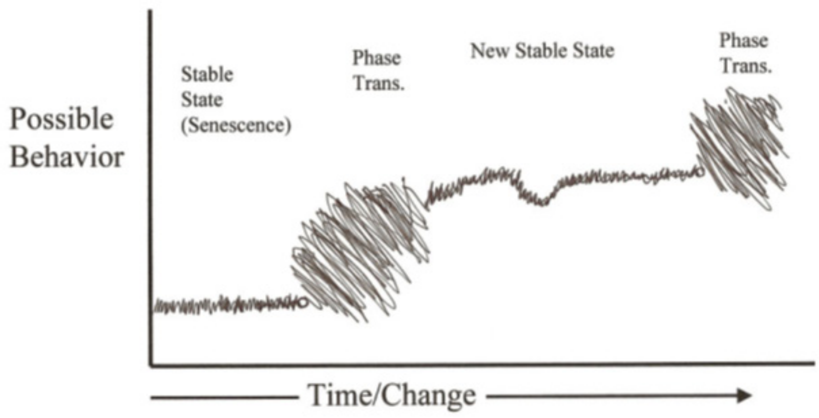

Figure 1: Life Cycle of an Attractor

evolution, where long periods of ecosystem stability are punctuated by shorter periods, following catastrophes, which make new and different ecosystems possible (Gould 2002). For example, the stable state of dinosaur-dominated ecosystems was punctuated by the comet strike that killed off the dinosaurs about sixty-five million years ago. That is, the attractor that made dinosaur-dominated environments a stable state for tens of millions of years dissolved, and the agents in it had to experiment in the resulting phase transition as they searched for physical structures and behaviors that would enable them to thrive in new conditions. As biologist Stanley Salthe (1993) notes, phase transition is the most creative period of any CAS's evolution, *precisely because of the freedom from the coherence among component agents imposed by an established attractor*. When the agents do find successful behaviors, they form habits, which continue as long as they succeed.

Over time, the agents build relationships practicing these behaviors. The longer habits succeed, the deeper the relationships become, and the more the agents rely on their relationships. The attractor that develops, such as that of the mammal-dominated ecosystems that arose after the comet, limits an agent's behavior because the agent now depends on it for its welfare. As experience accumulates and agents make more and more irreversible decisions, their freedom to adapt becomes further limited. Eventually, external change becomes so great that behaviors needed to adapt fall *outside* what the attractor allows. At this point, the phenomenon enters "senescence" (Salthe 1993), and even attempts to change end up reflecting old behaviors. Finally, environmental change becomes so great that agents can no longer survive if they remain limited by their attractor, an event that seems to be happening today in ecosystems around the world. The phenomenon's network collapses, and agents, still connected in smaller networks, must either fall apart or reenter phase transition and develop another attractor.

Figure 1 also reflects many of the important *cultural* phenomena for which big history must account. Philosopher Michel Foucault's (1974) description of the periods of continuity and discontinuity in the evolution of Western culture, economist Gerhard Mensch's (1979) explanation of the cycle of economic boom (stable state) and depression (phase transition), and economist Giovanni Arrighi's (2010) examination of the evolution of Western capitalism—all fit this pattern. Why do such different phenomena conform to it? They conform because *all phenomena that evolve* seem to oscillate between relatively long periods of structural stability and the shorter phase transitions, during which they re-organize their structures to meet changed environmental conditions.

This oscillating pattern is valuable in the discussion of emergence because, as Salthe notes, many more innovations arise during periods of phase transition, when the strength of relationships has broken down and many of the agents in any sub-system are free to search for new, more appropriate ways to behave. Subsequently, the dominant forms of life develop and become established during periods after mass extinctions. Similarly, many of today's most important religions—including those in Western monotheism, Buddhism and Hinduism in India, and Confucianism and Daoism in China—emerged during the Axial Age, circa 800-200 BCE, which followed the stable period

of polytheistic agriculture states, circa 3000-800 BCE (see Baskin and Bondarenko 2014).

From this perspective, cultural innovations emerge most intensely when a society's structure/attractor can no longer hold the system together. Sub-systems are then driven to find new ways of behaving so that they can survive. As they find those new ways, they reform the larger social systems of which they were part. Religion, I shall argue, is a key sub-system in societies and, at least until the late modern era, has been critical in the process of emergence by which societies revitalize themselves (Wallace 1966). This dynamic, I suspect, is very much what complexity theorist Jeffery Goldstein (2014) suggests when he discusses a self-transcending construction.

Religion as an Emergent Phenomenon

Before examining religion as an emergent phenomenon, it is important to note that the question, "What is religion?" is more difficult to answer satisfactorily than most people would assume. Nearly sixty years ago, historian of religion Wilfred Cantwell Smith noted that "religion" is "notoriously difficult to define." He adds that while the "phenomena that we call religious undoubtedly exist," treating them as a distinctive category may not make sense (1991, 17). Fifty years later, anthropologist Robert Winzeler echoes that thought: "There clearly is something in society that we can call religion, although exactly what it is may not be that simple to specify" (2012, 1).

Consider just a few of the many definitions of religion: philosopher Bertrand Russell defines it as a "disease born of fear"(1967), while psychologist William James characterizes it as a way to achieve our "supreme good" (2009). Freud writes about religion as a psychological adaptation, comparing it to a neurotic obsession (Gay 1995); Marx examines it as a way to adapt to economic oppression, the "opium of the people" (2009); and anthropologist Barbara King (2007) discusses it as a way to meet the human need to belong. One of the most explored single focuses in defining religion in recent years concerns why people believe in a "counterintuitive and counterfactual" world inhabited by supernatural agents (Atran 2002). Among these writers, philosopher Daniel Dennett (2006) suggests that religion grows from a "belief in belief"; evolutionary biologist Richard Dawkins (2006) points to the "misfiring" of neuronal networks; and psychologist Ara Norenzayan emphasizes society's need for "Big Gods" who watch and punish people, enhancing cooperation in large, anonymous societies (2013).

These are only a few of what some scholars estimate as more than three hundred definitions for the word. There is an excellent reason for this difficulty. Religion appears in many, many forms—from Siberian shamanism to Jainism to the Prosperity Gospel. Religious rituals range from cannibalism and human sacrifice to High Mass at the Vatican or mandala-making among Tibetan Buddhists. In fact, "religious" phenomena take so many different forms that thinkers from W. C. Smith (1991) to Indian culture critic S. N. Balagangadhara (2005) make credible cases that religion is not a useful academic category. However, there is another way to think about the abundance of religious phenomena: the apparent incoherence of religion as a category is evidence, not of a problem of coherence, but, rather, of its complexity and importance in human history. After all, in only the last 11,000 years our species has moved from living in bands of about thirty to cities of thirty million. If as I have argued (e.g., 2021), religion has been a key survival strategy for our race, one would expect it to take on this wide variety of forms.

For me, religion is the use social groups make of myth and ritual in order to understand and respond to critical, often mysterious challenges that inspire awe and terror (see Otto 1923)—from the realization that life lives on death, including our own, to the feeling of oneness with the universe; from the birth of a child to being conquered by others. Because our brains are structured so that we need to know *why* such experiences happen, we tell stories (mythology) in order to answer these questions (Gazzaniga 2011). By presenting these challenges symbolically in that mythology, humans have been able to explore many of the mysterious forces

that could not be examined rationally. By coupling these stories with ritual, religion also made it possible for human groups to respond to such challenges far more effectively. Because each group developed myths and rituals that reflect their particular conditions and values, it should be no surprise that the phenomena we call "religious" can seem nearly incoherent in their variety. The point I want to emphasize here is that the process by which the products of this conception of religion both arose and evolved (e.g., Hayden 2003; Bellah 2011) is emergence—the self-transcendence of religious forms and systems, as the many sub-systems within and around them change.

Other thinkers have begun to suggest that religion seems to be an emergent property. For instance, anthropologist Jonathan Turner and his coauthors explain that religion "emerges from *many* cognitive, emotional, and behavioral capacities and/or propensities that were hard-wired *for millions of years* in the neurology of higher mammals, higher primates, great apes and hominins" (Turner et al. 2018, 8; authors' italics). Similarly, cultural anthropologist Margaret Boone Rappaport and astronomer Christopher Corbally agree that it "is not one or even several . . . biological innovations that produce religious capacity. It is all of them. Without all these innovations operating at the same time, the human species would not have this neurocognitive trait" (2020, 15). A wide range of such biological innovations is involved. As examples, we will consider four of them: bipedalism and the opposable thumb, language, perception that transforms events around us into story-like models, and the enhancement of ritual.

Worth noting is that religion seems to have emerged as an adaptation to changes in the environment of our evolutionary ancestors over the last ten million years:

> Early in this period, several million years of warming began to turn parts of the East African rainforests into savannahs. By three to four million years ago, our ancestors had been driven out of the forests and onto the savannahs. The difference between living in the trees of a rainforest and on the ground of the savannahs would prove critical in our evolution, driving our ancestors to walk more and more exclusively on two legs and to live in small, nomadic bands. This difference would also drive two key sets of innovation.
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> Our hominin[5] ancestors would now need to develop a different way of living. The great apes that evolved into hominins had lived in the rainforests for more than twenty million years. They had developed instincts and habits that made their lives familiar; now, our ancestors were nomads, strangers in strange lands. In addition, the rainforests provided easily available food and water all year long; on the savannahs, both food and water were spaced out over far larger areas, and much of it was seasonal. As a result, our ancestors would have to live a far more adventurous life in which memory and the ability to plan were far more vital.
>
> They would also need to become much more closely bonded in their bands than the great apes were in the rainforest. The rainforest, after all, was dense with vegetation and places to hide from a limited group of predators to which our ancestors had long become accustomed. Travelling on the savannah, they were far more exposed to predators, and they would come into contact with species of predators with which they had no experience. So, as Robin Dunbar notes, "large social groups would . . . have been their main defence against predators on open pans and flood plains" (2016, 127). As a result, natural selection would favor innovations that would build much tighter bonds between members. (Baskin 2019)

As our australopith ancestors traveled through this new world, they would evolve to develop new ways to live in the world, as a variety of mutations enabled them to survive in it. As Rappaport and Corbally (2020) point out, these innovations, which made them

far better hunters and scavengers, also made religion possible. Consider four of the most important sets of these innovations:

Bipedalism and the opposable thumb. At some point, about 4 million years ago, australopiths began walking predominantly on two legs. We can be pretty sure, from the fossil of "Lucy," a female *Australopithecus afarensis*, that our ancestors had become bipedal by about 3.2 million years ago. Walking on two legs would have had several advantages. It enabled our ancestors to see farther and to move faster; it may also have led to larger brains because the brain has to work harder to monitor perception for individuals that walk on two rather than four legs; finally, it freed the hands to perform jobs such as making and using both tools and weapons. By about two million years ago, *Homo habilis* ("handy person") was doing just that. The opposable thumb also evolved between four and two million years ago, as Lucy's fossil demonstrates. Opposable thumbs are free to rotate and swivel in opposition to the other fingers (Wilson 1999). As a result, our ancestors would have become much more formidable scavengers and hunters, fulfilling the promise of bipedalism to make and use tools. While it may be possible to argue that these innovations resulted from a few mutations, the rise of bipedalism and the opposable thumb in roughly the same period to perform some of the same functions makes it more likely that they developed as a result of emergence, in the interaction between networks of genetic material.

Language. With language, the difference between a linear and an emergent approach toward evolution is even more clear cut. Linguistic theorist Noam Chomsky (1957) does theorize that language might have begun with a single mutation that created a language engine in the brain. Yet, given the number of innovations that were needed to make language possible, I find this difficult to accept. For me, even more than bipedalism and the opposable thumb, language[6] reflects the systemic causality of emergence. The sub-systems that contributed to the emergence of language include several areas of the brain—including the larger cerebellum, which provides the muscle control needed for articulate speech; Broca's Area, which controls production of speech; and Wernicke's Area, which processes speech comprehension. Another set of anatomical innovations in the throat and mouth make highly articulate speech possible. The hyoid bone, for instance, is part of the anatomical equipment that enables humans to articulate clearly. Exactly when these innovations came together to make language a reality has been widely discussed. Fossils of our evolutionary ancestors suggest that language as we know it—as a way of representing sophisticated thought—is likely to have begun no earlier than with *Homo erectus*, maybe about a million or million and a half years ago (Donald 1991; Everett 2017). Other scholars date language to the period of Neanderthals or even early *Homo sapiens*. Whatever the truth of this matter, the complex of functions that had to exist makes it likely that language developed as an emergent phenomenon.

Perception as Story-like Models. When I look around the office where I am writing this essay, I feel as though my senses were an organic HD video camera projecting images of what is "out there" onto my consciousness. What is actually happening is an act of selective reconstruction of *a model of what is out there*. In this process, people's sense impressions mix with memories, and the mixture is evaluated according to their mental models—the neural networks that store what they have learned to expect in various situations (Laughlin et al. 1990). Any details that do not fit the mental models are likely to be filtered out (Siegel 2010). In an area of the brain that Gazzaniga (2011) calls the interpreter module, the unconscious mind then creates several scenarios to explain what is happening and delivers the scenario that seems most likely to allow the person to survive to consciousness. These story-like models of what is happening enable that person to figure out how to respond.

Once again, this style of perception emerged from the interaction of a variety of evolutionary innovations.

These innovations begin with the expanded neo-cortex that provided increased memory and the "executive functions" that mediate abstract thought, anticipation of the future, planning, and the construction of images (Laughlin et al. 1990, 116-7). While these shifts in brain function probably evolved to enhance the hunting and scavenging of our australopith ancestors (Rappaport and Corbally 2020), they would prove essential in the development of story-like model construction. Another key innovation was the emergence of the left-brained interpreter, a concept that psychologist Michael Gazzaniga and neuroscientist Joseph Le Doux developed. Gazzaniga refers to the products of the interpreter as "make-sense stories" (2011). The need for such "make-sense stories" seems to reflect a human need to know *why* things happen. My speculation is that this way of perceiving is at the heart of mythology because, along with increased memory and the executive functions, it created the human tendency to experience events—in the case of mythology, the powerful, often mysterious events that elude rational understanding—in story-like models that explain *why* events happen. With a brain structured this way, it seems likely that hunter-gatherers, confronted, for example, with flooding or famine, would create stories that anthropomorphized the natural causes of these catastrophes as spirits or gods (Baskin 2019).

The Enhancement of Ritual. Another key set of innovations that made religion possible was the human enhancement of animal ritual.[7] Ritual behavior emerged about 150 million years ago among the first "social animals," certain early insects. Social animals—from ants and bees to cockatoos, wolves, and chimpanzees—live with several generations, hunt and defend the group together, and rely on group learning. As a result, they profit from having ways to communicate complex messages quickly and to strengthen group cohesion. With the increased social complexity of animals such as wolves and, even more so, chimpanzees, ritualized behavior became even more important. Wolves, for instance, have rituals to enforce group leadership (d'Aquili et al. 1979). One chimpanzee ritual, where groups of about fifty males will hoot, scream, and drum old logs, struck Jane Goodall as shockingly like human rituals (Turner et al. 2018).

With human beings, however, rituals became even more intense. For one thing, our evolutionary ancestors developed, perhaps three million years ago, a wider palette of emotions, including key social emotions such as guilt and shame, which allowed more powerful feelings of belonging. Moreover, as psychiatrist Eugene d'Aquili and his coauthors (1979) note, the rhythmic movement and chanting of ritual entrain the nervous systems of participants so that they can feel similar emotions. In this way, ritual creates a biologically based sense of community (see also Winkelman 2010). By the time of *Homo erectus*, who emerged around 1.8 million years ago, the brain had evolved to make it possible for our ancestors to mimic each other, creating what psychologist Merlin Donald (1991) calls "mimetic culture," grounded in the newly developed ability to rehearse and refine body movement. In this way, it became possible to use dance and mime to make symbolic statements and to tell stories through body movement. Such a capability would have made it possible to tell mythic stories without language. Of course, any mimetic myth, probably performed as ritual, would have been very different from what we think of in the linguistic myths we know. Still, such a form of mimetic ritual/myth would have been a powerful way to enhance social coherence. It might also have begun an integration of ritual and myth in an early form of religion as I have defined it.

In this essay, we can only touch on a few of the many shifts in genome, body type, and behavior that would interact to produce what we think of as religion. Still, this discussion illustrates how many sub-systems, which evolved to adapt to more immediate survival challenges, interacted to make religion possible. From this perspective, religion began in a gradual unfolding of innovations, which arose to meet different challenges. Their application of these innovations to religious ends would have been all but impossible to anticipate before they were used that way, as the principle of emergence

suggests. For instance, bipedalism and the opposable thumb made our ancestors more effective scavengers and hunters, leading to higher intake of protein and, very likely, larger brains. Those larger brains would make them even more efficient toolmakers and hunters. In addition, the increased memory and planning capabilities would lead to the story-like perceptions that, over time, would make them even more efficient toolmakers and hunters, as they developed the ability to tell mythical stories.

The principle of emergence also seems at work in the way religion has evolved over the last ten thousand years.[8] The earliest human religions seem to have been similar to shamanic animism found in small, nomadic hunter-gatherer bands, where the dependence of groups on the rhythms of nature leads to experience everything in the world as invested with living spirits. There, one person, the shaman, is able to intervene with those spirits to maintain the group and its members in harmony with their world. In addition, ritual was a shared responsibility of the group as a whole (Winkelman 2010). When the Ice Age ended, human communities became sedentary and group populations climbed to hundreds and thousands. Such groups, where it was impossible to know everyone, required political leadership. Recent archaeological evidence suggests that those political leaders appear to have transformed religion so that the spirits among which people lived became gods who were to be worshiped. Those leaders also appear to have developed secret societies that allowed them to identify themselves as conduits to the world of their gods (Hayden 2018). They also created rituals that they, themselves, were responsible for performing. This transformation—I believe—is another example of Goldstein's self-transforming construction so critical to emergence.

A similar set of transformations would occur during the Axial Age, as increased population and trade, iron metallurgy, and the use of writing to manage culture overwhelmed the ability of the older agricultural states to govern large societies. Axial transformations in Israel and Greece, India and China would lead to another stable state—the agricultural empire—starting about 200 CE. One key to driving the emergence of this new stable state during the cultural phase transitions would come from rewriting a society's mythology.[9]

Judaism, for instance, seems to have included a wide range of mythic sub-systems in order to begin fully emerging after the first reading of the Torah in Jerusalem in the middle of the fifth century BCE. Its God—YHVH, because Hebrew is written in only consonants, the accurate pronunciation of his name is honored as a mystery—is an amalgam of mythic forerunners from other cultures. They include the creator god of Ancient Mesopotamia, Marduk, and that culture's flood story; the thunder god/god of war of Canaan, Baal (Miles 1995); and a range of influences from Ancient Egypt, including possible borrowings from the monotheistic god and religion created by Pharaoh Akhenaton, its emphasis on personal piety and its judgment of the dead, and even what seem to be borrowings from Akhenaton's "Great Hymn" in the Bible's Psalm 104 (Assmann 1997). All those borrowings would be redirected in the Hebrew Bible, much of which was written after the Babylonian destruction of Jerusalem and Solomon's Temple (c. 587 BCE). In order to save the culture of Israel, the existing mythology was rewritten to make the conquered people responsible for their own demise—because they worshipped other gods than YHVH, the one true god. At the same time, they were promised that YHVH would again favor them—if they mended their ways (Akenson 2001). This sense of being active agents, even in catastrophe, seems to have been critical to Judaism's ability to survive all the subsequent catastrophes that it has absorbed over the nearly 2,500 years since the Torah was first read.

This transformation was typical of the societies that experienced the Axial Age as a cultural phase transition. In China, the traditional religion of the Zhou period (c. 1100-256 BCE) would evolve to adapt to the terrible chaos of the Axial Age, bringing together the traditional orientation of Confucianism with a range of other influences, from the many schools of religious philosophy of the time to the challenges

provided in Daoism and, later, Buddhism (Graham 1989). Similarly, Axial Age India would see the flourishing of both Buddhism and the Vedic tradition that the English would misidentify as Hinduism. Here, a focus on the human internal world would lead to what, to this day, seems to be among the most effective way to heal the sense of something being wrong with human life that Buddhists call *dukkha* and Christians call original sin (Armstrong 2006).

In this way, the Axial Age functions as the phase transition during which the polytheistic kingdoms of an age of agricultural states in four very different societies transformed their cultures so that they could thrive in what would become an age of agricultural empires. As anthropologist Dmitri Bondarenko and I show, the creation of a new way of thinking about the world would emerge, in the technical sense of the word, as people in those societies rewrote their mythologies and reconstructed their societies (Baskin and Bondarenko 2014).

Worth noting is that Christianity would emerge similarly, beginning as a form of messianic Judaism, as a sort of secondary wave of Axial Age transformation (Armstrong 2006). After the destruction of the Second Temple (70 CE), Christianity would increasingly appeal to non-Jews, mostly Greek Roman "pagan" communities, taking on elements of their "foreign" religious traditions. Perhaps most notable was Constantine's apparently successful attempt to make Christianity acceptable to his soldiers, many of whom worshipped Mithra. In this way, Mithra's birthday, December 25, would also become the birthday of Jesus, even though the gospels suggest that Jesus was born in the spring.

Even with this brief discussion, it seems clear to me that treating religion as an emergent phenomenon shows how powerfully it has helped people survive the dramatic changes of the last ten thousand years. For me, religion is one of the key survival strategies in human history. I am convinced that scholars need to approach religion very differently, in a way that incorporates the principle of emergence. Such an approach can help all of us understand the richness of history as a carnival, rather than as a timeline, with a methodology that is deeply embedded in work that was done in the physical sciences, from which complexity theory itself emerged.

With that in mind, I want to conclude this essay with some thoughts on how more deeply embedding the principle of emergence into the practice of big history might enhance our studies.

Emergence and Big History

First of all, I want to emphasize that much of what I have written here will be familiar to readers of this journal. After all, the multi-disciplinary approach I have connected with an emphasis on emergence is key to big history. Pick up any book on big history and you are likely to find references to fields ranging from quantum mechanics to archaeology, from geology and chemistry to economics and demography. In addition, a big history approach often explores the complexity of a world where a wide variety of causes can contribute to the way events unfold. I believe, nonetheless, that more fully incorporating the principle of emergence can open possibilities that may enable students of big history to examine the world in a richness that has the power to help them see things in ways that can take us beyond what we have done without it.

Before I explain why I believe emergence can be so valuable in the study of big history, it will be worth revisiting the key points about this principle. Emergence depicts the processes we see all around us as self-transcending constructions that are continually responding to many scales of change going on around them. As the apple seed sprouts into a tree, its transformation is guided by its DNA, its other internal matter, and the conditions of soil and weather that surround it. The relatively simple seed is thus driven to transcend itself to become the far more complex apple tree. To think this way demands that we think of our world as a dynamic, unfolding dance of matter—that is, energy-storage systems—that can best be described "in terms of forces and flows rather than a succession of equilibrium states" (Ho 2008, 29). So, as we consider life on a planet such as Earth, emergence,

with its dynamic, non-linear assumptions, can push us to think of the world as a riotous carnival, rather than the mechanical timeline that a more traditional, linear approach to history suggests.

In thinking about the world as a carnival, where emergence seems to be almost everywhere, several dynamics kick in that enable us in big history to perceive and explore the world differently. For one thing, the world we examine is suddenly full of agents, whose qualities and movements are continually enriching that carnival. As Bruno Latour notes (2005), in the human world, these agents begin with people but also include other living things, ideas, technologies, and even natural processes, such as global warming or the fall of a comet. Consider, for instance, how fundamentally technologies such as the automobile or the computer reinvented America's social carnival in the twentieth century. Moreover, what matters most is not the nature of individual things, but their relationships. This dynamic approach is unlike the traditional linear approach, which follows individual clumps of passive matter, driven to move as they respond to the universal laws of nature. In this way, the environment is no longer a collection of passive objects to be manipulated and controlled; it becomes a nested network of agents, many of which are capable of having deep and lasting effects on our world as they affect each other, a fact that people across the planet have recently witnessed in the emergence of the COVID-19 virus.

For another, integrating the principle of emergence shifts the way we think about how the processes around us function, transforming from the mechanics of determinism to the dynamics of uncertainty. As we just noted, the linear paradigm views matter as passively responding to its encounter with the laws of nature. Theoretically, then, if one could know all those laws and the position of every bit of matter, it would be possible to calculate the future, which had been determined from the beginning of the Universe. Nobel Laureate in Physics Robert Laughlin characterizes this quality of the Newtonian paradigm as "the idea that things tomorrow, the day after, and the day after that are completely determined from things now through a set of simple rules and *nothing else*" (2005, 24; author's italics). Once we incorporate the principle of emergence, all that changes. Viewed as a carnival, life on Earth is so abundant, and there are so many CASs interacting, that we *should* expect to be surprised. Consider the events of 2020. It was clear for decades that at some point the world would again experience a pandemic, yet who would have predicted that such a pandemic would undermine the reputation of the United States as fully as the Trump Administration's refusal to take COVID-19 seriously has damaged it? Former administrations had *quite literally* written the book on dealing with a pandemic, but the interplay of social sub-systems very nearly destroyed the country's ability to respond. As a result, at this publication, more than six million people worldwide have died of COVID-19 complications with more than one and a half million of these in the United States; America has become the object of ridicule; and the country's anti-science movement has become more and more vocal—all this while both China and Russia are becoming increasingly powerful.

This shift to the dynamics of uncertainty is important to big history because it can change the way thinkers within the discipline approach a wide variety of issues. For instance, consider the cosmology of big history, which currently charts a course from the Big Bang to the entropic death of our Universe. While this narrative emerges from some of the most impressive scientific advances our culture has made, it is also regularly articulated as deterministic. Once we incorporate the principle of emergence, however, we introduce an element of uncertainty that may open the way to think very differently about all sorts of issues. This point of view encourages us to look for alternative futures that might arise from systemic interactions that we have not examined, ones that we may not even be aware of yet. It also pushes us to approach such issues with a great deal more uncertainty. After all, for more than two centuries after Newton wrote his *Principia Mathematica*, scientists largely assumed that time and space were separate dimensions. With

Einstein's theory of special relativity, it would become clear that space and time were deeply interconnected. Such an observation does not diminish Newton's accomplishments. Rather, it emphasizes that the models of the world that scientists create depend on the best information available *when they are created*. As the amount of available knowledge continues to explode—and the tools we have for studying nature improve—it seems inevitable that many of the ideas we are surest of today may have to shift tomorrow, as new evidence appears. More fully integrating the principle of emergence into the study of big history may lead to understandings of the dynamics of the cosmos that provoke the sorts of questions about the origins of the universe—such as those voiced by astrophysicist Lee Smolin (2013)—offering a deeper understanding. Perhaps, we shall find further evidence that the cosmos did begin with a big bang and is likely to end with an entropic death. What is important here is to avoid the temptation of treating *any* model of the cosmos with the certainty that many scientists showed for Newton's model of space and time as separate and distinct.

Finally, when we combine the increased agency of the non-human world with the dynamics of uncertainty, we reframe the question of how we humans should participate in our planet's carnival life. As opposed to the linear worldview, which views human beings as the only source of active agency in the universe, a worldview that incorporates the principle of emergence makes it clear that we are an important part of the network of agency that is creating the future, but only a part. As we are learning from a number of sciences, climate change is an emergent phenomenon. As a result, we can trace today's global warming to deforestation—the intentional burning of forest areas—which started about fifteen thousand years ago and accelerated as societies burnt down forests so they could use the land for agriculture. Where rainforests once covered fourteen percent of our planet's surface, today they cover only six percent and continue to shrink ("Deforestation" 2021). The changes our species provoked accelerated with the beginnings of the Industrial Revolution in the eighteenth century and today threaten to lead to problems ranging from the spread of tropical disease to the flooding of coastal cities and largescale migration. With the linear Newtonian paradigm, we humans were the only active agents. The plants, animals, and geological formations among which we live were merely "resources" to be manipulated and controlled. The result has, at least partially, been the degradation of our environment with a very real possibility of a mass extinction in the near-term future (e.g., Kolbert 2014).

On the other hand, a paradigm that incorporates the principle of emergence offers a different way of thinking about our world, a way of thinking that is much more like the animism of hunter-gatherer societies. Here, we are part of a world that supports us. In that world, every bird and mammal, rock and stream has the agency that could make our lives easier or more difficult. Each has its own "spirit," in the sense that it is a participant in life's carnival, for good or ill. Is this not one of the key messages that has emerged from our studies in big history?

Let me close by repeating that I do not intend to criticize the current state of big history. Rather, I want to encourage thinkers in the discipline to consider shifts that might help us improve our studies. After all, in discipline after discipline, the last thirty to fifty years have witnessed an explosion in our understanding of the world, much of which is only slowly becoming widely known. My purpose in this paper has been to explain how more fully incorporating the principle of emergence might be helpful in big history. I hope you will agree it is, at the very least, worth discussing whether this position is valuable to us.

Notes

1. The emphasis on cause-and-effect to explain causality is a Western development. In Chinese philosophy, causation is generally thought of as systemic (Baskin 2007).

2. For a full discussion of how desktop computers made complexity theory studies possible, see Pagels, 1989.

3. I use the word "system" here because it is the most easily understood by the largest group of readers. Unfortunately, "system" sounds slightly mechanical. As a result, there is a strong argument for using other words, including "network" (Latour 2005) or "bundle" (Ingold 2011). I would prefer to side step that discussion, noting that I do not find the word "system" entirely accurate.

4. For a full examination of the history, dynamics, and implications of emergence, see Goldstein's three-part discussion, which appeared in *Emergence: Complexity and Organization* (2013a, 2013 b, and 2014).

5. I use the word "hominin" in its most recent sense, to identify the line of primates that broke off first from the great apes of the East African rainforest and then from the line of chimpanzees and bonobos. For a fuller discussion of the word, see Blaxland, 2020.

6. S.R. Fischer defines language as "the medium through which one conveys complex thoughts using arbitrary symbols . . . in a significant syntax" (1999, 33).

7. The key examination of this topic is *The Spectrum of Ritual* (1979), edited and predominantly written by d'Aquili, Laughlin, and McManus, which, as far as I know, remains the most comprehensive treatment of animal ritual as a precursor to human ritual.

8. For a full exploration of how religion has evolved, see Bellah, 2011.

9. For a full examination of the Axial Age as a cultural phase transition, see Baskin and Bondarenko, 2014, Chapter 2.

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Complex-Information Ethics Theory

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ABSTRACT

If ethics is of any interest to big historians, it might be primarily for analyzing the "ought to haves" and the "ought not to haves" of prior large scale human actions, e.g., does an agriculture-based lifestyle cause more harms to humans overall as compared with a hunter-gatherer lifestyle? However, big historians are also often concerned about the future events of Earth that can be influenced by humans, such as climate change, mass extinctions, and the predicted technological singularity. Because those concerns encompass both human and non-human complex systems such as the biosphere and possible future advanced artificial intelligence, big history requires an ethical framework that addresses anthropocentric as well as non-anthropocentric concerns and perspectives.

Complex-information (C-I) ethics is a new information-centric theory described in this paper. Several other information-centric variants have already been proposed. However, C-I theory seeks to enhance, broaden, and deepen this genre of ethical theory with the general directive that moral agents should perpetuate and enhance net positive deep informational artifacts and processes. Before introducing this directive, however, we will first explore and define its underpinnings in the disciplines of thermodynamics, information theory, and complexity science. By better understanding how entropy and its Janus-like counterpart, information, are relevant to C-I's ethical directive, we can also better appreciate why complex systems, as defined by their key characteristics, have intrinsic ethical value. We will also examine why artifacts and processes with deep semantic value can have instrumental ethical value to agents. Although many, if not most, complex systems are ethically and pragmatically worthy of being perpetuated and enhanced, some are not because of their negative effects on the broader complexity landscape. A couple of important caveats to C-I's directive are also described.

By bringing the findings and analytical tools of key physical sciences to bear, C-I theory opens new avenues for exploring what we as moral agents ought and ought not to have done in the past, as well as what we ought or ought not to do presently and in the future. This class of ethical theories also delineates some of the primary bridges from the natural and physical sciences to the more subjective realm of philosophical ethics.

Big History—Do We Need Ethics?

Ethics is the subdiscipline within philosophy that, stated in different ways, is concerned about what we ought versus ought not to do, or what is the Good versus what is the Bad. While a knee jerk response might be, "Yes, of course, big historians should be concerned with doing the right thing," a little more reflection might question, "what does ethics, especially formal philosophical ethics, have to do with the study of past events or even possible future events?" That is a fair question. After all, historians are generally more concerned what happened rather than doing a deeper ethical analysis of what should have been done by moral agents (those capable of making ethical decisions): we cannot rewrite history. Also, ongoing or near future events, like global warming and mass extinctions, do not seem to require a profound ethical analysis to decide whether humans ought or ought not to try to prevent these major events from occurring. A little more thought, however, exposes that even behind apparently obvious courses of desired action lurk many subtler ethical dilemmas. For example, should we try to save a rare obscure plant at the expense of losing agricultural land? It is difficult to be an environmentalist if you and your children are hungry. Should developing countries forego CO_2-producing industrialization despite its material benefits when developed countries have already largely contributed to global warming? Should artificial intelligence be given rights, and if so, at what level of "intelligence"?

These examples reveal at least a few reasons why we should have an interest in ethics: big historians often have a unique knowledge base, given our interest in vast spans of time, familiarity with multiple disciplines, and examination of overarching trends. With that unique background we are ostensibly well positioned to offer unique perspectives to assess the ethical dimensions of prior human events, current generalized human actions, and possible future actions and scenarios. The current COVID-19 pandemic offers but one contemporary example where historians can provide lessons regarding how societal dynamics and the viral pathogen itself will likely unfold. For example, the Spanish flu pandemic of 1918-1920 was met by public mask burning protests, the continued gathering of large groups of people, and healthcare systems being overwhelmed; many politicians minimized the disease's extent and severity (Barry 2005). These actions led to confusion, loss of trust in government, and needless deaths. Arguably, the same mistakes were made yet again with essentially the same ethical ramifications. For example, how should we balance personal freedom versus the welfare of the community? How should we fairly distribute limited healthcare resources? What is the role of governments and communities in facing a common, invisible threat?

Ray Kurzweil's predictions from his book, *The Singularity is Near*, provide an example where big historians might offer ethical lessons from the past to anticipate the future better. Kurzweil foresees a future utopia made possible by advanced artificial intelligence and nanotechnology (2006). Big historians, however, would likely urge strong caution about having unequivocal hopes regarding these new technologies and likely advise that we should proceed with due diligence. While "hope springs eternal," we can point out that every increase in complexity, whether it is the change from hunter-gatherer to agrarian societies or the onset of the information age, new sets of unanticipated problems invariably have occurred. Big history has likely never witnessed an unmitigated panacea with any wide-ranging change or advancement.

Ethics—Which One?

The classical, well-known ethical theories that have been promulgated by philosophers, religious leaders, and other thinkers over the past few millennia have almost universally been concerned with what was the right action to take for the sake of themselves and other humans, i.e., they are anthropocentric. Traditional theories like Aristotle's (384-322 BCE) virtue ethics focus on what human character traits would promote human flourishing (eudaimonia). Immanuel Kant's (1724-1804) deontological ethics states that we should faithfully follow rules that any rational human being would develop to avoid contradiction, hypocrisy, and other irrational practices, as well as have the qualification that the rules should be universalizable, i.e., followable by everyone. Jeremy Bentham (1748-1832) and John Stuart Mill's (1805-1873) utilitarianism argues that we should do the action that would lead to the greatest good for the greatest number of people (Panzas et al. 2010). This list is far from complete; nevertheless, with some exceptions like Jainism, most religious ethical codes and secular ethical theories are similarly anthropocentric (Mardia 2013).

With increasing awareness of the environment and its importance in the last century, ethical frameworks reaching beyond immediate human concerns have been proposed to include other living organisms, ecosystems, and Earth itself. A couple of examples include Aldo Leopold's (1887-1948) land ethic and Arne Naess's (1912-2009) deep ecology (Aldo Leopold Foundation 2021; Keller 2008). The unwritten, informal ethics of many Native American tribes expresses deep concern about their relationship to nature and long preceded those of Western thinkers (Reynolds 2007).

The latter theories that give ethical value to the biosphere are an important step in the direction of ethics being concerned about entities outside that of immediate human concerns. After all, Earth did and can do just fine without us (and in many ways did better). We, however, cannot do without Earth and its irreplaceable biosphere. Even ethical theories that include the biosphere, however, do not provide any framework in which to address other ethical issues

that we might face in the future. Advanced self-aware artificial intelligence, as proposed by Kurzweil, and the possible discovery of extra-terrestrial life are examples of entities that arguably have significant ethical value beyond what is useful for humans. Some theories that have a framework with which to address these potential new scenarios have been developed in recent years. Floridi's information ethics, Freitas's thermoethics, Maxwell's complexity ethics, Vidal and Delahaye's universal ethics, and Doyle's information-based ethics all propose to broaden that which has ethical value to systems that are concerned with informational content in the physical sense, or complex systems (Floridi 2006; Freitas 2008; Maxwell, n.d.; Vidal et al. 2018; Doyle 2016).

Of course, increasing complexity is one of the—if not *the*—overarching themes in big history. Anticipating and accommodating ethical issues relevant to other complexities, anthropocentric or not, is another desired feature for big historians. Before describing complex-information ethics, which I have developed over the past ten years or more, I would like first to look at the foundations upon which it and other similar theories are constructed. Although many readers might already be familiar with many aspects of these foundations, the definition and explanation of pivotal terms like *entropy*, *information*, and *complexity* can vary significantly from author to author. Hence, it is important for me to set C-I theory's particular foundation carefully. As the philosopher Socrates is quoted to have said, "The beginning of wisdom is the definition of terms."

Entropy—"The Devil"?

Increasing entropy is an inexorable and ongoing, fundamental process of the universe, and it is part and parcel of the second law of thermodynamics. This law has myriad articulations because the results make themselves known in various ways depending upon the focus. For example, a chemist will be interested in knowing whether a chemical reaction will occur spontaneously (i.e., occur without a net input of energy). If the reaction results in an increase in entropy, then the answer is "yes." A mechanical engineer, on the other hand, might be more interested in the second law's assertion that some energy involved in any process will not be available to do work but will irrevocably be lost to increased entropy—typically in the form of heat. She will then try to design a machine that maximizes the amount of energy that is available for work while minimizing that lost to heat so that it is more efficient. For the purposes of this paper, however, we will focus on what is perhaps the most understood aspect of the second law, which states that "[t]he entropy of the universe increases in the course of any spontaneous change," i.e., for any action or change that occurs, the overall entropy of the universe can never decrease (Atkins 2010).

As with the second law of thermodynamics, its key term, *entropy*, also has many different articulations because the results of entropy have varied manifestations. Most commonly, an increase in entropy is described as the inevitable trend of any system to progress from being ordered to disordered (e.g., things fall apart over time). Although describing entropy as "the degree of disorderliness" closely approximates its character, it is not rigorous enough for our purposes. (There are a few instances where an increase in disorderliness is not readily apparent.) Instead, a more accurate definition is this: *entropy is the logarithm (log) of the number of possible microstates that constitutes a system's macrostate* as described by the equation, $S = k \log W$, where S is entropy; k is Boltzmann's constant in the units of joules per degree Kelvin; and W is the number of microstates for a system's macrostate (Atkins 2010). This definition and equation, which was first described in the latter 1800s by the Austrian physicist Ludwig Boltzmann (1844-1906) and elaborated further by the American physicist Willard Gibbs (1839-1903), might sound obtuse. However, we can use a hypothetical teen's bedroom to explain the jargon in more parochial terms.

As a metaphor, we will state that a teen's bedroom represents a system. The room's overall condition, in turn, represents its macrostate. The furniture, apparel, garbage, and other articles metaphorically represent

its microscopic constituents, and one particular arrangement of these articles represents one microstate. When the bedroom is in a macrostate of tidiness, its articles are all placed where they should be, including the dressers, bed, desk, lamp, apparel, and any garbage placed in the trash can. Importantly, the number of possible microstates where the room's macrostate is still tidy are many because the various articles can be moved around or rearranged to a certain degree, and the room would still be tidy. For example, the room is still tidy if the socks are placed neatly together but in a different drawer, the bed has been moved a couple of centimeters, the garbage is in the trash but in a different arrangement, and so on. In the end, there are numerous possible microstates where the room has a macrostate of tidiness. However, the number of possible microstates where the articles are disordered and the room is messy is many magnitudes more enormous. Because a tidy room has comparatively few microstates, it is also described as being in a low entropy state, whereas a messy room is in a high entropy state. A room unfortunately destroyed and scattered about by a tornado would be in a state of maximal entropy.

Figure 1. The abstract phase space of a tidy room (lower entropy) is much smaller in area than the phase space of a messy room (higher entropy). One arrangement of the room's articles is represented by one point (the red dot) within their respective phase spaces. Note: The phase spaces are not drawn to scale. The phase space of a messy room would be much, much larger in comparison to the phase space of a tidy room.

An important concept and visual tool that will be relevant for our ongoing discussion is the idea of *phase space*. A phase space is an abstract area, whose size is proportional to the number of possible microstates that constitute a system's macrostate. Figure 1 represents the hypothetical phase space of a tidy room versus a messy room, where some point in each phase space would, in turn, represent a very particular arrangement of the room's articles. If drawn to scale, the phase space of a messy room compared to a tidy room would be much larger in area than would fit on a sheet a paper. The phase space of a room destroyed by a tornado would be many magnitudes larger still.

Of course, the pioneering physicists who pondered the nature of entropy did not think in terms of a tidy versus a messy bedroom. Instead, in a more typical physics example, a system might be a one-liter container of air molecules whose macrostate is described as having one unit of atmospheric pressure and a temperature of 20 degrees Celsius. That macrostate is in turn physically determined by a range of locations, densities, and velocities of the container's microscopic air molecules. The size of that range is again proportional to the size of its phase space.

Norbert Wiener, the twentieth-century mathematician of cybernetics fame, was perhaps the first to see that entropy is a correlate to the Bad, and that information is a correlate to the Good, when he remarked in his 1954 book, *The Human Use of Human Beings*, that (Wiener 1954)

> [t]he scientist is always working to discover the order and organization of the universe, and is thus playing a game against the arch enemy, disorganization. Is this devil Manichaean or Augustinian? . . . Just as entropy tends to increase spontaneously in a closed system, so information tends to decrease; just as entropy is a measure of disorder, so information is a measure of order.

Why did Wiener call entropy "this devil" (and often times, "the arch enemy")? Figure 2 helps to demonstrate his reasoning. If we use the analogy of teenagers' rooms or even more simply, triangles becoming more disordered (higher entropy) from left to right, we can equate that to a system becoming less well. The phase space also increases as a system

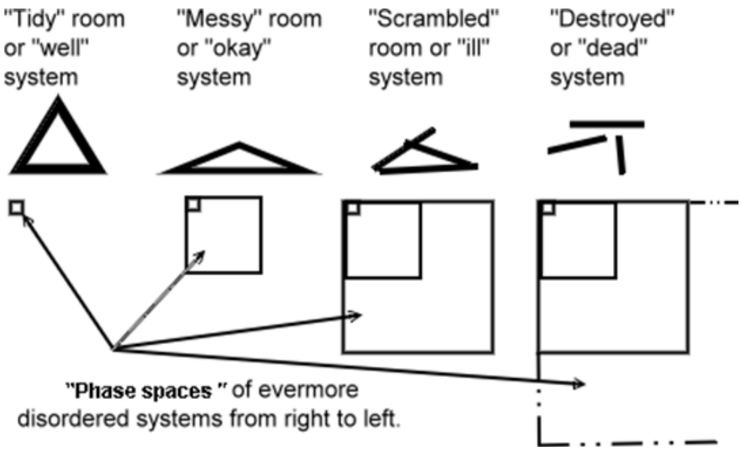

Figure 2. Each column abstractly represents a system that is progressively less ordered, or higher in entropy as one goes from left to right. Consistent with its degree of order, each triangle is progressively less restricted in its relationships until it is destroyed at the far right. The equilateral triangle on the left is most ordered, and its phase space is smallest as well, as depicted by the small square. There are a greater number of possible relationships and larger phase spaces as the triangle progressively fails. Analogously, for any "well" system, whether it is a tidy room or a healthy person, there are fewer ways for its constituents to be in relationship to each other than when they are less well. Note that the phase spaces are not drawn to scale but should be successively much, much larger.

becomes less well because the number of possible microstates for an ever more failing system becomes ever greater. In other words, there are ever more ways for a room to become haphazard or for a triangle to lose its geometry and become a less well equilateral one. Hence, more entropy correlates with a "bad" state.

Of course, according to the second law of thermodynamics, an increase in entropy must occur somewhere in the universe for any process to occur, including the processes that keep a system well. For example, you must eat, digest, and metabolize food to stay alive—never mind healthy. An increase in entropy had to occur with each step of the processes. Therefore, entropy is also an unavoidable Good—but then, every story needs a villain!

As noted in his earlier quotation, Wiener also stated that information, or order, is the obverse of entropy, which implies that it is a force for the Good—the hero in our story if you will (Weiner 1954, 21). How is it that information and order are equivalent? Let us look briefly at the fundamental nature(s) of information itself.

Information about Information

Before we make the claim that information is the equivalent of order and forms the basis of the Good, we need to look carefully at what underlies this seemingly ephemeral term. Terrence Deacon (2011), a neuro-anthropologist at University of California, Berkeley, importantly pointed out that much of the confusion regarding the nature of information is because "[t]his term is used to talk about a number of different kinds of relationships, and often interchangeably without discerning between them." I concur with his assessment as well as his way of parsing the main types of information used in everyday discourse: (1) syntactical; (2) semantical; and (3) pragmatic (more commonly called "surprise" as noted below).

Syntactical Information

The terms *syntax* and *syntactical* are used most often in the context of grammar, where it refers to how words are ordered in a language. The dictionary definition of *syntax*, however, is not restricted to language, but refers to how things in general are ordered or, more generally, how they are in relationship to one another. Those things can include atoms in a molecule, planets in a solar system, the living organisms of a temperate forest, individuals in a society, and . . . words in a sentence. Syntactical information also underlies the other types of information that will be described later. Not everyone who contemplates the underlying nature of information concurs with Wiener that information is fundamentally a measure of order or relationships. He and I have good company, however. That company includes Benjamin Schumacher, a physicist, quantum information authority, and protégé of the late famous physicist John Wheeler (1911-2008), Luciano Floridi, who is a leading professor of Information Philosophy at Oxford University, and neuroanthropologist Terrence Deacon. (Schumacher 2015; Floridi 2015; Deacon

2011). My own definition of (*syntactical*) *information* is "the relationship of entities in spacetime." I added "spacetime" to the definition because the fate of information in or on the surface of black holes—where the rules of physics are often conjectural— is not yet clear to physicists.

A hypothetical example can illustrate why relationships between things (a.k.a. relata) is synonymous with information. Imagine that you want to inform someone about a particle's location in otherwise empty spacetime—about the simplest kind of information that you could offer to someone. Unless that particle's location is in relation to something else, you cannot provide them with that (syntactical) information. You must give its physical location $X_{A,}$ Y_A, Z_A in relation to something else, such as the center or some boundary of that space; its position relative to particle B; or something mundane like three blocks west, two blocks south, and five stories above the street level of the Chrysler building in New York City. In fact, without particle A's being in relation to something else, you cannot even inform someone whether it is moving or not moving; it moves only in relation to something else. Similarly, with regard to informing someone about the particle's location in time, T_a, you also need to give its relation to another event in time, such as when Rome was legendarily founded or when Jesus Christ was believed to have been born. Even to inform someone that "John is happy" is to inform another indirectly and implicitly that happy is an emotional state relative to when he feels "okay" or "sad."

Many other key attributes of syntactical information were especially more deeply understood after the 1948 publication of a seminal paper, "A Mathematical Theory of Communication," by the mathematician-engineer Claude Shannon (1916-2001). Working on a task assigned to him by his employer, Bell Labs, Shannon quickly understood that an engineer needed to worry about only the syntactical information (i.e., the ordering of signals comprising a message) that was transmitted, not the meaning of the information. His paper is widely considered by scientists, engineers, and science historians to be one of the most important of the twentieth century because it introduces many concepts that helped to usher in the Information Age. His information theory introduced many concepts now taken for granted, such as the signal-to-noise ratio, the use of Boolean logic for computer operations, and other pivotal insights that helped to conceive and develop the information technologies of today.[1]

Most importantly for our purposes, Shannon also determined that syntactical information can be mathematically measured in units that he called bits—a contraction of <u>bi</u>nary dig<u>its</u> (a numbering system limited to using 0's and 1's). The amount of syntactical information of a message is determined by the formula $H = -k \log_2 M$, where H is the amount of information in bits, k is a constant for adding the unit of bits, and M is the number of possible messages. (Note: in this formula, each message has an equal probability of occurring. Measuring information where messages have varying probabilities has a slightly more complicated formula, but that does not change the following discussion in any substantial way (Schumacher 2015).

This mathematical equation also helped to reveal syntactical information's relationship to thermodynamics' entropy whose formula, $S = k \log W$, was noted earlier. These equations are the same in form except for the negative sign. This difference importantly reveals that information is mathematically, as well as conceptually, the antithesis of entropy. The ramifications of the Janus-like nature of entropy and information has been borne out in other ways and fields as well—too many, in fact, to recount in this article.[2]

Semantic Information

Semantic information is typically defined as "information that has meaning or purpose to an agent" although other more complicated definitions have been proposed by others as well (Zhong 2017; Floridi 2005). Semantic information is, therefore, dependent on apprehension, processing, and interpretation of syntactical information by an agent for its realization. It is typically difficult for us to

quantify semantic information mathematically, except the subtype called informational "surprise," which will be discussed in the next section. A semi-quantitative exception is semantics with which we can add qualifiers like incredible, deadly, life-sustaining, large, or other adjectives that belie the relative importance or magnitude of the message.

Nevertheless, there is not currently, and perhaps never will be a mathematical equation to determine the degree of semantical information present. For example, the novel *Moby-Dick* might quantitatively and qualitatively have a much greater amount of semantic information than the back of a cereal box, but we are not able to attach a derived number of bits of semantic informational content to either.

Although semantic information has meaning or purpose for an agent, it need not rise to the level of awareness for an organism. Simple life forms like bacteria might chemically sense nutrients in one direction and a noxious substance in another direction. Through a series of complicated but hypothetically traceable chemical reactions that end in the movement of its flagella or cilia, it would then move toward a nutrient (meaning = sustenance) and away from the noxious substance (meaning = danger). Even for higher organisms with advanced brains, information can have semantic content that the agent is not aware of or ignores. In the former case, the usually unconscious act of breathing is driven by the semantic information derived from the blood's pH, carbon dioxide, and oxygen levels.

For organisms with nervous systems, and especially those with advanced central nervous systems (i.e., brains) like dolphins or humans, how syntactical information is processed so that we are aware of that meaning remains a daunting and, for the foreseeable future, impregnable challenge to understand on the level of physics, chemistry, and the biological sciences. The philosopher David Chalmers labels this "the hard problem" because science does not have the tools, methods, or even a hypothetical basis on which it can explain how matter/energy—and I would add, fields of force—can eventually manifest these and other higher mental phenomena like consciousness, abstract thinking, and, I think he would include, moral decision making (Chalmers 1995). For problems like the apprehension of semantic information, consciousness, and even the origins of life, known physics can provide us with some boundaries or necessary conditions, but it is insufficient to explain fully how these phenomena become manifest. In other words, although thus far no living processes have been demonstrated to conflict with known physics, we are still especially far short of explaining the physics of higher mental phenomena.

Surprise Information

Claude Shannon, the founder of information theory, believed that a consensus on the real meaning of *information* would be unlikely. In that regard, he is correct thus far. There is still no universal agreement on what information ultimately is although others and I assert that it is fundamentally the relationships between things, or relata, as explained above. Shannon's own stated belief about information's character is that it is "that which reduces uncertainty" and called this reduction the "surprise" of information (Stone 2015). Relationships that are known can be viewed as information that reduces the uncertainty of how things are extant relative to other things, i.e., the more you know about something's relationships, the less uncertainty you have about them. Conversely, increased entropy results in a diminution of set relationships and an increase in uncertainty about them.

To illustrate how a message can have surprise information that is both demonstrable and measurable, we can use the storied example of how Paul Revere and other riders learned how the British troops were going to travel to Lexington: one lantern was to be lit in the Old North Church tower if they were traveling by land, two if by sea. When they saw two lanterns lit, the informational surprise of how the troops were going to travel was reduced by fifty per cent—the same as learning which side of a coin lands up. Of course, many examples are more complicated than this simple one and can require a little more math to determine the

message's surprise. The simplest version of the surprise of a message is this: $s(x) = \log_2 [1/p(x)]$, where s(x) is the surprise of a message as measured in bits, and p(x) is the probability of each message (Stone 2015). In the Old North Church tower case, $s(x) = \log_2 1/ ½ = \log_2 2 = 1$ bit. Hence, the riders gained one bit of information when they saw the two lanterns in the tower or, expressed in another manner, had their uncertainty reduced by one bit. If the probability of a particular message is small, then subsequently receiving that message increases its surprise. For example, burglar alarms are quiet the vast majority of time. If the alarm sounded off for one minute only once every ten years (~5,256,000 minutes), the surprise of its going off would be $s(x) = \log_2 1/ 1/5{,}256{,}000$ or $\log_2 5{,}256{,}000 \approx 22.3$ bits. The number of bits might seem small given the intuitively large amount of surprise that would occur if the alarm sounded, but logarithms make even large numbers more manageable.

Complex-Information (C-I) Ethics — A New Perspective. The Good is . . .

The preceding discussions have laid the groundwork needed for a line of argument that the Good can be based on that which is not necessarily dependent on human interests, i.e., non-anthropocentric. C-I theory grounds its values on that which inherently has deep syntactical informational content, or that which is imbued by agents, with a metaphorically deep amount of semantic information. Other authors have also argued for an association between information or relationships and the Good and, conversely, increased entropy and the Bad. C-I theory, however, seeks to broaden, further define, and clarify this genre of theory. To the point, C-I theory's central claim *is* that "[t]he 'Good' is that which perpetuates or enhances net positive, deep informational artifacts and relevant processes." Even with the foregoing discussions on entropy and information theory, this ethical rule begs to be further explored and explained.

Deep Informational Artifacts and Processes

The discussions of the second law of thermodynamics and information theory above set the stage for what we mean by *deep informational artifacts and relevant processes*. I proceed by describing how each of the three different types of information leads to artifacts or processes that are construed by and relevant to C-I ethics.

That with Deep Syntactical Information, i.e., Complex Systems

As discussed earlier, syntactical information generically refers to the relationship of things (a.k.a., relata) and makes things possible. Without relata, all that is present is the equivalent of the cosmic background radiation—random photons everywhere at essentially the same temperature. At syntactical information's most superficial level, we encounter fundamental structures as when different quarks relate to each other to form protons, neutrons, and other subatomic particles. At its deepest level, various relata occur to manifest complex systems, including living organisms, ecosystems, stock markets, the immune system, and human society. Complex systems (a.k.a. complexities) are syntactically deep because they are built upon many layers of relata: quarks to nucleons, nucleons plus electrons to atoms, atoms to molecules . . . cells to tissues, and ultimately, living species, soil, oxygen, water, etc., to the biosphere. This degree of hierarchy was proposed by the polymath Herbert Simon (1916-2001) in 1962 to measure the degree or depth of a system's complexity (Mitchell 2009, 109).

Authorities in the discipline of complexity science, which was arguably formalized in 1984 with the founding of the Santa Fe Institute in New Mexico, USA, have subsequently developed metrics for determining a system's degree of complexity. Unfortunately, these and other metrics, including Eric Chaisson's "free energy flow rate density" of which many big historians are familiar, all have significant shortcomings (Chaisson 2001). Although few would deny that the human brain has greater complexity than a bacterium or an ant

colony, it is not clear that any metric would be able even to semi-quantify and compare the complexity of New York City or a temperate rainforest.

Complexity science also has been unsuccessful in formulating a concise universally agreed upon definition for complexity although, again, many have been proposed (Mitchell 2009). These limitations might not seem to bode well for an ethical theory with *complexity* in its very name. However, there is much broader support for the characteristics necessary for complexities to be extant. Besides having deep syntactical content and processes, the following criteria are almost universally agreed upon as being required for a system to be recognized as complex (Mitchell 2009; Johnson 2007; Page SE 2009; Ladyman et al. 2012; Waldrop 1992; Gribbin 2004):

1. A complex system consists of multiple interactive components, or agents, that exchange and process information without a central control. A classic example of this process is a flock of birds or a school of fish that move in shifting formations without a central leader. Instead, each bird or fish, who is an agent, follows rules regarding proximities to its neighbor. The lack of central control extends to other complex systems, including brains and societies. Even though you might think that you are the agent in control of your brain, different assemblages of neurons are, in fact, carrying out a myriad of functions like respiration, digestion, circulation, balance, sensory processing, etc., without your awareness, never mind control. Similarly, even the most totalitarian government cannot manage every aspect of the members of its society.
2. Complex systems are dynamic and, therefore, require energy flow. *Dynamic* is a technical word for *changing*. Static systems like a parked car might not do anything interesting except decay with time (entropy again). Dynamic systems, however, have interactions both internally and externally with their environment, which require work energy to accomplish.
3. Their structure and processes are neither too ordered, as with a quartz crystal, nor too random, as with a room of air molecules. Instead, they exist somewhere between these two extremes.
4. They exhibit patterns of behavior that would not be predicted from the behaviors or characteristics of their more fundamental components. The phenomenon is usually referred to as "emergence." For example, no matter how much you studied a neuron, even a super-physicist-biologist-neuroscientist would not predict that a collection of them put together in just the right way could eventually manifest an individual who has self-awareness, might write songs, and solves math problems. An emergent phenomenon can be abstractly represented as A+B→C, where some relationship that occurs between its components, represented as A and B, yields an emergent product, C. The interacting components of a non-complex system, however, usually result in a simple summation or conjunction that could be represented as A+B→AB, where AB might be a new entity but has no unexpected properties.
5. They self-organize and self-regulate their structure and processes. These operations also require free energy flows.
6. They exhibit non-linear behavior that makes their behavior and even future structures difficult to predict; i.e., for any given input, the resulting output is not determinate, but statistical.
7. Additionally, most authorities in complexity science include adaptation as a requisite criterium or will divide complex systems into non-adaptive complex systems (e.g., stars, hurricanes) and adaptive complex systems (e.g., living organisms, the global Internet). In this context, adaptation means that something can alter itself or its progeny so it improves its function, or so it is more likely to persist despite changes in its surroundings. Adaptation also serves as a bright line for complexity because only life and systems derived from it attain this quality, whereas non-living entities and their derived systems persist or do not

> persist according to the more fundamental laws of nature. For example, stars might last many billions of years, have countless interacting parts, and have emergent properties like nuclear fusion and the creation of new chemical elements; however, they do not alter their structure, processes, or progeny to survive a changing environment better.

The proposition that complexities should be perpetuated implies that even passively allowing the loss of complexities like the panda bear, a rainforest, or a threatened native tribe is an event to be avoided. The act of enhancing complexities is consistent with historically ethical desired states such as happiness, health, flourishing, and the like. A complexities state of being well also adds informational depth because the specified order is increased. Conversely, failures of complexities' key relationships have been equated with the Bad such as death, sadness, suffering, disease, crime, and war to name a very few. There are many more ways for a complexity to be unwell because the range of failing and failed relationships amongst its constituents and the concomitant phase space is larger just as it is when a room is more disordered or a triangle loses its geometry.

Although I began working on C-I theory years ago, it is not the first theory to identify complexities and the wellness of complexities as a Good. Universal ethics as developed by Belgian philosopher, Clement Vidal, and physicist, Jean-Paul Delahaye, has a very similar articulation (Vidal et al. 2018). To paraphrase, universal ethics states that the Good is that which preserves, augments, and recursively promotes organized complexity. Their statement is synonymous with perpetuating and enhancing complexities, and I must acknowledge their precedence in publication and possibly in conception. One important way in which the theories differ, however, is *how* complexities are identified. This difference leads in turn to a substantially different list of what entities constitute a Good. Universal ethics relies on a metric for complexity called logical depth (LD), which was developed by the physicist and information theorist, Charles Bennett (1943-). As noted, all metrics are too flawed to be a reliable means of measuring complexity, never mind identifying them. Indeed, Bennett himself wrote that the logical depth was meant as a *measure* of complexity (Bennett 1988). I will discuss other problems regarding the use of this metric as well as acknowledge other similarities to and differences from related information-based ethics, as appropriate.

Why are Complexities a Good?

Universal ethics notes that various qualities that are indicators of a well complexity like health and happiness are widely considered Goods throughout philosophical history (Vidal 2018). A state like Aristotle's eudaimonia, which translates to *flourishing*, is a better catchall term because complexities like ecosystems do not experience the emotion of happiness, and it is metaphorical to state that the global economy is healthy. Nevertheless, their point is valid.

Still, why are complexities an important, even the predominant Good that morally deserves to be well and that is not dependent on its value to humans and thereby has great intrinsic value? The overriding reason is because if there are no complexities, then there are no ethical agents, hence, no ethics to be discussed at all. The practice of ethics requires advanced agents that are capable of moral decision making with the ability to project how their actions will affect themselves as well as (often) multiple other complexities' well-being. The ability for such abstract predictive and weighted thinking appears to be a capability of only a few advanced animals such as humans, likely our evolutionary predecessors, and a few mammals with advanced brains such as chimpanzees, dolphins, and elephants (De Waal 2006). Furthermore, moral agents like humans are dependent for their survival on other complexities like societies, ecosystems, and ultimately the biosphere. The wellness of those systems in turn affects the wellness of moral agents. In the end, complexities have intrinsic ethical value that is not dependent on their utility to humans or even other moral agents because they are prerequisites.

Of note, other systems that are less complex—perhaps even not complex by anyone's metric—but still necessary for a moral agent's existence like the sun, physical Earth, atoms, and the universe itself are not ethical patients. With our current and foreseeable technologies at least, we cannot in any significant way do actions that would affect these entities' existence or state of being. As recent events demonstrate, however, even a large complexity like the biosphere is an ethical patient because it can be adversely affected by our actions.

The Good of Other Types of Informational Artifacts and Processes

While artifacts and processes with deep syntactical information like a tallgrass prairie, summed social interactions, or bonobos have intrinsic ethical value, those with deep semantic or surprise information have extrinsic (a.k.a. instrumental) ethical value. An artifact like a claimed holy relic and a process like a Catholic liturgy has meaning, sometimes with ethical implications, to its devotees. Similarly, a Gutenberg Bible or a new important scientific discovery has deep informational surprise that is given value by agents. Syntactically, however, the information of a Gutenberg Bible or a shard of an alleged bone from Saint Thomas is not complex and is just there. As a litmus test, you can ask what value an extraterrestrial intelligence would assign an artifact or process without knowing more than that of which it is constituted and how it behaves.

Universal ethics claims that these and other items like music symphonies, award winning novels, and computer microprocessors are all complexities because they are syntactically deep as determined by their logical depth (Vidal 2018). However, it is a mistake to use solely logical depth (LD) to classify things as being complex for several reasons:

- As discussed, every metric proposed for measuring the degree of complexity is flawed. In the case of LD, there is "typically no practical way of finding the smallest Turing machine that could have generated a given object, not to mention determining how long that machine would take to generate it" (Mitchell 2009). Also, it is not typical for authorities to use a metric alone to determine whether a system qualifies as being complex. The only way in which artifacts and processes can count as being complex via LD is if the informational content of the creator is included. Extending the computational boundary this far, however, potentially makes all artificial artifacts more complex than the very complexity creating them, e.g., the LD (microprocessor) = LD (humans) + LD (microprocessor).
- The artifacts listed by Vidal and Delahaye as being created by humans and being complex fail to meet the nearly universally agreed upon criteria for even being non-adaptive complex systems. For example, even a symphony by Beethoven and advanced computer microprocessors are not self-organizing, composed of multiple agents without a central control, and so forth. Admittedly, some artificial systems do qualify as complexities, such as global economic trade and even (arguably) an improvisational jazz band. However, they qualify via their characteristics rather than computational time needed for their creation.

Again, a good litmus test for determining whether something can be classified as being complex is to take the perspective of an alien intelligence. If a Rafael painting or a Nobel prize winning novel were placed before it, would it proclaim that it had come upon a complex system? Without knowing our culture and its products, it would more likely state that it saw a canvas with pigment or papers with inked markings, respectively.

This paper is not meant to be a polemic against universal ethics. Indeed, I am indebted to Vidal and Delahaye's observations and analyses that had escaped my attention. As a case in point, the name for this ethical theory was simply "complex ethics" before their paper made me realize that semantic and surprise information could also be ethically relevant, hence, the

hyphenation and inclusion of the term *information* in complex-information theory.

Semantic Information—An Instrumental Good

We value many artifacts and processes because we imbue them with great meaning or purpose. In the lexicon of information, they have great semantical import to us. Some artifacts and processes have deep syntactical content as in the case of a Beethoven symphony. Others like a Christian cross, the Japanese flag, or a Catholic eucharist are simple syntactically but still hold a profound (metaphorically deep) meaning to their adherents. The meanings of these artifacts to their adherents are great enough that witnessing the artifacts being maligned in some manner can cause them anger, anguish, or both. We could forgive those who were not familiar with what these artifacts represented if they burned a Christian Cross's wood to keep warm, spread a national flag as a tablecloth, or interrupted a eucharist. After all, their value is extrinsic to the things or processes themselves and instrumental to only those who understand their abstract value.

Novel Information—Another Instrumental Source of the Good

Some Goods are deeply (a metaphor again) valued by humans for an important subset of semantic information that is worthy of consideration: they are either rare or they provide new knowledge or experience, i.e., a new understanding about relata. Recall that Shannon's surprise of a message is a measure of how unexpected that message was to its recipient; and the formula for measuring that surprise is $s(x) = \log 1/p(x)$, where $s(x)$ is the surprise measured in bits, and $p(x)$ is the probability of that message occurring. Therefore, messages, events, or other things that occur rarely are reflected by its surprise being consequently large. The informational surprise of finding life in the universe will be enormous, not just psychologically for us, but even from a purely physical-mathematical perspective because the vast majority of the universe is empty space; just a tiny percentage of mass consists of potentially life-sustaining planets—the remainder of the mass being inhospitable stars, nebulas, gas giants, black holes, and possibly dark matter.

Claude Shannon expressed the surprise of a message as being a way of how much it reduces one's uncertainty regarding some question. Similarly, science and other disciplines work to understand the laws, states, processes, etc. of the universe better. A new discovery reduces our uncertainty about some aspect of the universe, and some of these findings can have ramifications for our well-being or the well-being of other complexities and, therefore, have ethical value. A new medical treatment might mitigate pain or improve the chances of curing a cancer; a pioneering insight into thermodynamics or material science might provide a new source of sustainable energy; and a new microprocessor design or computer software program might make it possible to design a vaccine to cure distemper—a virus that is killing the endangered African wild dogs. Discoveries with sufficient import to have ethical value need not be limited to the sciences. New philosophical and political science perspectives and treatises have helped to promote the equality of all humans: the condemnation of slavery, the rejection of the subordination of women, and improved the status and rights of those in the LGBTQ community. New historical revelations might help us to navigate the future better; for example, the lessons gained from Rapa Nui offer a real lesson of what can happen when humans overstress their local environment. This list is, of course, far from complete.

Surprise or novelty can also be a measure of rarity, and something rare can become an increased Good, especially if it is not reproducible. The forty known Gutenberg Bibles, two hundred forty-four Stradivarius violins, rare Ming vases, and the single sculpture *David* by Michelangelo are all examples of non-reproducible rarities that are also important semantically to us because of their historicity and aesthetics (*Britannica* 2021; *New Violinist* 2021). Intentional damage or loss to any of these artifacts would be a wrong significant enough to make international news and result in collective human angst.

Combining Information Types

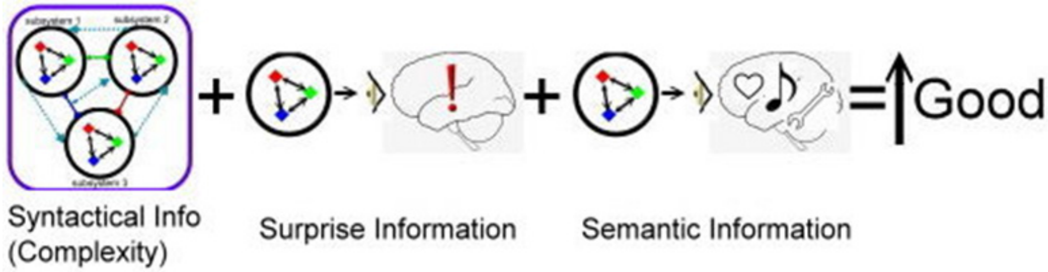

Figure 3. The box with the three interacting circles represents a syntactically deep complexity. The brain with an exclamation mark represents surprise, and the brain with a heart, musical note, and wrench represents semantics as perceived by an eye. The summation of different informational content can increase the value or good of an artifact or process.

An even more elevated Good can also be achieved by combining that which has a high degree of complexity (syntactics), meaning or purpose (semantics), and rarity (surprise). If we find the recently confirmed extinct ivory-billed woodpecker, it would be a great surprise both emotionally and mathematically, have great meaning to birders, and, of course, have deep syntactical content because it is a complex organism (Del-Colle 2021). Empirically, if not ideologically, society also seems to value some people more than others. If John or Joan Doe dies, their passing will likely be listed in the local newspaper's obituary, and their circle of friends and relatives will attend the memorial services because their relationship with the deceased had great meaning. While John or Joan was also truly unique in the strictest sense of the word, they might not have been so unique as a head of state, major religious leader, famous movie actor, or gifted athlete of a popular sport who dies. The nation and even the rest of the world will note their passing in the news, perhaps a biographical movie will be produced, and an executive order might be issued to fly the national flag at half-staff. It seems that these people are accorded additional social value when they had significant meaning to a greater number of people and their level of talent, position, circumstance, or other quality made them a greater surprise. Figure 3 is an abstract graphical representation of this proposition.

When is a Complexity Net Positive?

C-I ethics is a consequentialist, utilitarian ethical theory. This genre of ethical theories weighs what ought to be done by aiming for actions that result in "the greatest good for the greatest number" as one well-known quip states. Jeremy Bentham and J. S. Mill, the pioneers of utilitarian ethics, proposed weighing several different parameters to help decide how to maximize a Good: the immediacy of the anticipated Good; how certain it is and whether it likely to recur; how many people would benefit and for how long; how intense the Good is; how much associated pain is anticipated; and for Mill, the quality of the Good. Universal ethics also recounts various options for the distribution of a Good among complexities, including whether an action should aim to distribute a Good equally to all complexities, to those with the least, to those with the most, some to each to maximize the total, and a Nashian model where the summed Goods are determined by multiplication (Vidal 2018). Developing a more fully realized calculus for maximizing the Good amongst complexities is beyond the scope of this paper, but suffice it to say that making a utilitarian calculus can be daunting in many cases. I will limit my discussion to some of the desiderata relevant to judging whether a complexity is net positive.

Note that artifacts and processes with deep informational content that are not complexities are not good or bad except in how they are utilized by higher complexities like humans. The Khmer Rouge flag or the "Little Boy" atomic bomb might come to symbolize an ideology associated with atrocities or a new weapon capable of massive destruction, respectively. However, these artifacts just sit incapable of being good or bad until utilized by a higher complexity capable of moral decision making.

Rather than recount evermore examples of complexities being net positive or net negative, we

can broadly describe a few characteristics that would make a deep informational artifact or process ethically undesirable:

1. *Does the complexity intentionally or needlessly harm other deep informational artifacts/process directly or indirectly?* With a few notable exceptions exhibited by a few higher animals as noted earlier, it is complex people and groups of people who can project how their actions will affect other deep informational artifacts/processes and the future course of events. Our justice system and social mores recognize this fact and usually strive to limit or stop negative consequences to others, religious symbols, national flags, endangered animals, and other items highly valued by us and occasionally to higher animals—especially our pets.
2. *Lesser complexities that cause substantial harms to greater complexities*. Although we usually strive to avoid the extinction of higher animals, even those that cause us harm at times, like a poisonous snake, we do not share similar concerns about the loss or potential loss of much simpler complexities like mosquitos, smallpox, *Yersinia pestis* (the bacteria that causes the bubonic plague), and malaria. While even these simple organisms would be impossible to replicate with foreseeable technology, the misery that they impose on higher organisms, including humans, offsets any utilitarian calculus in their favor.

With further contemplation, C-I theory might reveal other broad rules for helping to determine when a deep informational artifact/process is not net-positive. Even with only these two caveats, it is often difficult to calculate reliably the best course of action a person should take in the complex landscape in which we exist.

It is a Complex World

C-I ethics, as with any other theory, will inevitably face shortcomings: no ethical theory is comprehensive in its ability to cover every contingency. Also, by having its precepts extended to include non-anthropocentric concerns, it often becomes more abstract in its application. The same problem occurs whenever you increase the sensitivity (so that you capture more cases or situations) of a medical test. You then lose specificity: you capture cases or situations that are not relevant. C-I theory would perhaps best find its stride by being a meta-theory—a theory that undergirds other theories that can be more easily applied in the field. Another important strength of C-I theory and others that incorporate complexity is that they recognize that the world is fundamentally (drumroll) . . . complex! Most traditional ethical theories, on the other hand, treat the world as though it is in some manner simple and that there is one primary variable that determines what is the Good, the best action to take, and so forth. In a more extended treatise, a complex-type ethical theory could more rigorously address some of the controversies that resonate in the field of ethics (and other philosophical areas as well). For example, accounting for the complexity of the world would

- Provide a new perspective on the issue of ethical relativism and subjectivism; i.e., there are fundamental reasons why it seems that ethics is relative to different times and cultures or why ethics seems to vary subjectively from person to person.
- Better explain why ethical theories founded on simpler precepts fail so frequently when applied to many real-world situations.
- Perhaps most boldly, complexity offers a possible basal explanation for how free will, which is needed for true ethics to be practiced by an agent, might be possible. Currently, many philosophers state that free will, despite its being apparent to us experientially, does not actually exist and that our choices are covertly deterministic a la Newtonian physics. Unfortunately, quantum mechanics, which is fully non-deterministic, is not a better answer for an underlying decision mechanism because it is fully random. Complexity science, however, has discovered several scenarios that are between a deterministic and indeterministic outcome—

and there might lie the substrate for a will that is free to make any of several choices. Ultimately, however, we should at least be agnostic regarding the final nature of apparent free will because we have much to learn about how the brain operates.

Complex-Information Theory Summary

Big historians need a broad ethical framework with which to examine better the ethics or morality of past events and especially events that might be looming in the "big future," such as human driven changes to the biosphere, artificial intelligence, transhumanism, and possible encounters with extraterrestrial life. Traditional ethical theories were primarily guided by human concerns, i.e., anthropocentric. A number of information-centric theories have been proposed in the past that broaden ethical concerns to that which is a complex system, various valuable artifacts, or at times even every thing that exists. C-I theory strives to broaden and refine these theories by beginning with a careful analysis of relevant laws or tenets from the second law of thermodynamics, information theory, and complexity science. Hopefully, by making the bridges from entropy to a careful analysis of information types and then to relevant complexity science, a solid theory can be constructed that has its foundation in the basic laws of physics but then can extend its grasp better to include all artifacts and processes worthy of ethical consideration.

Subsequently, others and I have identified complex systems as one important category of things that warrant our ethical consideration to the extent that to perpetuate and enhance them is ethically desirable—with some caveats. Clement Vidal and Jean-Paul Delahaye also identified various artificial human constructs as being complex systems and, therefore, worthy of preservation and promotion. However, if someone uses the usual criteria for identifying complexities, it quickly becomes apparent that many of their listed complexities such as works of art, microprocessors, and novels do not qualify as being such. Instead, C-I theory asserts that these and other items are valued for their deep semantical and surprise informational content. Furthermore, while complexities have intrinsic ethical value because ethics cannot exist without complex agents in a complex world, other types of informational content have instrumental value assigned to them by moral agents—in this case by humans.

Admittedly, C-I theory relies on abstractions that will often be difficult to apply in the field. It can still undergird more readily applied ethical theories and help to explain better the apparent limitations and contradictions that exist with traditional ethical theories. After all, as big historians well know, it is a complex world that is only becoming more complex as time unfolds.

Notes

1. As an aside for big historians, the "transistor" was first also developed and demonstrated at Bell Labs in December 1947 by physicists John Bardeen (1908-1991), William Shockley (1910-1989), and Walter Brattain (1902-1987). Hence, the "digital information age" arguably began at the very end of 1947 to 1948 at Bell Labs in Murray Hill, New Jersey (Riordan et al. 1999). Few, if any significant eras' origins can be pinpointed in location and time so precisely!

2. For a more thorough discussion about "information," please see my article, "The Unfolding of Information," (*JBH* 2:1). Please also note that there is an error on page 51, which states that the formula worked for only two equally likely messages—like the toss of a coin. Correctly stated, it measures any number of equally likely messages.

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Philosophical Questions Raised by Big History

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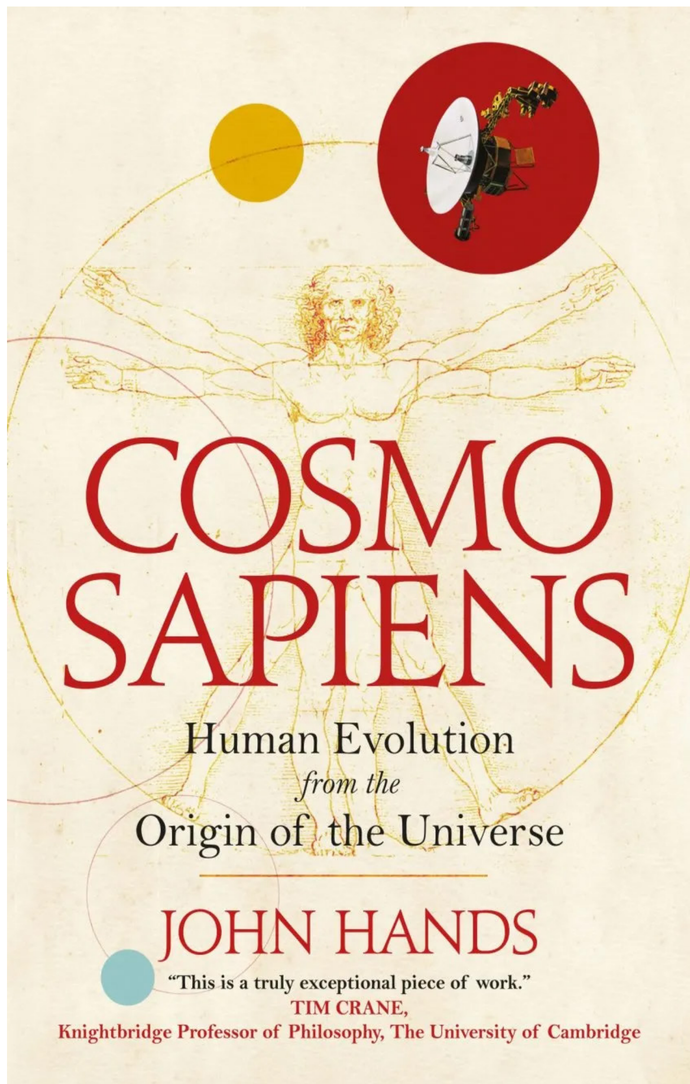
Hands, John. 2015. *Cosmosapiens: Human Evolution from the Origin of the Universe*. New York: Overlook Duckworth.

Considering the territory explored in John Hands's 674-page tome, *Cosmosapiens*, one might conclude that his aim was to examine the entire Big History narrative from Cosmos to Humanity. The book is subtitled *Human Evolution from the Origin of the Universe.* However, Hands's extensive bibliography omits any works by founders of the International Big History Association (IBHA): David Christian; Cynthia Stokes Brown; Fred Spier; or even Eric Chaisson, who has been peripherally associated with IBHA. Nor is there any mention of the Big History movement. If anything, this book demonstrates that examination and presentation of the 13.8-billion-year history of the Universe is occurring on many fronts outside the IBHA.

Hands does not utilize the kind of structure found among big historians: Fred Spier's hierarchy of "domains," David Christian's "thresholds," or Tyler Volk's "cosmogenesis" events. His book unfolds in three parts: The Emergence and Evolution of (1) Matter, (2) Life, and (3) Humans. Despite the occurrence of "emergence" within the titles of his three parts, emergence itself is limited to a definition (199, 633), albeit a comprehensive definition. Despite various attempts to explain emergence, it is easily understood as marking an imagined disjunction bridged where reality itself is continuous and needs no bridges. Hands's treatment is comprehensive when it comes to dealing with the broad outlines of the cosmic narrative and how it has developed through three states of human thinking: primeval, philosophical, and scientific.



Hands's treatment is more balanced than most of our own big history productions, which tend to focus on the specialized field of the writer. Astronomer Eric Chaisson's *Cosmic Evolution* (2001) and *Epic of Evolution* (2006) work with a seven-era structure, but his emphasis is primarily on the cosmic; his treatment of humanity is rather strictly limited to our increasing

consumption of energy. *A Most Improbable Journey* (2016) by the geologist Walter Alvarez, though subtitled *A Big History of Our Planet and Ourselves,* focuses primarily on the middle ground of historical geology. David Christian, a historian, weights *Maps of Time: An Introduction to Big History* (2004) toward human history with extensive treatment of changes in human organization since the Agricultural Revolution. The limitations big historians recognize concerning the single-discipline emphasis of the departmentalized academy affects them as well. The task of equal emphasis across half a dozen component disciplines remains a formidable challenge for big historians. Hands, a journalist, succeeds rather well in ranging across the entire spectrum of big-history data. His strategy is to outline the accepted mainstream narrative while interspersing it with philosophical questions that point to things unanswered within the accepted story or to weak spots in current theory. This book review is titled "Philosophical Questions Raised by Big History" because such questions are where the value of *Cosmosapiens* lies.

The broadly accepted view of beginnings is the Big Bang theory, which appears to be supported by a broad range of data, beginning with Edwin Hubble's discovery of the expanding universe. A reading of Steven Weinberg's *The First Three Minutes* (1993) or Alan Guth's *The Inflationary Universe* (1997) is likely to inspire confidence in the standard story of cosmic origins. The elegance of the origin story leads us to skirt the profound mystery of how the Universe was once compacted into what is called a "singularity" that, to revert to mythology, is just as puzzling as the theological doctrine of *creatio ex nihilo* (creation out of nothing). Hands addresses these kinds of problems by exploring alternate theories, for instance, the so-called Big Crunch that postulates that a contracting Universe preceded the Big Bang, which he describes as a "cyclical bouncing universe." The analogical relation between such a Big Crunch and black holes that swallow matter to the point of disappearance poses the possibility that black holes are offspring of our Universe that are giving birth to other universes beyond our ken. He calls this "multiverse conjectures." All such possibilities remain conjectures, thus pointing to Hands's thirty-nine numbered conclusions to the book. The first of these reads: "It is almost certain that the empirical discipline of science will never be able to explain the origin of the matter and energy of which we consist" (582).

In treating Guth's theory of a brief, extremely rapid expansion during the Big Bang as an explanation for minor density variations in the cosmic microwave background CMB), he quotes Guth's remark that "a theory of this sort is contrived with the goal of arranging the density perturbations to come out right" (117). This points to problems where, as Paul Steinhardt and others have noted, the standard model is fundamentally untestable and thus must be considered as scientifically flawed or incomplete.

The subsequent derivation of large structures—galaxies and stars—from density ripples in the cosmic microwave background became a mainstay of the overall narrative almost as soon as the Cosmic Microwave Background Explorer (COBE) sent back its images in 1989. A certain will to believe was evident when George Smoot declared it was "like seeing the face of God" and Steven Hawking called it "the discovery of the century, if not of all time" (81). A more cautious look at the evidence suggests that this "attitude of belief rather than reason" requires caution and perhaps correction: various theorists have argued that "one in 100,000 . . . is far too little density variation for gravitational instability to cause *any* structures to form" (117)—a claim equally difficult to prove.

The hypotheses of dark matter and dark energy provide additional evidence of problems we normally avoid contemplating. In order to account for the observed behavior of massive galaxies, for instance, dark matter amounting to as much as ninety percent of all matter, comes to the rescue. The similar introduction of dark energy accounts for an accelerating expansion of the Universe. In some ways, these resemble the fudge factor Albert Einstein introduced into his equations to account for divergence in cosmic behavior, which he later acknowledged as his greatest mistake.

Hands's enumeration of problems all through the cosmic narrative points to the typical way big

historians (and most cosmologists) deal with these. They look at the standard model presentations, including such "explanations" as dark matter and dark energy, recognizing the cognitive barrier they present to understanding, and then adopt a "good-enough-for-now" acceptance. In order to "get on" with the story, cosmologists and big historians have to bypass many profound mysteries without hesitation or regret.

Hands explores the various theories proposed for the origin of life. Decades ago, Stanley Miller and Harold Urey attempted to produce life by subjecting a gaseous mixture to an electric current. Amino acids were produced but nothing more. Later, it was realized that their gaseous mixture probably did not match the early Earth atmosphere. No subsequent experiments have yielded better results. Experiments based on Darwin's "warm little pond" as a likely environment for life's origin have not been successful, and no scientific evidence for intermediate steps between inanimate matter and living cells has emerged. The theory that life originated elsewhere and was brought to Earth as bacterial spores from outer space pushes life's origin elsewhere but begs the question of where and how life originated somewhere else. "As with the emergence of matter," Hands suggests, "it is very probably beyond the ability of science to explain the origin of life" (245).

In *Vital Dust* (1995), more than thirty years ago, Christian de Duve, who explored life's origins at length, set forth his view that the origin of life could have happened only once. His argument was that the first living cell would have immediately consumed any upstart followers. Such a conjecture can never be proved; it remains just as hypothetical today as then. When Hands concludes that "[i]t is highly probable although not certain, that life emerged only once on Earth, and that all living things on the planet evolved from this one event" (582), it appears that Hands, too, has stepped outside the rigorous scientific framework so evident throughout *Cosmosapiens*.

In evolutionary theory, it has long been recognized that Darwin's pioneering *Origin of Species* (1859) and *Descent of Man* (1871) were seminal studies but had limitations that subsequent evolutionists have been at pains to explore. Hands takes time to detail such limitations: while natural selection and sexual selection have great explanatory power, they have important limitations—not surprising considering that Darwin's books were opening volleys for a very complex theory. These limitations have since been addressed by new understandings of group selection and social cooperation, areas that Edward O. Wilson (often considered as the Darwin of the twenty-first century) explores in *Sociobiology* (1975) with sophisticated additions in *The Social Conquest of the Earth* (2012), both early enough for Hands to have assimilated. Significantly, the only Wilson work in his bibliography is *Consilience* (1998), which bypasses evolutionary theory in favor of pontificating on "the unity of knowledge."

In his treatment of what he calls "complexification," Hands acknowledges the still influential idea of intelligent design argued repeatedly by Michael Behe and others, noting the "uniformly hostile" response of evolutionists, though he does not mention the famous "creation science" court case—*Edwards v. Aguillard*, 482 U.S. 578 (1987)—in which the judge chastised intelligent design advocates for wasting court time and resources on an untenable theory. Superficially, it might seem that a discussion of intelligent design is out of place in *Cosmosapiens*, a book so rigorously scientific in its approach; but, as Hands points out, intelligent design or creationism are examples "arising from a more general problem, the inability of science to explain certain phenomena" (233). However, the position creationists have adopted fails: "The proposal that the first cell is irreducibly complex and could only have been caused by intelligent design is not supported by evidence; it is not falsifiable and so is not a scientific explanation" (245). This inability of science to explain everything accounts for surprising conversions: the scientist Fred Hoyle, who eventually adopted the idea of a superior intelligence behind evolution, and the well-known atheist philosopher Anthony Flew, who converted late in life to deism. The inability of science to explain everything defines the crevice, or multiple crevices, that provide openings for the 1998 wedge strategy of creationists to

establish intelligent design as the ultimate explanation for the existence of life (cf. "The Wedge Document").

Hands's treatment of emergence theory is up to date and fully in line with scientific recognition of emergence as a so-far unexplained but obvious feature of the Universe from the fusion of elements to human innovation. Erich Jantsch's emphasis on the "self-organizing Universe" along with Stuart Kauffman's "self-organizing complexity" and James Lovelock's "Gaia hypothesis" are acknowledged as significant contributions to his evolutionary emphasis.

Hands's three-part treatment of human cognitive development provides his main taxonomy for organizing human evolution. Rather than the traditional standard that treats the Agricultural Revolution some twelve thousand years ago in terms of a change in human interaction with their environment, Hands sees it as developing from a change in human cognition. He proposes the development of property, settled life, and the establishment of cities and states as emergent from changes in human thinking.

Primeval thinking sees the world animated by a spiritual force or spirits prior to the emergence of polytheism or monotheism. Philosophical thinking, marked by an inward focus on selfhood, emerged in Europe with the Greek philosophers—Thales, Plato, and Aristotle; in India with the Upanishadic sages and Shankara; in China with Lao Tzu and Mencius. Scientific thinking coalesced with Copernicus, Galileo, and Bacon, with scattered precursors in Classical times. The disciplines of the modern academy are the result of rigorous scientific thinking. A mixture of philosophical with scientific thinking motivates a few, such as the late Steven Hawking and Steven Weinberg, who yearned for a unified theory of everything. In some sense, big historians are part of this trend as they seek to produce a unified history or origin story of the human adventure.

Of particular interest is Hands's chapter on origin stories. These have been recognized among big historians, often with examples quoted, and David Christian made a forceful link in both *Maps of Time* (2004) and *Origin Story* (2018). Well-known origin stories include Hesiod's eighth-century BCE *Theogony*, Lucretius's first-century BCE *De Rerum Natura* (*On the Nature of Things*), and Ovid's first-century CE *Metamorphoses*. Hundreds have been published from oral stories collected from tribal people around the world with ancient printed versions from the Hindu *Rig Veda* and *Upanishads* (1500-800 BCE) and the Japanese *Kojiki* (712 CE). Recognizing the continuity between mythic origin stories and modern scientific accounts—the difference being a shift from narrative knowing to empirical evidence—is fundamental for an understanding of Big History.

Cosmosapiens is an impressive work, most notably in the coverage it attempts. It is a worthwhile book for big historians because it explores the many tributaries of the central narrative. It is valuable as a primer for reviewing the main currents and episodes across the full territory of Big History. For introducing Big History to the beginning student, the book may be too difficult because the primary pedagogical emphasis for the big history educator is communicating the sense of a continuous narrative that connects the distant origins of things with today's human situation. Meandering into the byways of unanswered questions and philosophical problems with the standard theory might best come later; a firm grasp of the big history mainstream should precede the many philosophical issues raised by the direct historical route. *Cosmosapiens* has its place in a survey of Big History, but one needs to find a well-paved route through the countryside before venturing into off-road dust storms along the way.

Figuring toward a Viable Future

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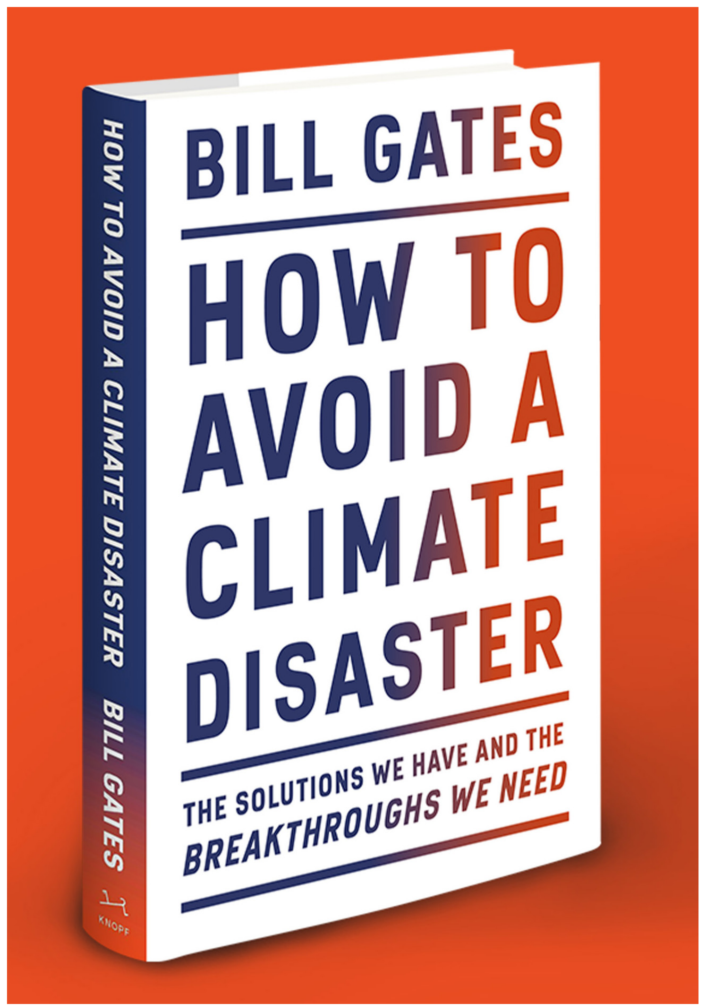
Gates, Bill. 2021. *How to Avoid a Climate Disaster: The Solutions We Have and the Breakthroughs We Need*. New York: Alfred A. Knopf.

I first saw this book on the library "hot picks" shelf two months after its initial publishing. I was hesitant at first after seeing many other books and articles about approaches to handle climate change. However, after a brief look, it seemed to be well organized and discussed topics in a more integrated way than I had typically encountered. This book delivered. You may wonder why Bill Gates, a person outside science and government, could present an integrated account of this topic. I think it is because he has vast curiosity and resources to explore and connect with the wide range of groups in science, technology, industry, government, environmental groups, while also being actively involved in deciding where to invest. Some may look at this as an excuse to dismiss parts of this book because of this conflict of interest, but Gates addresses this. He makes it clear where and why he invested (and sometimes failed in the process) but looks at the whole picture. He has assembled quite a team to collect information, develop models, and follow trends in his Breakthrough Energy organization (breakthroughenergy.org).

The book is concise and includes relatable numbers and stories. He develops a "thought experiment" to bound the cost of mitigating climate change by estimating the cost of constructing and operating a carbon capture and storage device (with near future technology, although still uncertain viability). The cost of reaching zero emissions, with technology that processes a ton of carbon for about $100, is about 6% of the world's current economy. He then develops estimates of "Green Premiums", i.e., the additional costs for making carbon-free products, processes, or energy. Throughout the book estimates of the Green Premi-



ums are made for both current technology or with potential advanced technologies in each of the five major activities contributing to greenhouse gases: making things (5), electricity (4) agriculture (3), transportation (2), and heating and cooling (1). (The numbers in parentheses are the relative amount of greenhouse gas

contributions by the activity.) He discusses both why these are large contributors and the possible technologies that are being pursued to mitigate them.

Before a deep dive into these areas, a framework of questions is developed to cover the scales of emissions, power, land required, and cost. The emissions are measured relative to the current global emissions of 51 billion tons (equivalent) per year. Power generation is relative to the current global use of 5,000 GW in factors of 1,000 from the 20% (1,000 GW) for the U.S., 1 GW for a mid-size city, 1 MW for a town, and 1 kW for a house. Land requirements vary over four orders of magnitude from over 1,000 square meters to support a typical house with wood to the 1/10th of a square meter needed for fossil fuels. Cost is measured based on the Green Premiums and the 6% global economic cost from the thought experiment.

You might wonder how this relates to big history. I would like to address this in a couple of paragraphs concerning topics that are outside the scope of the book. Many see the development of life (and human civilization in particular) leading to a major crisis or inflection point. Future scenarios often include a business-as-usual scenario in which fossil fuels continue to play a leading role in energy and production. This could lead to a climate with an unsustainable quality of life; a muddling-through scenario, where efforts are made to mitigate and adapt to climate change, but the actions are too little and too late to circumvent many societal and climatic impacts; and the optimists' scenario that the combination of technology breakthroughs, sufficient investment, government policy, and political will leads to a world that not only develops economic and environmental sustainability but also offers greater equity through global collaboration and participation.

In fact, this problem of environmental crisis near the globalization of the economy is being fervently researched through modeling techniques. In the related field of astrobiology, the question is whether any planet in the habitable zone around a star, which develops civilization, might also experience such an environmental crisis. The early results suggest that such a crisis might be common and act as a "Great Filter" determining whether advanced civilization continues to thrive after addressing this issue.

Throughout the book various perspectives are discussed and integrated to demonstrate the difficulty and challenge of the issue. Some history of energy use is relayed through the author's discussions with the well-known energy expert Vaclav Smil, who has written extensively about the history of energy use and our situation today. Gates has also interviewed leaders or participated in United Nations (UN) climate summits with them and traveled to developing countries to understand their predicaments (also as a part of his larger health campaign). As mentioned, he sees many innovators and relates to his own story of working with start-up funding and government policies.

This book reminds me of the initiative advocated by the late Richard Smally, Nobel Prize winner for his breakthroughs in nanotechnology, almost twenty years ago. Soon after the terrorist attack on the World Trade Center on September 11, 2001, Smalley went around the world from his base at Rice University to advocate for a global collaboration in developing inexpensive energy solutions. One of his main points at the time was that with relatively inexpensive clean energy, many problems can be more easily addressed. For example, with enough clean electricity, water shortages evaporate as fresh water can be distilled from ocean water. Unfortunately, his message did not gather enough support.

In the end, Gates calls for a collaboration of innovators, markets, and governments to develop incentives that can solve this issue in time and yet leave the world in a better condition in terms of both economic functionality and social equality. While this conclusion is not surprising, the details and organization of the possibilities and complexity of the issues leaves the reader with insights to apply to choices in activities, markets, investments, and government. One of the warnings is that while a goal of zero emissions might be a final goal, the intermediate goal of partially reducing emissions by 2030 might be counterproductive. This is due in part to the long-range investments that must be

made in the near-term. For example, currently replacing a coal-powered plant by one based on natural gas might reduce emissions in 2030 but still require another investment in 2050 to reduce the emissions to zero.